Waterproofing of natural materials to improve bearing capacity

Final Report

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ABSTRACT

Natural soil is both a complex and variable material. Yet, because of its universal availability and its low cost of winning, it offers great opportunities for skilful use as an engineering material. Altering the properties of the existing soil so as to create a new site material capable of better meeting the requirements of the task in hand. Due to the great variability of soils, no one method is ever successful in more than a limited number of soils. It must also be recognised that "stabilisation" is not necessarily a magic wand by which every soil property is changed for the better.

This project was a field trial conducted at Bracalba Quarry in which a road was constructed and was stabilised with the Consolid system. This was continued work on from the laboratory results attained by previous student Sam Fitzpatrick on the Consolid system in which he found that there was merit in the improvement to materials which had a higher clay content with this stabilisation. Therefore, this study aimed at using a type 2.5 unbound granular material in this trial, which was identified by the quarry. Pavement testing and Moisture gauges were conducted and fitted on the site to give an analysis of the performance.

Consolid System is two products, the Consolid 444 liquid and Solidry powder. As mentioned this method is recommended for use in clayey silty soil as well as flooded areas. The site location was at the, Bracalba Quarry, Daguilar, Queensland and was provided by the Brisbane City Council. The trial site is used as the primary entry to the quarry, and the control site that was used acts as the exit from the quarry, however they run parallel to each other. The determined profile of the trial site consists of a 250 mm layer of treated material broken into two 125 mm layers, on top of a 150mm subbase and then a subgrade. The control site consisted of 400 mm base material on the subgrade.

Previous laboratory study showed an increase in the treated samples modulus over that of untreated, this test site is able to support this theory as the results correlated to the modulus results found in the laboratory. Rainfall data and the impact on the moisture content was observed throughout the period of this study. There was consistency in the results from the control site as well. This is important to establish that the data is accurate from the equipment and testing is verifiable.

In conclusion this field study does support the results that were found in the laboratory for this particular site and over the period of testing. The modulus proved to increase over time as well. The importance of this field trial is to support that a low quality granular material can achieve a high strength provided moisture can be inhibited.

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NOMENCLATURE

τ	Shear Strength
c	Cohesion
σ	Stress
ϕ	Angle of Internal Friction
γ	Unit Weight
ρ	Density
g	Gravity
v	Volume
m	Mass

TABLE OF CONTENTS

ABSTRACT i

ACKNOWLEDGEMENTS iii

NOMENCLATURE v

TABLE OF CONTENTS vi

LIST OF FIGURES ix

LIST OF TABLES xi

1.0 INTRODUCTION .... - 1 -
1.1 Outline of Investigation .... - 3 -
1.2 Background .... - 5 -
1.3 Objectives .... - 7 -

2.0 LITERATURE REVIEW .... - 8 -
2.1 Fundamentals of Pavement Stabilisation .... - 8 -
2.1.1 Principles of Soil Stabilisation .... - 8 -
2.1.2 Structures .... - 9 -
2.1.3 Mechanistic – Empirical Design .... - 9 -
2.2 Subgrades .... - 10 -
2.2.1 California Bearing Ratio .... - 10 -
2.2.2 Resilient Modulus .... - 10 -
2.2.3 Permeability .... - 11 -
2.2.4 Soil Suction .... - 12 -
2.3 Testing Techniques .... - 12 -
2.3.1 Falling Weight Deflectometer Testing .... - 13 -
2.3.2 Elmod6 .... - 14 -
2.3.3 Moisture Sensors .... - 15 -
2.3.4 Atterberg Limits .... - 16 -
2.3.4.1 Shrinkage Limit .... - 16 -
2.3.4.2 Plastic Limit .... - 17 -
2.3.4.3 Liquid Limit .... - 17 -
2.3.4.4 Plasticity Index .... - 17 -
2.3.5 Maximum Dry Density (MDD) .... - 17 -
2.3.6 Optimum Moisture Content (OMC) .... - 18 -
2.4 Stabilisation Additives .... - 20 -
2.4.1 Mechanical Stabilisation .... - 20 -
2.4.2 Cementitious Stabilisation .... - 21 -
2.4.3 Lime Stabilisation .... - 23 -
2.4.4 Bituminous Stabilisation .... - 24 -
2.4.5 Foam Bitumen .... - 25 -
2.4.6 Bitumen Emulsion .... - 25 -
2.4.7 Other Types of Stabilisation .... - 26 -
2.4.7.1 Dry Powered Polymers (DDP) .... - 26 -
2.4.7.2 Chemical Dust Suppression .... - 26 -
2.5 Consolid System .... - 27 -
2.5.1 Consolid 444 (C444) .... - 27 -
2.5.2 Solidry .... - 28 -
2.6 Stabilisation procedures .... - 28 -

2.6.1 Plant Mixed Stabilised Materials ..... - 29 -
2.6.2 Insitu Stabilisation ..... - 30 -
2.7 Resilient Modulus ..... - 30 -
2.7.1 Resilient Modulus Influences ..... - 31 -
2.7.2 Compaction ..... - 31 -
2.7.3 Stress State ..... - 31 -
2.7.4 Moisture Content ..... - 31 -
2.8 Material Grading ..... - 31 -
2.9 Benefits of Stabilised Materials ..... - 32 -

3.0 METHODOLOGY ..... - 33 -
3.1 Investigation Method Overview ..... - 33 -
3.1.1 Prior to Treatment ..... - 33 -
3.1.2 Following Treatment ..... - 33 -
3.1.3 Final Analysis ..... - 34 -
3.2 Road Construction ..... - 35 -
3.3 Quality Testing ..... - 37 -
3.3.1 Treatment with Consolid 444 ..... - 37 -
3.3.2 Treatment with Solidry ..... - 38 -
3.4 Construction ..... - 38 -
3.4.1 Watering ..... - 38 -
3.4.2 Levelling ..... - 39 -
3.4.3 Placing and Compaction ..... - 39 -
3.5 Materials Samples ..... - 40 -
3.5.1 Consolid 444 ..... - 40 -
3.5.2 Solidry ..... - 40 -
3.5.3 Application Rates ..... - 41 -
3.6 Falling Weight Deflectometer ..... - 42 -
3.7 Installation of Moisture Gauges ..... - 42 -
3.8 Calibration of Moisture Gauges ..... - 43 -
3.9 Plant Equipment ..... - 44 -

4.0 RESULTS ..... - 46 -
4.1 Pavement Profile ..... - 46 -
4.1.1 Treated Material Profile ..... - 46 -
4.1.2 Control Material profile ..... - 47 -
4.2 Particle Size Distribution ..... - 48 -
4.3 Laboratory CBR and Moisture Density ..... - 50 -
4.4 Atterberg Limits ..... - 51 -
4.5 FWD Deflection Results ..... - 51 -
4.6 Backcalculation from ELMOD6 ..... - 52 -
4.6.1 Treated Material ..... - 52 -
4.6.2 Control Site ..... - 55 -
4.7 Resilient Modulus ..... - 57 -
4.7.1 Treated Material Site ..... - 57 -
4.7.2 Control Material Site ..... - 58 -
4.8 Permanent Deformation of Subgrade ..... - 59 -
4.9 Moisture Readings ..... - 60 -
4.10 Summary of Results ..... - 62 -

5.0 DISCUSSION ..... - 63 -
5.1 Treatment Procedure ..... - 63 -
5.1.1 Application ..... - 64 -

5.2 Control Site - 66 -
5.3 Treated material - 67 -
5.3.1 Modulus Improvements - 69 -
5.4 Particle Size Distribution - 69 -
5.5 Compare Laboratory and Field tests - 70 -
5.6 Moisture Readings - 71 -
5.7 Visual Inspection - 72 -
6.0 CONCLUSION - 73 -
7.0 RECOMMENDATIONS - 74 -
REFERENCES - 75 -
APPENDICIES - 78 -
Appendix A – Log Book - 78 -
Appendix B – Gantt Chart - 83 -
Appendix C – Material testing - 84 -
Appendix D – FWD deflection results - 87 -
Appendix E – Vertical strain calculation & SAR's - 91 -
Appendix F – Installation of Moisture sensors - 99 -
Appendix G – Previous material for Laboratory Testing - 100 -
Appendix H – Material supplied to site - 101 -
Appendix I – Poster Presentation - 102 -

LIST OF FIGURES

Figure 1.1 - Site Location, Bracalba Quarry .... - 4 -
Figure 1.2 - Trial section prior to Consolid application .... - 4 -
Figure 1.3 - Soil phase diagram for optimum composition .... - 5 -

Figure 2.1 - Typical load from a resilient modulus test .... - 11 -
Figure 2.2 - Modes for determining subgrade support .... - 13 -
Figure 2.3 - Falling weight Deflectometer setup .... - 14 -
Figure 2.4 - ELMOD6 interface for analysis .... - 15 -
Figure 2.5 - Atterberg Limits .... - 16 -
Figure 2.6 - Compaction curve .... - 18 -
Figure 2.7 - Zero air voids compaction tests results .... - 19 -
Figure 2.8 - Lime stabilisation effective curve .... - 24 -
Figure 2.9 - Foam bitumen process .... - 25 -
Figure 2.10 - Consolid System improvements .... - 28 -

Figure 3.1 - Section boxed out to 250mm….. .... - 36 -
Figure 3.2 - Material is spread on mixing pad .... - 36 -
Figure 3.3 - Material treated with C444…. .... - 36 -
Figure 3.4 - Grader windrows material…… .... - 36 -
Figure 3.5 - Transported material to site…. .... - 36 -
Figure 3.6 - Material placed and spread…… .... - 36 -
Figure 3.7 - Material treated with Solidry…. .... - 36 -
Figure 3.8 - Trial site compacted……………. .... - 37 -
Figure 3.9 - Consolid 444 sample .... - 40 -
Figure 3.10 - Solidry quality test .... - 41 -
Figure 3.11 - Position of Moisture sensors in material .... - 42 -
Figure 3.12 - Tractor and Power Harrow .... - 44 -
Figure 3.13 - Material tip truck .... - 44 -
Figure 3.14 - Smooth drum roller .... - 44 -
Figure 3.15 - Water spray truck .... - 45 -
Figure 3.16 - Front end loader .... - 45 -
Figure 3.17 - Grader .... - 45 -

Figure 4.1 - Final trial section after construction .... - 46 -
Figure 4.2 - Trial pavement profile .... - 47 -
Figure 4.3 - Control pavement profile .... - 47 -
Figure 4.4 - Particle size distribution results, Test 1 .... - 48 -
Figure 4.5 - Particle size distribution, Test 2 .... - 49 -
Figure 4.6 - Laboratory soaked CBR .... - 50 -
Figure 4.7 - Laboratory optimum moisture content .... - 50 -
Figure 4.8 - Elastic Modulus Calculated for Consolid trial site .... - 57 -
Figure 4.9 - Elastic Modulus Calculated for Control site .... - 58 -
Figure 4.10 - Moisture Sensor readings against annual rainfall data .... - 60 -

Figure 4.11 - Moisture Sensor readings against elastic modulus for Trial site .... - 61 -

Figure 5.1 - Distribution of C444 .... - 64 -
Figure 5.2 - Application of Solidry 25kg bags .... - 65 -
Figure 5.3 - Solidry dusting from harrowing.. - 65 -
Figure 5.4 - Over compaction surface cracking .... - 67 -
.Figure 5.5 - First visual inspection (22nd April 2016)…. .... - 68 -
Figure 5.6 - Second visual inspection (20th May 2016)…. .... - 68 -
Figure 5.7 - Third visual inspection (8th July 2016)…………………………………………………………… - 68 -
Figure 5. 8 - Fourth visual inspection (14th September 2016) .... - 68 -

LIST OF TABLES

Table 2.1 - Types of Stabilisation and benefits .... - 22 -

Table 4.1 - Particle size distribution, test 1 results .... - 48 -
Table 4. 2 - Particle size distribution, test 2 results .... - 49 -
Table 4.3 - Atterberg Limits for the Type 2.5 granular material .... - 51 -
Table 4.4 - Elastic Modulus results from Trail FWD testing (1) .... - 52 -
Table 4.5 - Elastic Modulus results from Trail FWD testing (2) .... - 53 -
Table 4.6 - Elastic Modulus results from Trail FWD testing (3) .... - 53 -
Table 4.7 - Elastic Modulus results from trial FWD testing (4) .... - 54 -
Table 4.8 - Elastic Modulus results from Control FWD testing (1) .... - 55 -
Table 4.9 - Elastic Modulus results from Control FWD testing (2) .... - 55 -
Table 4.10 - Elastic Modulus results from Control FWD testing (3) .... - 56 -
Table 4.11 - Elastic Modulus results from Control FWD testing (4) .... - 56 -
Table 4.12 - Number of cycles till failure (SAR's) .... - 59 -

Table 5.1 - MRTS05 Unbound Pavements grading comparison to trial sample .... - 70 -
Table 5.2 - Reported laboratory results from previous study .... - 71 -

1.0 INTRODUCTION

Soils are one of the most ancient construction materials and have been used widely due to the low cost, availability and the easy workability. The wide variety of applications extend not just in road construction however for all types of building instances. Certain soils in an untreated state can be inefficient and lack the strength and the stability which in turn can leave them unsuitable for the requirements that are needed in the application of their construction (INGLES, 1972). This can impose the limitations of the insitu properties which leaves the option to either replace the soil currently available by another material, which reaches the specific requirements or to increase the properties by the process of stabilisation (INGLES, 1972). The stabilisation process is the addition of material to the existing material to enhance the properties of the pavement. Stabilisation materials can include the use of products such as cement, lime, blended cements, bitumen and chemicals as well as additional granular material which improves the grading of the soil and hence the inter-particle friction.

Soil stabilisation began to be accepted in Australia in the 1940s and has taken off since then. The process had its usages as it was carried out for road construction, rehabilitation and heavy patching in road maintenance throughout not only Australia but worldwide (INGLES, 1972). Australia has a vast network of roads both that are sealed and unsealed. Cost effective solutions are generally imperative for road construction as there are generally restricted budgets on road assets to help keep them maintained. This also includes the impacts of environmental and social costs. Though stabilisation has primarily been used in road design it is also used in the construction of railways, airfields, infrastructure, dams and mining (INGLES, 1972).

Australia standards set guidelines for pavement material in their application in construction. This process is able to take advantage of unsuitable material and transform it to allow it to conform to the standards. One of the main benefits is being able to recycle these materials which reduces the need for excavation, transportation and the replacement of alternative material. Stabilisation has been adopted in Australia due to a number of increasing issues such as increased traffic volumes, the number of heavy vehicles on Australian roads, innovative methods used for pavement design, the benefits towards environmental and social parameters due to the construction efficiencies and the reduced traffic disruption in stabilisation (INGLES, 1972). Whilst stabilisation is still most often thought of in the context of road construction, as knowledge of techniques has increased so has the range of application; from highways to deep excavations, from dust prevention to trench reinstatement. The present increasing concern with the environment must also lead to increasing use of stabilisation for slope protection and erosion control.

1.1 Outline of Investigation

This investigation has engaged the University of the Sunshine Coast Engineering into a collaborative arrangement with Brisbane City Council, Australblend Australia and Consolid of Switzerland, as well as Pavement Management Services to implement a pilot study of a new stabilisation material for use in road making to prevent the intrusion of moisture. If successful, this investigation will then aim for the results to be integrated into pavement construction guidelines throughout Australia and the standards set for pavement design.

Previously in 2015, a desk top study was undertaken by a final year student from the University of the Sunshine Coast. In following on from this result that were derived from the previous study, Austrablend has opted to extend the research to a pilot study to help prove the merits of the stabilization product. With the critical participation from the Brisbane City Council (BCC), that has allowed this pilot study to be implemented at their quarry site at Bracalba, which is located just West of Caboolture, Queensland and can be seen in the Figure 1.1 below.

The proposed site as shown in Figure 1.2 was inspected on Thursday 15th March along with Mr. Deryck Fell, a Director of Consolid Switzerland, Mike Farrar from Consolid Australia and Peter Harris from the Bracalba Quarry. This inspection was used to assess the suitability of the proposed feeder road for the pilot study as the efficacy of the site is vital to the research project. The project is aimed to have engineered the experiment with supervision of the study to continue though out the year and this final report has been conducted to give to all necessary parties that are involved namely, Austrablend, Brisbane City Council and the University of the Sunshine Coast evidence from the outcome.

If this process is successful and the stabilization product is able to hold up on its merits, this product will also be able to seek the accreditation of TIPES. An area of further purpose is the stabilization of “black soil”. This will be integrated as a modifier to be used as the substrate for a future autonomous truck road. A concept that is being developed at the University of the Sunshine Coast. Soil stabilisation is seen as the future in pavement design. Utilising in-situ material by incorporating a stabilising additive is a cost effective solution for the improvement of subgrade material in all pavement designs.

Figure 1.1 - Site Location, Bracalba Quarry

Figure 1.2 - Trial section prior to Consolid application

1.2 Background

It is well known that if you can keep the water out of a subgrade, or natural soil, then it will provide an adequate strength for road building. This concept is important for regions around Queensland where soils can bake in the sun and become as hard as a brick. This process has been used over time and was significant during WWII, which this principle was used to make bricks out of mud in kilns beside the roads that were inadequate to drive on (SLIM, V, W., 1956). These bricks were carried by soldiers to the end of the road and dropped in the mud to help gain advancements by soldiers (SLIM, V, W., 1956).

It is also well known that the construction of a pavement draws water up under the bituminous surface. Remove the surface and it always will be wet underneath even during long periods of drought. This is why tree roots heave the pavement upwards in search of water that is closer to the surface. The products C444 and Solidry are designed to inhibit the rise of capillary water in the pavement and preserve the intrinsic shear strength of the natural material. If the shear strength is inadequate then we must improve it by mechanical stabilisation, with methods such as the addition of other material that can improve the shear strength of the material by increasing either the cohesion factor and or the angle of friction as shown in Equation 1 below.

The optimum ration of sand: silt: clay is indicated as 1/3:1/3:1/3 which places the optimum mixture for treatment with C444 and Solidry at approximately the centroid of the soil phase diagram as shown in Figure 1.3 below.

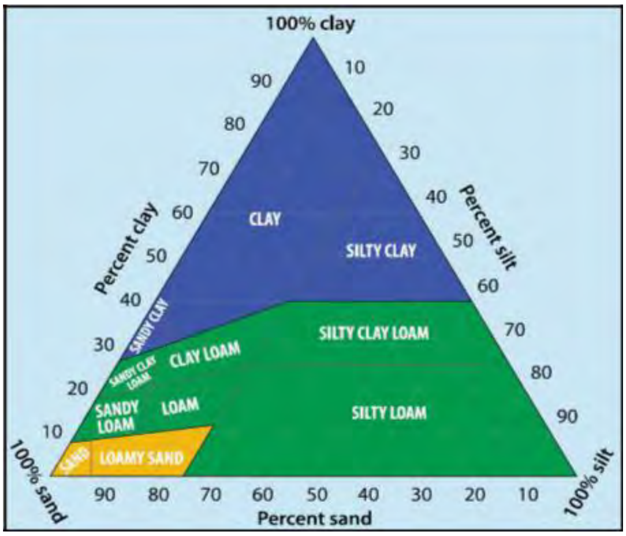

Figure 1.3 - Soil phase diagram for optimum composition

C444 and Solidry are products that have been in use for the past thirty years for improving the bearing capacity of the subgrade and subbase materials, but never before in Australia. The Consolid system is aimed to increase the natural process of solidification of cohesive soil. This process consolidates the soil and changes the behavior though does not directly act as a binder or chemical reactant. Once a soil is treated it is intended that the material will be permanently treated and be able to maintain the advantages without limitations. The improvement of the treated soil is substantial and incorporates up to 3% of clayey, silty fines material which has been recognized as being unacceptable in road construction and rehabilitation (ref). The Consolid system is designed to be able to be used with almost all types of soil.

Though Consolid soil stabilisation can act to increase compaction, it changes the behavior of the soil. As water affects the stability of soil, the Consolid system is effective in preventing the damage found from capillary rise. C444 is used alone to treat the deeper layers in a pavement, whereas due to the issue of surface water that can penetrate the upper layers a combination of Solidry and C444 is required to protect due to the complexity of the stabilisation process.

During 2015 the University of the Sunshine Coast evaluated the materials in a laboratory tests and concluded that the products had some merit in improving the Resilient Modulus of subgrade materials and should therefore proceed to field trials.

On the 9th April 2016, within the boundary of the Brisbane City Council's Bracalba Quarry along the feeder road the weighbridge, which can carry up to 350 truck movements per day, the pilot study was conducted. The trial area is approximately 240m^2 to a depth of 250mm. The site was instrumented for moisture content with the use of Pacific data systems moisture sensors (GS3), within the treated material and the subgrade. Site inspections along with Falling Weight Deflectometer (FWD) testing have been conducted throughout the trial period and provided a means of analysis for the site along with the results compared against traffic volume and weight.

The fundamentals of quality pavement design are inherently reliant on the quality of the subgrade material on which it is constructed on. Layering of compacted unbound materials produces a stable base on top of the subgrade from which the wearing surface can be placed.

Layering of compacted unbound materials produces a stable base on top of the subgrade from which the wearing surface can be laid (Austroads, 2013).

The incorporation of additives to improve the preparation of the subgrade for the foundations has many benefits such as;

- Significantly reduced permeability
- Increased material strength
- Utilization of insitu material
- Reduced pavement depths
- Increased life cycle

1.3 Objectives

The current road construction industry is continually assessing processes and materials in order to maximise the life cycle and minimise the expense of pavement designs. The idea in pavement design is to spread the load of a vehicle tyre evenly across the various layers, minimising the load on the natural material i.e. the subgrade. The strength of a subgrade or base course of a road is measured by the resistance to shear. The California Bearing Ratio test (CBR) is a surrogate shear test. Shear is governed by a physical law:

$$\tau = c + n \tan \phi \qquad \text{Equation 1}$$

Where τ = shear strength

c = a cohesion factor

n = the normal load

ϕ = the angle of friction

The objective of this pilot study was to test the proposition that C444 and Solidry will minimise the rise of capillary water in a soil thus preserving the intrinsic shear strength of the material and improving it over time, even under extreme levels of heavy traffic. This report will look into investigation of the products in field testing conditions and analyse the how the material's resilient modulus is affected over the course of the trial.

2.0 LITERATURE REVIEW

2.1 Fundamentals of Pavement Stabilisation

Identifying the subgrade stiffness is an important element in understanding how a pavement will react under load to beneficiate the design phase of a pavement (Elliot, 1988). This is often due to the resilient modulus and the modulus of the subgrade in which generally determines the performance of the load bearing capacity of the subgrade (Kameswara, 2010). A poor subgrade can cause issues for the overlaying pavements which are necessary to avoid. To help improve a subgrades performance, engineers use techniques such as removing and replacing the soil with a high quality fill, which although simple can be expensive. They allow for additional base layers on top of a subgrade; however, this can also be expensive and may not produce an adequate pavement (Elliot, 1988). Therefore, companies have headed development into stabilisation materials that can increase the subgrades stiffness, among other benefits, by applying additives to the soil.

2.1.1 Principles of Soil Stabilisation

Natural soil offers great variability that can be used in engineering applications. Soil is quite easily accessible and due to its complexity there are many methods to use it in skilful ways. The issues that arise, however, is that sometimes the natural soil can either be partially or wholly unsuitable (INGLES, 1972). Australian standards as well as council guidelines have in place requirements that must be reached before a soil can be accepted. The options involved with deciding a course or action when designing with granular material to either accept the material and conform to standards so the existing can be used, remove and replace the existing material or alter the properties so as to create a new material to meet the standards (INGLES, 1972). The last method is a form of stabilisation, however the properties of a material are able to be altered in many different ways. Due to the variability in soil there is no method that is able to be successful across all soil stabilisation. Volume, stability, strength, permeability and durability are the primary properties in which are concern when designing with a granular material (INGLES, 1972).. Although soil stabilisation should be considered as a corrective and preventative method from future adverse conditions.

2.1.2 Structures

Pavement structures provide traffic a surface of acceptable riding quality, sufficient traction, non-reflective coating and low noise generation (El-Korchi, 2009) whilst reducing the permeability through to the subgrade. According to AASHTO a pavements surface deflection under load is a telling sign of how a pavement will perform (Ping, 2011). The subgrade has often been found to be the major contributor to surface deflection. Testing for this deflection can be done in a laboratory, however the test is a relatively small sample size of the subgrade (George, 2003). Due to this there are often uncertainties as well as certain limitations from the testing procedures within a laboratory. Therefore, a Falling Weight Deflectometer (FWD) and the process of back-calculation through software are utilised as a viable device for direct testing of the resilient modulus of a subgrade.

2.1.3 Mechanistic – Empirical Design

There are various ways in which the subgrade may be analysed for the purpose of pavement design. Mechanistic and empirical are both utilised and are dependent on the approach. The empirical method looks into measuring and or estimating a CBR value, resilient modulus and deflection bowl, in which limits can be applied to these values and relies on previous successful practice. The empirical method was originally developed during the time of World War II and is considered to be outdated (Drumm et al., 1997). The practice looks at a linear relationship in which exists between the CBR and shear stress after a determined number of traffic loading. The mechanistic approach is considered to be much more scientifically accurate and pavement design is slowly directing towards using it (Drumm et al., 1997).

The mechanistic approach calculates the stresses and strains that are determined by load repetitions of the design traffic loading. Fatigue tables are used to determine the applied load repetitions and that they will be able to meet the desired life of the pavement design period (Drumm et al., 1997). Individual layers are checked to ensure that the pavement will maintain its structure (Lay, 1986). These checks include permanent deformation, flexural failure, fatigue, moisture damage, shrinkage cracking rutting and creep.

2.2 Subgrades

A subgrade is predominately responsible for a pavements performance under traffic loading conditions. The subgrades importance is based around its ability resist permanent deformation. During the pavement design process, it is important to identify the bearing capacity as it is critical during the process (NG, et all, 2013). The moisture that is able to penetrate the subgrade influences its performance heavily as it can cause permanent deformation. The determination of the subgrade stiffness for this project will be using Falling Weight Deflectometer (FWD) however there are also other techniques discussed briefly.

2.2.1 California Bearing Ratio

In the process of pavement design, it is important to understand a materials bearing capacity in comparison to that of a well-graded granular material. The use of CBR tests values are primarily used for the design and construction of pavements. These tests are often capable of identifying significant information about the pavements subgrade and are simple, cost effective tests (American Association of State Highway and Transport Officials, 2011). Although the method that they are evaluated has recently been scrutinized and a re-evaluation of how they are conducted and interpreted may be necessary. The use of CBR values is primarily for non-stabilised materials according to AASHTO (American Association of State Highway and Transport Officials, 2011).

2.2.2 Resilient Modulus

The resilient modulus is one of the fundamental material properties (Elliott and Thornton, 1988). The general behavior of a granular material is shown in Figure 2.1. This Figure shows that as the load is applied to the material, the stress increases as well as the strain (Elliott and Thornton, 1988). According to AASHO Road Test shows that there is a clear indication between the pavements surface deflection as a function of load as to how well the pavement will perform. However, surface deflection is an indicator of the causes behind how a road is being affected (BUCHANAN, S. 2007). Testing for the resilient modulus is aimed at simulating the behavior of granular material over a traffic loaded data (Elliott and Thornton, 1988). This test can be done in the lab as a sample can be prepared, which includes, the conditioning, and conducting the test so as the replicate the insitu conditions.

