University of Southern Queensland

Faculty of Health, Engineering & Science

Pacific Highway Glenugie: Case Study of the Use of Heavy Duty Granular Pavement in Northern NSW

Submitted by

M. Beaumont

in the partial fulfilment of the requirements of

Bachelor of Engineering (Honours)

Submitted: October, 2016

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences, and the staff of the University of Southern Queensland, do not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with this dissertation.

Persons using all or any part of this material do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course pair entitled "Research Project" is to contribute to the overall education within the student's chosen degree program. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user.

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

M. Beaumont

0061035164

Acknowledgements

The Author would like to thank and acknowledge the following people for their very valuable assistance towards the successful completion of this dissertation:

Ben Churton, Rob Ticknor, Michael Hughes, John Howell, Dale Morgan and others from the Roads and Maritime Services for their support and advice throughout the project;

Jo Devine (USQ – Academic Supervisor) for her professional advice, guidance and her kind words of encouragement throughout the research project process.

I would also like to thank my partner, Britt Hargreaves, for her patience and support whilst undertaking this project. This support over the 12 months has been invaluable in making this project possible.

Abstract

In September 2011, the Glenugie upgrade of the Pacific Highway was completed. This upgraded section was effectively a trial to gain a better understanding of whether or not heavy duty granular pavement design would be a feasible option in Northern NSW. A considerable amount of time and effort was expended in the development of the standard and suitable gravels to meet this standard. In 2014, failures were first observed in the upgraded section of pavement at Glenugie in the form of flushing, rutting and shoving. Over the following year, these failures continued to deteriorate with pot holes forming in a number of areas.

The objective of the project is to evaluate the pavement performance thus far and determine the mechanism which is the cause of any failure in the pavement. Examination of the root cause of the failure mechanism, with the aim of improving performance and maintenance of heavy duty granular pavements in Northern NSW in future.

The project proposes to achieve this objective through carrying the following:

- Research the background of Glenugie Pacific Highway upgrade and the relevant standards and specification regarding heavy duty granular pavement in NSW and surrounding states and territories;
- Assessment of the pavement's performance to date and the extent of the pavement failure in the segment of road of interest. This has been conducted using two sets of data: defect mapping from a visual inspection of the road and a data set from the RMS RAMS database including cracking, roughness and rutting data.
- Assessment of the cause of the current failures and there root cause in areas of the Glenugie pavement. This assessment will be based on a range of soil testing which has been carried out by RMS in areas of the pavement which have shown a high rate

of pavement failures and will utilise TSD data from the RMS RAMS data base. This test data will be used to compare with a range scientific literature, specifications and construction data to develop substantial theory supported by evidence as to the mechanism or mechanisms which is cause the failures in these areas of pavement.

Overall the study shows that pavement at Glenugie is performing below expectations. With the primary cause of the rutting and failures being the breakdown of material and associated reduction in shear strength and modulus of the material. The evidence presented report also identifies that the secondary cause of failures is likely to be due to moisture content of the pavement material. This is supported be the defection data which indicates that earthworks upper zone or subgrade material are unlikely to be the cause of the failures.

Contents

Chapter 1 : Introduction 1

1.1 Brief introduction 1

1.2 Idea initiation 2

1.3 Aims, objective and scope 3

1.4 Expected outcomes and benefits 4

1.4.1 Ethical consequences 5

Chapter 2 : Literature Review 7

2.1 Gathering of information 7

2.2 Pavement types 7

2.2.1 Flexible granular pavement 7

2.2.2 Rigid concrete pavement 8

2.3 Pavement Design 9

2.3.1 Mechanistic pavement design 9

2.3.2 Empirical design approach 10

2.3.3 Traffic loading 12

2.4 What is heavy duty payment 12

2.5 High Traffic Granular Pavement in NSW and Surrounding States. 13

2.5.1 RMS specification 13

2.5.2 Heavy duty granular pavement in Queensland 14

2.5.3 Heavy duty granular pavement Victoria 17

2.6 Soil testing 21
2.6.1 Particle size distribution 21
2.6.2 Atterberg limits 22
2.6.3 CBR 23
2.7 Deflection testing 24
2.7.1 Benkelman Beam 25
2.7.2 Falling weight Deflectometer 25
2.7.3 Travel speed deflectogragh 26
2.8 Performance Data 27
2.8.1 Visual Road inspections 27
2.8.2 Rutting data 29
2.8.1 Roughness Data 30
2.8.2 Cracking Data 30
2.9 Soil properties 31
2.9.1 Moisture content 31
2.9.1 Shear strength 32
2.9.2 Plasticity 34
2.10 Common granular pavement failure types 34
2.10.1 Flushing/bleeding 34
2.10.2 Shoving 35
2.10.3 Rut/Rutting 36

2.10.4 Cracking.....37
2.11 Road Construction Techniques.....38
2.11.1 Compaction.....38
2.11.2 Boxed out pavement construction.....39
Chapter 3 : Background information.....40
3.1 Pacific Highway Upgrade: Glenugie.....40
3.1.1 Gleuugie upgrade.....40
3.2 Development of the Heavy Duty Flexible Granular Pavement for Glenugie.....41
3.2.1 Compactive effort during construction.....43
3.2.2 Testing carried out during construction.....44
3.2.3 Pavement maintenance plan.....44
3.2.4 Failures in the Glenugie pavement.....45
Chapter 4 : Methodology.....46
4.1 Background research on Glenugie Upgrade and Heavy Duty Granular Pavement......47
4.2 Defect mapping.....47
4.3 Pavement performance RAMS data.....52
4.3.1 Rutting.....53
4.3.2 Roughness.....54
4.3.3 Cracking.....55
4.4 Soil testing data and construction documentation.....55
4.4.1 Moisture content results.....59

4.4.2 Particle sizes distribution results....62
4.4.3 Atterberg limits....64
4.5 Travel Speed Deflection Data....65
Chapter 5 : Results, Analysis & Discussion....68
5.1 Defect mapping....68
5.1.1 Results....68
5.1.2 Major failure area description....70
5.1.3 Inner and outer lanes....70
5.1.4 Limitation of method used....71
5.2 Pavement performance RAMS data....72
5.2.1 Pavement rutting results....72
5.2.2 Pavement roughness....73
5.2.3 Pavement cracking....75
5.2.4 Overall results from the performance data....76
5.3 Soil testing results....78
5.3.1 A graphical representation of the test pit....78
5.3.2 Optimum Moisture Content....82
5.3.1 Verge material....83
5.3.2 Relationship between pavement condition and moisture content....84
5.3.3 Limitations of analysis of moisture content data....86
5.3.4 Overall finding from the moisture content testing....87

5.3.5 Particle size grading..88

5.3.6 Particle mass retained on the sieve compared RMS material specification............92

5.3.1 Investigate of the cause of the breakdown of the material......................................97

5.3.2 Overall findings from the particle size grading tests 100

5.3.3 Atterberg Limits..100

5.4 Travel Speed Deflection results..102

5.4.1 Findings from Travel Speed Deflection results 104

Chapter 6 : Key Finding and Recommendations 105

6.1 Key findings..105

6.2 Recommendations and Further Research...108

6.2.1 Recommendations...108

6.2.2 Further research 109

List of Figures

Figure 2.1: Empirical design chart of granular pavements with thin bituminous surfacing from Austroads Guide for DESA of 10^5 to 10^8. 11

Figure 2.2: Empirical design chart of granular pavements with thin bituminous surfacing from Austroads Guide for DESA of 10^3 to 10^5. 11

Figure 2.3: Vic roads design chart for flexible granular pavement, a modified version of Austroads chart. 18

Figure 2.4: Example of a grading sieve 21

Figure 2.5: drop pan device with grooving tool in bottom right of picture 23

Figure 2.6: CBR testing apparatus 24

Figure 2.7: The Traffic Speed Deflectometer schematic drawing. 27

Figure 2.8: The effect of different grading curves on the modulus of the material 34

Figure 2.9: Example of flushing on local road with rutting also visible in the right lane. 35

Figure 2.10: diagram of the mode of rutting failure 37

Figure 2.11: Example of distress cracking on local road. 38

Figure 3.1: Typical pavement profile for Glenugie 43

Figure 4.1: Proposed area of road to be defect mapped 48

Figure 4.2: GoPro mounted on the car with tethering system 49

Figure 4.3: Image from the video used for the defect mapping of a section of road with no defects. 50

Figure 4.4: Image from the video used for the defect mapping, heavy patch can be seen of the left side of the image. 51

Figure 4.5:ARRB Group pavement survey cars 52

Figure 4.6: Maps of the test pit locations 58

Figure 4.7: Moisture content sample being dried back in the soil oven. 61

Figure 4.8: Moisture contents sample from Atterberg tests after being oven dried 65

Figure 4.9: ARRB Groups TSD truck which was used to collect TSD data 66

Figure 5.1: Defect mapping of the south bound lanes. 68

Figure 5.2: Defect mapping of the northbound lanes 69

Figure 5.3: Average Rutting in mm graphed against the chainage of the pavement examined 72

Figure 5.4 : Average international roughness index in m/km graphed against the chainage of the pavement examined...74

Figure 5.5: Average cracking in cracked frames per 100m graphed against the chainage of the pavement examined. 75

Figure 5.6: Graphical representation of the test pit 1, 2, 3, 4 and 5 in the southbound outer lane. 79

Figure 5.7: Graphical representation of the test pit 7, 8 and 9 in the southbound inner lane. .80

Figure 5.8: Graphical representation of the test pit 9, 10 and 11 in the northbound outer lane. 81

Figure 5.9: Shows pavement condition vs moisture content for the base, lower base and sub-base with linear lines of best fit. 84

Figure 5.10: Particle size distribution results from the base material for the 3 test pits sampled 88

Figure 5.11: Particle size distribution results from the upper sub-base material for the 3 test pits sampled 89

Figure 5.12: Particle size distribution results from the lower sub-base material for the 3 test pits sampled 90

Figure 5.13: Change in material retain on the sieves for the base material at test pit 3 97

Figure 5.14: Change in material retain on the sieves for the base material at test pit 4 98

Figure 5.15: Change in material retain on the sieves for the base material at test pit 5 98

Figure 5.16: Middle Layer Index value vs rutting data 102

Figure 5.17: Lower Layer Index value vs rutting data...103

List of Tables

Table 2.1: RMS traffic categories and traffic loading 13

Table 2.2: Specified requirement of RMS 3051 material specification.................................. 14

Table 2.3: Fines component properties for Type 1 gravels. 16

Table 2.4: Particle size distribution for type 1gravels 16

Table 2.5: Fines component properties for Type 2 gravels. 16

Table 2.6: Particle size distribution envelopes for type 2 gravels 17

Table 2.7: Test Requirements for classes 1, 3 and 4 pavement material 19

Table 2.8: Grading Limits for 20 mm Class 1 or 2 Base from Granitic Rocks 19

Table 2.9: Grading Limits for 20 mm Class 3 Subbase from Granitic Rocks. 19

Table 2.10: Grading Requirements for Class 4 Crushed Rock 20

Table 3.1: The adopted rolling pattern for the Glenugie project to achieve the 100% modified compaction requirement.. 44

Table 4.1: Ranking system for defect mapping 50

Table 4.2: Rutting in mm values and there corresponding pavement condition. 54

Table 4.3: IRI roughness values and there corresponding pavement condition. 54

Table 4.4: Cracking values and there corresponding pavement condition. 55

Table 4.5: Test pit locations with surface and pavement conditions 56

Table 5.1: Results from the pavement condition analysis based of rutting data...................... 73

Table 5.2: Results from the pavement condition analysis based of roughness data 74

Table 5.3: Results from the pavement condition analysis based of cracking data 76

Table 5.4: Percentage of optimum moisture for the base and sub-base material. 82

Table 5.5: Test results for the Atterberg limits tests carried out on test pit 3, 4 and 5. 101

Acronyms & abbreviations

CBR	California bearing ratio
RMS	Roads and Maritime Service
OWP	Outer wheel path
NSW	New South Wales
PI	Plastic index
NCR	Non-conformance report
TSD	Travel speed deflection
ESA	Equivalent standard axles
OMC	Optimum moisture content
UZF	Upper zone formation
TMR	Department of Transport and Main Roads

Chapter 1 : Introduction

1.1 Brief introduction

Traditionally in NSW heavy duty pavements have been rigid concrete based pavement or flexible full depth asphalt, heavily bound or a combination of these. Similarly, flexible granular pavement has been mainly used for standard pavement situation (Nash et al. 2011). Granular pavement per area is generally considerably cheaper to construct then these concrete and asphalt pavements (Nikolaides 2014) traditionally used for heavy duty pavements in NSW. Over the last ten years RMS has developed their specifications and construction techniques so that flexible granular pavement can be used as heavy duty pavement. This has included a trial section in the south western regions of NSW using a draft specification (Nash et al. 2011).

In September 2011, the Glenugie upgrade of the Pacific Highway was completed. This consisted of a 6.5 kilometre section of dual carriageway made of heavy duty granular pavement. This was the first time heavy duty granular pavement had been used in Northern NSW and was seen as a trial to test the feasibility of the pavement and specification in the area. The trial was to test the specification of the granular pavement and to provide the ground work so heavy duty granular pavement could be used in future in Northern NSW, like sections of the Pacific Highway Upgrade (Nash et al. 2011).

In 2014, failures were first observed in the upgrade section of pavement at Glenugie in the form of flushing and shoving. Over the following years, these failures continued to deteriorate with pot holes forming in a number of areas. These failures appeared in only small sections of the road, generally grouped together over 10 to 200m of the alignment. Almost all the failures observed have occurred in the outer wheel path in the outer lane.

For heavy duty granular pavement is to be an option for future upgrades to Pacific Highway and other high traffic roads in Northern NSW, the performance of the trial section at Glenugie needs to be measured and analysed, with the mechanisms which have resulted in any failures in the pavement being understood. Through understanding and analysing how the pavement has performed and the cause of any failures, the specifications, construction techniques and maintenance requirements can be further developed to make heavy duty granular a more feasible option for future projects. The ability to use heavy duty granular pavement in the future over more expensive concrete and asphalt based options could result in large cost saving, potentially resulting in large savings for the NSW taxpayers over the following years as the large sections of the Pacific Highway in Northern NSW are upgraded to dual highway.

1.2 Idea initiation

Initially, this topic arose as a result of discussions with Ben Churton and Rob Ticknor from Roads and Maritime Service (RMS, Northern Geotechnical Branch base in Grafton). Ben had some involvement in the identification of recent failures in the Glenugie section of pavement of the Pacific Highway near Grafton NSW. It was put forward that the potential benefit for RMS and NSW taxpayers of undertaking a case study of the Glenugie pavement would also improve heavy duty granular pavements overall.

The section of pavement had been used as a trial for the application of the recently developed heavy granular duty pavement. A considerable amount of time and money was spent in the development of the blended gravel mixture which was capable of meeting the heavy duty granular specifications outlined in RMS 3501. In late 2011, the upgraded section was completed and trafficked (Nash, 2011) with the first signs of failures noted in 2014. These have continued to deteriorate over the following years. Little to no follow up work had been carried out on the section of highway to examine the how the trial section was performing since being trafficked in 2011.

The fact that RMS felt it was necessary to build this trial section acts as evidence that little is known about the performance of the heavy duty granular pavement in the unique climate and geologically condition found in Northern NSW. The evaluation of the trial section and understanding of the root causes of the current failures experienced at Glenugie will, undoubtedly, play an important role in the development of heavy duty pavement as a feasible option for future high traffic road construction in Northern NSW.

1.3 Aims, objective and scope

The trial pavement at Glenugie offers very little gain in understanding how heavy duty granular pavements preform in Northern NSW. Follow up analysis of the pavement performance and any failures which occur in the pavement will be carried out.

The objective of the project is to evaluate the pavement performance thus far and determine the mechanism which is the cause of any failure in the pavement. Examination of the root cause of the failure mechanism, with the aim of improving performance and maintenance of heavy duty granular pavements in Northern NSW in future.

The project proposes to achieve this objective through carrying the following:

- Assessing the pavements' performance and the extent of the pavement failure;
- Assessing the failure mechanism causing the current failures and determining the root cause of the failures;
- Examining the role pavement design and construction techniques has played in the pavement failure;

- Analysis of the current maintenance plan given the information gain in the earlier sections of the report

It was expected that the assessment of the pavement performance would show that the pavement has deteriorated at a faster rate than expected and some areas along the section have considerable number of failures. It is anticipated that these pavement failures are in some way linked to the climatic and geological environments which are unique to this area. This would suggest that the ingression of moisture in the pavement or break down of material has played a role in the failure of the pavement. With this in mind, the project looked to examine these areas first with a view to ascertaining their role in the failures before broadening the analysis.

1.4 Expected outcomes and benefits

The expected outcomes for the project are as follows:

- Identification and mapping of current failure in the Glenugie section of pavement;
- Evaluation of the pavement performance thus far;
- A determination of the contributing factors to the failures with relation to the material, design and construction techniques used;
- Recommendation of further research and testing to confirm theory and ideas developed in the project;
- To make recommendations to improve of the performance granular pavements in Northern NSW in the future;
- To make recommendations to improve the current maintenance plan for granular pavements at Glenugie.

The analysis of the pavement failures at Glenugie will benefit the ongoing upgrade of the Pacific Highway and high traffic roads in Northern NSW by producing work and outcomes that help improve the application and maintenance of heavy duty granular pavement in the future. Through analysing and understanding the pavement at Glenugie, valuable knowledge and learnings can be gained and applied to future construction techniques, design, maintenance schedule, specifications and standards to improve the perform and feasibility. This research aims to contribute to the further development of heavy duty granular pavement so it may be used on high traffic roads in Northern NSW in the future over the more expensive concrete and asphalt options. This could potentially result in sizeable savings in projects like the Pacific Highway upgrade which still has several large sections to complete in Northern NSW over the next 4 years.

1.4.1 Ethical consequences

As stated in the Engineering Australia code of Ethics, engineers should consider ethical consequences of any work they carry out (Engineers Australia 2010). This project could be a small part of a larger volume of work which may lead to the use of heavy duty granular pavement over the tradition heavy duty options of concrete and full depth asphalt pavement. This could, potentially, have ethical consequences that need to be considered from the community and sustainability point of view.

The use of heavy duty granular over traditional heavy duty pavement material represents a substantial improvement in sustainability. Firstly, looking at concrete pavement, the making of cement is energy intensive, resulting in high greenhouse emissions. For every ton of cement made, 900 kg of CO^2 is released in the atmosphere making the production of cement one of the biggest greenhouse emissions contributors around the world (Song & Chen 2016). By reducing the reliance on concrete pavement and the use of cement for heavy duty applications, greenhouse emissions would be decreased by using heavy duty pavement.

Asphalt pavements, like concrete, are created using energy intensive methods to process the materials and construct the pavement. Furthermore, asphalt relies heavily on the finite resource, crude oil, for the production of bitumen as a key constituent of the materials' make up (Yang et al. 2015). The reduction of concrete and asphalt heavy duty pavements in favour of granular pavement would represent a decrease in the use of finite crude oil and energy resources. It is worth noting that heavy duty granular pavement is still relatively energy intensive, with a large amount of energy needed to achieve compaction and it does, generally, use some bitumen product in the sealing of the pavement but it uses less finite resources than the traditional options. The granular provides a more environmentally sustainable option when compared to more traditional heavy duty pavement.

The potential consequences of the project for the most part appear to be positive from an ethical stand point, with the most likely consequences being an increase in more sustainable practices used to carry out heavy duty pavement construction.

Chapter 2 : Literature Review

2.1 Gathering of information

As a part of the project development a literature review was conducted to develop a fuller understanding of the research topic. The review assembled significant information on a range of topics.