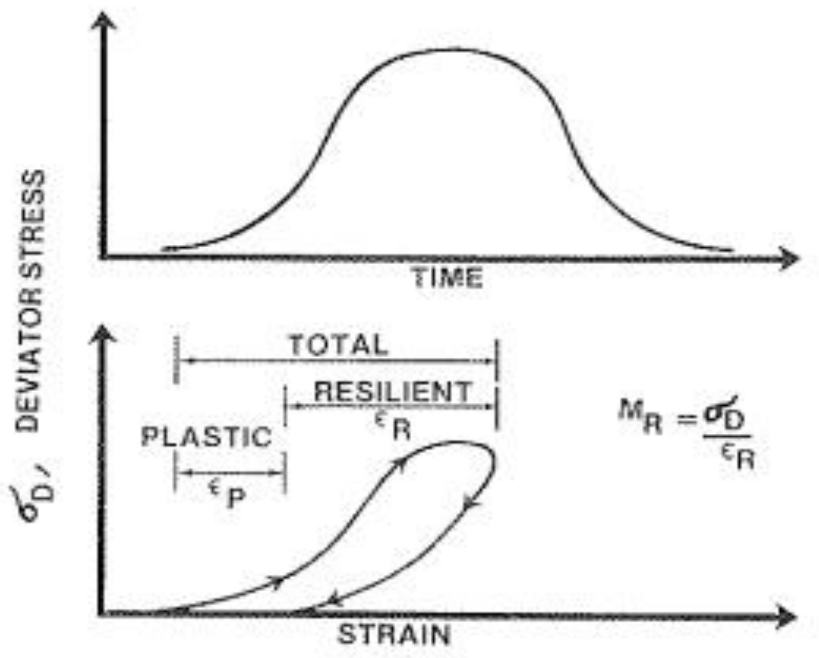

Figure 2.1 - Typical load from a resilient modulus test (BUCHANAN, S. 2007)

2.2.3 Permeability

Permeability is the flow of water movement that occurs in soils. This movement can occur in large pores, fissures as well as clays which have a voluminous system of micropores (INGLES, 1972). Soils often vary as natural open-textured create very permeable soils. The permeability of a soil can cause problems for engineers with either pore pressure dissipation or seepage flow. However, if there is inadequate dissipation this can lead to slip failures whereas excessive seepage flow may cause tunnelling failures (INGLES, 1972). This can occur in regions with irregular rainfall the permeability can result in issues at construction as impermeable clay can form water tables, drainage problems and affect the bearing capacity. Low permeability is an issue which can result in the lack of adhesion between a bituminous seal and occurs in soils which usually contain high clay content (INGLES, 1972). High permeability can happen from poor compaction in soil, as clay chunks aren't compacted as well and creating voids. Permeability can be measured either in the field or in the laboratory however laboratory conditions are preferred as small changes can affect the measurements. Field measurements require an understanding of the water table and the inflow and outflow of the soil (INGLES, 1972). Problems related to the permeability in soils can be altered by different methods such as drainage, compaction and stabilisation.

2.2.4 Soil Suction

If water contained in the voids of a soil were subjected to no other force than that due to gravity, the soil lying above the water table would be completely dry. However, powerful molecular and physical-chemical forces acting at the boundary between the soil particles and the water cause the water to be either (a) drawn up into the otherwise empty void spaces or (b) held there without drainage following infiltration from the surface. The attraction that the soil exerts on the water is termed soil suction and manifests itself as a tensile hydraulic stress.

2.3 Testing Techniques

There are two primary modes that are utilized for estimating the subgrade support, with either tests done in the field or in the laboratory (AUSTROADS 2009). It is often critical to accurately determine the suitability of a subgrade for design purposes and also life spans. Laboratory testing is used when the subgrade soil conditions are expected to be similar to the proposed pavement as well as determining the subgrade support from first principles. Field testing however is appropriate to use when the support values from in situ subgrade soil are expected to be similar to the proposed pavement (AUSTROADS 2009). Although when conducting laboratory testing it is important to incorporate the sample density, moisture and soaking conditions to replicate the expected pavement conditions. There is a number of testing methods that can provide a CBR of the subgrade in which these are based on empirical correlations that have variability. Figure 2.2 from Guide to pavement technology part 2: Pavement Structural design illustrates the two modes.

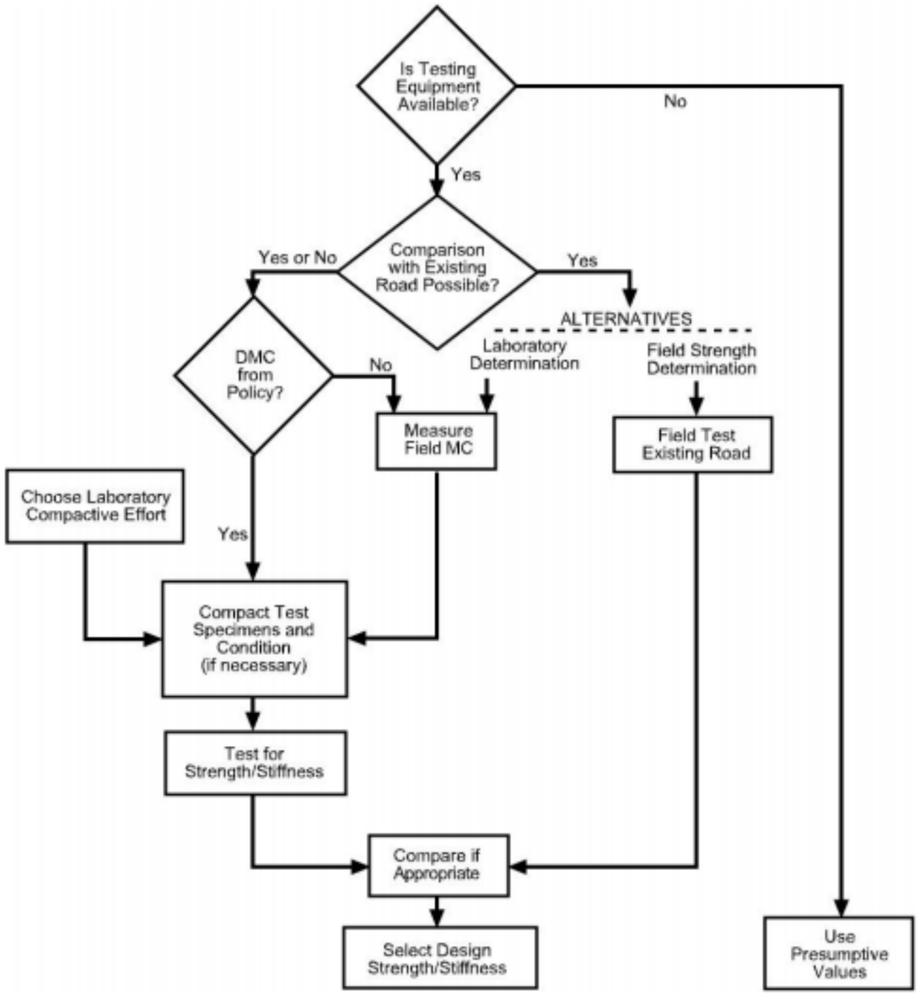

Figure 2.2 - Modes for determining subgrade support (AUSTROADS, 2013)

2.3.1 Falling Weight Deflectometer Testing

The Falling Weight Deflectometer (FWD) is an instrument that has been used for the evaluation of pavements by means of non-destructive testing. This type of test is able to measure the vertical deflection response of a surface to an impulse load as shown in Figure 2.3. This method of testing was introduced in Europe to help maintain the networks of flexible pavements and then expanded into being used for different types of pavement. This method is the world's standardised dynamic plate bearing test that prevents non-destructive analysis of the structural capacity of a pavement (Karim Chatti, 2004). The equipment is generally attached to a trailer and consists of nine seismic geophones which can measure the deflection of the pavement. This is designed to apply an impacting load that is equivalent to a wheel load that is moving across the surface. This load is a known applied load that is subjected to the surface and the response is then analysed through varies software programs in which can indicate the elastic moduli, the stress and the strain of each layer (Karim Chatti, 2004). The surface of the pavement performs and deflects in the form of a bowl which the deflection depends on the stiffness of the modulus of the subgrade reaction.

A number of models have been designed to help with the back calculation of the elastic moduli. The FWD is raised by a hydraulic ram along a vertical guide and lifted to a predetermined height that can vary by a catch mechanism that is performed to drop when reached by the operator. Once the catch is released, the weight is dropped and a force is transposed to a circular plate onto the ground and then this process is repeated.

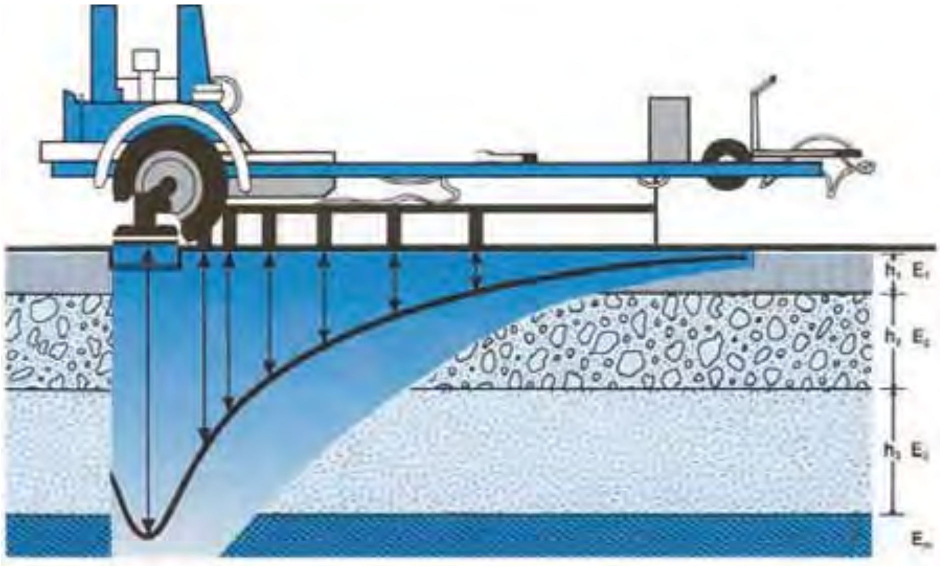

Figure 2.3 - Falling weight Deflectometer setup (Dynatest, 2016)

2.3.2 Elmod6

Elmod is a pavement analysis program designed by Dynatest to model pavement performance. Elmod analyses a pavement response that is given from the FWD and HWD testing by determining the modulus as well as the stress and strain of each layer (Dynatest, 2016). The benefits of this program is that it allows for rapid analysis. Elmod uses backcalculation which is a method that can evaluate the structural capacity of a material by giving an estimate on the moduli of pavement layers which is taken from the deflections measured by the FWD testing (Dynatest, 2016). Below in Figure 2.4 shows the interface for the EMOD6 program which displays a typical reflection of the deflection bowl created by Elmod from the testing conducted at the Bracalba Quarry.

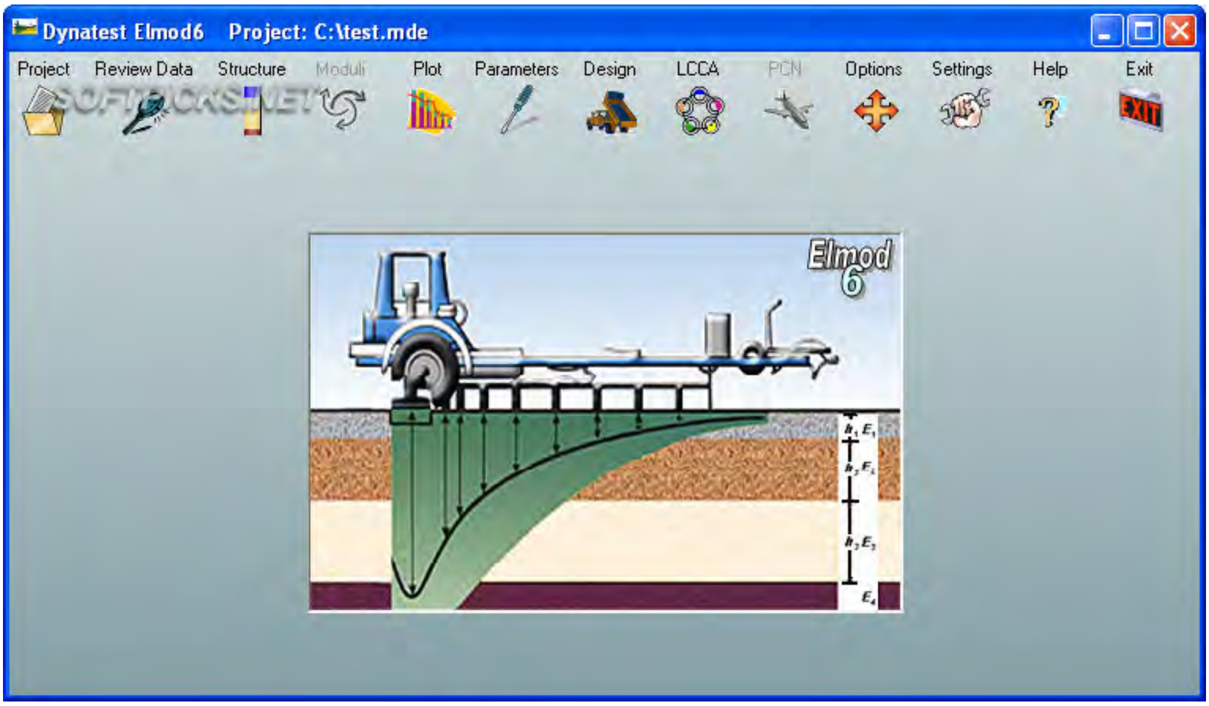

Figure 2.4 - ELMOD6 interface for analysis (Dynatest, 2016)

2.3.3 Moisture Sensors

Moisture is a significant factor which influences a pavements performance. The moisture that is associated with a pavement affects the unbound materials stiffness/strength whilst the subgrade is also dependent on the moisture content. There are a number of factors in which need to be considered and assessed when designing a pavement. Understanding the rainfall/evaporation pattern can be crucial for how a pavement is going to perform. One of the effects of variation in moisture can result in reactivity in certain types of subgrade materials. Though moisture can affect a pavement in different ways, whether the wearing surface is permeable, how deep the water table is, sealed or unsealed condition of the shoulders, as well as adequate pavement drainage. Moisture changes in pavements can result in transfer of moisture, in either the liquid or vapour states known as soil suction. Though the biggest effect of moisture in unbound granular material is that it can experience significant loss of strength/stiffness.

The sensors used for the trial are the GS3 – Water content, EC and Temperature Sensors produced by Decagon Devices. The sensor uses an electromagnetic field which is able to measure the dielectric permittivity of the surrounding material. Stored charge is able to be proportional to the substrate dielectric and volumetric water content. The dielectric reading is then able to be converted to water content by a calibration equation specific to the material that it is implemented in. The GS3 is calibrated in different types of materials. This creates a generic calibration equation that can work for all types of substrate.

$$VWC\left(\frac{m^3}{m^3}\right) = 5.89\ x\ 10^{-6}E^3 - 7.62\ x\ 10^{-4}E^2 + 3.67\ x\ 10^{-2}E - 7.53\ x\ 10^{-2}$$

(Source: Decagon Devices, Inc. 2016)

2.3.4 Atterberg Limits

The Atterberg limits have been modified for geotechnical engineering purposes. There are three states in which contribute to the limits. Firstly, the shrinkage limit (SL), secondly the Plastic limit (PL) and finally liquid limit (LL). The plasticity index is referred to as the stage between the PL and the LL as the soil remains plastic. The limits can be seen in the Figure 2.5 below.

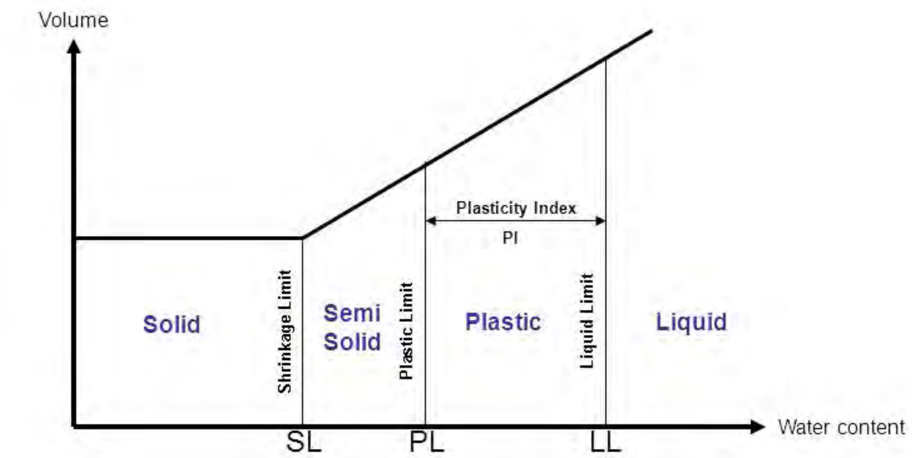

Figure 2.5 - Atterberg Limits

2.3.4.1 Shrinkage Limit

If a soil is below this limit it is susceptible to becoming more brittle in its behavior as well as not reducing in volume as drying occurs.

2.3.4.2 Plastic Limit

This limit is the lowest limit in which is defined as the moisture content that a soil crumbles when rolled to threads. The water content gives a plastic nature to the soil.

2.3.4.3 Liquid Limit

The Liquid limit is the state in which the soil changes from a plastic substance to liquid behaviour.

2.3.4.4 Plasticity Index

The plastic index is the water content that lies between the plastic limit and the liquid limit. The plasticity index can be found from the Equation below.

$$Plasticity\ Index\ (PI) = Liquid\ Limit\ (LL) - \ Plastic\ Limit\ (PL)$$

2.3.5 Maximum Dry Density (MDD)

The maximum dry density of a material is determined by establishing the moisture-density relationship of the material when prepared and compacted at different moisture contents. The modulus depends on both density and moisture content. It is essential that the design modulus be estimated for conditions which approximate those to occur in-service. Where samples are to be tested for the determination of design modulus, testing should be conducted at conditions of anticipated field moisture content and density.

In the absence of more reliable site-specific information, in severe environments, such as the following, soaked conditions may be adopted:

- Floodway, causeways and other pavements likely to be regularly inundated
- Cuttings below the water table or when seepage is likely
- Other situations where the water table is within one metre of the subgrade level

2.3.6 Optimum Moisture Content (OMC)

The optimum moisture content (OMC) is the value at which the soil can achieve its maximum dry density. This is the degree or percentage of moisture in a soil at which the soil can be compacted to its greatest density. When water is added to a dry soil, this allows the solid particles to become close due to a coating of water. As water content is increased, water begins to act as a lubricant, this allows particles to come closer due to the workability. The soil-water-air mixture occupies less volume under a given amount of compactive effort thus increasing in dry density. More and more water can be added as a stage is reached to which the air content of the soil reaches a minimum volume resulting in a maximum dry density. The water level that corresponds to the maximum dry density is in turn the optimum moisture content. Addition of water beyond the optimum reduces the materials dry density as this extra water begins to occupy the space in which the soil could occupy.

As shown in Figure 2.6 the curve of the peak is known as the compaction curve. This shows the state at the peak which is to be that of 100% compaction to create a hyperbolic form when the points are joined from particular compactive effort.

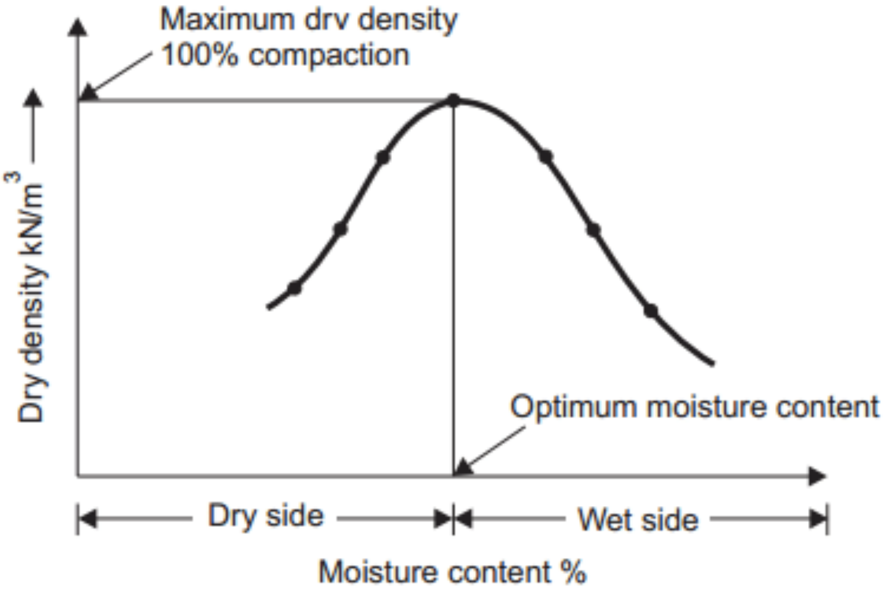

Figure 2.6 - Compaction curve

For given moisture content, the maximum dry unit weight is obtained when no air is in the void spaces, therefore when the degree of saturation equals 100%. The maximum dry unit weight at a given moisture content with zero air voids can be obtained. Figure 2.7 shows moisture content and its relative location with respect to the compaction curve. Under no circumstances should any part of the compaction curve lie to the right of the zero-air void curve.

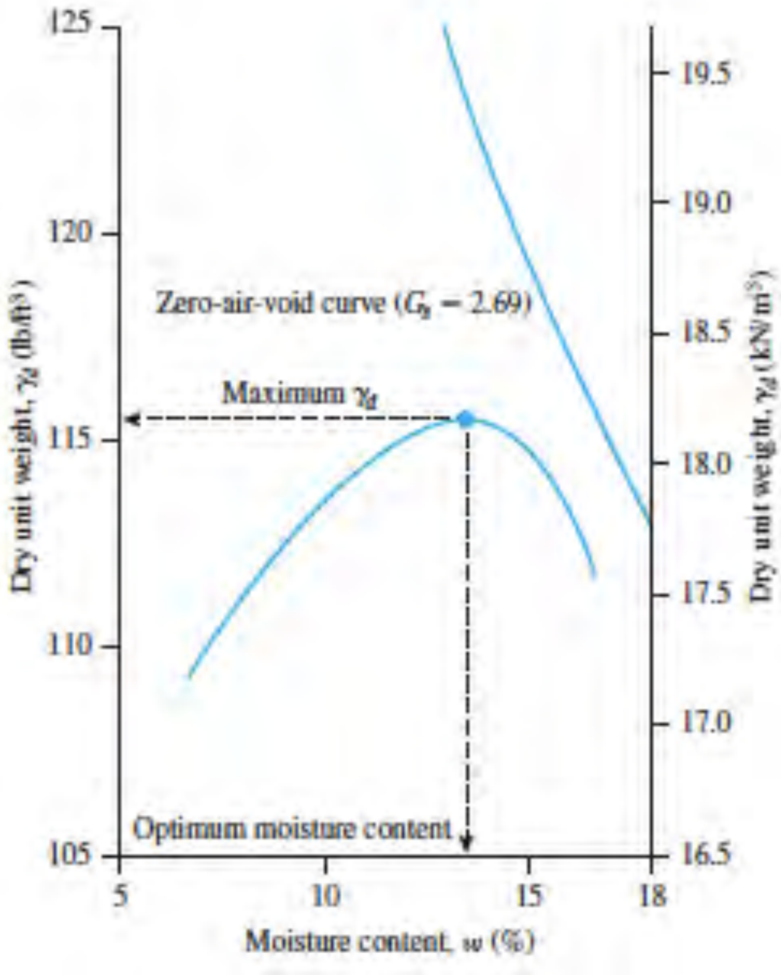

Figure 2.7 - Zero air voids compaction tests results

2.4 Stabilisation Additives

Stabilisation is the process of altering the intrinsic properties of a pavement material by the addition of stabilisation additives which are designed to enhance the performance in its operating, geological and climatic environment (LTD, A. 2015). Stabilisation can be used for new road construction or during the rehabilitation of existing pavements (LTD, A. 2015). There are some main focuses for stabilisation.

- Alleviate granular material deficiencies such as particle size distribution and or plasticity
- Increase the bearing capacity by increasing the unconfined compressive strength and or resilient modulus of the material
- Reduce the permeability to prevent loss of strength from moisture sensitivity
- Cost-effective new pavement layers
- Increase the wearing course of unsealed pavements
- Improve the subgrades strength
- Enhance the compaction of unbound granular material

There are a number of variations available to add to pavements for different outcomes as well as for different purposes.

2.4.1 Mechanical Stabilisation

Mechanical stabilisation is the improvement of a certain material by blending it with one or more granular material. This type of stabilisation provides a means to alter the particle size distribution (PSD) in the material and improve the inter-particle friction (LTD, A. 2015). Altering of the PSD can also enable changes to the plasticity, by changing the Atterberg limits of the material as well. Most importantly compaction can be increased by mixing water in at optimum moisture content. Materials produced by mechanical stabilisation have properties similar to conventional unbound materials and can be evaluated by conventional methods (LTD, A. 2015).

As mentioned previously, internal friction and cohesion are two main factors that can affect the stability of base and subbase materials. The internal friction is a result of the characteristics of soil particles grading (AUSTROADS, 2013). The cohesiveness is primarily in regards to the quantity and nature of the clay, which is determined by plastic properties and maximum dry strength.

Granular or mechanical stabilisation can involve:

- Mixing of materials from various parts of a deposit at the supply
- Mixing of selected materials with in-situ materials
- Mixing of existing pavement layer materials with water only
- Mixing two or more selected, imported natural gravels, soils and or quarry products on site or in a mixing plant
- Mixing recycled materials with existing pavements

2.4.2 Cementitious Stabilisation

Cementitious stabilisation refers to the use of either cement or supplementary cementitous materials. The utilisation of this type of stabilisation is to strengthen existing pavements, improve low quality material for a base and subbase, mitigate increasing base thickness to achieve design strength and to dry out wet pavements (LTD, A. 2015). The reaction of stabilising binders is with water and soil; this essentially leads to the formation of the materials (LTD, A. 2015). The stabilising binders are used to stabilise a wide range of materials such as gravels, silts, sands and low plasticity cohesive materials (AUSTROADS, 2013).

Hydration is the primary reaction of the cementitous stabilising binder with the water in the soil. This results in to formation of a cemented material. Hydration releases hydrated lime and can cause a secondary reaction with any pozzolans in the soil (LTD, A. 2015). Pozzolans are a silicate-based material and their reactions are slow to react and continue over a period under the circumstance that there is moisture present (LTD, A. 2015). Temperature also has a major factor in the sensitivity of the reactions, the rate will increase with increasing temperature. The best results for stabilisation with cementitous material relies upon the amount of lime, pozzolans and pavement material (AUSTROADS, 2013).

Table 2.1 - Types of Stabilisation and benefits

Stabiliser	Type	Comments
Cement	Portland Cement	• Defined in AS3972. • Hydraulic cement • manufactured as homogeneous product • Produced by grinding together Portland cement clinker and calcium sulphate • Can contain up to 5% of mineral additions
Cement	Blended Cement	• Hydraulic cement containing Portland cement • Added quantity comprised of 5% fly ash or ground granulated iron blast furnace slag • Up to 10% silica fume • Increasing trend towards the use of blended cements • Allows longer working times to achieve better compaction and smoother surface • Reduces possibility of shrinkage cracking
Cementitious materials	-	• Provide alternative to GP cement • Extended working time for compaction and finishing • These blends are used where technically and economically feasible • Pavement gains higher strength over time and reduced cracking
Pozzolans	Ground Granulated Blast Furnace Slag	• A siliceous or alumina siliceous material • Chemically reacts at ordinary room temperatures with calcium hydroxide • Granulated blast furnace iron slag is formed when high pressure, high volume water sprays hit molten slag • Reaction causes molten slag to explode and form granulated particles • Common combination of slag/lime blends (85:15)
Fly ash	-	• Product of the power generation industry • Chemical composition and PSD is determined by the plant • Derived from burning black coal, high in silica and alumina • Derived from brown coal is unsuitable for use in stabilisation • Should conform to AS3582.1

2.4.3 Lime Stabilisation

Lime stabilisation is effective for plastic soils to help improve their strength and workability. However, in cohesion-less or low cohesion materials, lime stabilisation is ineffective and requires the addition of pozzolanic additives (LTD, A. 2015).

The addition of lime into suitable clay materials results in:

- Reduced plasticity
- Drying out of wet materials
- Increased CBR
- Reduced shrink/swell
- Facilitates compaction

Lime stabilisation can be used in subgrades and there are two approaches that can be used. The minimum lime content plus 0.5% and determine the resultant CBR (LTD, A. 2015). This result is used to determine the pavement thickness required above the treated subgrade. The use of a range of lime contents above the minimum content to ascertain the resultant unconfined compressive strength (UCS). From this point a minimum UCS is determined to optimise the pavement design (LTD, A. 2015).

Small amounts of lime modify the clay to a granular material and therefore increases the permeability. Though due to the chemical change the resultant soil structure does not attract and absorb water (LTD, A. 2015).

Types of Lime

- Hydrated lime (Calcium Hydroxide)
- Quicklime (Calcium Oxide)
- Dolomite lime (Calcium/Magnesium Oxide)
- Agricultural lime (Calcium Carbonate)
- Limestone ($CaCO_3$)

Hydrated and Quicklime are the most effective types of lime used for stabilisation. Agricultural lime is not suitable for stabilisation whilst dolomitic lime is less effective. The oxide reacts with the available water and forms hydroxides and results in the immediate effect on clay by improving the grading and handling properties of the clay. The long term effects on strength are improved over time as shown in Figure 2.8. The lime also allows a reduction in thickness required for the pavement as the material can be used as a lower subbase.

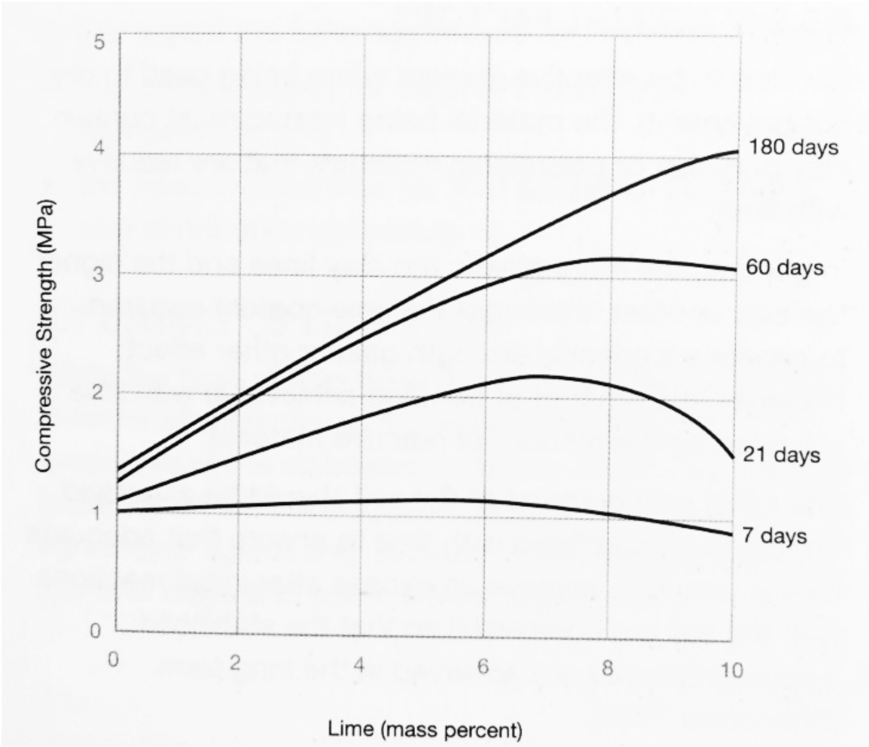

Figure 2.8 - Lime stabilisation effective curve (LTD, A. 2015)

2.4.4 Bituminous Stabilisation

Bitumen stabilisation involves pavement materials that are treated with bitumen emulsion or foamed bitumen. The materials treated are generally granular materials, cement treated materials or asphalt pavement (AUSTROADS, 2013). This form of stabilisation is intended to cause cohesion into non-plastic materials as well as make cohesive materials less sensitive with increased moisture.

There are a number of benefits of bitumen stabilisation. Like other stabilisation the strength increased with bitumen treatment allows this to act as a replacement for high quality materials (LTD, A. 2015). Whilst the finer particles that are encapsulated in the bitumen are immobilised and therefore increase the durability as well as moisture sensitivity. This type of stabilisation has advantages in regards to the environmental impacts as it conserves natural aggregates, material wastage, noise, exhaust, dust emissions as well as traffic disruptions (LTD, A. 2015).

2.4.5 Foam Bitumen

The foam bitumen is a combination of air, water and hot bitumen. This is produced by injecting small amounts of cold water into the hot bitumen which, creates an instantaneous expansion in the bitumen, this process is shown in Figure 2.9. This can create up to 15 times the original volume (LTD, A. 2015). The viscosity is enhanced by the increase in the surface area which allows the mixing with damp and cold aggregates. Rapid mixing is required to help disperse the bitumen through the material as the foamed bitumen collapses reasonably quickly.

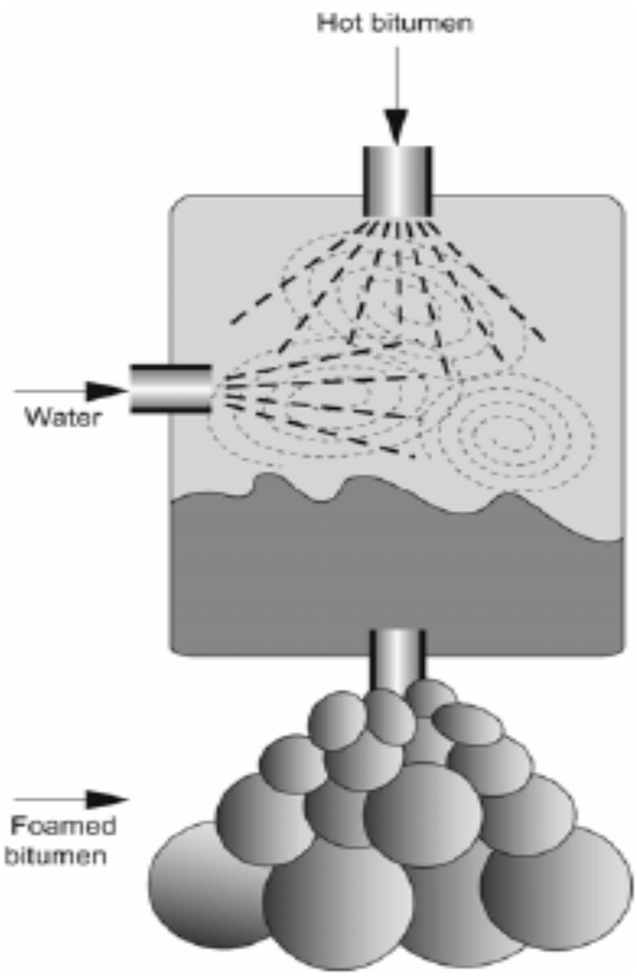

Figure 2.9 - Foam bitumen process (LTD, A. 2015)

2.4.6 Bitumen Emulsion

Bitumen emulsions are formulated from fine droplets of bitumen in water. Standard mixtures are designed from approximately 60% bitumen and 40% water with the small addition of emulsifier (LTD, A. 2015). Though higher content of bitumen can also be present up to 80%. The process involves separating and removing water to leave the solid bitumen remaining (LTD, A. 2015). AS1160 is used to help comply with the manufacturing of Bitumen emulsions as this can allow for two classes which are Anionic bitumen emulsion and Cationic bitumen emulsion (LTD, A. 2015).

2.4.7 Other Types of Stabilisation

2.4.7.1 Dry Powered Polymers (DDP)

DDP is used as a binder for stabilisation in the rehabilitation of granular materials in pavements. This product is considered to water proof the materials to help reduce the strength losses causes by moisture ingression (AUSTROADS, 2013). DPP stabiliser is able to be remixed, reshaped and re-compacted without any loss in dry strength. This can be carried out using plant and equipment that is used in cementitous binders (LTD, A. 2015).

2.4.7.2 Chemical Dust Suppression

Dust suppressants are used to help control dust on unsealed roads. This type of stabilisation should be used with other methods of stabilisation as dust suppressions are restricted to a short life time and often require further applications (LTD, A. 2015). These chemical suppressants are classified by the following:

- Non-bituminous organic products – these are a by-product of the paper pulping industry, the reaction in the soil is by gluing the soil particles together and make the clay more plastic and increase the density.
- Water attracting – these consist of chlorides and salts and react by trapping moisture and keep the wearing course moist.
- Petroleum products – This type of product consist of bituminous emulsions and tars. These can have environmental consequences however create agglomerations of dust particles.
- Microbiological binders – This acts by consuming clay fraction and create a polymeric residue to act as a binder.
- Polymers

2.5 Consolid System

The Consolid system stabilisation system was expressly developed for soil stabilisation. The Consolid system does not react as binder or oxidant (Consolid Ltd UK). The system is aimed to speed up the natural process of solidifying of all kinds of cohesive soil. It has a favourable influence to the soils characteristics. There are two products in which are used together to create this type of stabilisation. Consolid 444 (C444) and Solidry. The C444 is a liquid product and the Solidry is a powder component. Both of these components are mixed thoroughly through the material so that they are distributed uniformly. It is essential to properly mix products so that the particles surfaces are covered. The material is then able to be compacted as this should also take place to maintain OMC. If the moisture content is too high, then there is a problem that can arise from entrapped moisture resulting in deflection and cracking under traffic. Improvements of the materials properties are aimed to reduce the permeability and the capillary rise whilst also increasing the CBR as well as the unconfined compressive strength and stiffness (Consolid Ltd UK). Consolid can be used in to reduce swelling in reactive soil as it helps to prevent water from softening the soil after curing. The moisture content remains low during soaking and the dry strength is retained. The strength is gained by the evaporation of moisture (Consolid Ltd UK). The system works in areas with high humidity. A surfacing is generally required as for other types of treated or untreated base course so to prevent abrasion (Consolid Ltd UK).

The areas in which the Consolid System are aiming to be applied are:

- Heavy-duty roads including major highways
- Low volume roads including rural and urban
- Pavement shoulders
- Embankments
- Car parking
- Road rehabilitation
- Airports

2.5.1 Consolid 444 (C444)

The C444 product is designed to reduce the surface tension of water around soil particles so that the film surrounding them is dispersed. This develops an agglomeration of the fines material. This helps to waterproof the material as C444 is not a binding compound. The C444 is mixed with water and is applied at a rate of from 0.4 to 0.8L/m^3 and is applied to depths of 150 to 300mm (Consolid Ltd UK). The mechanism of stabilisation is basically the formation of cations during evaporation as higher strengths are achieved through keeping the soil dry.

2.5.2 Solidry

The Solidry is much similar to the C444 in its mechanisms and the formation. However, the Solidry is able to be applied to the upper layer to 50 to 100mm of the pavement that has been treated prior with C444. The powdered product is applied at a rate of 0.5 to 1% by weight of the soil.

Country:	Soil Type:	Soaked C.B.R. untreated	Soaked C.B.R. treated	INCREASE in %
U.K.	clay	2-3	15	500
	silty clay	1-3	35	1200
	keuper marl	3	85	2800
Italy	A-7-6 lagoon sludge	3.5	14	400
	A-7-5 lagoon sludge	2	6	300
	A-7-5 lagoon sludge	1	5	500
France	silty clay	12	28	230
	clayey silt	10	24	240
U.S.A.	Silty clay	7	38	540
	Clayey silt	6	35	580
Australia	Sandy clay (CL)	2	50	2500
	Basaltic clay (CH)	2	9	450
	Silty sand (SP)	12	110	910
	Clayey gravel	25	80	320
	Sandy silt (GM)	12	45	375
	Gravelly sandy silt (ML)	11	35	310
	Silty sand (SM)	22	90	405
	Gravelly silty sand (SM)	4	20	500
	Silty clayey gravel (GC)	20	95	475
	Silty sand (SM)	6	45	750
	Silty sand (SM)	6	70	1150
	Red sand	3-4	40-45	1100
	Sandy silty clay	2,5	35	1400
	Mixture clay:crusherrun 1:1	3	40	1300
Indonesia	Lateritic clayey gravel	21	78	370
Philippines	A-4-5 silty clay	9	23	250
Neuzealand	clayey silt	4	38	950
South Africa	clayey silt	5	55-70	1400
	lateritic clayey gravel	67	225	330
Zimbabwe	clay	1	20	2000

Figure 2.10 - Consolid System improvements

2.6 Stabilisation procedures

For stabilisation to be effective it is essential for an assessment to be conducted first of the materials types. This is inclusive of the materials within and beneath the pavement as well as the condition. There are two types of stabilisation in which can take place such as Plant mixed and In-situ. The climate conditions also must be considered to ensure the suitability for construction process and binder reactions. Australia is known for its diverse climates of which the extreme conditions experienced can affect road stabilisation. Guide to pavement technology – Part 4D: Stabilised Materials and Part 4L: Stabilising Binders should be considered for guidance, testing and the quality control of the materials suitable for stabilised pavement.

2.6.1 Plant Mixed Stabilised Materials

For plant mixed stabilisation the materials and binder are blended through a Pugmill, which in turn discharges into a truck or an off-road delivery vehicle. The blended material is normally laid on site through a paver (AUSTROADS, 2009). The parent crushed materials for plant mixing are typically stockpiled close to the mixing plant generally as approved or compliant stockpiles in terms of meeting rushing and screening specifications.

The stationary plant is most applicable where all the material is sourced from a single supplier, a high degree of uniformly is required and the haul to the placement area is relatively short. Care should be taken in using Pugmills to ensure that the binder selected has a working time sufficient to allow for haulage to site, placement and compaction (AUSTROADS, 2009).

The delivery requirement of plant-mixed stabilised materials depend upon the designated working time and ambient weather conditions at the time of placement. It is recommended that, regardless of the weather conditions, all plant mixed stabilised material is delivered in covered trucks with a maximum transportation time of half the working time of the binder (AUSTROADS, 2009). In this manner, loss of moisture through evaporation or wetting due to rain is minimised during transportation and sufficient time to place and compact is available at the site. Transport time = ½ working time (AUSTROADS, 2009).

Placement is undertaken by a grader spreading and shaping or by paver. When selecting a paver, the width should be governed by the ability of the rollers to apply full compaction within the working time without excessive drying out.

2.6.2 Insitu Stabilisation

There are many factors affecting production levels however, experience has shown that production rates for stabilisation depths up to 200mm are 3000 to 5000m^2 per day and 2000 to 4000m^2 per day for depths greater than 200mm for one set of plant (AUSTROADS, 2009). In planning an insitu stabilisation project all factors affecting production levels should be taken into account to minimise the risk of assuming unrealistic production rates (AUSTROADS, 2009).

In urban areas where there are fixed levels, an increase to the levels from a granular overlay will necessitate the raising of kerb and gutter and medians as well as the adjustment to driveways, footpaths and service covers. Where kerb levels cannot be altered, incorporating a recycled pavement can still be accomplished by lowering the formation level and reconstituting a thicker overlying pavement (AUSTROADS, 2009). The pavement material is removed to one side to expose the formation. The new top of subgrade will be formed often requiring disposal of some material (Kowalski and Starry Jr, 2007). The pavement material previously saved is then placed on the subgrade and stabilised. Sometimes additional material is added at this time if a thicker pavement is required(Kowalski and Starry Jr, 2007).

2.7 Resilient Modulus

The resilient modulus is an important mechanical property widely used for the analysis and design of pavements. The determination is therefore important as it is used for the mechanistically based design/analysis procedure for pavements (Stolle et al., 2009). For stabilised materials the resilient modulus is dependent upon the fatigue relationship used in design. It is important to understand that the resilient modulus is in fact a measure of the stiffness and is not the strength in which the point where material permanently deforms or fails (Stolle et al., 2009). Pavements are designed to withstand various magnitudes of design axle (single, tandem, tridem and quadem) load applications

- Granular stabilisation – Confined triaxial tests or UCS relationships
- Modified stabilisation – Indirect tensile tests or UCS relationships
- Bound stabilisation – flexural tests, triaxial compression tests or UCS relationships

2.7.1 Resilient Modulus Influences

As the resilient modulus is used to determine a pavements stiffness under loading conditions there are a number of influences in which have a direct affect to the resilient modulus (Buchanan, S., 2007).

2.7.2 Compaction

Maintaining the density that is observed at the target field is important for specimens to be able to obtain the most realistic performance for the resilient modulus (Buchanan, 2007). This is evident as when a sample is compacted at a lower density it shows a result of a lower moduli when compared to that of a higher density (Buchanan, 2007). The compaction however can also be resulted from the aggregate size, particle shape and grading as well.

2.7.3 Stress State

The stress state is appropriate to be calculated correctly so that the resilient modulus can be found. The stress state is a function of confinement and applied stress to the material. The bulk stress is calculated and represents the total materials stress state. It is critical to determine the relationship between resilient modulus and stress state. A higher fines component results in a decreased stress state and the further the material lies in the pavement structure.

2.7.4 Moisture Content

A materials performance can be affected drastically by the moisture content. Due to this it is important to test materials at their optimum moisture content (OMC) by Proctor testing. Though it is important to reach the materials OMC it is also essential for the material to be tested close enough to the field conditions (Buchanan, 2007). The resilient modulus will decrease as the moisture content increases along with the saturation.

2.8 Material Grading

Material grading can be accurately measured and checked by making a reference to the plasticity. The grading enables research to assess a relationship of the PSD which helps to determine the resilient modulus and how this is impacted. High fines percentages in a materials PSD can cause a decrease in the resilient modulus as oppose to the opposite which results in a higher gravel percentage increasing the resilient modulus.

2.9 Benefits of Stabilised Materials

The benefits of soil stabilisation are aimed to improve the quality of the subgrade materials for recycling and to reduce the need for imported materials. The high production rates of stabilisation can improve the construction expediency. Whilst stabilisation reduces the shrinkage rate of high plastic clay and increases bearing capacity. Mechanical mixing and compaction of extremely weathered rock improves permeability by reducing the scope for seepage through lenses, fissures and other faults. The environmental benefits can reduce the quantities necessary of quarry products, export to tip sites and less traffic loading on the surrounding roads. The permeability helps to improve the physical and chemical properties of clay which results in a stronger material. The process often will increase the strength of the material to be able to handle increased traffic loadings.

3.0 METHODOLOGY

This section covers the procuring, furnishing, mixing and placing of approved soil or on the top of the subbase at the Bracalba Quarry feeder road. This includes the provisions of the additives Consolid 444 and Solidry and their correct application in the construction of a base course in accordance with the requirements of these specifications.

3.1 Investigation Method Overview

3.1.1 Prior to Treatment

For the purpose of classification, the material used in this study, prior to treatment is identified as a type 2.5 unbound granular material, as specified by the Bracalba Quarry, shown in Appendix C. Prior to the pilot study, a 100kg sample of the approved unbound granular material was obtained to be used for the following tests. Though the testing of the material is provided from the quarry.

- Particle size distribution
- Lower Liquid Limit
- Lower Plastic Limit
- Plasticity Index
- Clay to Silt ratio
- Dry weight and optimum moisture content (also to include zero air voids line)
- CBR test.

As the product is aimed at decreasing the capillary rise it was deemed necessary to obtain moisture gauges in which are implemented into the material at the subgrade and upper layer.

3.1.2 Following Treatment

During the mixing and compaction is when the moisture gauges were fitted into the treated material at the mid depth.

At 14 days, 30 days, 60 days, 90 days:

- Falling Weight Deflectometer tests at 10 m spacing and 5 m stagger across the Test material and the parallel Control site.
- Determine the resilient modulus of the treated layer by back calculation of the deflection bowl to be carried out in the program ELMOD 6.
- Visual inspection of the site
    - Identify potholing and any deformation
    - Identify cracking by type
        - Fatigue
        - Shrinkage
        - Settlement
- Measure moisture content

3.1.3 Final Analysis

- Plot pavement resilient modulus at each test point of the FWD testing
- Calculate the mean Modulus and coefficient of variation for the site and the elapsed time
- Use this value of modulus to calculate the strain at the top of the subgrade
- Use the strain data to determine the number of cycles to failure for the permanent deformation for each time interval
- Chart the moisture contents at both locations by time

3.2 Road Construction

The methodology used to assess this study utilised the resources available in regards to testing apparatus from USC and the storage facilities at USC. The time and equipment provided by from Brisbane City Council workers at Bracalba Quarry was invaluable to concluding this trial. Falling Weight Deflectometer (FWD) testing and advice from Pavement Management Services (PMS) and material supplied (C444 and Solidry) by Austrablend along with guidance on its use provided great assistance thought-out this period.

The trial study was conducted at Bracalba quarry on 9^{th} April 2016. The proposed area was initially boxed out to the area of 30 m by 8m and to a depth of 250mm. A mixing pad of approximately $230m^2$ was required for the premixing and treatment of the soil. The soil was then split into two 104 ton samples and initially a 52-ton sample of road base at approximately 5 m wide was spread to depth of 100 to 150 mm. This initial sample was then treated with approximately 45 Litres of prepared C444 solution that was uniformly spread over the sample and then was mixed with a power harrow with five passes to guarantee an absolute mix. On the treated base, the additional 52 tons of road base was repeated with the treatment of C444 application, with the equivalent method to the previous sample. Once the site was prepared to the required depth of 250mm the sample was transported to the site and spread to a depth of 125mm after compaction with a pad foot roller. This first layer was then compacted and the corners as well as other inaccessible areas were compacted with a whacker plate.

This process was repeated and conducted for the final sample of the road base with the initial mixing process with 52-ton road base harrowed and graded before applying the 1 ton of Solidry product. It is important to distribute the Solidry uniformly, the Solidry is supplied in 25kg bags which enabled a distribution at approximately one bag per 6 m^2. This was further assisted by the harrowing process and grading of the material. The Solidry had to be fully incorporated, to a minimum of five passes at 100 to 150mm depth. The process was then repeated identically on the final 52 tons before transporting to the site.

The excavator helped to effectively spread the treated material with the use of a grader before compaction with the smooth drum roller. At all times the process had to be observed to ensure optimum moisture content. The treated road base was aimed to maintain approximately 10%

so that when squeezed in the hand, the road base holds firm without showing finger indentations which will indicate that there is effectively too must moisture. The final sample was then compacted and the final product of the road construction was completed. It should be noted that the initial surface cracks that were present were due to the over compaction of the material. The surface cracks were rectified before the end of the process. The process from the treatment and construction of the trial site can be shown in the following Figures below.

Figure 3.1 - Section boxed out to 250mm

Figure 3.2 - Material is spread on mixing pad

Figure 3.3 - Material treated with C444

Figure 3.4 - Grader windrows material

Figure 3.5 - Transported material to site

Figure 3.6 - Material placed and spread

Figure 3.7 - Material treated with Solidry

Figure 3.8 - Trial site compacted

3.3 Quality Testing

Improve the insitu soil, wherever possible and feasible by intermixing it with low-cost material available locally before treating the soil with the Consolid additives. Gap-sized material should be improved, if possible, by adding the missing fractions. The soil that is to be treated should be thoroughly loosened and pulverised in order for the Consolid additives to be dispersed equally into the entire soil surface. For this purpose, it is essential to use appropriate application equipment and suitable mixing tools. The treated soil after application of the additives but prior to compacting should show the OMC or a value slightly above the OMC. The compacting/rolling of the treated layer should be avoided until the moisture content is close to OMC. In this instance, resulting in a plastic condition of the soil, therefore the soil should be loosened again with a mixer and continue mixing along with airing and ventilation until the soil is acceptable for compaction. Due to the Consolid system allowing construction of load bearing layers, it is often advised that to protect the surfacing from defects and mechanical abrasion a thin wearing course should be applied.

3.3.1 Treatment with Consolid 444

Before the Consolid additives could be applied, some preparatory work had to be carried out on the road. It is essential to ensure that the subgrade and subbase is properly compacted and is able to allow to build up the treated base course without any problems. The subbase level has to be fully stable under traffic and provide no movement otherwise it makes it difficult to compact the treated base course properly. If problems are evident then the subbase must be compacted until stable. However, if the moisture is too high for compaction, the subbase should be allowed to dry out or rotate the soil to help aid the process.

Prepared the required quantity of Consolid 444 solution by adding 100 – 200 cl Consolid 444 to as much water as required to get the soil near the OMC. The amount of water for dilution of Consolid 444 is actually required can be calculated from the NMC in the soil and the OMC, these are provided by Bracalba Quarry. Usually the soil to be treated is more or less at OMC and in this case it is approximated to use 4L of water for the dilution of 100 -200 cc Consolid 444 p/m^2 to avoid over moistening. The 4L solution is equal to approximately 1% increase in the moisture content of the soil. To calculate the proper quantity of solution needed is done by multiplying sq.m by litres solution. Immediately after the Consolid 444 solution has been applied to the material mixing is required. This is essential to avoid the surface soil is over moistened.

3.3.2 Treatment with Solidry

Solidry is recommended to be added to the top 150mm layer of the Consolid solution pre-treated base course. But under certain conditions it can be applied to the entire base course layer in the way the C444 is and concentrated to the top layer. The recommended quantity of Solidry was calculated and a working solution 1:1 prepared. Solidry is a powdered product and was applied with proper spreading equipment which allows the application of the powder very close to the soil to reduce dusting.

Solidry is mixed into the soil at first with low speed to avoid dusting and in this instance was mixed into the top 150mm of material. The concentration can be adjusted by gradual increase to the desired amount for the amount of material.