2.2 Pavement types

In the modern world, pavement construction is categorised in three ways: granular, asphalt and rigid (Sharp 2005). Each of these have different advantages and disadvantages and some are more suited to different situations.

2.2.1 Flexible granular pavement

Granular pavements consist of a number of layers over the subgrade material, with each layer improving the strength characteristics when compared to the layer below. A typical granular pavement comprises of the following starting at the bottom, with subgrade. The subgrade is usually made naturally with soil occurring in the area with effort made to compact it.

On top of this layer is the layer often referred to as a select layer. This is made up of lower quality gravel material and is not always present in all granular pavement, especially those with lower traffic loading.

The next layer is called the sub-base and is made of better quality gravel.

This is followed by the base layer which is usually the best quality gravel found in the pavement.

The very top layer has two functions: to seal the road from moisture and to provide a wearing course for road user. The layer is normally in the form of a thin non-structural layer of asphalt ,approximately 50mm or bitumen spray seal and chip process (Nikolaides 2014).

Australia's regional road network is commonly made up of granular pavement with thin bitumen or asphalt seal over unbound granular base layers placed on nature subgrade (Siripun, Jitsangiam & Nikraz 2012).

Granular pavements have relatively low construction costs, have good performance under low traffic load, use simple construction techniques and, in general, have readily available materials making them ideal for the vast road network across the region (Thom 2014). Australia's vast territory and low population has led to a large amount of granular pavement road construction in the past and still to this day.

2.2.2 Rigid concrete pavement

The term rigid pavement is used to describe pavement made of concrete. This can be further broken down to 4 main types used in Australia:

- Plain concrete pavement (PCP) which, as the name suggests, is plain concrete with joints 8 to 15m and the occasional use of steel fibre reinforcement for special applications like roundabouts;
- Joint reinforced concrete pavement (JRCP) is very similar to PCP but with reinforcement running though the joints;
- Continuously reinforced concrete pavement where jointing is expected to occur every 1-3m.
- Doweled plain concrete pavement (PCP-D) is, again, very similar to PCP but with a dowel running though the joints which are spaced up to 5m apart.

Modern rigid pavement usually has structural sub-base layers made of gravel or lean mix concrete with concrete making up the top base layer. Concrete pavement makes up approximately 2% of Australia's road network, primary in heavy duty application (Sharp 2005).

Rigid pavement's greatest quality is its strength and ability to handle high design traffic loads. However, this does come at a cost, with rigid pavement generally being more expensive to build and having a larger environmental foot print when compared with granular pavements. The construction process for rigid pavement also allows for reduced susceptibility to wet weather delay as compactions only need to be achieved on lower subbase layers. This is even more valid if lean mix subbase is used. Rigid pavement has limited flexibility when compared to both granular and asphalt pavements and is often unsuitable where subsidence in expected in the subgrade due traffic loading over time (Moss 2009).

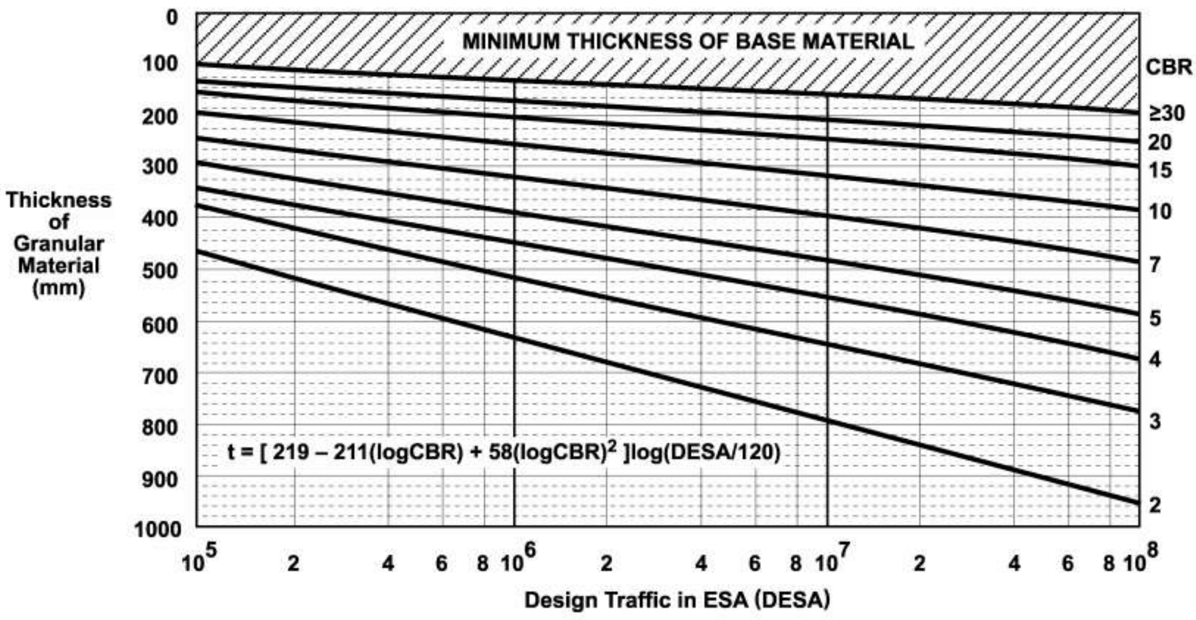
2.3 Pavement Design

2.3.1 Mechanistic pavement design

For pavement design in Australia, a Mechanistic Design approach is commonly used. Input parameters like material quality, structure design, subgrade strength, design traffic and performance criteria are used to determine the life of a pavement design. These inputs can be modified until the desired life is obtained (Jameson 2013). A computer software commonly used to do this is CIRCLY Pavement design. CIRCLY uses a Mechanistic Pavement Design as outline in AUSTROADS Guide to Pavement Technology in an integrated computer program to assist with pavement design (CPEE 2012). One of the key inputs in this design program is design traffic which can have a major effect on the pavement type and depth required. CIRCLY has its limitations and does not account some factors in its modelling, such as climate variations, high moisture environments or expansive subgrade soils (Ghadimi et al. 2013).

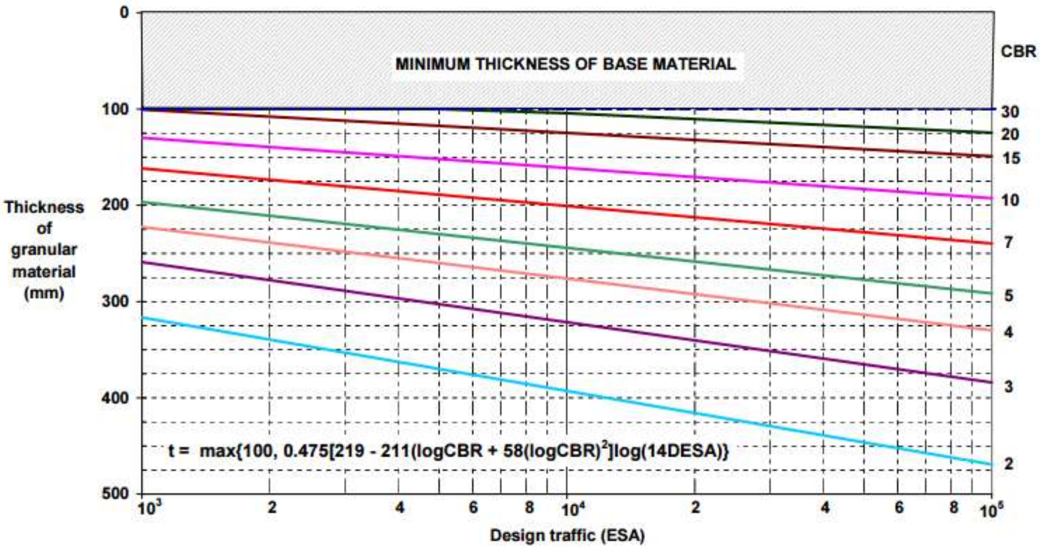
2.3.2 Empirical design approach

Empirical design charts are used for the design of flexible granular pavement used in many countries around the world, including Australia. The empirical pavement design procedures outlined in various guidelines treat pavement design as a deterministic process, through variability of a limited number of input parameters and use of a relatively simple equation. From this, a required thickness of the pavement material can be determined (Maji & Das 2008). In Australia, the Austroads pavement technology guides use two empirical charts to assist in the design of flexible granular pavements. The charts use two inputs: design traffic (DESA) for the life of the pavement and CBR of the underlining subgrade material to determine the required thickness of base and sub-base material for the design (Liddle 2005). The two charts cover different ranges in design traffic loading, DESA 10^3 to 10^5 and 10^5 to 10^8. The equations used to develop the charts can be seen in Figures 2.1 and 2.2 in the left hand bottom corner of the charts.



(Hubner & Jameson 2012)

Figure 2.1: Empirical design chart of granular pavements with thin bituminous surfacing from Austroads Guide for DESA of 10^5 to 10^8.



(Liddle 2005)

Figure 2.2: Empirical design chart of granular pavements with thin bituminous surfacing from Austroads Guide for DESA of 10^3 to 10^5.

2.3.3 Traffic loading

Design traffic loading is one of the main considerations when choosing and a designing a pavement. It is a calculation of the expected loading due to traffic over the life of the pavement. In Australia, traffic loading is typically calculated using the Austroad method. This method focuses on much more than just traffic volume on a given road, which makes it well suited to the great variety of the vehicular traffic that can be found on Australian roads, from road trains to bicycles.

Austroads classes these vehicles in 12 classifications. Classes 1 and 2 consist of light vehicles, which have been shown to contribute very little if anything to the deterioration of roads. As a result, only the heavy vehicle, classes 3 to 12 are considered for the calculation of traffic load in relation to pavement design. The damage to the pavement from heavy vehicles also depends on several other factors regarding how the load will transfer to the road surface. These factors include the number of axles, the grouping of the axles and load applied to pavement through each axle. The volume of heavy vehicle and there gross weight combined with the transfer facts are key to determining the traffic loading for a given road (Jameson 2013).