3.4 Construction

Once the base course has been properly prepared with both solutions and treated in the method, it can then be ready to be properly levelled and compacted.

3.4.1 Watering

Water required before the material is compacted shall be added in successive applications by means of a water truck to apply the water evenly and uniformly of the area. The water should be thoroughly mixed with the material to be compacted by means of harrowing mixers and a grader. Where the material is suitable preference must be given to mixing by the harrowing mixer. The mixing should continue until the required amount of water has been added and until a uniform mixture is obtained before compaction is commenced.

The amount of water to be added shall be sufficient to bring the material to the proper OMC for the compaction equipment used and the density required. The compaction water shall contain the required amount of Consolid 444. The dosage shall be evenly distributed through the successive applications to ensure even and uniform spread over the area concerned. The Solidry shall be mixed with water in the proportion 1:1 to 1:5 and shall be applied to the top 125 mm of the trial site. The Solidry shall be spread over the loose soil and mixed in.

3.4.2 Levelling

Carried out with the grader, it has to be observed that the shape of the road is already at the time of construction more or less at right level in order to avoid cutting into low level treated material material in the final stage of construction. The final level should have a gradient of 3-5% towards the sides of the road, which should be also treated in the top 150mm.

3.4.3 Placing and Compaction

Before the base course is constructed the underlying layer shall conform to the requirements of the layer concerned and approved by the constructor and Austrablend representative. The base material shall then be dumped and spread in an even layer of 150 mm thickness. Compaction can be started immediately after the mixing in of the additives with pad foot roller and should be continued during levelling with the grader. When the pad foots have been taken out from the material, a sign of good compaction. The rolling is interrupted for the final levelling with the grader and continued with a smooth drum roller (with vibration). The treatment of the base course layer of the road is terminated should have a smooth surface on the main road.

3.5 Materials Samples

3.5.1 Consolid 444

The liquid CONSOLID 444 should be of white milky colour and a sample can be seen in Figure 3.9. However, if the steel drums are standing for a longer period some iron rust can change the colour and therefore the colour can be brown yellowish, but this does not harm the effect. To control the effect of the C444 it is able to be tested by taking two transparent plastic containers and fill with water and with a small amount of clay soil. This is then mixed until the clay is dissolved in the water. Thus following from this give one container the same drops of C444 and then you mix it well. An immediate the agglomeration of the clay particle should be present.

Figure 3.9 - Consolid 444 sample

3.5.2 Solidry

The Solidry can be tested for quality also with a water test. This can be done by taking a glass and fill it with water. Than placing on the water surface the Solidry. The Solidry must swim on the surface and no particle should sink down. This test can be left for several days and it must resist the water a example of this is shown in Figure .

Figure 3.10 - Solidry quality test

3.5.3 Application Rates

Quantities for Consolid 444 and Solidry in the schedule of quantities are respectively based on 0.8L/m^3 and 10 L/m^3 respectively. These rates may however be varied and this has been determined during the construction of the base-course. The following values are recommended.

- 1m^3 of soil of soil 2000kg (2 tons)
- 1m^2, 25cm deep, therefore 500kg
- 1m^2, 10cm deep, therefore 200kg

Standard quantities of the additives, empirical tests revealed the following amounts for the overwhelming majority of existing soils:

- for Consolid 444: 0.2L per m^2
- for Solidry: 1% to 2% of soil weight = 2kg to 4kg per m^2

3.6 Falling Weight Deflectometer

The scope of work involved a FWD survey of the section of road (30m) in the Bracalba Quarry. The testing was to be performed at 10m intervals, staggered between wheel paths (5m stagger) in both directions. The site was tested on four different occasions on the 22nd April, 20th May, 8th July and 14th September. An indication of the drops was prepared and provided for the tester. The setup of FWD/HWD was carried out testing in accordance to the FWD survey procedure PMS-TP4-001. At each test point 4 drops were required. Drop 1, 2 & 3 requires a target load of 566 KPa 40KN followed by a drop at 60KN. GPS co-ordinates were required for each test location so that a map of the testing can be produced and cross-referenced.

3.7 Installation of Moisture Gauges

The Moisture sensors were provided by Pacific data systems. Due to a delay in the supply of the moisture gauges, they were not able to be installed on the initial day. The gauges were fitted on the 14th of May with the use of a coring device to a depth of approximately 250mm and 125mm shown in Appendix F. The location of the Moisture sensors is shown in Figure 3.11. Prior to the installation of the gauges it was necessary to calibrate them. The moisture gauges are able to give a reading of the dielectric, electric conductivity as well as the temperature. These readings are taken every 15 minutes and are uploaded to a portal once a day. An initial graph to represent the data being recorded is shown in Figure 3.3.

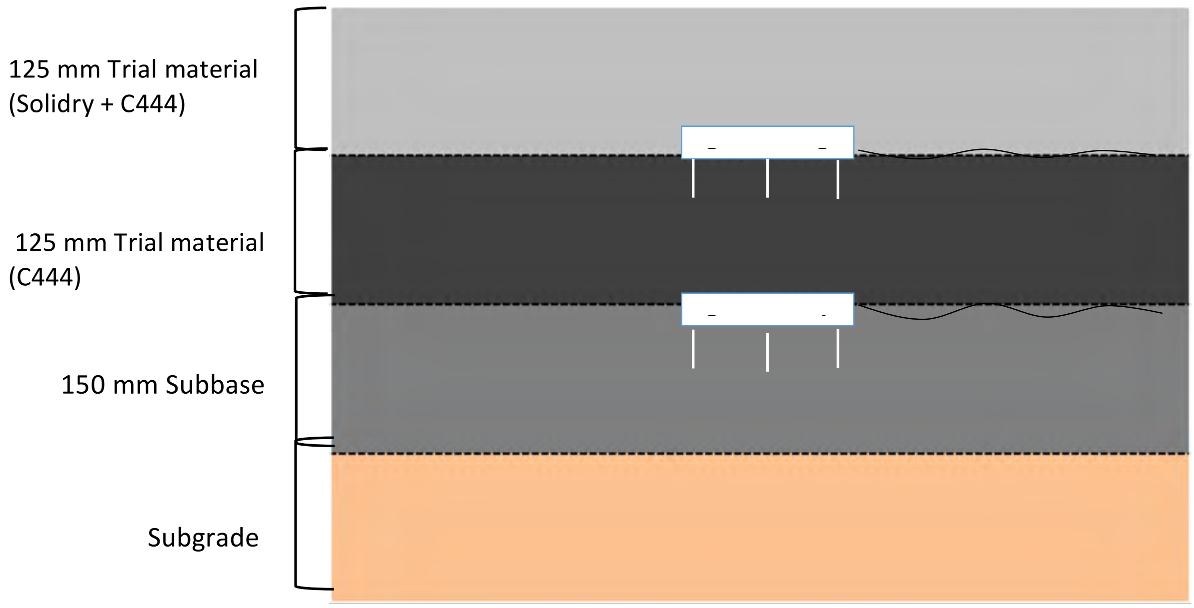

Figure 3.11 - Position of Moisture sensors in material

3.8 Calibration of Moisture Gauges

The 2.5 unbound road base sample material provided by Bracalba Quarry was used to calibrate the Moisture Gauges prior to their installation. This was deemed necessary to help understand the potential results the sensors would provide from the trial site. An oven dry sample of the material was used at 110°C overnight and provided the base reading for each of the gauges. Following, the sample was then compacted into a mould and the moisture sensors were set up with the data reader. At determined 30 minute intervals a known percentage of water was added to the sample which was then uniformly mixed to gain a even distributed sample.

The process was as follows:

- 2% water by weight and repeat the reading
- Another 2% and repeat
- Repeat at 4%, 6%, 8%, 10% and 12%
- Graph reading against actual moisture

3.9 Plant Equipment

Figure 3.12 - Tractor and Power Harrow

Figure 3.13 - Material tip truck

Figure 3.14 - Smooth drum roller

Figure 3.15 - Water spray truck

Figure 3.16 - Front end loader

Figure 3.17 - Grader

4.0 RESULTS

This section outlines the results found from the testing procedures the were utilised for the trial material shown in Figure 4.1 below

Figure 4.1 - Final trial section after construction

4.1 Pavement Profile

The pavement profiles for both the trial site and the control site had to be determined in order to correctly process the results. The pavement profile has a major role, as it is important to understand how many layers are below the surface and how each layer is designed.

4.1.1 Treated Material Profile

The trial site consisted of three layers of unbound material above the subgrade. The initial site had pre-existing granular material after the site was initially boxed out to a depth of 250 mm. The existing layer consisted of approximately 150 mm of granular material as shown in Figure 4.2 below. The improved layer consisting of C444 was approximately 125mm and then the improved layer consisting of Solidry and C444 layer was approximately 125mm as shown below in Figure 4.2.

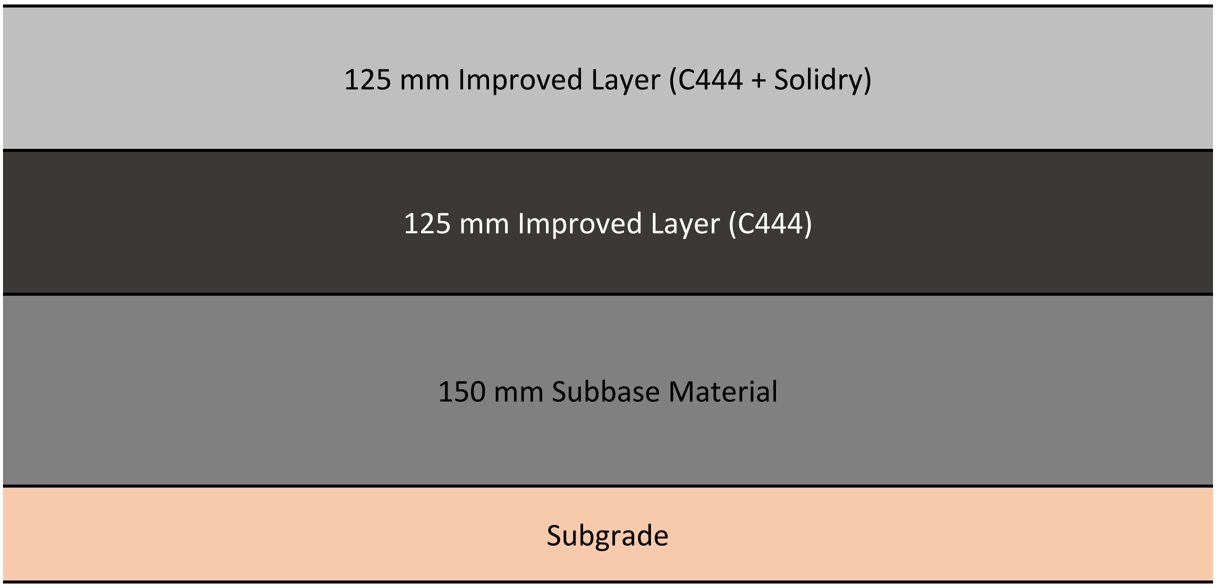

Figure 4.2 - Trial pavement profile

4.1.2 Control Material profile

The control site was determined to have an approximate depth of 400 mm of granular material above the subgrade. The control site consisted of the same profile as the trial site prior to the treated material being placed. The profile can be seen in Figure 4.3 below.

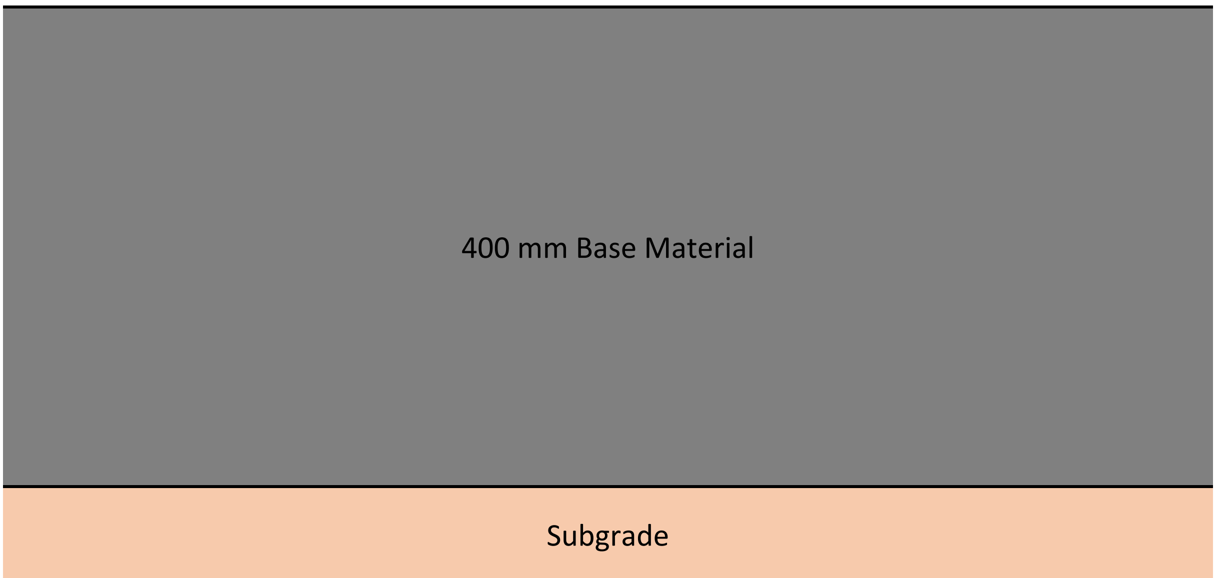

Figure 4.3 - Control pavement profile

4.2 Particle Size Distribution

Table 4.1 - Particle size distribution, test 1 results

AS Sieve Size	Min	Max	% Passing	Particle Distribution	PSD Category	% Recommended by Consolid
37.5mm	100	100	100	28	Gravel	5.3
19.0mm	80	100	92			
9.5mm	55	90	72			
4.75mm	40	70	52	48	Sand	-14.7
2.36mm	30	55	39			
0.425mm	12	30	24			
0.075mm	5	20	15.8	24	Fines	9.3

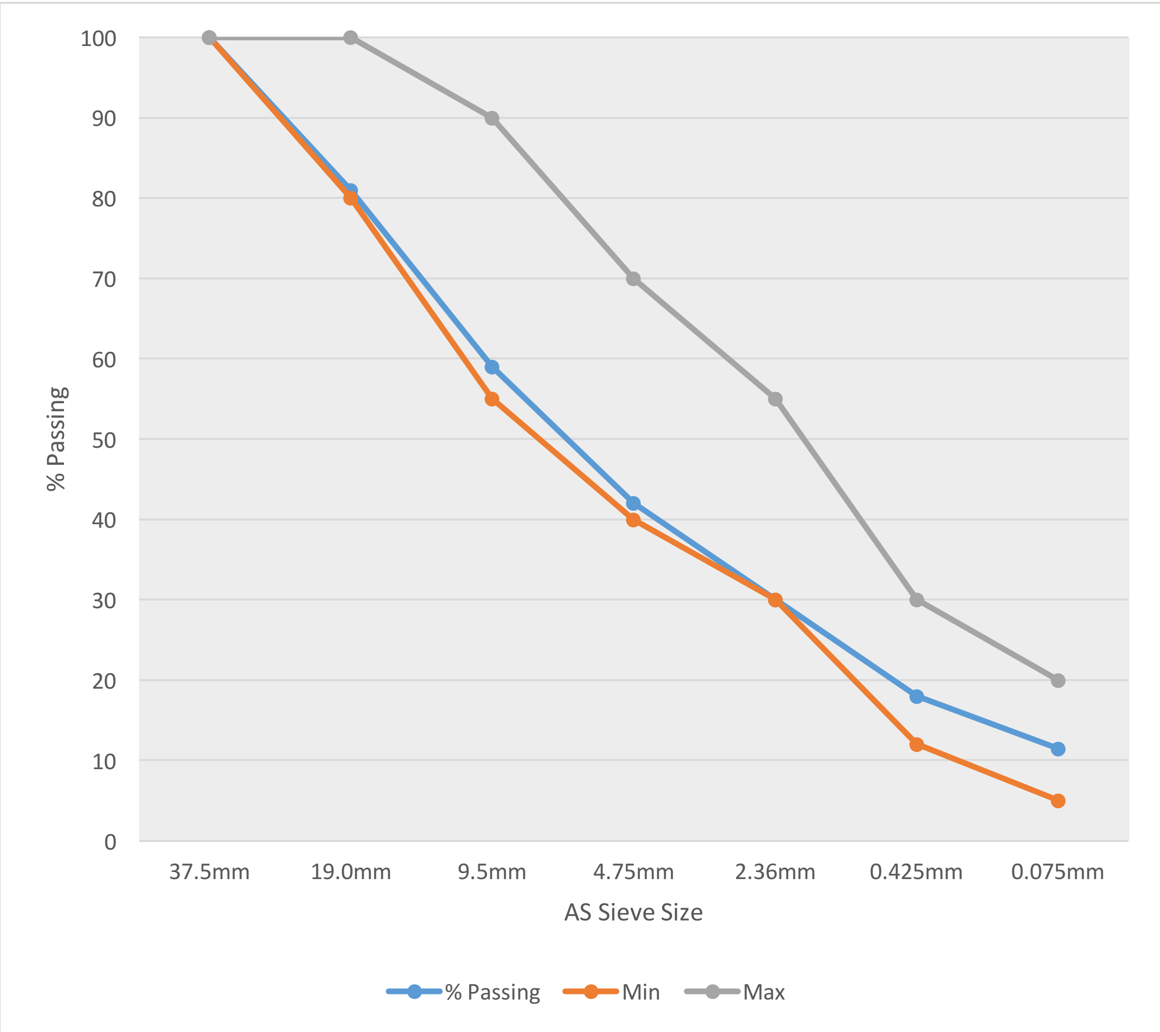

Figure 4.4 - Particle size distribution results, Test 1

Table 4. 2 - Particle size distribution, test 2 results

AS Sieve Size	Min	Max	% Passing	Particle Distribution	PSD Category	% Recommended by Consolid
37.5mm	100	100	100	41	Gravel	-7.7
19.0mm	80	100	81			
9.5mm	55	90	59			
4.75mm	40	70	42	41	Sand	-7.7
2.36mm	30	55	30			
0.425mm	12	30	18			
0.075mm	5	20	11.5	18	Fines	15.3

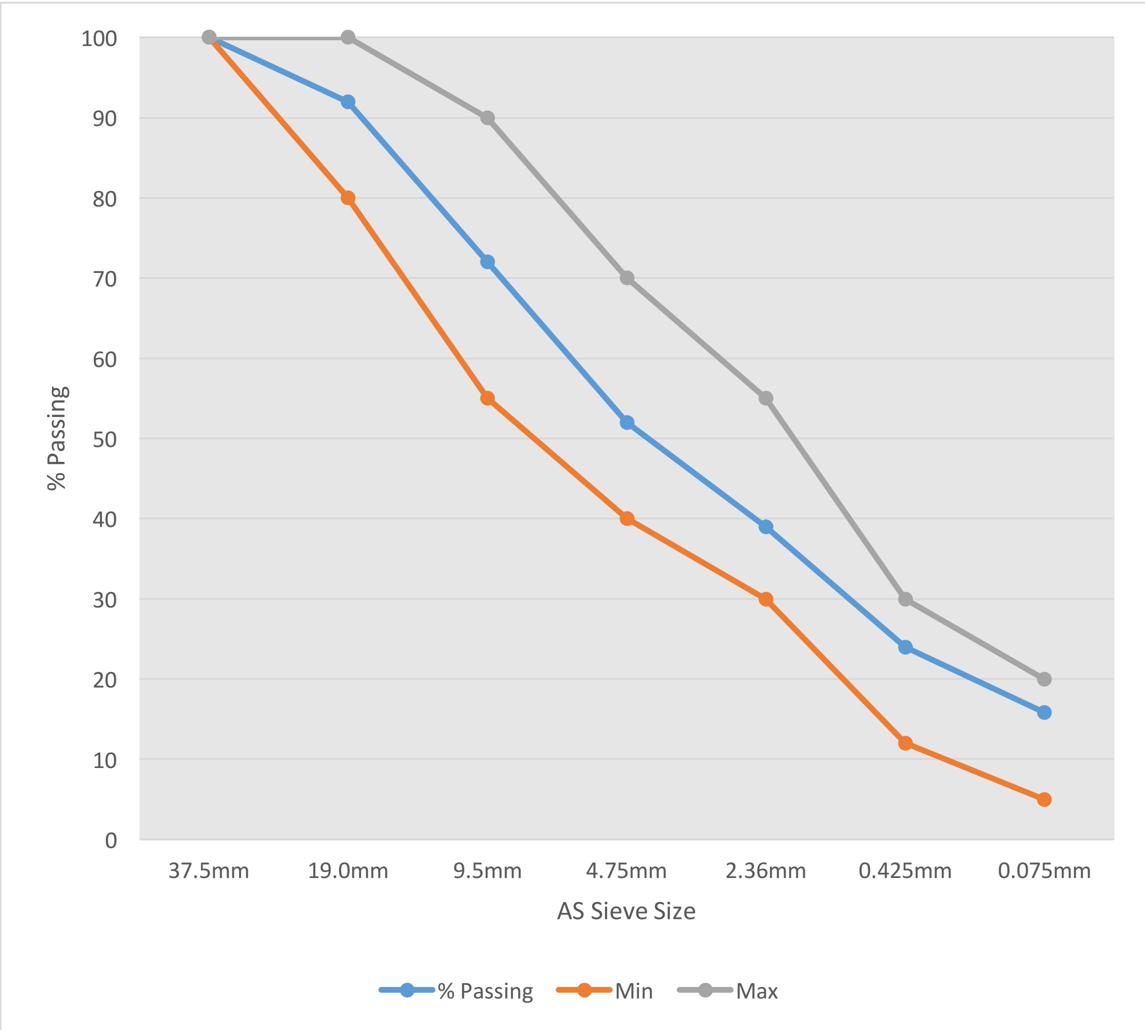

Figure 4.5 - Particle size distribution, Test 2

4.3 Laboratory CBR and Moisture Density

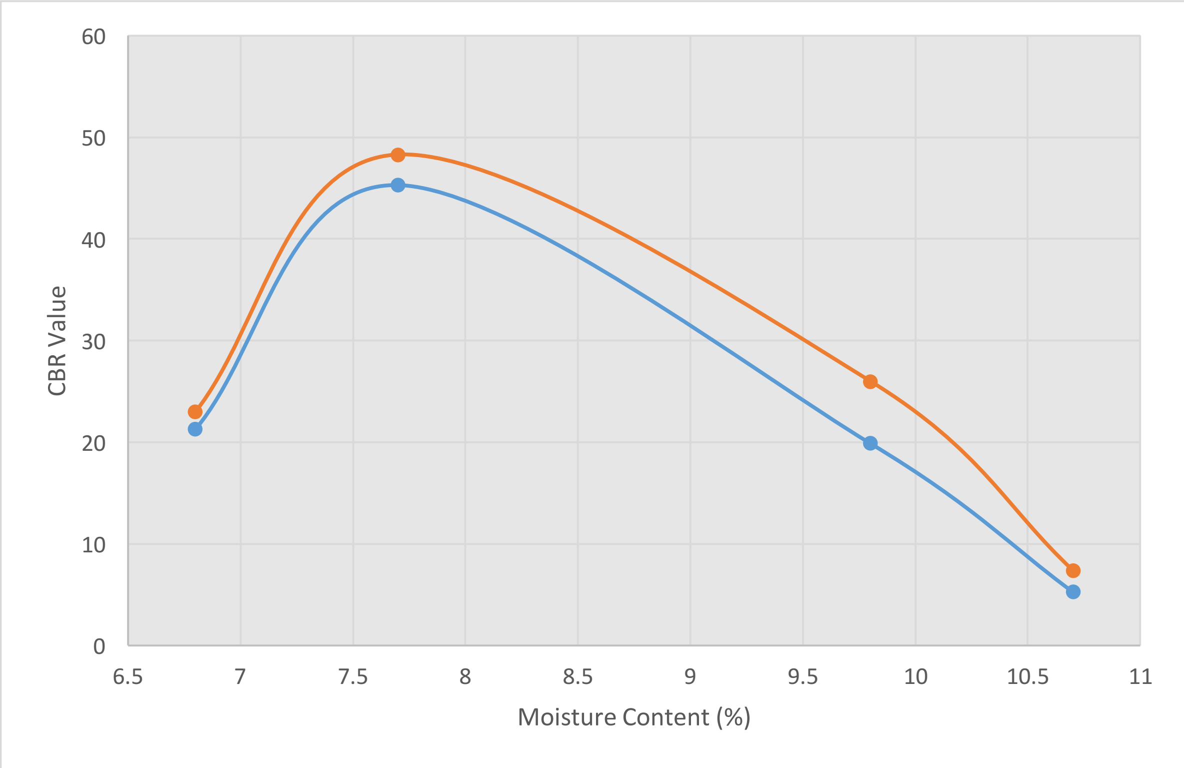

Figure 4.6 - Laboratory soaked CBR

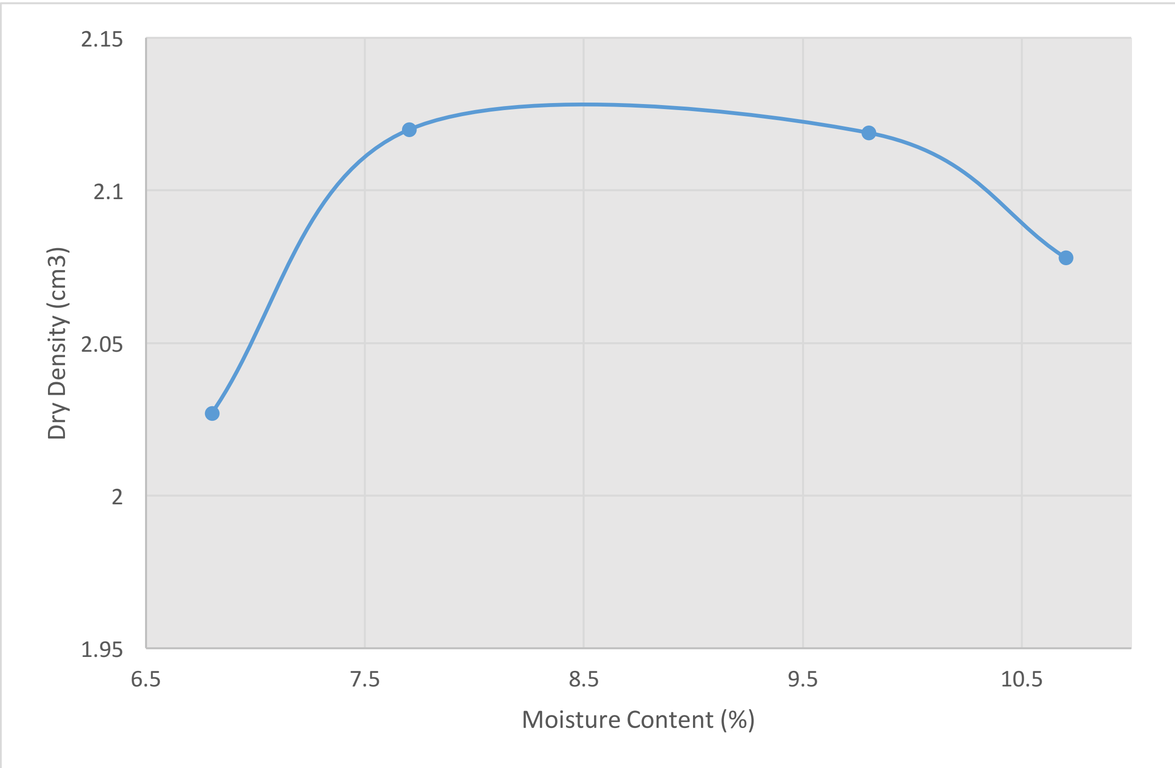

Figure 4.7 - Laboratory optimum moisture content

4.4 Atterberg Limits

Table 4.3 - Atterberg Limits for the Type 2.5 granular material

Tests Type	Test Result 1	Test Result 2
Liquid Limit	31.6	28.8
Plastic Limit	18	19.2
Plastic Index	13.6	9.6
Linear Shrinkage	5.8	4.8
P.I x % 0.425mm	321	168
L.S x % 0.425mm	136	84
Fines Ratio	0.67	0.65

4.5 FWD Deflection Results

The FWD measures the pavement's response to loading and the surface of the pavement performs a deflection bowl under the load. These deflections are dependent on the stiffness of the modulus from the subgrades reaction. The FWD deflection results in which were calculated from the site testing are shown in Appendix D. These results are the deflection in micro millimeters that were collected at the testing for use in the backcalculation process. These results show both the treated material and the control material deflections.