2.4 What is heavy duty payment

Road pavement in NSW are generally designed with an intended design life of 20 or 40 years depending on a couple of parameters. If the design traffic load for a 20 year period is equal to or greater than 10^7 equivalent standard axles (ESA), the pavement requirement is considered to be heavy duty and designed with a 40 year design life. When the traffic load is less, the pavement considered follows a standard and is designed with a 20 year design life (Tamsett 2015).

Traditionally in NSW, heavy duty pavements have been rigid concrete based pavement or flexible asphalt in the form of full depth asphalt, asphalt with lean mix or standard concrete sub-base. Similarly, flexible granular pavement has mainly been used for standard pavement situations (Nash et al. 2011) with traffic load less than 10^7 ESA.

2.5 High Traffic Granular Pavement in NSW and Surrounding States.

2.5.1 RMS specification

The RMS material specification determines the pavement material to be used base on the design traffic over 20 year design period. The specification has 4 traffic category based of the Design Equivalent Standard Axle loading in 20 year design period. The categories associated traffic loading can be seen below in the table.

Table 2.1: RMS traffic categories and traffic loading

Design Traffic, N (DESA) (1, 2)	Traffic Classification	Traffic Category (3)
$N \geq 10^7$	Very heavy	A
$10^7 > N \geq 4 \times 10^6$	Heavy	B
$4 \times 10^6 > N \geq 10^6$	Medium	C
$N < 10^6$	Light	D

The specification states that DGB20(HD) is the only unbound granular pavement that can be used for traffic A loading. DGB20(HD) has increased aggregate strength, tightly controlled particle size distribution, a permeability requirement and a plasticity requirement to provide increased resistance to high traffic loading, low permeability and a cohesive surface finish resistant to the effects of traffic prior to sprayed sealing. It is specified that the material is to a permeability of 5×10^{-8} m/second to achieve a low permeability. The requirements in the specification relating to shear strength are;

- the “% Retained” requirements
- the “% Mis-shapen Particles” requirements
- the “Fractured Faces” requirements

The particle size distribution and mass retain between sieves can be seen below in the table

Table 2.2: Specified requirement of RMS 3051 material specification

Sieve Size AS (mm)	***Test Value before Compaction***	
	Limits of Grading (% Passing)	**% Retained between Sieves**
26.5	100	
19	95-100	7-17
13.2	78-92	8-16
9.5	63-83	14-24
4.75	44-64	8-18
2.36	33-49	14-28
0.425	14-23	6-13
0.075	7-14	3-7
0.0135	3-7	

2.5.2 Heavy duty granular pavement in Queensland

The Queensland Department of Transport and Main Roads (TMR) supplement to ‘Part 2: ‘Pavement Structural Design’ of the Austroads Guide to Pavement Technology states that in a rural environment a heavy-duty unbound granular pavement with sprayed seal surfacing may be suitable following project-specific assessment for road with an average daily traffic of 100 to less than 3000 ESA in the design lane the year of opening. Furthermore, the use of heavy duty granular pavement for roads with greater than 3000 ESA is described as typically unsuitable due to anticipated poor or uncertain performance. Thicknesses for the pavement layers in Queensland are typically determined by Figure 2.1 and 2.2 of the Austroads guide 2012 shown above or the mechanistic design approach typically undertaken using the latest version of CIRCLY (TMR 2013).

TMR specifies that heavy duty granular pavement base material for high traffic (1000 to 3000 ESA daily) will consist of high standard granular material that is specified through an appropriate project-specific technical standard. These standards should be based on local experience with the particular material, including its construction and handling requirements, historic performance and future performance expectations for the project. The use of laboratory methods may assist in predicting the likely performance of these materials over a range of moisture conditions relative to standard materials (TMR 2013). It could be expected that standards specified for such products would be similar to the one specified for lower traffic granular pavements by TMR with small variations to improve the pavements' performance capacities in some identified areas.

For areas with a rainfall of greater than 800mm annually and a traffic loading of between 100 and 1000 ESA, TMR specified that gravel type 1.1 or 2.1 is used as base material (TMR 2013). It is expected a project-specific technical standard would have considerable similarity to the higher quality gravel type 1.1 of the two gravels mentioned above. For sub-base gravels, TMR specifies that for locations with a rainfall of greater than 800mm annually and a traffic loading of between 1000 and 3000 ESA that gravel type 1.2 or 2.3 is to be used (TMR 2013). Requirements of the specifications for the gravels of interest are listed below in various tables. Note that for table 2.4, gravel type 2.1 may use grading envelope B or C and type 2.3 may use grading envelope B, C or D as stipulated in the specification (TMR 2015).

Table 2.3: Fines component properties for Type 1 gravels.

Property	*Subtype*	
	Type 1.1	**Type 1.2**
Liquid Limit maximum	25	28
Plasticity Index maximum	4	6
Linear Shrinkage maximum	2.5	3

(TMR 2015)

Table 2.4: Particle size distribution for type 1gravels

AS Sieve Size	*Percentage by mass passing*		
(mm)	**Target**	**Minimum**	**Maximum**
37.5	100	100	100
26.5	100	85	100
19	87	75	100
9.5	69	58	80
4.75	54	45	62
2.36	39	33	45
0.425	18	14	22
0.075	7	5	10

(TMR 2015)

Table 2.5: Fines component properties for Type 2 gravels.

Property	*Subtype*	
	Type 2.1	**Type 2.3**
Liquid Limit maximum	25	28
Plasticity Index maximum	6	8

Linear Shrinkage maximum	3.5	4.5

(TMR 2015)

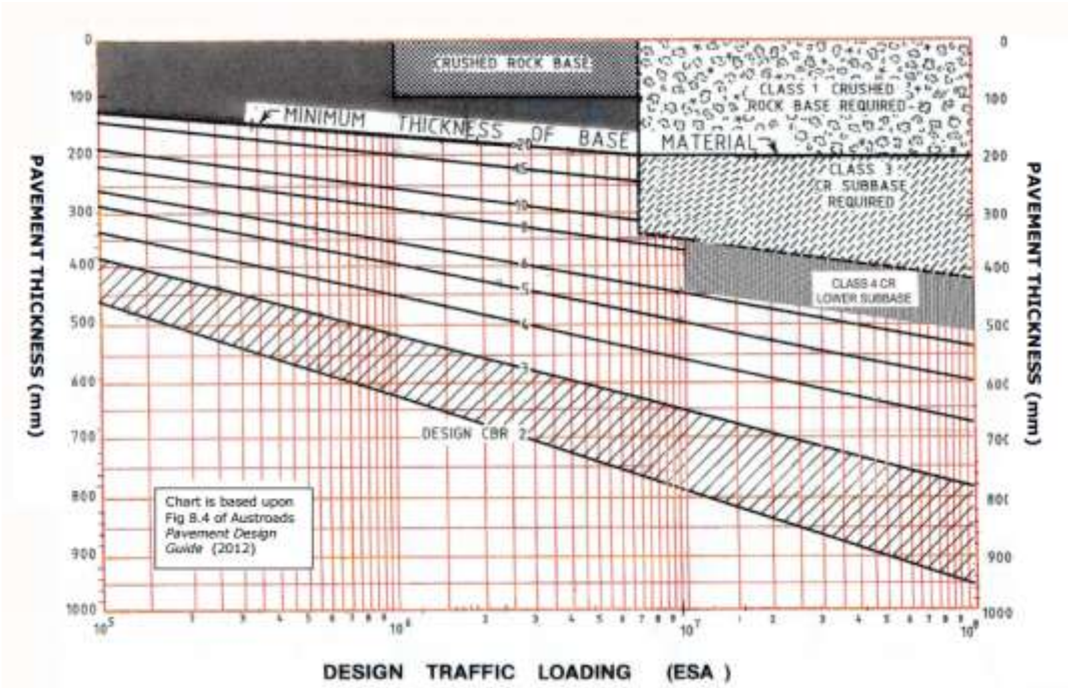
Table 2.6: Particle size distribution envelopes for type 2 gravels

AS Sieve Size (mm)	***Percentage passing by mass***		
	Grading B	**Grading C**	**Grading D**
53.0	100	100	100
37.5	100	100	100
26.5	85-100	100	100
19	55-90	80-100	100
9.5	40-70	55-90	80-100
4.75	28-55	40-70	55-90
2.36	20-45	35-55	40-70
0.425	10-25	12-30	20-40
0.075	4-15	5-20	8-25

(TMR 2015)

2.5.3 Heavy duty granular pavement Victoria

Vic Roads do not have a specified heavy duty granular pavement material but their regular granular pavement is specified for a design traffic of up to $1x10^8$ ESA which covers the range of traffic loading RMS would consider heavy duty. All unbound flexible pavements in Victoria are designed to meet the structural requirements of figure 2.2 for traffic loading of $1x10^5$ to$1x10^8$ DESA over the pavements' life. CIRCLY is generally used as well to confirm the pavement design will handle the traffic loading over its life. For M class national highways, like the Pacific Highway, Vic Roads typically use a design life period of 30 years when designing a new road (Vic Roads 2013).



(Vic Roads 2013).

Figure 2.3: Vic roads design chart for flexible granular pavement, a modified version of Austroads chart.

The three crushed rock classes used in high traffic pavement in Victoria are Class 1, 3 and 4. Class 1 can be described as premium cohesive pavement base material for unbound pavements where a very high standard of surface preparation for a sprayed sealed or thin asphalt surfacing is required. It has a minimum plasticity index requirement and may have additional requirement for maximum permeability when used for heavy duty unbound pavements. Class 3 is a high quality upper sub-base material for heavy duty unbound flexible pavements. It may have a minimum permeability requirement to provide positive drainage to the sub-surface drains. Class 4 is a lower sub-base material for heavy duty pavements or a sub-base material for most other types of pavements. It may have a maximum permeability requirement (Vic Roads 2011). Requirements of the specifications for the 3 classes of crushed rock pavement material of interest are listed below in the various tables.

Table 2.7: Test Requirements for classes 1, 3 and 4 pavement material

Test	*Test Value*		
	Class 1	**Class 3**	**Class 4**
Liquid Limit % (max)	30	35	40
Plasticity Index (range)	2-6	0-10	0-20
California Bearing Ratio (%)	-	-	20
PI x % passing 0.425 mm sieve (max)	-	-	450
Crushed Particles (%) (min)	60	50	-

(Vic Roads 2011)

Table 2.8: Grading Limits for 20 mm Class 1 or 2 Base from Granitic Rocks

Sieve Size AS (mm)	*Test Value before Compaction*	
	Limits of Grading (% Passing)	**% Retained between Sieves**
26.5	100	
		0-5
19	95-100	
		7-18
13.2	78-92	
		10-16
9.5	63-83	
		14-24
4.75	44-64	
		10-20
2.36	29-48	
		15-29
0.425	13-21	
		7-14
0.075	5-9	

(Vic Roads 2011)

Table 2.9: Grading Limits for 20 mm Class 3 Subbase from Granitic Rocks.

Sieve Size AS (mm)	*Test Value before Compaction – Limits of Grading (% Passing by mass)*

26.5	100
19	95-100
13.2	75-95
9.5	60-90
4.75	42-76
2.36	28-60
0.425	10-28
0.075	2-10

(Vic Roads 2011)

Table 2.10: Grading Requirements for Class 4 Crushed Rock

AS Sieve Size (mm)	***Percentage passing by mass***	
	40mm nominal size	**20mm nominal size**
53.0	100	
37.5		
26.5		100
19	64-90	
9.5		
4.75		42-76
2.36		
0.425	7-23	10-28
0.075	2-12	2-14

(Vic Roads 2011)

2.6 Soil testing

2.6.1 Particle size distribution

Soil particle sizes in a particular soil or gravel can have a large effect on its structure properties and is of interest to any engineer designing a structure of or on soil based material. Soils are classified in 4 general categories: gravel, sand, silt and clay, with soil often made of a mixture of these. Soil is classified by the grading which is the percentage of each size of particle found in the soil (Das 2010). In Australia, this is often carried out by a sieve analysis. This entails removing all moisture from the material by dry oven at 105 to 110ºC and sieving the sample through a series of sieves from largest to smallest. Australian Standards suggests that the suitable sieve size for such testing largest to smaller, are: 75mm, 37.5mm, 19mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 600µm, 425 µm, 300 µm,150µm and 75µm. The mass of the sample capture on each sieve is then recorded to calculate the particle size distribution of the soil sample (Austrailian standards 2009). Generally, some of the sample captured after traveling through the smallest sieve can be used to carry out Atterberg limits testing.

Figure 2.4: Example of a grading sieve

2.6.2 Atterberg limits

Atterberg limits or consistency limits are the point at which a clay exhibits particular behaviour due to it varying water content. These limits can play a vital role in the suitability of soil material for some geotechnical and structural applications. The plastic limit is defined as the point at which the change in moisture content results in transition from ductile to brittle behaviour. The liquid limit is the point at which the behaviour of the clay changes from liquid to plastic in nature as result of water content (Haigh & Vardanega 2014). To test plastic limit in a soil sample, moisture content is adjusted until it can be rolled out into 3.2mm thick threads at which the soil crumbles. At this point, the moisture content is measured to calculate the samples' plastic limit.

The liquid limit is tested by making a paste from the sample and placing in a drop pan device. A grooving tool is then used to cut a part in the sample and the pan is then dropped 10mm 25 times. The goal is to have 12.7mm along the groove close up at the end on the 25 blows. When this is achieved, the moisture content of the sample in measured, resulting in the liquid limit.

Figure 2.5: drop pan device with grooving tool in bottom right of picture

The plastic index is important when classifying fine grained soils. It is calculated by subtracting the liquid limit form the plastic limit (Das 2006). The PI is often used as one of the parameters in RMS specifications.

2.6.3 CBR

The California bearing ratio (CBR) has been commonly used for testing the strength of road construction material for more than sixty years. This test is applied to a wide range of natural soil and gravel products (Magnan & Ndiaye 2015). A CBR test places a value on a material's inherent strength. This is done by compacting the sample at optimum moisture content using a defined amount of compactive effort. The sample is than soaked in a water bath for 4 to 28 days depending of the martial permeability. A plunger of a standard area is then used to penetrate the soil sample with the force required to penetrate the sample recorded against the time taken. This information is then graphed and the CBR of the material is established from the results (Austrailian Standards 2014).

Figure 2.6: CBR testing apparatus

2.7 Deflection testing

The surface deflection of a flexible pavement under an applied load is an important indicator of its structural condition. It is also an important parameter in the design of structural overlays and, together with the pavement layer thicknesses, in the back-analysis of existing pavements to estimate the pavement layer and subgrade moduli.

As an indicator of structural condition, deflections aid the selection of appropriate structural rehabilitation treatments, if any are required, by identifying:

- The structural adequacy of the overall pavement;
- Areas of weak pavement (inadequate thickness, poor quality pavement materials, soft subgrade) requiring specific treatment;
- Areas for more detailed pavement investigation.

Because of the capability of some methods to measure deflection rapidly, it is possible to use deflections to characterise a substantial length of pavement at one time to provide relevant and accurate indication of pavement strength (Jameson & Harrison 2011). There are several methods currently used in Australia to collect the deflect data. Some of the more commonly used methods are can be found in the section below.

2.7.1 Benkelman Beam

The Benkelman Beam road deflection test was developed in the 1950s. The testing device is simple in nature, operating on a lever arm principle and typically truck mounted or on a towed trailer. The test applies an 8okN load to the pavement through a single axle with dual tyres inflated to 480 to 550 kPa to give a contact area of approximately 0.048m^2 with the pavement surface. The test measures the pavement surface rebound as the loaded axles moves away from the test spot. The measurement is made by positioning the end of the beam between the dual tyres and recording the pavement surface rebound as the loaded trye moves forward.

The Benkelman Beam is low cost but is also slow, labour intensive and does not provide a deflection bowl (Huang 2004).

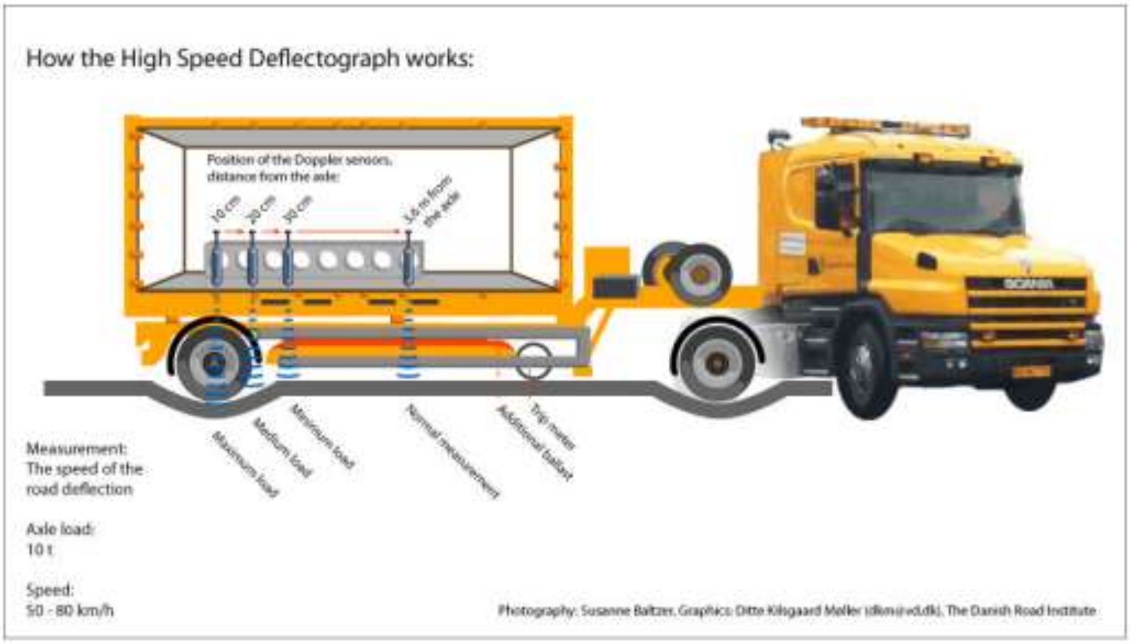
2.7.2 Falling weight Deflectometer

This is a vehicle-mounted or towed device which moves along a section of road, taking readings while stationary. Normally, a standard load plate with a 300 mm diameter is used to apply a load to the pavement surface. This load is in the form of a falling weight with a variable drop height while the Falling weight Deflectometer is at rest. The device records pavement surface deflection bowls at discrete test points on the pavement surface. Surface deflections are measured at distances ranging from 0 mm to a user-defined maximum, normally 1500 mm but can be up to 2400 mm from the centre of the test load (Austroads 2011).

2.7.3 Travel speed deflectogragh

The Travel speed deflectograph (TSD) was develop by Greenwood Engineering in Denmark and Danish Road Directorate. A relatively new technology is showing itself to be a useful device for measuring pavement deflection in Australia, with RMS starting to use it in 2010. Originally known as HSD, the device was renamed the TSD. The name reflects the device's ability to collect deflection data while traveling at legal driving speeds for normal traffic (Kelley & Moffat 2012). The TSD is a rolling wheel deflectometer for measuring pavement deflections at the network level and comprises a truck with a 10 tonne load applied on a rear, dual-tyred, single axle. The velocity of the deflected pavement surface under this load is measured using four Doppler laser sensors positioned at different distances from the centre of the load (i.e. the dual tyres). All sensors are aligned in a single wheel path. The four sensors measuring the pavement response are made up of Doppler vibrometer heads each connected to their own velocimeter controller unit. The controller unit processes the signal and extracts the velocity measurement from the frequency content of the reflected laser (Rabe 2012).