4.6 Backcalculation from ELMOD6

The backcalculation of the pavement layer modulus was performed through ELMOD6. The moduli of the pavement layers are calculated from the deflections that are measured by the FWD testing. The results calculated through ELMOD6 are shown below.

4.6.1 Treated Material

The first test was conducted on the 22nd April 2016 at the Bracalba Quarry. The treated material had been in place for approximately 14 days at when this test occurred. The results from backcalculation through ELMOD6 are shown in Table 4.4 below

Table 4.4 - Elastic Modulus results from Trail FWD testing (1)

Chainage (km)	Base (MPa)	Subbase (MPa)	Subgrade (MPa)
0	199	141	71
0.005	609	334	136
0.01	229	133	103
0.015	289	228	99
0.02	119	73	104
0.025	225	141	58
0.03	282	207	55
Mean	279	180	89
Standard Deviation	156	85	29
Coefficient of Variance (CV)	56%	47%	33%
10th Percentile	167	109	57
90th Percentile	417	270	117

The second test conducted on the treated material occurred on the 20th May. This was approximately 41 days after the treated material was placed at the site and can be seen below in Table 4.5.

Table 4.5 - Elastic Modulus results from Trail FWD testing (2)

Chainage (km)	Base (MPa)	Subbase (MPa)	Subgrade (MPa)
0	748	260	94
0.005	712	475	140
0.01	273	350	91
0.015	436	709	111
0.02	402	22	49
0.025	368	339	77
0.03	386	466	71
Mean	475	374	90
Standard Deviation	182	212	29
Coefficient of Variance (CV)	38%	57%	32%
10th Percentile	330	165	62
90th Percentile	726	569	123

The third test was conducted on the treated material occurred on the 8th July. This was approximately 90 days after the treated material was placed at the site and can be seen below in Table 4.6.

Table 4.6 - Elastic Modulus results from Trail FWD testing (3)

Chainage (km)	Base (MPa)	Subbase (MPa)	Subgrade (MPa)
0	1055	419	125
0.005	1076	667	208
0.01	825	570	139
0.015	542	1347	166
0.02	601	941	108
0.025	473	395	98
0.03	478	237	75
Mean	721	654	131
Standard Deviation	263	380	45
Coefficient of Variance (CV)	36%	58%	34%
10th Percentile	476	332	89
90th Percentile	1063	1103	183

The fourth test was conducted on the treated material occurred on the 14th September. This was approximately 158 days after the treated material was placed at the site and can be seen below in Table 4.7.

Table 4.7 - Elastic Modulus results from trial FWD testing (4)

Chainage (km)	Base (MPa)	Subbase (MPa)	Subgrade (MPa)
0	680	215	74
0.005	668	884	126
0.01	823	286	103
0.015	870	482	142
0.02	326	465	141
0.025	533	811	113
0.03	290	79	40
Mean	599	460	106
Standard Deviation	227	300	37
Coefficient of Variance (CV)	38%	65%	35%
10th Percentile	312	161	60
90th Percentile	842	840	141

4.6.2 Control Site

The Control site was tested at the same time and dates as the treated material. This was important to maintain the reliability of the data.

Table 4.8 - Elastic Modulus results from Control FWD testing (1)

Chainage (km)	Base (MPa)	Subgrade (MPa)
0	476	75
0.005	961	76
0.01	479	89
0.015	596	82
0.02	523	86
0.025	676	67
0.03	293	191
Mean	572	95
Standard Deviation	208	43
Coefficient of Variance (CV)	36%	45%
10th Percentile	403	72
90th Percentile	790	130

Table 4.9 - Elastic Modulus results from Control FWD testing (2)

Chainage (km)	Base (MPa)	Subgrade (MPa)
0	502	86
0.005	414	74
0.01	762	61
0.015	448	73
0.02	435	99
0.025	581	107
0.03	521	73
Mean	523	82
Standard Deviation	120	16
Coefficient of Variance (CV)	23%	20%
10th Percentile	427	68
90th Percentile	653	102

Table 4.10 - Elastic Modulus results from Control FWD testing (3)

Chainage (km)	Base (MPa)	Subgrade (MPa)
0	412	58
0.005	595	103
0.01	402	72
0.015	527	48
0.02	509	66
0.025	584	86
0.03	584	75
Mean	516	73
Standard Deviation	81	18
Coefficient of Variance (CV)	16%	25%
10th Percentile	408	54
90th Percentile	588	93

Table 4.11 - Elastic Modulus results from Control FWD testing (4)

Chainage (km)	Base (MPa)	Subgrade (MPa)
0	442	83
0.005	479	83
0.01	362	69
0.015	387	75
0.02	387	68
0.025	501	80
0.03	408	55
Mean	424	73
Standard Deviation	52	10
Coefficient of Variance (CV)	12%	14%
10th Percentile	377	63
90th Percentile	488	83

4.7 Resilient Modulus

4.7.1 Treated Material Site

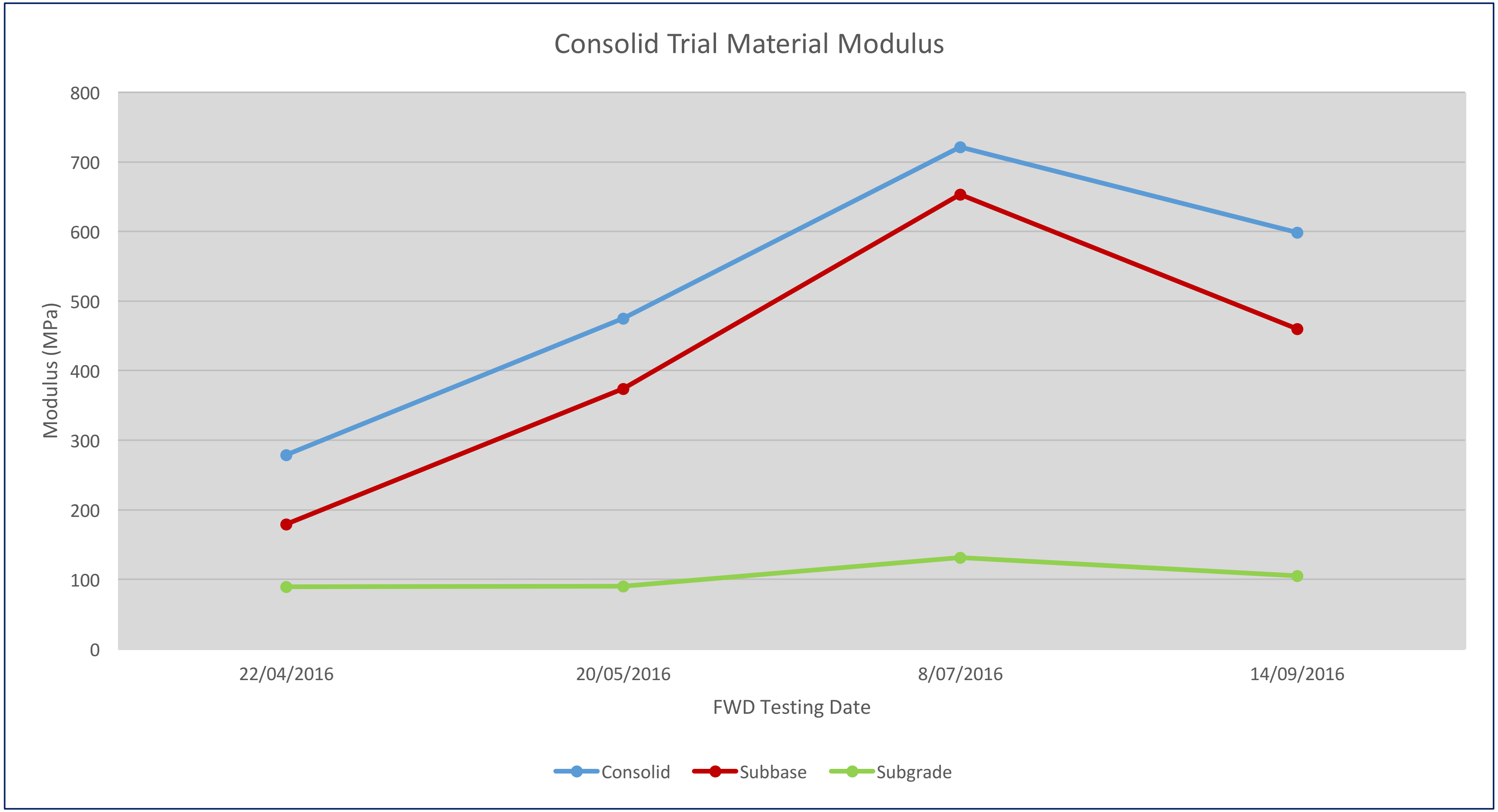

Figure 4.8 - Elastic Modulus Calculated for Consolid trial site

4.7.2 Control Material Site

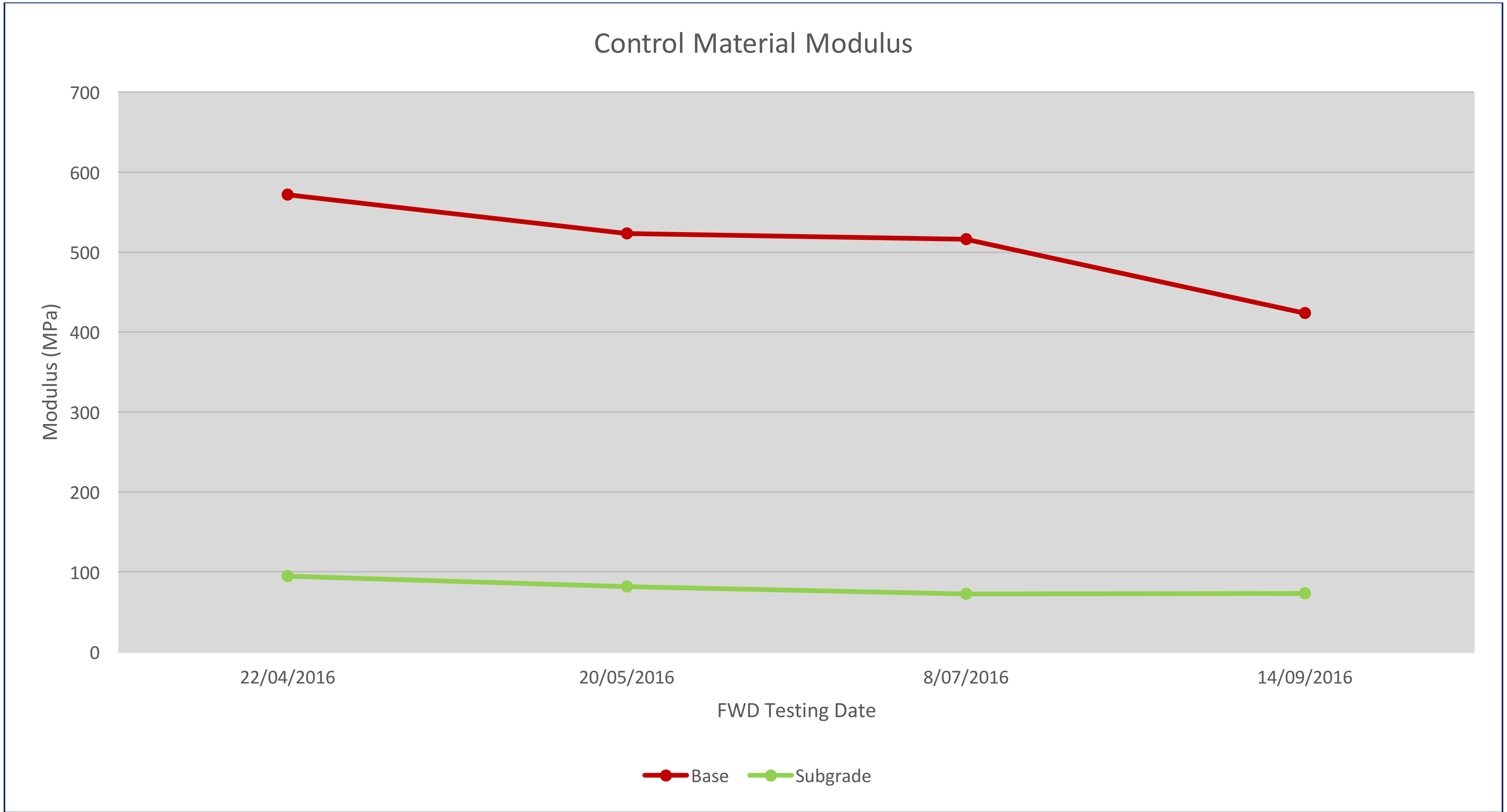

Figure 4.9 - Elastic Modulus Calculated for Control site

4.8 Permanent Deformation of Subgrade

The permanent deformation of the subgrade was calculated for each test on both the Treated material and the control material once the modulus was determined for each test. This method was calculated by using the Austroads Guide to Pavement technology: Part 2. The strain was calculated at the top of the subgrade for each test. The strain was then used in Equation 2 in which was able to give the number of cycles till failure for each period. The results can be seen in Table 4.12 below. The results used to calculate the strain at the top of the subgrade are shown in Appendix E.

$$N = \left(\frac{9300}{\mu\epsilon}\right)^7 \qquad \text{Equation 2}$$

Where:

N = Number of Cycles to Failure

$\mu\epsilon$ = Compressive Microstrain

Table 4.12 - Number of cycles till failure (SAR's)

Test Number	Test Date	Number of Cycles to Failure	
		Treated Material (SAR's)	Control Material (SAR's)
1	22nd April	1.80E+08	4.31E+09
2	20th May	1.19E+09	1.90E+09
3	8th July	2.45E+10	1.20E+09
4	14th September	4.53E+09	5.98E+08

4.9 Moisture Readings

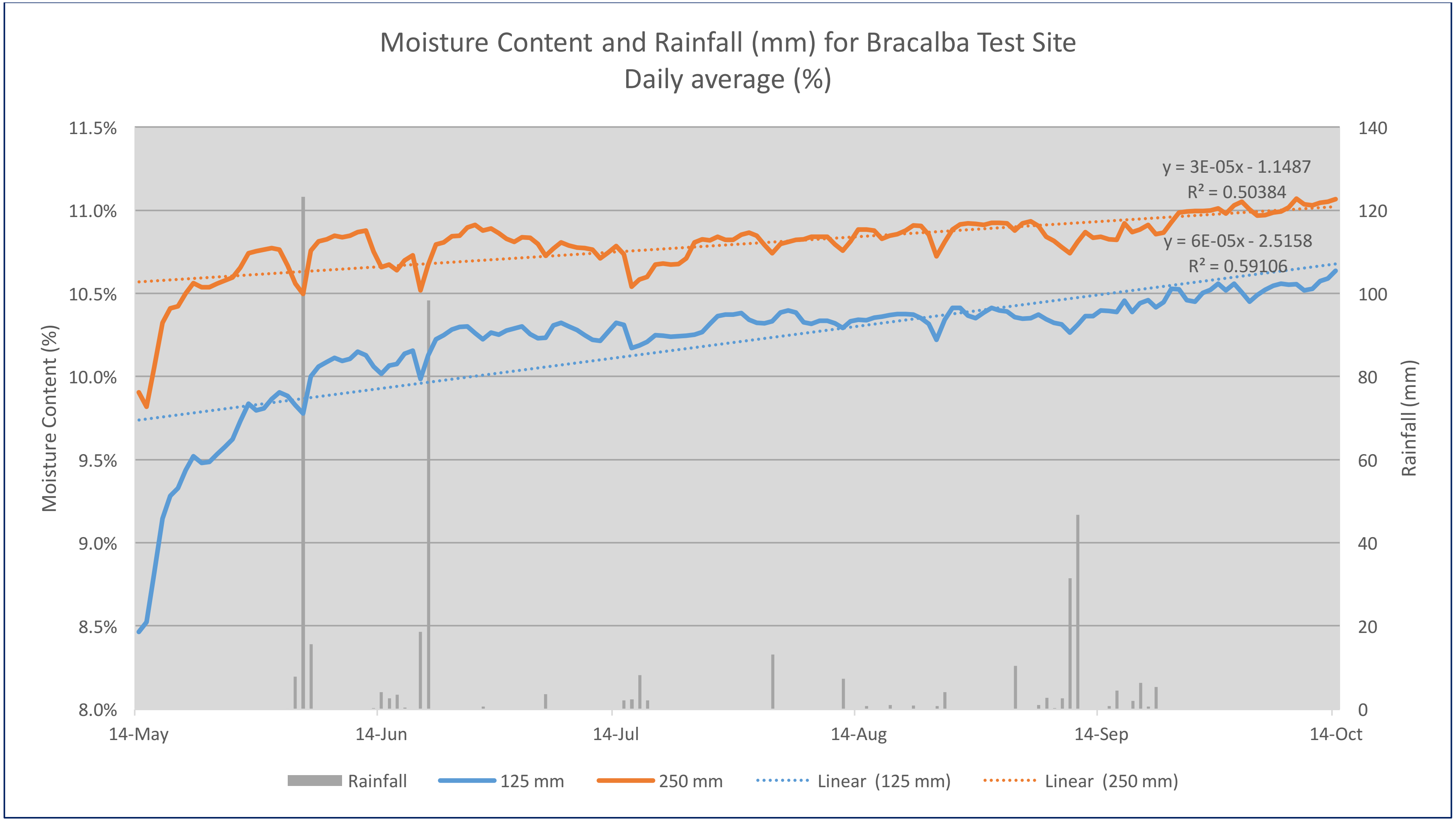

Figure 4.10 - Moisture Sensor readings against annual rainfall data

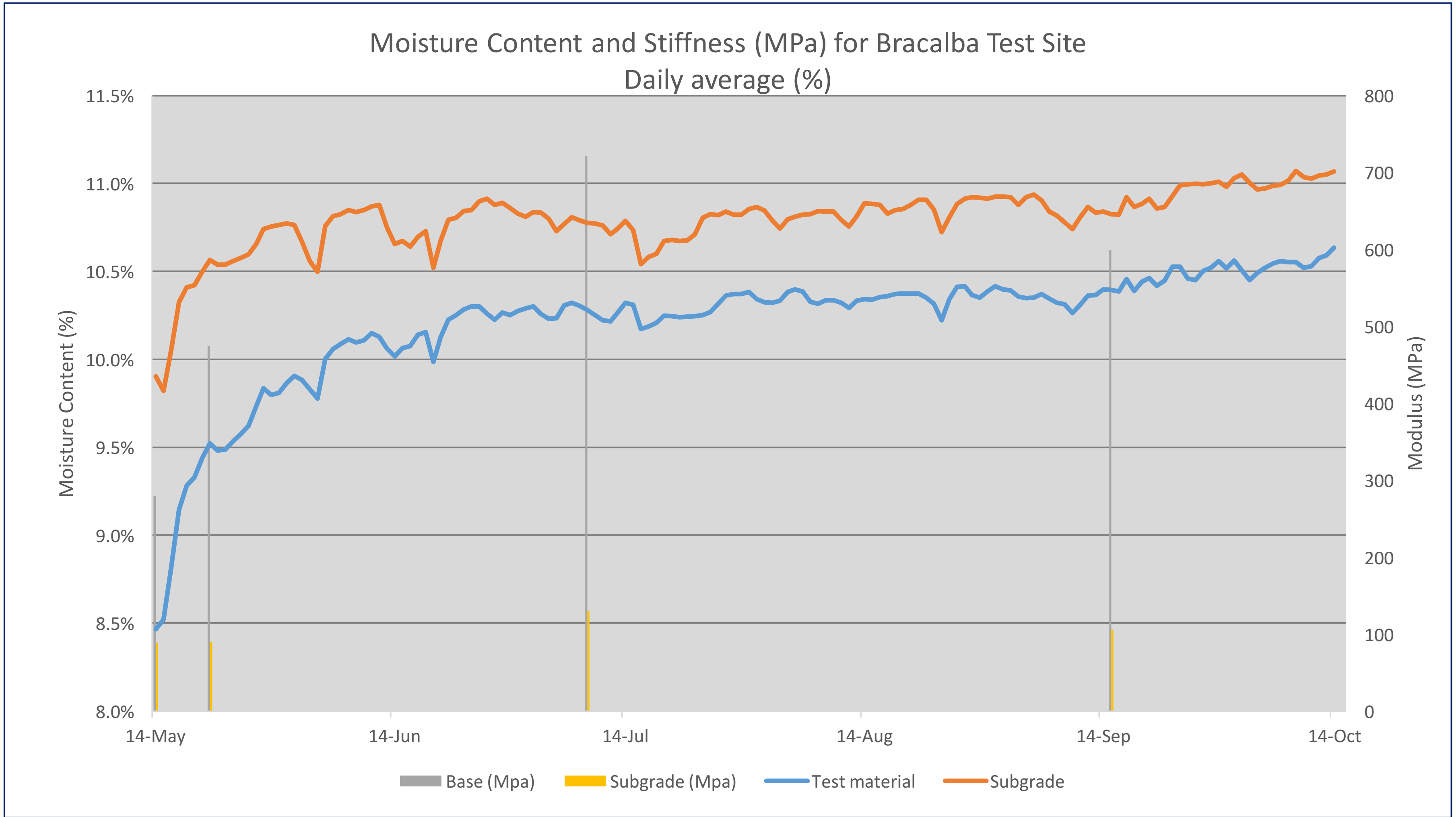

Figure 4.11 - Moisture Sensor readings against elastic modulus for Trial site

4.10 Summary of Results

The results obtained during the period of testing for the project showed a number of comparisons between the Consolid system and untreated control site. There were a number of critical findings that were seen in the results and these will be discussed further below. However, as an overview it is important to note

- There proved to be a distinct consistency in the results calculated from the Control site.
- The treated material showed that is increased from a low modulus to reach a high modulus by the end of the testing
- The moisture content was relatively unaffected by rainfall and other wetting of the surface.
- The FWD testing was conducted by a professional and within the Australian standards
- The material showed a higher clay content as recommended from Consolid and the laboratory results conducted previously
- The Moisture sensors were recorded readings constantly during the course of the project.

The further analysis of the results will be explored in more detail below.

5.0 DISCUSSION

Now that the Methodology and Results have been provided, the outcome of the Consolid System as a soil stabilizing product can be analysed. This will help to determine the effectiveness of the field trial, relative to the aims of the project and the previously conducted laboratory results. This section will outline the impacts observed by the use of the stabilizing agent that have been calculated from the pavement testing as well as the results found from the moisture sensors that are installed in the material. The type of material used will also be analyzed as this is relative to the type of material that is recommended for the system to be effective. Finally, the discussion will provide a comparison of the results throughout the testing period and relate back to the initial findings reported in the laboratory results.

5.1 Treatment Procedure

Consolid soil stabilization was permitted to be mixed in conjunction with the type 2.5 Unbound granular material supplied at the Bracalba Quarry site. This form of stabilization has so far been untested and was a completely new method introduced to all those that were involved in the treatment and construction. There are improvements that can be done to enhance the process for which below the positive and negative implications that were observed during the treatment procedure will be highlighted.

The treatment of the material was conducted on a mixing pad in close proximity to the proposed trial site at the Bracalba Quarry. As the quarry is operational from Monday to Saturday of each week it was important to limit the disruption in the accessibility for the trucks in and out of the site. Due to this the site was not able to be boxed out to the required depth for treatment until the morning of the 9th April. For this method of stabilisation, it would be beneficial to be able to conducted it insitu, to alleviate the transport of materials and the necessity of requiring an area large enough to treat the sample of material. However due to time constraints, the availability of the quarry a profound solution was considered to treat the material whilst the proposed site was boxed out.

The risks that occur with treating the material in this manner is the quality control of the product into the material as well as any other materials from the area that may be picked up in the process. As there was no separation to prevent the material below treatment to be mixed into the process. In most instances the quarry operators were able to remove the treated material without contaminating the product as was observed.

5.1.1 Application

The C444 was transported to the site in measured containers as shown in Figure 5.1. The C444 was then poured into distributing cans in which were applied to the material by hand. This type of soil stabilization is important to get a uniform distribution so that the particles of the material are sufficiently coated. The method that was used to apply the C444 solution can result in improper application rates as it relied on the person to distribute the product evenly. However once the C444 was applied, a water truck was able to spray the sample in which was then followed by the grader to mixed the material to attain a uniform distribution throughout the material. This method appeared to aid in the uniform application as due to time constraints, equipment availability and the cost associated with the trial, an ideal solution was not available.

Figure 5.1 - Distribution of C444

The Solidry was available on site in 25 Kg. The Solidry was then calculated for distribution across the material at 1 bag per 6 m^2 shown in Figure 5.2. The creation of Solidry dust by the harrowing was quite significant as was as shown in Figure 5.3. As this product is very fine and the application amounts should be precise for the Consolid System to work effectively. This was improved by the use of the water truck to spray water to suppress the dust creation from the Solidry product. It was also necessary to apply a disposable dust respirator to ensure that no Solidry dust was inhaled by those that were on site and in contact with the product. It was important to get a thorough mix of the Solidry through the product which made the use of a grader essential to help windrow the material.

Figure 5.2 - Application of Solidry 25kg bags

Figure 5.3 - Solidry dusting from harrowing

The entire 208 tons of material was treated with both products and compacted to 250 mm as proposed for the trial site. The issues raised the treatment process were in regards to the quality control of the material and the Consolid products. It was stated after construction that the trial site seemed very “soft” in natural and this was assured to be normal procedure. However, the trial material is showing to be very stiff and hard on the surface. One measure that was put in place to control the outcome was the monitoring of the moisture content throughout the construction process. It was recommended that the OMC was kept at 10% or within 1%. This was monitored by the use of a portable moisture sensor that was placed into the soil, as well as visual inspection by professionals to determine whether further water was required.

5.2 Control Site

The control site is situated parallel to the trial site at the quarry, however it should be noted that this was unaffected in the process and the material was not altered or changed in this field trial. The control site consists of a high quality gravel with less clay particles (type 2.1) compared to the low quality type 2.5 granular material that was used to treat with the Consolid system and placed in this trial. The importance of establishing a control site was decided during the pavement testing process as it was necessary to be able to relate the results that were observed. As it was deemed that the results calculated from the control site should show a consistency in the testing equipment, though slight changes occurred as changes in moisture and density take place.

The Moduli calculated from the backcalculation through ELMOD6 showed a consistency from the FWD testing. The results showed a variation from 572 MPa to 516 MPa from the first three tests that occurred. The fourth test result showed a Modulus of 424 MPa which was a slight drop in comparison to the first three test, however this reduction was also showed in the test material discussed later. It is assumed that this reduction can be due to slight moisture changes in the material and/or a result of density changes as the fourth test occurred in a much large period of time frame. The control site was not fitted with moisture sensors to support this statement however based off the results found in the relating material it is considered to be the case. Although based on the results it is difficult to make a comparison between the control and the test site as the materials do not correspond with each other. This primary purpose has been to ensure that there is quality in relation to the collection with the equipment and this can reflect on to the test material as the testing was conducted in the same manor.

5.3 Treated material

The treated material was placed and compacted in two separate layers in a boxed out area of approximately 30 m in length and a width of 8 m. The compaction of the material first experienced over compaction on the final layer as shown in Figure 5.4. This was not the desired finish for the surface therefore re-compaction had to occur to avoid surface cracking. This was achieved by the wetting of the surface and trafficked to slurry the surface. The Consolid system, is recommended to have a thin asphalt surfacing layer, however due to availability and cost restrictions this was not able to be placed. The asphalt layer is to prevent the granular material from deformation and other distresses. Although without the surfacing layer there has proved to be very minimal defects on the surface of the granular material. This is evident from .Figure 5.5, Figure 5.7, Figure 5.7, and Figure 5.7 taken from visual inspections conducted at each pavement testing on the site.

Figure 5.4 - Over compaction surface cracking

.Figure 5.5 - First visual inspection (22nd April 2016)

Figure 5.6 - Second visual inspection (20th May 2016)

Figure 5.7 - Third visual inspection (8th July 2016)

Figure 5. 8 - Fourth visual inspection (14th September 2016)

5.3.1 Modulus Improvements

The Modulus calculated through backcalculation has seen a variation in the strength of the material over the course of this study. The first test resulted in an average modulus of 279 MPa across the treated material. The first test showed a consistency in the modulus calculations though at Ch.0.005 here was an increase to 609 MPa. This may be due to the method that was applied to the uniform distribution of the C444 and Solidry products as there may have been a slight higher concentration. This is also a result of the compaction at the beginning as this section may have experienced a better compaction at the time of placing resulting in less strain on the subgrade in turn increasing the Modulus. The trial site showed an overall increase in the strength and it is understood that although the Consolid system is able to be trafficked directly after compaction, the strength is increased as the unbound layer in consolidated over a period of time. The data collected from the second round of testing showed an average modulus of 475 MPa which was a distinguished increase on the previous. There was evident strength at the beginning of the section though overall the modulus was higher then the previous as shown in Table 4.4. The third round of testing displayed the highest calculated results which had an average modulus of 721 MPa. This is a significant increase for an unbound granular material that has been treated with C444 and Solidry. The fourth test calculated an average modulus of 599 MPa. This was a decrease from the third result, however it should be noted that an overall decrease was observed from the control site as well. As stated earlier this can be due to the slight moisture changes, in the material, as well as the density. The overall results calculated from the pavement testing showed that the treated had a significant increase in strength after construction.

5.4 Particle Size Distribution

The optimum particle size distribution as nominated by Austrablend is 1/3:1/3:1/3, however is recommended for materials with a high clay content. The particle sizing of this material is shown in Table 4.1 and Table 4. 2. Although not the optimum distribution the particle size appeared to meet the requirement of a high clay and from Table 5.1 below the material can be classified as Type 2 with a Grading of E in accordance with Technical Specification - MRTS05 Unbound Pavements. This shows that the material is therefore be classified as a Type 2.5 if used in a base or subbase. This was previously specified by Bracalba Quarry in their material grading in Appendix C.

Table 5.1 - MRTS05 Unbound Pavements grading comparison to trial sample

AS Sieve Size (mm)	Percent Passing by Mass					
	Grading B	Grading C	Grading D	Grading E	Result 1	Result 2
75.0	100	100	100	100	-	-
53.0	100	100	100	-	-	-
37.5	85 – 100	100	100	85 – 100	**100**	**100**
19.0	55 – 90	80 – 100	100	-	**81**	**92**
9.5	40 – 70	55 – 90	80 – 100	40 – 100	**59**	**72**
4.75	28 – 55	40 – 70	55 – 90	-	**42**	**52**
2.36	20 – 45	30 – 55	40 – 70	20 – 100	**30**	**39**
0.425	10 – 25	12 – 30	20 – 40	10 – 80	**18**	**24**
0.075	4 – 15	5 – 20	8 – 25	4 – 30	**11.5**	**15.8**

5.5 Compare Laboratory and Field tests

Previous laboratory results that were conducted in 2015 by the University of the Sunshine Coast looked into the perceived benefits of the Consolid System and whether there was significant improvement to the treated material. The testing consisted of a Dynamic Modulus test in which used three materials to compare. The results from the modulus effect of the laboratory results are shown below in Table 5.2. These results proved that with the use of a similar material as used in this trial, with high clay content (Obi Obi material) had an increase of approximately 35% to the treated material compared to the untreated sample. However, the high quality granular material shown in the results both showed that the reaction was less significant as the Consolid system was unable to create effective bonds. This was conceived as the lack of clay fines in the material, which enhanced the properties of the low quality granular material.

Table 5.2 - Reported laboratory results from previous study

Material Sample	Measured CBR	Un-stabilised Modulus (MPa)	Stabilised Modulus (MPa)
Image Flat	100	646	538
Obi Obi Overburden	30	471	637
Moy Pocket 2.3	100	494	316

The results that were observed from the field testing in the third and fourth result correlate the laboratory results observed from the Obi Obi Overburden that were found in 2015. The two materials consist of similar particle size distribution and this can be seen in by comparing Appendix C and Appendix G.

5.6 Moisture Readings

The moisture content showed very minimal variance during the testing period and increased in increments, however was consistent. The Bracalba Quarry experienced a number of heavy rainfall events during the month of June 2016, however this proved to have no effect on the moisture content that was measured in the material. The next Major rain event occurred in September however this also did not affect the moisture content in the treated material. Unbound material strength is strongly influenced by the moisture content present. As the moisture increases the strength of the material is often reduced. However, the treated material appears to be resilient to the effects of water. The material testing provided by Bracalba shown in Appendix C, calculated the OMC for the Type 2.5 material at 8.6%. As evident from the moisture sensors installed at the site, the current moisture content of the material is at approximately 10.5%. Though this increase is minimal it is still significant in terms of the Consolid system water proofing the material.

The Bracalba Quarry, has approximately 350 truck movements daily through the site. As this site is unbound this can subject the area to an excess of dust disturbance. The quarry in this instance implements a water truck to suppress the effects from dust at the site. The water truck is estimated to spray approximately 2 Litres/m^2 of water from the spray nozzle and can pass up to five times daily. This is important to consider as this can relate to approximately 25 mm of water sprayed from the water truck daily on the treated material. Essentially creating a substantial rainfall event daily. However, from the moisture results shown there is no considerable increase in the moisture content despite the amount of water applied to the site.

5.7 Visual Inspection

Visual inspections were also taken during the period of time allowed by the quarry for testing of the pavement. It should be noted that the visual inspections that have occurred of the period of testing it was observed that there was minimal amounts of defects or erosion on the trial material. Figures 5.5, 5.6, 5.7 and 5.8 above shows a time lapse of from the inspections to show the changes in the material.

6.0 CONCLUSION

The intent of this project was to investigate the merit of the Consolid system stabilisation process through the utilisation of a field study as a continuation from laboratory results that were conducted in 2015. This process was then intended to establish effective means of pavement testing at site at the Bracalba Quarry for further study to be able to continue in the same respect.

The unique treatment methods and construction of the trial section at the Bracalba Quarry has proved to be effective in developing a road for heavy truck movements with the use of Consolid system and unbound granular material. As this road is primarily used as the entry point to the quarry, it was important that the solution was adequate and was not subjected to failure as this would disrupt the truck movements in and out of the quarry. In relation to the primary aim, the Consolid system has produced a conforming stabilised material for use at this particular location. The stabilized material has produced some significant increases to the granular material and exceed the requirements for Type 2.5 material as specified by Austroads.

The results that are shown from the field study correlate and support the results that were observed in the laboratory result conducted in 2015. Thus, this field trial has proved a low quality granular material can produce a high modulus value with stabilisation of Consolid system. However, as the control site was not a traditional control site in terms of being an untreated section of the material used in the study, makes it difficult to make a comparison between the two results. Although the elastic modulus was seen to increase with stabilisation. It is evident that the results show that a low quality granular material can achieve a high modulus with this method and application.

In regards to the moisture content, the results proved to not be greatly affected by rainfall events or other water effects on the trial site. This supports the overall aim which was to investigation a waterproofing agent to increase the bearing capacity of natural material. Analysis of these results can be utilised as a case study for future research and application of this form of stabilisation agent.

7.0 RECOMMENDATIONS

The results presented in this report showed that the Type 2.5 granular material treated with C444 and Solidry was able to increase the initial modulus across the testing period and exceed the expected modulus for that type of material. The following points are made for recommendations for further study:

1. The control site should be established with the same material (Type 2.5) that has currently been treated at the Bracalba Quarry, to provide a comparison between the results from untreated and treated material.
2. A dynamic modulus test should be conducted on the material to allow a comparison between the material used in this field study, and an accurate laboratory test result.
3. Site inspections, FWD testing and moisture sensors should remain the primary means of testing and should be continued for an extended period of time.
4. Boreholes should be conducted at the site on both the trial and control to ensure a accurate pavement profile

Further study is necessary and should continue for a more accurate understanding of the effects and perceived benefits that are gained from stabilizing with C444 and Solidry. Investigations should continue to occur for another year, minimum, at the Bracalba Quarry soil stabilized trial site.

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APPENDICIES

Appendix A – Log Book

No.	Date	Time	Communication	Activity	Who
1	9/09/2015	1	Meeting	Discussion of Final Year Project	John Yeaman
2	25/09/2015	1	Meeting	Discussion of Final Year Project	John Yeaman
3	25/09/2015	4	Research	Research on AustraBlend/Consolid	
4	26/09/2015	4	Research	Research of previous study conducted	
5	28/09/2015	4	Research	Research of previous study conducted	
6	13/10/2015	1	Email	Confirmation of Final Year Project	John Yeaman
7	22/10/2015	0.5	Email	Project Brief received	John Yeaman
8	26/10/2015	2	Meeting	Clarification of mistakes in brief	John Yeaman
9	3/11/2015	0.5	Email	Arrange meeting with AustraBlend	Mike Farrar
10	5/11/2015	2	Meeting	Discuss project with client	John Yeaman/Mike Farra
11	10/11/2015	1	Email	Arrange meeting with Caloundra Waste Facility	Mike Farrar/Council Representative
12	11/11/2015	0.5	Email	Confirmation of proposed site visit	Mike Farrar
13	13/11/2015	2	Study	Prepare PPE of site visit at Caloundra Waste Facility	
14	16/11/2015	2.5	Meeting	Site Visit of Proposed site at Caloundra Waste Facility	
15	18/11/2015	1.5	Phone/Email	Discussion of suitability of site	Mike Farrar/John Yeaman
16	14/12/2015	1	Email	Update on the progress to aquiring a site	Mike Farrar
17	15/12/2015	2	Phone	Update on the progress to aquiring a site	John Yeaman
18	16/12/2015	2	2	Prepare document to register project Prepare document to register project	Prepare document to

19	17/12/2015	2		Prepare document to register project Prepare document to register project	
20	19/12/2015	2		Prepare document to register project Prepare document to register project	
21	21/12/2015	1.5		Prepare document to register project	
22	22/12/2015	1	Email	Registration of Project	Rchard White
23	10/01/2016	2	Email/Meeting	Address questions raise by Caloundra Waste Facility	Mike Farrar/John Yeaman
24	12/01/2016	2.5	Email/Meeting	Prepare document to Caloundra Waste Facility	Mike Farrar
25	12/01/2016	2.5		Further information required for Caloundra Waste Facility	
26	14/01/2016	3	Research	Research Consolid and method	
27	15/01/2016	1	Meeting	Discussion of proposed request to Caloundra Waste Facility	
28	18/01/2016	1	Submission of Proposal to Caloundra Waste Facility	Mike Farrar/John Yeaman	Mike Farrar/John Yeaman
29	15/02/2016	2	Research	Research testing equipment required for monitor the site	
30	16/02/2016	4	Research	Research consolid stabilisation	
31	16/02/2016	1	Phone	Discussion of response from Caloundra Waste Facility	Mike Farrar
32	19/02/2016	4	Research	Research previous study	
33	22/02/2016	0.5	Email	Arrange meeting with Pavement Management Services	Ernesto Urbaez
34	26/02/2016	1	Meeting	Discuss proposed testing for the site	Ernesto Urbaez
35	26/02/2016	3	Study	Prepared Haznet Risk assessment	Catriona Taylor
36	26/02/2016	0.5	Study	Approved Risk Assessment	John Yeaman
37	27/03/2016	0.5	Study	Prepare Haznet Risk assessment	
38	27/02/2016	3	Study	Project Brief	Richard White
39	28/02/2016	4	Study	Project Brief	Richard White
40	2/03/2016	2	Meeting	Update on current progress	John Yeaman
41	3/03/2016	1.5	Email	Discussion on whether Caloundra Waste Facility is still suitable	Sunshine Coast Counsil
42	3/03/2016	1	Phone	Update on proposed site	Mike Farrar

41	3/03/2016	1.5	Email	Discussion on whether Caloundra Waste Facility is still suitable	Sunshine Coast Counsil
42	3/03/2016	1	Phone	Update on proposed site	Mike Farrar

43	8/03/2016	3	Study	Lecture on Fundamentals of Pavement design	
44	10/03/2016	3	Research	Research Consolid trials	
45	10/03/2016	2	Email	Submit proposal to Brisbane City Council	Greg Stephenson
46	11/03/2016	0.5	Email	Caloundra Waste Facility declined the proposal	Caloundra Waste Facility
47	12/03/2016	2	Email	Revise porposal to submit to Brisbane City Council	Greg Stephenson
48	14/03/2016	2	Email	Submit proposal to Brisbane City Council	Greg Stephenson
49	16/03/2016	2	Meeting	Site visit at Bracalba Quarry	Mike Farrar/Peter Harris
50	18/03/2016	1.5	Study	Revise the program for the project	John Yeaman
51	18/03//2016	0.5	Email	Enquire about Moisture gauges	John Yeaman
52	19/03/2016	3.5	Research	Research CBR testing on consolid	
53	20/03/2016	3	Research	Prepare document for media press release	John Yeaman/Jarna Baudinette
54	22/03/2016	0.5	Study	Arrange additional soil for testing at the laboratories	Mke Farrar
55	23/03/2016	0.5	Study	Acqure Atterbergs testing from quarry for material	Mike Farrar
56	25/03/2016	4	Research	Understand process for road building	
57	26/03/2016	4	Research	Research soil stabilisation	
58	27/03/2016	4	Research	Calibration of Moisture Gauges	
59	29/03/2016	1.5	Phone	Update on current progress	Mike Farrar
60	29/03/2016	3	Research	Research soil	

61	2/04/2016	1.5	Research	Research	
62	5/04/2016	0.5	Phone	Pacific data systems for moiture gauges	Paul Gapes
63	5/04/2016	2	Email	Clarify requests in Project proposal	Greg Stephenson
64	6/04/2016		1	Email	Pacific Data systems for moiture gauges
65	7/04/2016	2.5	Meeting	USC laboratories	Bernhard Black
66	8/04/2016	1.5	Meeting	Update on current progress	Mike Farrar/John Yeaman
67	9/04/2016	8	Study	Observe and assist in the development of the road at Bracalba	John Yeaman/Mike Farra
68	11/04/2016	3	Study	Report on the activities observed during road construction	John Yeaman
69	12/04/2016	2	Meeting	Proposal testing to be done on site	Ernesto Urbaez

70	12/04/2016	0.5	Email	No concern with the road	Mike Farrar
71	13/04/2016	2	Study	Prepare abstract for report	John Yeaman
72	18/04/2016	0.5	Email	Requesting trial testing to be done on site	Ernesto Urbaez
73	21/04/2016	0.5	Email	Approved testing	Tent McDonald
74	22/04/2016	2	Study	Falling Weight Deflectometer	Trent McDonald/Peter Harris
75	22/04/2016	1	Study	Site Inspection	Peter Harris
76	24/04/2016	1.5	Email	Report on Site inspection	John Yeaman/Mike Farra
77	27/04/2016	0.5	Email	Moisture gauges have arrived	Paul Gapes
78	29/04/2016	3	Study	Consolidate photos taken during installment of the road	Mike Farrar
79	2/04/2016	3	Study	Consolidate photos taken during installment of the road	Mike Farrar
80	4/05/2016	2	Study	Laboratory Testing	Bernhard Black
81	5/05/2016	3.5	Study	Calibration moisture gages	Bernhard Black

82	5/05/2016	0.5	Email	Arrange another FWD testing	Mike Farrar
83	9/05/2016	1.5	Meeting	Discuss progress so far	John Yeaman
84	10/05/2016	3.5	Study	Calibration of Moisture Gauges	John Yeaman
85	12/05/2016	2	Study	Moistues Gauges are installed	Mike Farrar/John Yeaman
86	12/05/2016	1	Study	Site Inspection	
87	15/05/2016	1.5	Study	Progress Report	
88	18/05/2016	3	Study	Progress Report	
89	20/05/2016	3	Meeting	Falling Weight Deflectometer	Robert Kinzett
90	20/05/2016	1	Meeting	Site Inspection	Brian Smith
91	21/05/2016	1	Phone	Report on site inspection	John Yeaman/Mike Farra
92	22/05/2016	2	Study	Collate the FWD data	Mike Farrar
93	24/05/2016	3.5	Research	Collect the moisture sensor data	Mike Farrar
94	24/05/2016	2	Research	Learn progam Elmod6	Trent McDonald
95	24/05/2016	0.5	Research	Traffic volume data being processed	Peter Harris
96	26/05/2016	2	Study	Checked mositure Sensors	
97	27/05/2016	5	Study	Progress Report	
98	28/05/2016	3	Study	Progress Report	
99	29/05/2016	5	Study	Progress Report	
100	31/05/2016		Study	Progress Report Submission	
101	25/06/2016	4	Study	Collect Moisture data	
102	28/06/2016	4	Study	Consolidate moisture data	
102	08/07/2016	4	Study	Collect FWD testing data	
103	10/07/2016	3	Study	Analyse FWD data	
104	12/07/2016	2	Meeting	Discuss FWD results	John Yeaman
105	10/08/2016	5	Study	Prepare final report	

106	18/08/2016	5	Research	Research for final report	
107	25/08/2016	4	Study/Research	Analyse of results and further research	
108	14/09/2016	5	Research	Conduct FWD test	
109	15/09/2016	4	Study	Gather moisture data	
110	20/09/2016	4	Research	Prepared all the moisture readings	
111	01/10/2016	5	Study	Analysis of results	
112	10/10/2016		Meeting	Draft Submission	
113	16/10/2016	6	Study	Prepare Oral presentation	
114	21/10/2016	3	Study	Oral Presentation	
115	24/10/2016	5	Study	Final Considerations	
116	26/10/2016		Report	Final submission	

Appendix B – Gantt Chart

ID	Task Name	Duration	Start	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16
1	Develop Project Idea	50 Days	3/10/2015													
2	Project Supervisor	5 Days	14/11/2015													
3	Prepare Project Proposal	30 Days	21/11/2015													
4	Aims/Objectives	20 Days	21/11/2015													
5	Literature Review	200 Days	19/12/2015													
6	Deisgn Concept	50 Days	2/01/2016													
7	Submit Project Proposal	1 Day	20/02/2016													
8	Testing Principles	100 Days	21/02/2016													
9	Testing Methodology	90 Days	6/03/2016													
10	Testing Regime	10 Days	20/03/2016													
11	Conduct Testing	100 Days	3/04/2016													
12	Prepare Draft / Mid semester report	20 Days	17/04/2016													
13	Prepare Poster Presentation	3 Days	18/05/2016													
14	Submit Mid Semester Report	1 Day	28/05/2016													
15	Analysis	100 Days	29/05/2016													
16	Future Methods	30 Days	12/06/2016													
17	Further Testing and investigation	50 Days	24/07/2016													
18	Prepare Final Presentation	10 ays	2/10/2016													
19	Prepare Final Draft	4 Days	16/10/2016													
20	Submit Final Draft	1 Days	21/10/2016													
21	Finalise Report	8 Days	23/10/2016													
22	Submit Thesis	1 Day	26/10/2016													

Appendix C – Material testing

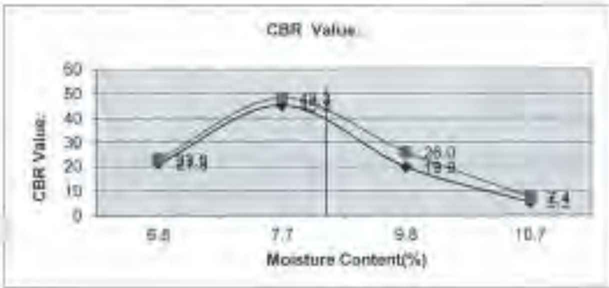
BRISBANE CITY COUNCIL T/A

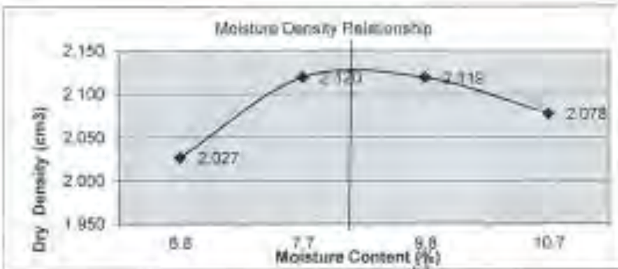
BRACALBA QUARRY

Soils Laboratory – Accreditation No. 11912
A.B.N. 72 002 765 795
PO BOX 138
WAMURAN QLD 4512
Phone: (07) 5429 9013 Fax: (07) 5496 6995

Report For	**UBP 2:5 40mm Roadbase.**	**Report No.**	14290
Lab Number	BQ16 / 0020	Lot Number	16 / 389.
Job Number	Bracalba Quarry	Chainage	
Item Number	51400	Sample Loc	Sales / Compliance
Submitted By	Wayne W Mahon.	Bench	Shot No.
Sampled By	Wayne W Mahon.	Depth	Layer
Sample Method	AS1141 .3.1 Clause 6.9.5	Material Source	South Quarry
Date Sampled	14 / 01 / 2016		
Date Tested	16 / 01 / 2016	Item Desc	2:5 (40mm) Roadbase.

Initial Moisture Content	Calculated Dry Density (t/m^3)	Bearing Ratio 2.5mm	Bearing Ratio 5.0mm	Swell (%)	Moisture Content After Penetration (%)
6.8	2.027	21.3	23.0	0.6	11.2
7.7	2.120	45.3	48.3	0.3	9.6
9.8	2.119	19.9	26.0	0.1	10.7
10.7	2.078	5.3	7.4	0.0	10.7





Test Condition Soaked. (4 days)	
Compactive Effort 100% STD	
Test Method Q113A	
Moisture Content Q102A	
◊ =	CBR 2.5mm
□ =	CBR 5.0mm
CBR OMC (%)	**8.6%**
CBR MDD (t/m^3)	**2.124**
CBR 2.5mm	38
CBR 5.0mm	42
Material CBR Value	42

Remarks:

Checked By: **Wayne W Mahon.** 25/1/16 Date:

Signatory: **Wayne W Mahon.** 25/1/16 Date:

Page 1 of 1 CF/0892/S36

NATA

BRISBANE CITY COUNCIL T/A

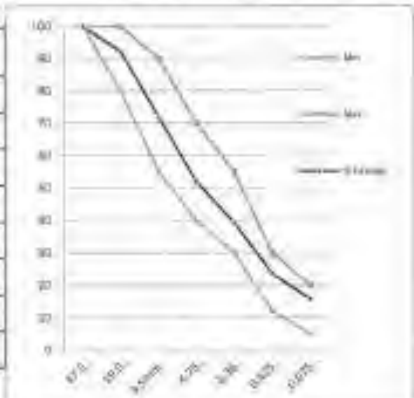
BRACALBA QUARRY

Soils Laboratory – Accreditation No. 11912
A.B.N. 72 002 765 795
PO BOX 138
WAMURAN QLD 4512
Phone: (07) 5429 9013 Fax: (07) 5496 6995

Report For:	**UBP 2.5 40mm Roadbase**	**Report No.**	14289
Lab Number:	BQ16 / 0019.	**Lot Number**	15 / 389.
Job Number	Bracalba Quarry	**Chainage**	
Item Number	51400	**Sample Loc**	Sales / Compliance.
Submitted By	Wayne W Mahon	**Bench**	Shot No.
Sampled By	Wayne W Mahon	**Depth**	Layer
Sample Method	AS 1141 3.1 Clause 6.9.5	**Material Source**	South Quarry.
Date Sampled	14 / 01 / 2016.	**Item Desc**	
Date Tested	18 / 01 / 2016.		2.5 (40mm) Roadbase.