Network-level review work undertaken for Austroads by RMS and TMR to compare deflections in the same wheel path captured by the FWD and TSD of test data from both NSW and Qld showed a correlation between the two. This correlation confirmed that the TSD can differentiate between weak and strong structures for typical Australian flexible pavements. Furthermore, the development of the 'area under the curve' method provides a basis for replacing the TSD manufacturer's estimates of vertical deflections and, therefore, confirms that the TSD can give a reliable means for obtaining equivalent FWD deflection data that is understood by pavement design professionals (Roberts et al. 2014).



(Baltzer et al. 2010)

Figure 2.7: The Traffic Speed Deflectometer schematic drawing.

2.8 Performance Data

2.8.1 Visual Road inspections

Traditional visual inspections have played an important role in the management of infrastructure assets in Australia. Often decisions regarding the life span and maintenance of infrastructure assets rely heavily on the data collected in visual inspections. Visual inspections allow for considerable amount of relevant data to be captured on an asset's performance and condition at a low cost to the governing agency (IPWEA 2006). This is very true for road infrastructure where visual inspection are a major pavement assessment tool. A visual survey or inspection of the pavement condition is one of the simplest and often most relevant data sets used to assess pavements. For the management of smaller road networks, this data is often use as a major source of information regarding the pavement's condition with field testing rarely used, usually for reasons of low cost and little equipment needed. The level of detail and rigour of a visual survey can vary significantly depending on the method used (Jameson & Harrison 2011).

For visual inspection to be effective for knowledgeable decision making regarding maintenance and relative life left in a pavement, it is important the survey capture the required information. This information should include:

- Distress Type – identify the type of distress present and potential causes of physical distress in the pavement;
- Distress Severity – determine and record the severity of each distress type identified;
- Distress Extent and Location – determine and record the location and relative area of the test area affected by each distress type and severity.

Visual surveys and inspections should be systematic in their approach to mapping the pavement distress with the use of a referencing system for the locations. Key features along the piece of roadway of interest should also be recorded. These features may include vegetation, cuts, fills, structures, water and drainage. It is important that the location, all distresses and features are recorded as accurately as possible as it allows close correlation of different condition data sets (Jameson & Harrison 2011).

For flexible pavement visual survey and inspections, it is of great importance that the position of the relevant section of road be accurately recorded. The survey should record the following things:

- Surfacing and pavement type - sprayed seal (single or double application), asphalt, slurry;
- Surface deterioration – stripping, ravelling, flushing;
- Deformation – rutting, shoving;
- Cracking, including existing construction joints;

- Edge defects and shoulder condition;
- Potholes;
- Patching;
- Condition of subsoil and surface drainage (whenever possible).

(Jameson & Harrison 2011).

2.8.2 Rutting data

Rutting refers to the coverage of ruts over a pavement and is a pavement condition parameter that characterises the transverse profile of a road surface. A rut is a pavement defect in the form of a longitudinal depression on the surface, usually in a wheel path. Rutting is a pavement condition parameter that characterises the transverse profile of a road surface and aims to quantify the severity and extent of ruts over a pavement surface. 'Rutting' and 'rut depth' are commonly used terms for a particular aspect of pavement shape that is measured and more precisely described as transverse profile. Objective measures of transverse profiles are used to estimate the depth (severity) and extent of rutting and are among the more common road condition parameters. As with most road condition parameters, rutting or transverse profile data is collected to support efficient and effective management of road networks. Rutting information is used for road network condition monitoring, screening of candidate treatment sections and treatment selection network level prioritisation as well as whole of life cycle cost analysis managing maintenance contracts research, for example development and refinement of deterioration models and assessment of structural strength. Rutting information can also be used to assess pavement structural health as a road safety measure (Moffatt 2006).

2.8.1 Roughness Data

Road roughness is a condition parameter which characterises deviations from the intended longitudinal profile of a road surface with characteristic dimensions that affect vehicle dynamics (and hence road user costs), ride quality and dynamic pavement loading. Roughness is a measure of surface irregularities with wavelengths between 0.5 m and 50 m in the longitudinal profiles of either or both wheel paths in a traffic lane. Historically, roughness values were derived from the physical response of a vehicle to a road surface like the NAASRA Roughness Meter. NAASRA Roughness Meter systems are not recommended for use at the sealed road network level and they have not been used for some time. Current practice is to measure the longitudinal profile of the road and to mathematically model the response of a hypothetical vehicle, like a profilometer and quarter-car simulation (Moffatt 2007).

The wheel path profiles measured by a profilometer have been correlated to the response of an NRM, and as a result many roughness results determined by a profilometer have been reported in units of counts/km as if they had been measured by an NRM. Typically, at a road network level, roughness should be reported as Lane IRIqc (commonly referred to simply as IRI (m/km)). This is the standard, composite IRI value representing the roughness of a traffic lane within a section of road. It is determined by averaging two individual Single Wheel path IRIqc values obtained separately in each wheel path of a lane (Moffatt 2007).

2.8.2 Cracking Data

A crack is an unplanned break or discontinuity in the integrity of the pavement surface, usually a narrow opening or partial fracture, often indicating vertical splitting of the pavement though not necessarily extending through the entire thickness of a course or pavement. A crack may be caused either by environmental factors or by the passage of loaded wheels. Cracks allow the ingress of water and can be exacerbated by the ingress of water .The term ‘cracking’ is used for the process of development of a crack and as a collective noun describing the coverage of cracks over a pavement (Moffatt & Hassan 2006).

Because road pavement cracks commonly initiate beneath the surface, the appearance of cracking on the surface has long been recognised as a sign of some form of distress of the pavement (except for cracks that are entirely caused by embrittlement of surface bitumen, which is mostly due to long exposure to ultra-violet radiation). Cracks may be linear (transverse or longitudinal), interconnected (crocodile or block), or irregular (meandering, diagonal, crescent and edge cracking), single and isolated or in groups, with varying spacing between them. In the context of network-level data collection, cracking does not include joints, sealed cracks, or saw-cuts. All pavements, regardless of type, will deteriorate at a much slower rate if they do not experience the ingress of water into their structure in any direction. Once cracking is initiated, the potential is much greater for accelerated deterioration of the pavement. This is recognised in many pavement deterioration models. The appearance of cracks on a pavement surface indicates an immediate loss of waterproofing and may indicate cracking below the surface within the pavement structure. With surface cracking, both the structural and surface integrity of the pavement are at risk unless an appropriate and timely form of intervention is undertaken (Moffatt & Hassan 2006).

2.9 Soil properties

2.9.1 Moisture content

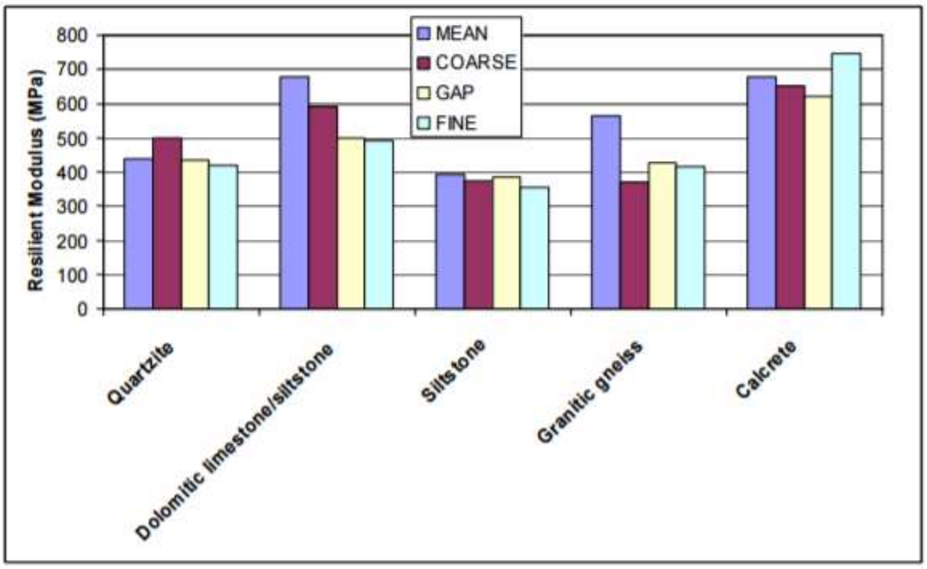
The moisture conditions in unbound granular pavement materials can also have a major affect on performance. When the degree of saturation of unbound granular materials exceeds about 70% of the material’s optimum moisture content, the material can experience significant loss of strength/modulus (Hubner & Jameson 2012). Design and construction of pavements are performed with the aim of keeping the structure drained but, unfortunately, water often finds its way into the structure, affecting its performance. Excess water in a pavement structure can decrease its life by more than half. Increased moisture content reduces the resilient modulus of granular materials, their frictional strength and resistance to deformation Water influences bearing capacity and pavement performance. The change in moisture content is the most important factor for the amount of rutting of unbound materials, as increased moisture content causes a decrease in the resilient modulus. If all other conditions remain the same, increased moisture content will lead to a greater elastic strain and therefore more rutting (Saevarsdottir & Erlingsson 2013).

One of the reasons for a reduced resilient modulus with increased moisture content is the lubricating effect of water, causing lower inter-particle forces. Another reason is that, if the soil has a low conductivity, excess poor water pressure might accumulate with repeated loading causing the effective stresses to decrease, leading to a reduction in the strength and stiffness of the material and less resistance to permanent deformation. Several studies have been carried out to investigate the impact moisture has on the mechanical properties of aggregates. The effects of moisture are more significant on materials with a high proportion of fines and densely graded than the influence of water on coarse granular materials. The coarser grading material experiences a small reduction in resilient modulus when brought close to satu ration, whereas material with an increased fine content and more evenly distributed ???? showed a substantial decrease in the resilient modulus as the water content increased (Saevarsdottir & Erlingsson 2013).

2.9.1 Shear strength

Shear strength is defined as the resistance to shear stress, at failure, on a surface within a soil mass. Rutting and shoving are the major surface defects that depict shear failure in base layers. Shear failure in the base can lead to thinning of the pavement layer (rutting within the base) and disruption of the surface seal. If due to lack of base shear strength, the aggregate in a spray seal penetrates into the base leaving a flushed surface. The surface may be hazardous in rainy conditions as surface skid resistance is reduced due to the loss of surface texture and aquaplaning related to the channelling of water in wheel paths can occur (Vuong et al. 2008).

It has been shown in a number of studies that the particle size distribution, or grading, of granular materials seems to have influence on granular modulus and the shear strength of pavement material. When a crushed rock has less fines (finer than 0.425 mm) it is generally defined as bony and the load transfer is through point-to-point contact of aggregate fractions, resulting in high modulus and low moisture sensitivity. In contrast, a material with high fines content relies more on the strength of the fine matrix material surrounding the aggregate fractions to achieve modulus. Where aggregate particles are flat or flaky, this mechanical interlock is further reduced (Vuong et al. 2008). In the figure below, the effect of the grading curves on the modulus of a range of materials are presented. It be seen that the range of grading curves effect the materials differently. An example of this the granitic material that performs much better when it is well graded compared with coarse, fine or gap grading curves.



(Vuong et al. 2008)

Figure 2.8: The effect of different grading curves on the modulus of the material

As plasticity and fines content influence soil suction, it is reasonable to assume that stiffness is also affected by these factors. This is particularly so when suction is the primary stress that binds particles together (e.g. at unconfined or low confining stress conditions and/or in a dry condition). In this case, higher fines content and higher cohesive fines will result in higher suction and, hence, higher stiffness. However, when suction is very small compared to confining stresses (e.g. as in the saturated condition), higher fines content and higher cohesive fines may result in lower stiffness due to the effects of particle size and lubrication as discussed above. It has been reported in a number of studies that for a fines-content between 2-10%, the influence of fines content on the stiffness was not well defined and can be dependent on aggregate type (Vuong et al. 2008).

2.9.2 Plasticity

A plasticity of a pavement material increase over specified limits of a material so does the moisture susceptibility of the material weakening the pavement under traffic during wet periods which can lead to distress reflecting through the sprayed seal surfacing. This can result in accelerated deterioration of a road pavement and plastic deformation of the road pavement over time. Plastic Index testing in generally a good indicator of the plasticity of pavement material and is determined using Atterberg limits testing which is relatively simple to perform and uses somewhat inexpensive equipment to carry the testing (Midgley 2009).

2.10 Common granular pavement failure types

2.10.1 Flushing/bleeding

Flushing/bleeding and scabbing are the two principal modes of distress seen in chip seals. Scabbing occurs when the aggregate's adhesion with the binder reduces. The reasons a reduction could arise include climate, aggregate properties or change in traffic conditions with the major aggregate loss taking place during initial trafficking.

Flushing occurs as a combination of two things: surplus of bitumen and hot weather conditions. As the temperature of the seal increases, the excess binder rises to the surface producing a slick or smooth surface (Aktaş et al. 2013).

Figure 2.9: Example of flushing on local road with rutting also visible in the right lane.

2.10.2 Shoving

Shoving and rough surface is one of the major failure modes experienced on the Pacific Highway at Glenugie. A shove is where a bulge is formed in the pavement on one side of the wheel line with the wheel path generally sinking to some degree. One of the causes of such a failure is the high stress in the pavement caused by vehicles braking or turning (Wang & Al-Qadi 2010). Other causes include the structural shear failure of pavement layers, poor compaction, settlement of underline layers or subgrade and the breakdown of material in these layers (Moffatt 2006).

2.10.3 Rut/Rutting

A rut is defined as a longitudinal depression that forms in a wheel path of a road. The length-to width ratio would normally be greater than 4:1. Rutting may occur in one or both wheel paths of a lane (Moffatt 2006). Where rutting is associated with shoving (can be seen in below as mode 1), it is indicative of the shear strength in the upper pavement layers being inadequate to withstand the applied traffic loads. In this case, there will be poor correlation between the severity of rut depth and measured deflections. As alternatives, trenching across the lane-width and between ruts can be used to identify the critical pavement layer or layers. Laboratory testing of the affected materials sampled from the pavement will further assist in evaluating whether the shear deformation is related to deficiencies in the specification for that material or to the use of non-conforming material. Inadequate pavement strength is the result of pavement layers being too thin or of insufficient quality to distribute the applied load sufficiently to avoid overstressing lower layers in the pavement or the subgrade (figure below mode 2). To assess whether rutting is due to inadequate pavement strength, it is useful to plot measured pavement deflections at various chainages against measured rut depth at the time of deflection testing. The higher the correlation of rut depth and deflection, the more likely the rutting is due to inadequate pavement strength. If rut depth does not correlate with pavement deflection and there is little or no shoving, the most likely cause is densification of the pavement layers under traffic early in the life of the pavement (figure below mode 0) (Jameson & Harrison 2011).

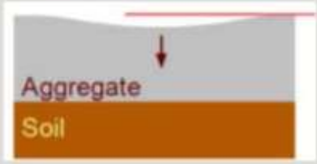
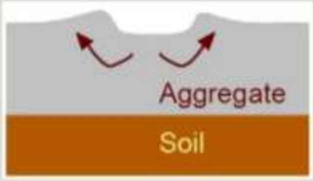
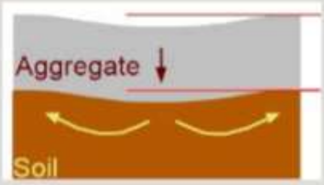
Mode of rutting	Brief description	Schematic illustration
Mode 0	Rutting caused by compaction of non-saturated material. However, generally the compaction during construction is assumed sufficient to avoid further deformation under traffic. This mode of rutting is self-stabilising.	
Mode 1	Rutting that happens in weak granular materials. This rutting mechanism involves material heaving on the side of the wheelpaths. This mechanism can be named shear-failure of the base course.	
Mode 2	When aggregate quality is good and uniform, then the pavement as a whole may rut due to subgrade deformation resulting in pavement surface deformation, while no deformation occurs in the granular layer.	

Figure 2.10: diagram of the mode of rutting failure

(Bodin & Kraft 2015)

2.10.4 Cracking

Cracking is a pavement defect that is usually identified as one or more visible discontinuities at the surface, often indicating unplanned vertical splitting of the pavement. However, particularly for unbound granular pavements with thin bituminous surfacing's, surface cracking may not be associated with vertical splitting of the pavement to any significant extent. The condition of pavement surfaces is an important guide to the overall condition and future performance of the pavement structure. The onset of surface cracking has been recognised as an indicator of overall pavement conditions since road pavements were first sealed. Surface cracking can lead to loss of pavement durability due to water entering the pavement through cracks in the surface and weakening the structural integrity of the pavement (Moffatt & Hassan 2006).

Figure 2.11: Example of distress cracking on local road.

2.11 Road Construction Techniques

2.11.1 Compaction

Uncompacted materials are compressible and will compact/consolidate under loading over time, providing a tendency for moisture to be held in the material and consequently affecting its load bearing properties. The objective of compaction is to improve a material's properties, in particular to increase its strength and bearing capacity, reduce compressibility and to decrease its ability to absorb water. The compaction process artificially densifies a material by pressing the particles together, expelling the air from the mass and filling the voids, thus making the material more dense, increasing its strength and hence resistance to rutting (Hubner & Jameson 2012).

2.11.2 Boxed out pavement construction

Where pavement materials are expensive or wide verges and flat batters are used, it may be more economical to adopt boxed instead of full-width construction. Boxed pavement is a style of road pavement construct where a box is formed along the edges of the pavement to be built. Once this is formed, the pavement is constructed inside the edges. This results in the pavement only being the area that is required and can lead to a reduction of the needed pavement material. Extreme care must be taken with this form of cross-section to avoid softening of the subgrade because of poor drainage during construction and to ensure that excessive moisture does not collect in the pavement during its service life. When it is not possible to effectively drain the pavement and/or subgrade, the pavement design should be based on subgrade strength values obtained from soaked test specimens. Verges should be shaped to lead water away from the pavement and, for high standards of performance, comprehensive subsurface drainage is usually required. Pavement materials should be chosen to avoid the use of moisture-sensitive materials (Hubner & Jameson 2012).

Chapter 3 : Background information

3.1 Pacific Highway Upgrade: Glenugie

3.1.1 Gleuugie upgrade

One of the largest ongoing infrastructure projects within Australia in the last 20 years has been the upgrade of the Pacific highway to four lane divided road between Sydney and Brisbane. This project started in 1996 with a completion target of 2020 (RMS 2015). In Northern NSW there is a large amount of construction work commencing or about to commence over the next four years on the Pacific Highway as there is a push to meet the 2020 completion date.

In September 2011, the Glenugie upgrade of the Pacific Highway was completed. This was a very small section of the overall Pacific Highway upgrade and it consisted of a 6.5km section of dual carriageway made of heavy duty granular pavement. The principal driver for the upgrade was to eliminate several lower standard curves and replace the existing two lane configuration with a four lane divided road. The project utilised 3.5 km of the existing highway by rehabilitating it and incorporating it as the southern end of the north bound lane. This section of 3.5km road does not consist of the heavy duty granular but redeveloped section of the existing pavement.

The Glenugie Upgrade forms part of the larger 80km long ‘Wells Crossing to Iluka Road’ project to duplicate the Pacific Highway to dual carriageway from Sydney to Brisbane. This upgraded section was effectively a trial to gain a better understanding of whether or not heavy duty granular pavement design would be a feasible option for future sections of the Pacific Highway upgraded in Northern NSW. A considerable amount of time and effort was expended in the development of the standard and suitable gravels to meet this standard (Nash et al. 2011)

The Glenugie upgrade is situated just 15 to 23km southeast from the township of Grafton. Like most of coastal Northern NSW, the annual rainfall in the Grafton area is relatively high. Grafton's average annual rainfall is approximately 1380mm and on average it has 94.5 rainy days a year (BOM 2016). From a road construction and maintenance point of view, the North Coast of NSW region is the second highest rainfall region within NSW, with only higher rainfall area being in the humid mountains around Perisher Valley (Tamsett 2015).