Specification Requirements

Grading Report	**C Grading Limit**		**Q103A**
AS Sieve Size	Min	Max	% Passing
37.5mm	100	100	**100**
19.0mm	80	100	**92**
9.5mm	55	90	**72**
4.75mm	40	70	**52**
2.36mm	30	55	**39**
0.425mm	12	30	**24**
0.075mm	5	20	**15.8**



Tests		Subtype					
		2.1	2.2	2.3	2.4	2.5	Result
Liquid Limit	Q104D	25.0	25.0	28.0	35.0	40.0	**31.6**
Plastic Limit	Q105						**18.0**
Plastic Index	Q105	6.0	6.0	6.0	12.0	14.0	**13.6**
Linear Shrinkage	Q106	3.5	3.5	4.5	6.5	7.5	**5.8**
P I x % 0.425mm	Q105	150	150	200	360	-	**321**
L.S x % 0.425mm	Q106	85	85	110	195	-	**136**
Fines Ratio		0.30 - 0.55		0.30 - 0.65	-	-	**0.67**
Flakiness Index	Q201	35	35	40	40	-	
Total Spec. Defects							

Remarks:

Checked By: **Wayne W Mahon.** ________ 25/1/16. Date

Signatory: **Wayne W Mahon.** ________ 25/1/16. Date

CF/0790/S08 Page 1 of 1

NATA

BRISBANE CITY COUNCIL T/A

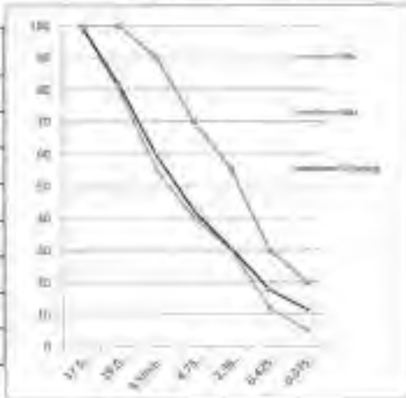
BRACALBA QUARRY

Soils Laboratory – Accreditation No. 11912
A.B.N. 72 002 765 795
PO BOX 138
WAMURAN QLD 4512
Phone: (07) 5429 9013 Fax: (07) 5496 6995

Report For:	**UBP 2.5 40mm Roadbase**	**Report No.**	14297
Lab Number:	BQ16 / 0028	**Lot Number**	16 / 389
Job Number	Bracalba Quarry	**Chainage**	
Item Number	51400	**Sample Loc**	Sales / Compliance
Submitted By	Wayne W Mahon	**Bench**	Shot No
Sampled By	Wayne W Mahon	**Depth**	Layer
Sample Method	AS 1141 3.1 Clause 8.9.5	**Material Source**	South Quarry
Date Sampled	28 / 01 / 2016	**Item Desc**	
Date Tested	02 / 02 / 2016		2.5 (40mm) Roadbase

Specification Requirements

Grading Report	**C Grading Limit**		**Q103A**
AS Sieve Size	Min	Max	% Passing
37.5mm	100	100	**100**
19.0mm	80	100	**81**
9.5mm	55	90	**59**
4.75mm	40	70	**42**
2.36mm	30	55	**30**
0.425mm	12	30	**18**
0.075mm	5	20	**11.5**



Tests		Subtype					
		2.1	2.2	2.3	2.4	2.5	Result
Liquid Limit	Q104D	25.0	25.0	28.0	35.0	40.0	**28.8**
Plastic Limit	Q105						**19.2**
Plastic Index	Q105	6.0	6.0	8.0	12.0	14.0	**9.6**
Linear Shrinkage	Q106	3.5	3.5	4.5	6.5	7.5	**4.8**
P.I x % 0.425mm	Q105	150	150	200	360	-	**168**
L.S x % 0.425mm	Q106	85	85	110	195	-	**84**
Fines Ratio		0.30 - 0.55		0.30 - 0.65	-	-	**0.65**
Flakiness Index	Q201	35	35	40	40	-	
Total Spec. Defects							

Remarks:

Checked By: **Wayne W Mahon.** 11/2/16. **Date:**

Signatory: **Wayne W Mahon.** 11/2/16. **Date:**

CF/B790/508 Page 1 of 1

Appendix D – FWD deflection results

Trial Site test 1

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	516.00	36.44	1933.60	719.80	284.00	89.10	57.70	49.60	41.50	27.70	21.00
1	2	FALSE	557.00	39.39	1320.80	546.20	271.20	127.90	77.60	59.10	47.60	32.60	22.90
1	3	FALSE	565.00	39.92	1240.10	525.00	268.90	131.50	81.40	64.00	49.50	32.20	24.80
1	4	FALSE	842.00	59.48	1777.90	756.90	411.20	204.60	127.10	97.10	76.40	50.70	36.60
2	5	FALSE	553.00	39.09	758.00	397.20	243.60	126.80	70.10	47.90	35.00	28.20	22.40
2	6	FALSE	571.00	40.35	769.70	409.60	253.20	132.70	74.00	49.00	37.30	29.10	23.00
2	7	FALSE	563.00	39.78	755.90	400.60	248.00	130.50	72.90	49.00	36.80	28.80	22.70
2	8	FALSE	835.00	59.04	1070.60	600.50	382.20	207.10	116.40	78.20	56.20	44.80	35.20
3	9	FALSE	566.00	39.99	1303.40	644.10	341.60	155.90	97.80	76.80	60.60	42.20	30.60
3	10	FALSE	562.00	39.73	1267.30	632.00	339.70	158.70	99.30	76.70	61.30	42.60	31.90
3	11	FALSE	571.00	40.35	1266.10	636.60	343.70	161.90	102.40	78.40	63.10	42.50	31.60
3	12	FALSE	818.00	57.81	1779.10	981.30	541.00	254.20	157.70	118.30	93.70	62.70	43.90
4	13	FALSE	827.00	58.44	1255.10	788.40	561.60	364.30	250.80	178.30	131.50	80.40	55.20
4	14	FALSE	538.00	38.05	774.70	459.10	326.30	213.50	149.20	106.80	79.60	48.80	33.70
4	15	FALSE	537.00	37.96	773.00	460.70	327.50	213.90	149.50	106.90	79.40	49.20	33.80
4	16	FALSE	819.00	57.91	1231.90	769.40	551.20	361.40	249.90	178.00	132.20	81.10	56.10
5	17	FALSE	561.00	39.68	392.10	242.60	168.10	112.70	79.40	55.50	41.70	27.00	19.90
5	18	FALSE	568.00	40.14	383.80	236.60	165.90	112.10	78.90	56.30	42.60	27.90	20.70
5	19	FALSE	570.00	40.28	388.60	236.80	165.80	112.50	79.30	55.40	41.80	28.20	21.00
5	20	FALSE	827.00	58.42	576.40	366.60	262.30	180.00	127.60	89.00	66.50	44.60	33.10
6	21	FALSE	815.00	57.61	1947.10	878.30	367.90	80.60	53.20	63.20	56.50	44.20	33.70
6	22	FALSE	578.00	40.88	1388.20	609.10	260.20	65.90	39.40	39.40	35.80	29.60	23.40
6	23	FALSE	573.00	40.47	1335.90	597.00	259.60	68.90	41.20	40.70	36.30	29.50	22.90
6	24	FALSE	874.00	61.77	1873.10	869.80	388.10	106.70	68.10	72.10	63.40	49.00	36.80
7	25	FALSE	551.00	38.95	929.80	527.40	335.90	200.40	133.20	94.80	69.50	43.90	31.30
7	26	FALSE	559.00	39.53	933.00	536.00	342.90	204.60	136.40	96.80	70.80	44.90	31.30
7	27	FALSE	573.00	40.52	944.90	548.80	353.90	212.70	141.50	100.20	73.50	45.80	32.50
7	28	FALSE	813.00	57.43	1347.20	796.80	522.40	318.80	212.60	151.10	110.50	69.30	48.20

Control Site test 1

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	536.00	37.91	472.60	173.00	117.60	78.00	56.80	41.90	32.00	21.90	16.40
1	2	FALSE	569.00	40.21	669.10	185.80	127.40	84.80	61.80	45.30	35.00	24.40	18.30
1	3	FALSE	569.00	40.22	579.10	185.80	127.50	84.60	61.80	45.00	34.60	24.60	18.10
1	4	FALSE	825.00	58.34	944.80	279.20	197.20	134.90	98.80	72.70	56.10	37.70	29.00
2	5	FALSE	542.00	38.31	570.00	297.00	204.30	135.80	102.60	76.20	62.20	40.10	27.40
2	6	FALSE	575.00	40.63	455.60	264.20	189.20	132.30	99.30	83.90	65.90	40.50	31.30
2	7	FALSE	562.00	39.73	437.80	255.40	182.20	128.40	97.30	81.30	64.40	39.40	31.30
2	8	FALSE	818.00	57.79	939.40	399.00	290.10	208.90	161.20	123.10	101.80	67.80	49.90
3	9	FALSE	544.00	38.45	641.40	228.60	157.30	108.00	79.10	60.00	45.50	30.50	23.60
3	10	FALSE	563.00	39.80	465.60	233.90	162.60	113.20	82.00	62.00	48.20	31.90	24.80
3	11	FALSE	559.00	39.53	448.90	233.80	164.40	113.90	81.80	62.40	47.70	31.80	24.30
3	12	FALSE	806.00	56.99	1035.10	350.10	251.40	176.30	128.80	93.90	76.20	48.60	38.40
4	13	FALSE	543.00	38.37	565.40	332.90	222.40	140.50	97.20	70.00	50.50	31.40	22.50
4	14	FALSE	559.00	39.53	466.80	278.60	194.70	131.60	95.40	69.20	54.20	37.00	25.70
4	15	FALSE	559.00	39.48	445.90	274.00	192.30	130.40	95.10	71.20	54.10	36.80	26.40
4	16	FALSE	815.00	57.61	884.00	430.20	313.90	214.40	156.40	115.90	88.00	57.70	41.20
5	17	FALSE	563.00	39.76	423.10	290.10	201.40	130.40	91.80	67.60	49.20	29.70	21.30
5	18	FALSE	575.00	40.61	380.00	254.10	178.50	119.40	87.50	65.30	48.90	32.50	23.50
5	19	FALSE	557.00	39.37	365.00	242.40	170.10	113.60	83.50	62.30	46.80	31.40	22.50
5	20	FALSE	831.00	58.70	551.70	390.50	282.20	194.10	141.70	107.40	77.70	51.50	37.10
6	21	FALSE	567.00	40.10	510.10	306.70	209.20	143.00	105.10	79.20	57.60	36.20	25.00
6	22	FALSE	550.00	38.86	391.90	243.60	171.00	123.10	94.10	73.20	56.00	37.50	27.50
6	23	FALSE	561.00	39.62	393.10	247.80	174.80	126.40	97.20	74.80	58.10	38.80	28.60
6	24	FALSE	832.00	58.81	589.50	402.40	296.00	216.40	165.80	126.00	96.20	62.30	44.90
7	25	FALSE	552.00	39.04	375.40	209.60	140.30	93.80	69.10	53.00	41.60	26.40	19.40
7	26	FALSE	562.00	39.69	328.20	203.90	138.60	93.30	69.60	53.40	41.40	29.10	22.20
7	27	FALSE	574.00	40.57	330.40	204.00	140.30	94.80	71.20	54.60	40.70	30.30	22.60
7	28	FALSE	824.00	58.23	476.40	319.40	225.50	156.40	118.60	89.90	69.10	48.20	36.10

Trial Site test 2

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	565.00	39.96	412.80	286.30	205.80	141.80	95.20	66.80	52.10	33.30	23.50
1	2	FALSE	569.00	40.21	418.30	283.60	204.90	143.80	94.80	67.50	51.80	33.70	24.20
1	3	FALSE	563.00	39.78	413.30	276.70	200.80	138.10	93.60	65.80	51.20	33.10	23.80
1	4	FALSE	845.00	59.75	623.30	436.50	311.00	219.00	153.00	105.00	81.90	53.60	37.30
2	5	FALSE	559.00	39.51	710.30	363.40	222.20	135.60	101.60	70.60	56.90	36.20	23.40
2	6	FALSE	567.00	40.06	692.00	357.10	216.90	137.00	95.60	71.40	58.80	37.90	23.80
2	7	FALSE	569.00	40.18	680.40	347.80	211.60	136.80	94.00	69.90	58.80	37.80	22.10
2	8	FALSE	829.00	58.56	962.00	522.60	318.70	205.10	145.80	106.10	93.30	58.60	30.00
3	9	FALSE	561.00	39.65	1061.80	752.10	565.40	383.40	272.40	178.70	129.20	72.00	46.10
3	10	FALSE	563.00	39.78	1036.60	725.90	551.00	379.00	269.70	178.30	127.90	73.60	47.00
3	11	FALSE	568.00	40.17	1035.20	720.40	549.70	379.80	272.10	178.80	129.80	74.50	46.60
3	12	FALSE	822.00	58.12	1536.40	1093.60	844.50	582.30	407.50	264.90	197.30	102.20	70.30
4	13	FALSE	567.00	40.04	598.30	306.60	224.50	171.30	125.60	89.30	60.30	38.30	25.10
4	14	FALSE	567.00	40.10	588.70	305.60	224.70	174.70	122.40	90.60	59.20	36.00	22.10
4	15	FALSE	566.00	39.99	583.30	303.20	224.90	173.50	125.80	90.80	59.50	37.00	22.60
4	16	FALSE	849.00	59.98	892.90	494.60	377.10	282.30	200.10	150.60	101.10	64.80	40.90
5	17	FALSE	567.00	40.10	355.40	217.20	162.70	115.60	83.40	61.20	50.90	31.30	24.10
5	18	FALSE	568.00	40.11	352.00	213.80	158.50	111.90	81.50	60.60	48.70	31.30	24.30
5	19	FALSE	567.00	40.08	350.60	214.20	161.80	118.30	82.10	60.70	51.50	31.60	24.80
5	20	FALSE	853.00	60.29	516.80	329.40	250.40	183.50	135.70	96.90	81.30	49.00	38.20
6	21	FALSE	562.00	39.73	486.60	268.00	206.00	154.90	119.40	90.30	70.80	49.50	39.30
6	22	FALSE	565.00	39.90	485.90	268.90	206.80	156.70	121.80	91.40	71.50	50.70	40.00
6	23	FALSE	568.00	40.14	485.50	269.10	205.50	156.70	121.60	91.50	70.90	50.50	40.70
6	24	FALSE	842.00	59.48	715.80	418.40	319.40	247.30	197.90	144.40	114.20	75.90	60.00
7	25	FALSE	564.00	39.89	625.90	361.80	276.90	183.60	136.90	100.40	80.90	48.70	35.20
7	26	FALSE	565.00	39.96	622.40	358.20	275.00	182.20	132.80	100.80	80.50	49.70	36.20
7	27	FALSE	567.00	40.10	623.10	357.60	272.60	182.80	136.10	99.80	79.70	50.20	34.80
7	28	FALSE	843.00	59.57	964.00	585.90	452.20	302.50	222.70	164.50	130.60	82.20	56.10

Control Site test 2

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	564.00	39.87	427.00	266.50	191.80	129.70	88.90	64.80	48.80	31.10	22.80
1	2	FALSE	565.00	39.92	418.80	260.70	186.70	125.60	88.00	62.10	46.30	33.40	23.50
1	3	FALSE	565.00	39.92	414.90	259.60	186.10	126.60	87.90	62.50	47.10	33.90	23.70
1	4	FALSE	836.00	59.09	620.40	411.20	306.50	211.10	146.30	106.30	80.40	53.90	36.00
2	5	FALSE	559.00	39.50	456.40	243.80	174.40	121.00	86.20	65.50	48.40	32.80	24.90
2	6	FALSE	567.00	40.04	453.50	243.90	175.20	121.50	86.40	65.80	49.20	34.40	26.60
2	7	FALSE	567.00	40.06	450.30	242.70	174.30	121.10	86.00	65.90	48.10	33.00	26.80
2	8	FALSE	831.00	58.74	627.10	363.10	272.30	193.30	138.10	104.80	77.30	52.90	40.30
3	9	FALSE	561.00	39.65	465.50	279.60	170.30	115.00	81.90	62.80	50.10	36.00	26.70
3	10	FALSE	563.00	39.76	459.90	274.90	169.20	115.10	81.90	63.00	50.50	37.20	29.20
3	11	FALSE	568.00	40.15	459.40	274.10	170.00	116.20	83.10	63.50	50.70	37.50	29.50
3	12	FALSE	839.00	59.27	638.80	411.40	260.90	181.80	132.20	99.50	78.30	57.70	45.20
4	13	FALSE	559.00	39.50	457.60	250.50	158.30	97.30	71.80	55.40	41.40	23.30	33.70
4	14	FALSE	566.00	39.99	454.60	249.40	159.30	99.30	73.80	57.00	42.30	23.90	30.20
4	15	FALSE	566.00	40.03	451.30	248.30	157.00	99.90	72.60	57.20	42.80	24.90	29.80
4	16	FALSE	840.00	59.36	616.10	368.30	243.80	157.70	114.30	91.30	69.00	40.50	42.60
5	17	FALSE	562.00	39.71	353.90	215.20	149.80	95.90	61.00	48.60	36.90	25.10	21.10
5	18	FALSE	566.00	40.01	349.80	214.00	148.30	95.10	60.60	48.70	37.10	26.00	22.00
5	19	FALSE	563.00	39.76	344.80	211.20	146.90	94.20	60.40	47.90	36.50	25.70	22.20
5	20	FALSE	843.00	59.57	491.60	315.80	230.30	151.70	99.00	77.10	57.50	39.10	33.80
6	21	FALSE	561.00	39.65	505.60	279.20	202.50	147.10	107.30	79.00	56.60	39.20	30.90
6	22	FALSE	564.00	39.85	495.20	273.90	198.40	144.30	106.80	77.20	53.30	38.10	31.90
6	23	FALSE	567.00	40.08	492.80	273.20	197.80	144.40	106.80	77.40	53.20	38.10	32.10
6	24	FALSE	833.00	58.90	712.70	422.20	321.40	235.00	175.20	127.40	88.40	59.80	48.40
7	25	FALSE	561.00	39.62	374.80	188.80	121.20	80.00	55.60	41.40	32.80	18.70	23.80
7	26	FALSE	564.00	39.89	372.10	186.70	121.30	80.10	55.70	41.60	33.30	21.00	23.50
7	27	FALSE	566.00	39.99	369.70	185.60	120.70	80.00	55.50	41.70	33.50	21.00	23.60
7	28	FALSE	841.00	59.41	513.30	274.90	183.40	123.80	86.60	66.20	52.50	39.70	29.70

Trial Site test 3

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	594.00	41.97	363.70	262.10	200.20	142.60	97.10	70.20	53.10	33.10	24.10
1	2	FALSE	557.00	39.34	298.20	207.20	159.20	115.30	82.70	61.50	47.70	30.80	22.50
1	3	FALSE	571.00	40.35	302.90	211.90	163.80	118.50	85.10	63.30	49.50	32.10	23.60
1	4	FALSE	838.00	59.26	452.90	329.70	257.10	189.30	135.00	100.70	76.90	50.70	37.20
2	5	FALSE	598.00	42.27	384.70	250.60	184.30	130.20	97.70	72.80	54.60	34.40	24.50
2	6	FALSE	567.00	40.10	322.70	210.10	154.40	109.10	84.00	64.90	49.60	33.10	24.10
2	7	FALSE	565.00	39.90	317.80	206.80	152.20	107.20	82.80	63.70	49.10	32.10	23.30
2	8	FALSE	845.00	59.73	475.20	320.10	241.90	175.10	135.50	104.30	80.00	53.30	38.20
3	9	FALSE	589.00	41.60	521.60	314.30	228.70	166.00	123.50	93.10	71.30	44.80	30.80
3	10	FALSE	567.00	40.06	397.80	241.90	181.10	136.90	106.20	83.00	65.40	43.80	30.80
3	11	FALSE	561.00	39.65	385.90	235.80	176.60	134.10	104.40	81.80	64.50	43.40	30.70
3	12	TRUE	845.00	59.69	615.60	393.10	298.30	226.00	174.10	134.90	105.60	69.20	48.70
4	13	FALSE	598.00	42.27	733.00	460.90	331.30	232.60	162.60	119.30	88.90	53.90	36.10
4	14	FALSE	570.00	40.26	588.90	376.10	273.40	195.10	139.90	105.40	79.40	50.40	35.00
4	15	FALSE	569.00	40.21	580.50	372.10	271.40	194.10	138.00	103.80	79.10	50.10	34.30
4	16	FALSE	845.00	59.72	885.10	595.50	439.60	316.00	225.00	169.30	128.00	80.40	54.60
5	17	FALSE	586.00	41.42	279.40	168.20	131.60	94.80	72.90	55.90	41.60	26.80	18.50
5	18	FALSE	577.00	40.77	248.70	149.80	116.20	86.20	66.10	50.50	38.50	26.60	18.90
5	19	FALSE	561.00	39.68	241.40	145.70	112.20	83.70	64.40	49.00	37.00	25.70	18.10
5	20	FALSE	844.00	59.66	372.30	234.40	183.70	138.30	106.10	82.00	62.80	41.70	30.20
6	21	FALSE	579.00	40.95	425.10	221.70	160.90	120.40	93.00	73.70	55.90	37.30	26.50
6	22	FALSE	573.00	40.49	356.10	186.40	138.70	106.70	84.40	69.90	52.00	35.60	26.40
6	23	FALSE	565.00	39.94	347.20	182.80	136.60	104.80	83.10	69.20	50.90	35.00	26.40
6	24	FALSE	845.00	59.75	529.40	317.80	233.80	178.40	139.10	108.30	87.30	59.30	43.00
7	25	FALSE	579.00	40.95	623.10	350.10	241.20	166.90	119.10	85.40	61.80	38.90	26.40
7	26	FALSE	570.00	40.28	503.40	288.90	205.30	146.10	106.30	77.60	57.60	37.10	26.00
7	27	FALSE	567.00	40.08	490.70	283.70	202.40	144.10	105.10	76.90	57.00	36.30	26.10
7	28	FALSE	838.00	59.22	739.70	448.90	326.20	234.00	169.60	123.80	91.50	57.60	40.60

Control Site test 3

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	585.00	41.32	513.10	311.00	208.70	138.70	98.60	71.60	52.00	31.30	20.70
1	2	FALSE	559.00	39.48	397.70	241.10	169.70	117.30	87.50	64.90	48.20	30.30	20.20
1	3	FALSE	578.00	40.88	402.20	249.90	176.50	122.80	91.10	68.60	51.50	32.70	22.30
1	4	FALSE	844.00	59.64	569.00	390.10	281.60	197.80	145.90	108.20	80.90	50.10	33.70
2	5	FALSE	574.00	40.56	600.90	365.40	244.50	163.40	120.50	89.20	66.90	40.10	29.10
2	6	FALSE	561.00	39.68	468.80	296.10	208.20	146.80	111.20	84.60	65.70	40.90	31.80
2	7	FALSE	568.00	40.17	464.40	297.00	209.40	148.30	112.50	85.60	66.90	41.80	32.50
2	8	FALSE	839.00	59.31	691.80	466.90	337.90	240.40	181.20	136.30	104.10	66.20	47.00
3	9	FALSE	595.00	42.06	698.00	395.40	250.70	151.50	100.40	71.70	53.30	34.60	24.30
3	10	FALSE	562.00	39.75	520.10	301.10	201.90	132.80	94.60	70.50	54.10	36.30	26.10
3	11	FALSE	565.00	39.96	512.90	300.20	202.10	133.80	96.10	70.90	55.50	37.40	25.80
3	12	FALSE	848.00	59.91	740.30	477.40	332.90	222.70	158.30	116.30	87.80	57.30	40.80
4	13	FALSE	590.00	41.70	738.10	429.70	276.60	174.40	116.70	80.20	57.20	34.10	23.00
4	14	FALSE	568.00	40.17	544.30	334.80	226.40	152.40	107.60	78.50	58.10	36.00	26.40
4	15	FALSE	567.00	40.04	531.30	324.40	221.00	150.10	106.70	78.30	58.40	36.50	26.00
4	16	FALSE	845.00	59.69	772.70	518.30	359.30	244.90	171.30	123.50	90.80	55.90	39.90
5	17	FALSE	586.00	41.42	466.50	291.40	191.70	117.10	78.40	54.40	39.00	24.70	18.20
5	18	FALSE	561.00	39.64	364.70	223.50	150.50	95.40	65.80	48.30	35.30	23.00	17.60
5	19	FALSE	565.00	39.96	359.60	226.10	152.80	96.10	67.20	48.40	36.00	23.80	17.50
5	20	FALSE	841.00	59.45	517.50	355.50	248.50	161.20	112.40	79.40	58.60	37.90	28.30
6	21	FALSE	588.00	41.55	722.70	475.30	317.20	204.30	140.20	101.90	74.50	44.30	31.40
6	22	FALSE	564.00	39.83	502.50	331.10	229.00	155.60	113.40	85.60	65.40	42.30	30.20
6	23	FALSE	569.00	40.24	496.30	331.60	230.60	155.80	113.60	85.90	65.40	41.30	30.00
6	24	FALSE	839.00	59.29	731.20	520.10	374.10	258.90	187.50	140.10	105.90	65.40	47.90
7	25	FALSE	602.00	42.57	487.60	266.20	161.70	98.00	68.00	50.40	37.90	25.70	19.40
7	26	FALSE	556.00	39.29	360.80	207.10	129.90	82.00	58.30	45.10	34.10	24.40	18.30
7	27	FALSE	585.00	41.32	372.90	218.40	138.00	87.50	62.30	47.60	36.40	25.50	19.20
7	28	FALSE	849.00	60.03	521.30	328.00	215.50	139.50	100.00	75.80	57.90	39.90	29.90

Trial Site test 4

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
1	1	FALSE	590.00	41.73	684.20	355.40	225.20	134.80	87.00	67.80	48.80	31.10	23.90
1	2	FALSE	567.00	40.08	616.20	325.90	211.30	128.90	83.80	65.10	47.80	31.30	23.90
1	3	FALSE	561.00	39.68	608.40	320.50	209.10	127.80	82.70	64.30	47.00	30.20	23.10
1	4	FALSE	729.00	51.53	770.70	421.40	279.30	173.80	113.30	87.20	63.40	42.40	30.30
2	5	FALSE	586.00	41.44	470.10	306.40	222.80	147.50	97.40	70.10	47.40	28.80	21.60
2	6	FALSE	554.00	39.12	390.10	247.80	178.60	118.00	79.00	58.80	41.30	27.70	21.20
2	7	FALSE	564.00	39.83	397.10	252.40	182.50	121.40	82.00	62.10	45.40	29.40	22.80
2	8	FALSE	724.00	51.16	519.90	337.40	244.80	164.90	112.20	84.20	61.20	39.80	29.70
3	9	FALSE	567.00	40.08	611.80	328.70	221.40	137.80	92.90	70.60	51.30	33.60	25.80
3	10	FALSE	551.00	38.97	519.30	264.40	180.20	116.40	81.60	64.10	48.40	33.80	26.00
3	11	FALSE	562.00	39.75	524.60	267.70	183.00	118.70	83.50	66.10	50.20	34.80	27.30
3	12	FALSE	711.00	50.22	658.90	349.50	241.90	158.50	112.60	89.40	66.30	45.80	34.90
4	13	FALSE	575.00	40.63	1139.90	711.40	505.60	332.20	215.80	159.70	106.20	59.70	39.90
4	14	FALSE	557.00	39.34	1023.40	643.50	464.60	310.50	204.80	152.70	103.20	58.70	39.40
4	15	FALSE	566.00	40.03	1034.00	651.40	472.00	316.30	209.70	155.40	106.00	60.90	39.50
4	16	FALSE	714.00	50.43	1296.20	835.70	611.20	411.40	272.50	199.70	136.90	78.20	50.70
6	21	FALSE	594.00	41.95	399.10	241.60	188.30	135.20	94.00	74.70	54.30	34.70	25.70
6	22	FALSE	547.00	38.69	332.30	198.50	155.40	113.70	80.60	65.40	49.90	32.80	25.50
6	23	FALSE	574.00	40.59	348.90	209.10	164.00	120.00	86.30	70.00	52.80	34.90	26.20
6	24	FALSE	715.00	50.56	439.40	268.90	212.50	156.80	113.10	91.80	69.20	45.90	33.80
7	25	FALSE	564.00	39.85	337.40	220.50	161.50	115.40	80.60	62.60	45.10	28.30	21.50
7	26	FALSE	544.00	38.44	305.70	199.00	148.10	106.40	76.20	60.60	45.20	29.70	23.20
7	27	FALSE	568.00	40.11	316.60	209.00	154.80	111.50	80.70	65.30	48.00	32.80	24.70
7	28	FALSE	716.00	50.58	405.80	274.60	206.10	149.80	109.50	86.90	64.70	42.70	32.30
8	29	FALSE	573.00	40.49	499.40	293.10	217.10	156.90	117.60	94.10	69.50	44.40	30.80
8	30	FALSE	552.00	39.04	406.90	240.70	182.80	135.90	103.90	85.60	64.50	43.50	31.10
8	31	FALSE	567.00	40.10	415.00	246.50	187.30	139.30	106.60	87.80	66.40	45.10	32.00
8	32	FALSE	719.00	50.82	528.60	326.50	249.90	187.10	143.70	117.20	88.20	59.50	41.50

Control Site test 4

StationID	DropID	History	Stress	Force	D1	D2	D3	D4	D5	D6	D7	D8	D9
2	5	FALSE	573.00	40.47	570.80	307.90	219.20	142.90	97.20	73.50	56.30	35.10	26.60
2	6	FALSE	549.00	38.81	523.00	284.10	202.70	133.20	91.90	71.40	51.30	33.10	24.50
2	7	FALSE	577.00	40.77	550.90	300.80	215.60	142.60	97.90	76.60	55.20	36.00	26.40
2	8	FALSE	720.00	50.91	684.10	383.60	278.30	187.00	129.50	100.80	73.00	47.80	34.10
3	9	FALSE	577.00	40.75	734.10	402.20	271.80	176.70	125.50	98.10	70.70	43.30	30.40
3	10	FALSE	555.00	39.25	611.80	309.60	217.90	149.50	110.40	89.60	66.90	44.10	31.80
3	11	FALSE	570.00	40.31	623.40	315.40	223.30	153.80	113.70	92.60	69.80	45.80	33.00
3	12	FALSE	723.00	51.11	778.30	409.80	295.90	206.20	152.60	122.90	92.00	59.90	42.30
4	13	FALSE	580.00	40.96	659.80	328.00	214.00	136.90	94.50	73.60	55.40	38.10	27.50
4	14	FALSE	550.00	38.90	549.50	259.60	178.20	120.40	83.50	66.60	51.80	36.00	26.80
4	15	FALSE	574.00	40.54	566.80	271.40	185.40	125.70	89.20	71.70	55.70	39.30	28.90
4	16	FALSE	720.00	50.91	699.60	351.30	242.90	166.40	120.10	97.40	74.50	52.30	37.30
5	17	FALSE	575.00	40.67	735.40	359.40	218.10	128.60	79.60	58.20	39.00	24.00	18.10
5	18	FALSE	552.00	39.04	592.00	291.80	188.20	118.20	77.50	58.50	40.90	26.20	20.00
5	19	FALSE	574.00	40.56	600.10	301.10	196.20	124.70	81.50	61.30	43.30	27.40	19.70
5	20	FALSE	713.00	50.38	726.10	385.40	255.00	164.20	107.50	80.90	55.80	35.40	25.40
7	25	FALSE	574.00	40.57	677.10	369.30	250.80	167.30	124.80	102.90	72.90	43.90	31.30
7	26	FALSE	555.00	39.20	554.10	296.50	206.80	141.90	106.00	88.10	64.70	41.40	30.90
7	27	FALSE	573.00	40.52	565.00	300.80	213.40	146.20	109.80	90.90	67.20	43.70	30.90
7	28	FALSE	726.00	51.32	700.40	388.30	279.70	198.20	145.80	119.30	89.30	58.50	39.90
8	29	FALSE	568.00	40.15	579.80	282.20	180.90	110.70	74.30	58.00	42.30	29.00	22.60
8	30	FALSE	552.00	39.00	483.90	238.00	158.10	100.90	70.00	56.20	42.40	29.30	22.60
8	31	FALSE	566.00	40.01	487.40	241.90	161.40	104.20	72.80	58.70	44.30	31.00	23.60
8	32	FALSE	724.00	51.14	603.70	311.90	213.30	140.30	99.00	79.60	60.60	41.20	31.00
9	33	FALSE	575.00	40.67	594.30	277.80	173.80	104.90	70.10	55.60	41.50	28.50	21.90
9	34	FALSE	549.00	38.79	492.40	222.10	145.30	92.90	64.30	53.30	40.00	28.80	23.00
9	35	FALSE	568.00	40.17	505.60	228.50	150.80	97.30	68.80	56.00	43.10	30.70	23.60
9	36	FALSE	716.00	50.58	623.40	291.70	197.10	129.70	91.70	73.10	56.60	41.00	31.50

Appendix E – Vertical strain calculation & SAR's

PAVEMENT MANAGEMENT SERVICES

Mechanistic Design Report

Pavement Management Services
Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Austroads Guide to Pavement Technology[1]

Report Date:	15-Oct-16	**Prepared By:**	Hayden Curran
Project No.:	2016000	**Growth Rate:**	0.0%
Report No:	2016257-01	**Design Period:**	5
Analysis Method:	PMS-QP4-002	**Project Reliability:**	90.0%
Location:	Bracalba Quarry Feeder Road	**Treatment Description:**	Remaining Life

Client: Bracalba Quarry

Loading

Total Gear Load:	8.00E+04 N
Tyre Pressure:	750 kPa
Gear Name:	Standard Axle
No. Tyres:	4
No. Repetitions:	1.20E+05 SAR5 (Fatigue of Asphalt)
	1.75E+06 SAR7 (Rutting & Shape Loss)
	1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing

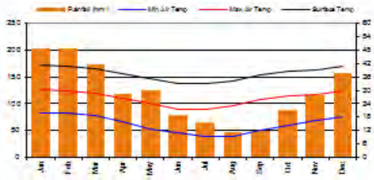
Tyre No	X	Y
1	-165	0
2	165	0
3	1635	0
4	1965	0

Evaluation Points

Tyre No	X	Y
1	0	0
2	165	0
3	1635	0
4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		250	Rainfall Adjustment	Dry Mod.*	279
Layer 2	Granular(Existing)		150	Rainfall Adjustment	Dry Mod.*	180
Layer 3	Subgrade		0	Rainfall Adjustment	Dry Mod.*	89

* Modulus or UCS in MPa

Pavement Structure

	AC	Cemen	Deform	Degree of Anisotrop	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☐	☐		2	0.35	243	254	271	279	276	262
Layer 2	☐	☐	☐	2	0.35	157	164	175	180	178	169
Layer 3	☐	☐	☑	2	0.45	77	81	86	89	88	84

Vertical Strains

Calculate

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	250	780	745	699	678	685	722
Top	Layer 3	400	663	634	594	577	582	613

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	250	371	355	333	323	326	343
Bottom	Layer 2	400	357	341	320	310	314	330

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 3	1	0%	0%	0%	0%	0%	0%	5.8
							1%	Accepted
							1.80.E+08	SAR's
							5	Years

Reliability

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Austroads Guide to Pavement Technology[1]

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date: 15-Oct-16
Project No.: 2016000
Report No: 2016257-01
Analysis Method: PMS-QP4-002
Location: Bracalba Quarry Feeder Road

Client: Bracalba Quarry

Prepared By: Hayden Curran
Growth Rate: 0.0%
Design Period: 5
Project Reliability: 90.0%
Treatment Description: Remaining Life

Loading

Total Gear Load: 8.00E+04 N
Tyre Pressure: 750 kPa
Gear Name: Standard Axle
No. Tyres: 4
No. Repetitions: 1.20E+05 SAR5 (Fatigue of Asphalt)
1.75E+06 SAR7 (Rutting & Shape Loss)
1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing

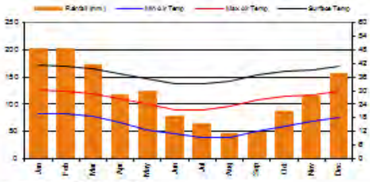
Tyre No	X	Y
1	-165	0
2	165	0
3	1635	0
4	1965	0

Evaluation Points

Tyre No	X	Y
1	0	0
2	165	0
3	1635	0
4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		400	Rainfall Adjustment	Dry Mod.*	572
Layer 2	Subgrade		0	Rainfall Adjustment	Dry Mod.*	95

* Modulus or UCS in MPa

Pavement Structure

	AC	Cement	Deform	Degree of Anisotrop	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☐	☐	☐	2	0.35	498	521	555	572	566	538
Layer 2	☐	☐	☑	2	0.45	83	86	92	95	94	89

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	400	421	403	378	366	370	390

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	400	220	211	198	192	194	204

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 2	1	0%	0%	0%	0%	0%	0%	5.8

0% Accepted
4.31.E+09 SAR's
5 Years

Austroads Guide to Pavement Technology[1]

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date:	15-Oct-16	Client: Bracalba Quarry	Prepared By: Hayden Curran
Project No.:	2016000		Growth Rate: 0.0%
Report No:	2016257-01		Design Period: 5
Analysis Method:	PMS-QP4-002		Project Reliability: 90.0%
Location:	Bracalba Quarry Feeder Road		Treatment Description: Remaining Life

Loading

Total Gear Load:	8.00E+04 N
Tyre Pressure:	750 kPa
Gear Name:	Standard Axle
No. Tyres:	4
No. Repetitions:	1.20E+05 SAR5 (Fatigue of Asphalt)
	1.75E+06 SAR7 (Rutting & Shape Loss)
	1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing

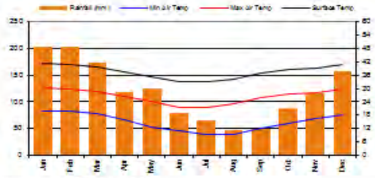
Tyre No	X	Y
1	-165	0
2	165	0
3	1635	0
4	1965	0

Evaluation Points

Tyre No	X	Y
1	0	0
2	165	0
3	1635	0
4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		250	Rainfall Adjustment	Dry Mod.*	475
Layer 2	Granular(Existing)		150	Rainfall Adjustment	Dry Mod.*	374
Layer 3	Subgrade		0	Rainfall Adjustment	Dry Mod.*	90

* Modulus or UCS in MPa

Pavement Structure

	AC	Cemen	Deform	Degree of Anisotrop	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Season / Modulus (MPa)					
Layer 1	☐	☐		2	0.35	413	432	461	475	470	447
Layer 2	☐	☐	☐	2	0.35	325	340	363	374	370	352
Layer 3	☐	☐	☑	2	0.45	78	82	87	90	89	85

Calculate

Vertical Strains

		Depth (mm)						
Top	Layer 2	250	383	366	344	333	337	355
Top	Layer 3	400	506	484	454	440	445	468

Horizontal Strains

		Depth (mm)						
Bottom	Layer 1	250	195	187	175	170	172	181
Bottom	Layer 2	400	268	256	241	233	236	248

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 3	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							1.19.E+09	SAR's
							5	Years

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Austroads Guide to Pavement Technology[1]

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date:	15-Oct-16	Client:	Bracalba Quarry
Project No.:	2016000	Prepared By:	Hayden Curran
Report No:	2016257-01	Growth Rate:	0.0%
Analysis Method:	PMS-QP4-002	Design Period:	5
Location:	Bracalba Quarry Feeder Road	Project Reliability:	90.0%
		Treatment Description:	Remaining Life

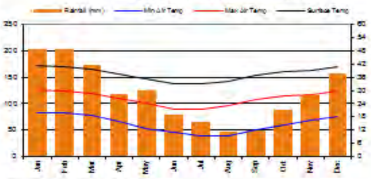
Loading

Total Gear Load: 8.00E+04 N
Tyre Pressure: 750 kPa
Gear Name: Standard Axle
No. Tyres: 4
No. Repetitions: 1.20E+05 SAR5 (Fatigue of Asphalt)
1.75E+06 SAR7 (Rutting & Shape Loss)
1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing: Tyre No	X	Y	Evaluation Points: Tyre No	X	Y
1	-165	0	1	0	0
2	165	0	2	165	0
3	1635	0	3	1635	0
4	1965	0	4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		400	Rainfall Adjustment	Dry Mod.*	523
Layer 2	Subgrade		0	Rainfall Adjustment	Dry Mod.*	82

* Modulus or UCS in MPa

Pavement Structure

	AC	Cemen	Deform	Degree of Anisotrop	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☐	☐		2	0.35	455	476	507	523	518	492
Layer 2	☐	☐	☑	2	0.45	71	75	80	82	81	77

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	400	473	452	424	412	416	438

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	400	247	236	222	215	217	229

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 2	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							1.91.E+09	SAR's
							5	Years

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Austroads Guide to Pavement Technology[1]

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date: 15-Oct-16
Project No.: 2016000
Report No: 2016257-01
Analysis Method: PMS-QP4-002
Location: Bracalba Quarry Feeder Road

Client: Bracalba Quarry

Prepared By: Hayden Curran
Growth Rate: 0.0%
Design Period: 5
Project Reliability: 90.0%
Treatment Description: Remaining Life

Loading

Total Gear Load: 8.00E+04 N
Tyre Pressure: 750 kPa
Gear Name: Standard Axle
No. Tyres: 4
No. Repetitions: 1.20E+05 SAR5 (Fatigue of Asphalt)
1.75E+06 SAR7 (Rutting & Shape Loss)
1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing

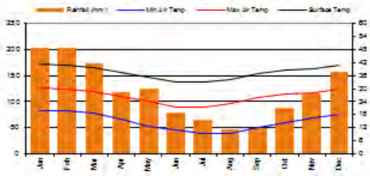
Tyre No	X	Y
1	-165	0
2	165	0
3	1635	0
4	1965	0

Evaluation Points

Tyre No	X	Y
1	0	0
2	165	0
3	1635	0
4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		250	Rainfall Adjustment	Dry Mod.*	721
Layer 2	Granular(Existing)		150	Rainfall Adjustment	Dry Mod.*	654
Layer 3	Subgrade		0	Rainfall Adjustment	Dry Mod.*	131

* Modulus or UCS in MPa

Pavement Structure

	AC	Cement	Deform	Degree of Anisotropy	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Season / Modulus (MPa)					
Layer 1	☐	☐		2	0.35	627	656	699	721	714	678
Layer 2	☐	☐	☐	2	0.35	569	595	634	654	647	615
Layer 3	☐	☐	☑	2	0.45	114	119	127	131	130	123

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	250	223	214	200	194	196	207
Top	Layer 3	400	329	314	295	286	289	304

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	250	113	108	102	99	99	105
Bottom	Layer 2	400	173	166	155	151	152	160

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 3	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							2.45.E+10	SAR's
							5	Years

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Austroads Guide to Pavement Technology[1]

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date:	15-Oct-16	**Prepared By:**	Hayden Curran
Project No.:	2016000	**Growth Rate:**	0.0%
Report No:	2016257-01	**Design Period:**	5
Analysis Method:	PMS-QP4-002	**Project Reliability:**	90.0%
Location:	Bracalba Quarry Feeder Road	**Treatment Description:**	Remaining Life

Client: Bracalba Quarry

Loading

Total Gear Load:	8.00E+04 N
Tyre Pressure:	750 kPa
Gear Name:	Standard Axle
No. Tyres:	4
No. Repetitions:	1.20E+05 SAR5 (Fatigue of Asphalt)
	1.75E+06 SAR7 (Rutting & Shape Loss)
	1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing

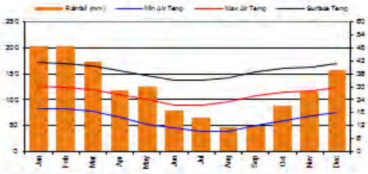
Tyre No	X	Y
1	-165	0
2	165	0
3	1635	0
4	1965	0

Evaluation Points

Tyre No	X	Y
1	0	0
2	165	0
3	1635	0
4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		400	Rainfall Adjustment	Dry Mod.*	516
Layer 2	Subgrade		0	Rainfall Adjustment	Dry Mod.*	73

* Modulus or UCS in MPa

Pavement Structure

	AC	Cemen	Deform	Degree of Anisotrop	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☐	☐		2	0.35	449	470	501	516	511	485
Layer 2	☐	☐	☑	2	0.45	64	66	71	73	72	69

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	400	503	480	451	437	442	465

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	400	261	250	234	227	230	242

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 2	1	0%	0%	0%	0%	0%	0%	5.8
							0%	**Accepted**
							1.25.E+09	SAR's
							5	Years

Austroads Guide to Pavement Technology[1]

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Mechanistic Design Report

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Report Date:	15-Oct-16	Client:	Bracalba Quarry
Project No.:	2016000	Prepared By:	Hayden Curran
Report No:	2016257-01	Growth Rate:	0.0%
Analysis Method:	PMS-QP4-002	Design Period:	5
Location:	Bracalba Quarry Feeder Road	Project Reliability:	90.0%
		Treatment Description:	Remaining Life

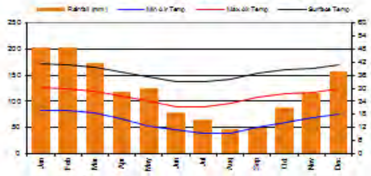
Loading

Total Gear Load: 8.00E+04 N
Tyre Pressure: 750 kPa
Gear Name: Standard Axle
No. Tyres: 4
No. Repetitions: 1.20E+05 SAR5 (Fatigue of Asphalt)
1.75E+06 SAR7 (Rutting & Shape Loss)
1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing Tyre No	X	Y	Evaluation Points Tyre No	X	Y
1	-165	0	1	0	0
2	165	0	2	165	0
3	1635	0	3	1635	0
4	1965	0	4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs)	Jan	Mar	May	Jul	Sep	Nov
Distribution	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		250	Rainfall Adjustment	Dry Mod.*	599
Layer 2	Granular(Existing)		150	Rainfall Adjustment	Dry Mod.*	460
Layer 3	Subgrade		0	Rainfall Adjustment	Dry Mod.*	106

* Modulus or UCS in MPa

Pavement Structure

	AC	Cemen	Deform	Degree of Anisotrop	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Modulus (MPa)					
Layer 1	☐	☐	☐	2	0.35	521	545	581	599	593	563
Layer 2	☐	☐	☐	2	0.35	400	419	446	460	455	432
Layer 3	☐	☐	☑	2	0.45	92	96	103	106	105	100

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	250	310	296	278	269	272	287
Top	Layer 3	400	418	400	375	364	367	387

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	250	159	152	143	139	140	148
Bottom	Layer 2	400	221	212	199	193	195	205

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 3	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							4.53.E+09	SAR's
							5	Years

Austroads Guide to Pavement Technology[1]

PAVEMENT MANAGEMENT SERVICES

Pavement Management Services

Unit 7b 26 Powers Rd
Seven Hills, NSW, 2147

Mechanistic Design Report

Report Date:	15-Oct-16	Prepared By:	Hayden Curran
Project No.:	2016000	Growth Rate:	0.0%
Report No:	2016257-01	Design Period:	5
Analysis Method:	PMS-QP4-002	Project Reliability:	90.0%
Location:	Bracalba Quarry Feeder Road	Treatment Description:	Remaining Life

Client: Bracalba Quarry

Loading

Total Gear Load: 8.00E+04 N
Tyre Pressure: 750 kPa
Gear Name: Standard Axle
No. Tyres: 4
No. Repetitions: 1.20E+05 SAR5 (Fatigue of Asphalt)
1.75E+06 SAR7 (Rutting & Shape Loss)
1.31E+07 SAR12 (Fatigue of Cemented Materials)

Tyre Spacing

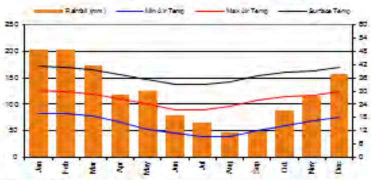
Tyre No	X	Y
1	-165	0
2	165	0
3	1635	0
4	1965	0

Evaluation Points

Tyre No	X	Y
1	0	0
2	165	0
3	1635	0
4	1800	0

Seasonal Traffic / Environmental Details

Site: Beerburrum Forest Station (040284)
Latitude: 26.96 °South



Traffic (SARs) Distribution	Jan	Mar	May	Jul	Sep	Nov
	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
Fatigue of Asphalt	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04	2.01E+04
Rutting & Shape Loss	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05	2.92E+05
Fatigue of Cemented Materials	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06	2.19E+06

Environment	Jan	Mar	May	Jul	Sep	Nov
Rainfall (mm)	202.5	144.9	101.2	54.9	67.6	136.2
Min. Air Temp (°C)	19.8	17.1	11.8	9.4	13.3	17.5
Max. Air Temp (°C)	29.9	27.6	22.9	22.4	26.7	29.0
Surface Temperature (°C)	40.9	38.7	34.2	33.7	37.8	40.0
Granular Reduction Factor	0.87	0.91	0.97	1	0.99	0.94

Pavement Materials

	Material	Description	Thickness (mm)	Modulus Calculation Method	Constants	
Layer 1	Granular(Existing)		400	Rainfall Adjustment	Dry Mod.*	424
Layer 2	Subgrade		0	Rainfall Adjustment	Dry Mod.*	73

* Modulus or UCS in MPa

Pavement Structure

	AC	Cement	Deform	Degree of Anisotropy	Poisson's Ratio	Jan	Mar	May	Jul	Sep	Nov
						Season Modulus (MPa)					
Layer 1	☐	☐		2	0.35	369	386	411	424	420	399
Layer 2	☐	☐	☑	2	0.45	64	66	71	73	72	69

Calculate

Vertical Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Top	Layer 2	400	559	534	501	486	491	517

Horizontal Strains

		Depth (mm)	Jan	Mar	May	Jul	Sep	Nov
Bottom	Layer 1	400	293	280	262	254	257	271

Damage Permanent Deformation

	Reliability Factor	Damage Factor (%)						
Layer 2	1	0%	0%	0%	0%	0%	0%	5.8
							0%	Accepted
							5.98.E+08	SAR's
							5	Years

Reliability

Appendix F – Installation of Moisture sensors

Appendix G – Previous material for Laboratory Testing

WAGNER SOIL TESTING
ABN: 49 416 679 791

NATA ACCREDITED FOR TECHNICAL COMPETENCE

PO Box 171 Wamuran Qld 451
296 Old North Road, Wamuran Qld 451
Phone: 07 5496 671
Mobile: 0438 924 63
Fax: 07 5496 671
Email: admin@wagnersoiltesting.com.au
Web: www.wagnersoiltesting.com.au

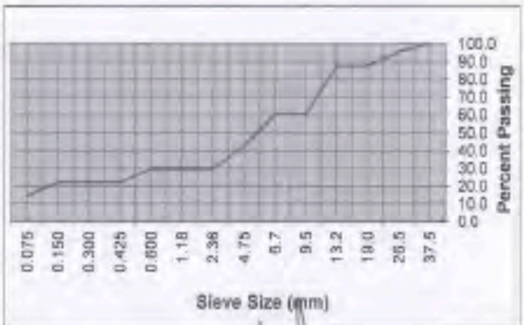
Report on Particle Size Distribution

Client:	Shadforths Civil Contractors			Job No:	J15/37
Client Address:	99 Sandalwood Lane Forest Glen Qld 4556			Date:	7/09/2015
Project:	Peregian Breeze Stages 5, 6, 7 & 8			Tested by:	JF
Location:	Peregian Springs Qld			Checked:	JL
Report Number:	124	Page	1 of 1	Order No:	

Test Method	AS1289 6.1.1	Sample Method	Q060
Lab Number	W15/12418	Preparation Type	Oven Dried Sample
Sample Location	Boral Obi Obi Gravel		

Particle Size Distribution

Sieve Size (mm)	% Passing
26.5	95.6
19.0	87.4
9.50	60.1
4.75	42.4
2.36	29.3
0.425	21.8
0.075	14.2



Date 11/09/2015

Dean Wagner - Managing Director
Authorised Signatory
Accredited for compliance with ISO/IEC 17025.

NATA 15070

Form No:W65 Version:1 Date:15/8/03

CONSTRUCTION MATERIALS TESTING

Appendix H – Material supplied to site

Appendix I – Poster Presentation

Waterproofing of natural materials to improve bearing capacity

An investigation into testing the in capillary rise of water into a soil with the use of soil stabilisation

2016 Thesis Project – ENG401 – University of the Sunshine Coast
Hayden Curran
Supervisor
John Yeaman

Abstract

Consolid C444 and Solidry are products that have been in use for the past thirty years for improving the bearing capacity of subgrade and subbase materials, but never before in Australia. The University of the Sunshine Coast evaluated the materials in laboratory tests during 2015 and concluded that the products had some merit in improving the Resilient Modulus of subgrade materials and should therefore proceed to field trials.

In April 2016, a pilot study was undertaken within the boundary of Brisbane City Council's Bracalba Quarry on a feeder road to the weighbridge carrying 350 truck movements per day. The trial area is 350 m² by 250mm deep. The site was instrumented for moisture content within the treated material and the sub grade. Site inspections and Falling Weight Deflectometer testing was conducted at 7 days, 14 days 28 days and 90 days and results compared against traffic volumes and weight.

Figure 1 – Treatment of material

Figure 2 – Spreading and compacting of material

Methodology

The proposed area was initially boxed out to the area of 47 x 7.5 m to a depth of 250 mm. The granular material was then treated by being split into two 104t samples and then for treatment, split again into two 52t samples of road base spread at 2.8 m wide to depth of 150 mm.

From the use of a watering can, shown in Figure 1, 45L of prepared C444 was uniformly spread over the first sample and then mixed with a power harrow and grader to guarantee absolute mixing. On to the treated material, the additional 52t of road base was repeated with the treatment of C444 application. Once the material was prepared the sample was transported and to site and spread and compacted to depth of 125 mm as shown in Figure 2.

The process was then repeated for the final sample of road base, with 52t road base having added 1 ton of Solidry. The Solidry was in 25 kg bags enabling uniform distribution at one bag per 5.75 m². Distribution was further assisted by the harrowing and grading process so that the Solidry was thoroughly mixed through. At all times the process had be observed to ensure optimum moisture content. The treated road base was aimed to maintained approximately 10%. The final surface was compact and the final product of the road construction is shown in Figure 3.

The site has since been subjected to testing with the use of Falling Weight Deflectometer (FWD), to determine the pavements stiffness and to identify whether the product increases the resilient modulus. The site has also been fitted with moisture and temperature sensors that record data at 15 minute intervals.

Figure 3 – Falling weight deflectometer testing

Figure 2 – Final product

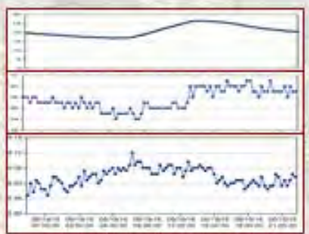


Figure 5 – Sensor readings (Temperature, Electric Conductivity, Dielectric respectively)

Benefits

• Reduced permeability • Increased bearing capacity • Reduce the capillary rise • Increased material strength • Utilisation of insitu material

In Association with - AustraBlend, Brisbane City Council and Pavement Management Services