At the time that the Glenugie upgrade was completed, the road carried around 8500 vehicles per day with 23% of these being heavy vehicles, which gives a design traffic (N_{DT}) for the road of 7.14 x 10^7 equivalent standards axle (Nash et al. 2011). This means it is well in the range that the RMS would classify as a heavy duty pavement.

3.2 Development of the Heavy Duty Flexible Granular Pavement for Glenugie

The development process for the heavy duty flexible pavement was quite sizable as this type of pavement had not been used in the northern region of NSW before. This kind of pavement had been trialled in western and south western regions using a draft specification but the climatic and geological condition in the northern region varies greatly to other regions, making the project very challenging. The pavement was developed as a complete system, comprising 3 major parts: revised material specification, pavement design with emphasis on preventing water penetration and requirement for high construction quality. The RMS material specification 3501 was revised at the time to include heavy duty flexible granular pavement material (DGB20 (HD). This was similar to the VicRoads specifications with some modification to allow for lessons learned by RMS in early trial of draft specifications (Nash et al. 2011).

No quarry in the area near the project site produced a conforming DBG20 HD gravel so it was necessary for the RMS to work in conjunction with local quarries to develop a suitable material. After considerable testing and trials at local quarries, two sources of conforming DBG20HD material were produced. From these two, one was chosen due it having a greater potential to maintain high performance over a longer period and it had no restriction on production. The chosen gravel was a blend of rock types which were found in the same quarry. The first is a fresh, medium to coarse grained granite and the second a fine grained argillite which has undergone some contact metamorphism. The argillite was added to the mix to help reduce the permeability and improve the workability of the material so it could meet the specification. The final ratio selected for the blend was 70% -22.5mm Granite / 15% -10mm Argillite Scalps / 15% -20mm Argillite. Small changes were made to this throughout the project to insure the conformity was achieved with 3501 specification (Nash et al. 2011).

The road used a "boxed out" technique during the construction with subsurface drain provided on both sides of the pavement to help drain any moisture which might still enter the pavement. The blended gravel was wet mixed by pug mill at the quarry to within 0.05% of OMC before being trucked to site. Once on site, the mixture was spread using graders with universal total station grade control system and moisture content was checked. To achieve the relatively high compaction needed for the pavement to handle the traffic loads, the pavement layer had to be relatively thin (Millichamp et al. 2012). As can be seen below.

Pavement	Wearing Surface	Wearing surface: Prime and 14mm / 7mm double double seal
	Base	Base: 125mm DGB20(HD), 100% modified compaction
	Subbase	Upper subbase: 100mm DGB20(HD), 100% modified compaction Lower subbase: 100mm DGB20(HD), 98% modified compaction
Earthworks Upper Zone of Formation (Uzf)	Select Material Zone (Smz)	Upper SMZ: 150mm CBR>30%, 102% standard compaction Lower SMZ: 150mm CBR>15%, 102% standard compaction
	Capping Layer or	In fill: Min 150mm capping layer of material with CBR>7%, Swell<1% at 98% standard compaction
	Drainage Layer or	In cut: Existing subgrade preparation or approximately 300mm drainage layer construction, based on R44 and geotechnical inspection.
	Bridging Layer	Drainage: 625mm thick, geotextile wrapped. Bridging: where required 500mm thick.
Subgrade	Existing Subgrade or	Existing subgrade: natural or cut surface of existing material.
	Stabilisedsubgrade	Stabilised subgrade: to dry out subgrade and improve workability.

Figure 3.1: Typical pavement profile for Glenugie

(Millichamp et al. 2012)

3.2.1 Compactive effort during construction

During construction of Glenugie project, it was quickly realised that the compactive effort to achieve the 100% modified compaction requirement, over a relatively thin pavement layer, would need a different approach. The traditional methods of using vibrating padfoot rollers with heavy vibrating smooth drum rollers, did not achieve the compaction target during the trials. Further trials at varying moisture contents and roller combinations (including static three point, heavy multi tyre and heavy smooth drum) to determine the most successful combination. The adopted rolling pattern is listed in the table(Millichamp et al. 2012).

Table 3.1: The adopted rolling pattern for the Glenugie project to achieve the 100% modified compaction requirement.

Compaction	Moisture	Comment
1a. Initial compaction - vibration 8 passes heavy vibration of 20T roller (ie 4 passes of 2 x 20T rollers in tandem) 8 passes light vibration of 20T roller (ie 4 passes of 2 x 20T rollers in tandem)	At OMC	2 rollers are used in tandem to achieve compaction while material is close to OMC. There is only a 2 hour time window (approximately, depending on weather) to achieve compaction before material starts to dry back too much. A water cart is used to control moisture before full compaction is achieved.
1b. Initial compaction - static rolling (if necessary to achieve dry-back) 20T smooth drum or 22T multi-tyre	As material dries back	Static rolling introduced during periods of cooler weather to assist dry back prior to placement of next layer.
2. Static rolling after final trim of base layer only 4 passes of 14T double drum roller	~ 1-2% < OMC	Material must be dry enough to ensure pavement does not move, but cannot be too dry such that further compaction cannot be achieved. Double drum used to ensure no damage to final surface. Three-point roller could be used as an alternative.

(Millichamp et al. 2012)

3.2.2 Testing carried out during construction

A considerable amount of testing was carried out during the construction on the Glenugie upgrade. The DGB20 HD stockpiles were tested in parallel by RMS and quarry laboratories throughout the construction to confirm the conformance of the material to the specification. Nuclear density of the finished pavement before sealing was taken along the length of the alignment to confirm required densities for the design and specifications had been conformed too. Benkelman Beam deflection testing was also carried out the along the Glenugie section road during the construction at the UZF to insure sufficient stiffness (Nash et al. 2011).

3.2.3 Pavement maintenance plan

A proposed pavement maintenance diary has been developed for the pavement to allow it to meet a 40 year design life. The proposed intervention to meet a 40 year design life includes:

- Year 8 PMB reseal with 14mm aggregate

- Year 15 Rehabilitation – 40mm AC14 and 7mm seal
- Year 23 PMB reseal with 14mm aggregate
- At Year 30

  -Option A: Rehabilitation – 40mm AC14 and 7mm seal (with or without milling off AC)

  - Option B: Rehabilitation – Insitu stabilisation to 350mm, then 40mm AC and 7mm sprayed

(Nash et al. 2011).

3.2.4 Failures in the Glenugie pavement

In 2014 the failures were first observed in the upgrade section of pavement at Glenugie in the form of flushing, shoving and rutting. Over the following years these failures continued to deteriorate with pot holes forming in a number of areas. The failures in the section heavy duty pavement granular generally started as server flushing in the outer wheel path followed by slight rutting with shoving developing over time and increasing in severity. From this, a pot hole generally developed and the failure would grow in size. It has been observed that the development of failures has commonly been more rapid after large rain events.

Chapter 4 : Methodology

The following project methodology has been developed in 2016 in consultation with Ben Churton who is a part of RMS geotechnical team in Northern NSW and John Howell an RMS Northern region pavement maintenance manager. An outline of the project methodology is included below:

- Research the background of Glenugie Pacific Highway upgrade and the relevant standards and specification regarding heavy duty granular pavement in NSW and surrounding states and territories;
- Assessment of the pavement's performance to date and the extent of the pavement failure in the segment of road of interest. This has been conducted using two sets of data: defect mapping from a visual inspection of the road and a data set from the RMS RAMS database including cracking, roughness and rutting data.
- Assessment of the cause of the current failures and there root cause in areas of the Glenugie pavement. This assessment will be based on a range of soil testing which has been carried out by RMS in areas of the pavement which have shown a high rate of pavement failures and will utilise TSD data from the RMS RAMS data base. This test data will be used to compare with a range scientific literature, specifications and construction data to develop substantial theory supported by evidence as to the mechanism or mechanisms which is cause the failures in these areas of pavement.

4.1 Background research on Glenugie Upgrade and Heavy Duty Granular Pavement.

Chapter 2 and 3 of this report provides a literature review of relevant information and background of the development and construction of the Glenugie Pacific Highway upgrade. The applicable standards and specification regarding heavy duty granular pavement in NSW and surrounding states and territories are outline along with other essential information.

4.2 Defect mapping

The visual defect mapping was carried out for all the heavy duty pavement constructed as a part of the Glenugie Upgrade. This includes 4.1km of north bound carriageway and 6km south bound carriageway. These segments are contained in the area where heavy duty granular pavement was constructed and as a part of the highway upgrade in 2011. The northbound section is shorter due to the project utilising 1.9km of the pre-existing highway by rehabilitating it and incorporating it as the southern end of the north bound lane. Therefore, this section of highway is not heavy duty granular pavement and was not included in the analysis of the pavement for the study. The area of road to be mapped can be seen in the aerial photo below of the Glenugie area with the north bound marked in red and the south bound marked in blue.

(Google Maps 2016)

Figure 4.1: Proposed area of road to be defect mapped

Traditionally, visual inspections of road way are carried out by physically walking over the road and inspecting its condition. Due to the cost of traffic control and limited budget for the project, a video recording will be used in place of a physical walk through. This will greatly reduce the safety risk to the person conducting the inspection and road users. This approach still allows the inspection to be carried out with a high level of accuracy and the defect mapping to be based on the most current road condition information.

The video recording was carried out by a camera mounted on the front of the car using a suction cup mount with secondary tethering system in place to restrain the camera in the event that the suction mount was dislodged (see figure below). Some testing was carried with the camera in different positions but it was found that the camera position at the front of the car produced better vision for identifying pavement defects. Therefore, the camera was positioned on front of the car in the centre of the vehicle. A Bluetooth controller was used to operate the camera from inside the car for the project. Originally it was proposed that a GoPro Hero camera be used but after some testing it was established that a better quality camera would be required to capture quality video at a safe highway operating speed of 90 to 100km per hour. As a result, a better quality GoPro Hero 4 Black was sourced for the project. This was capable of capturing video of the required quality at a safe highway operating speed. This camera was used to carry out the video recording for the defect mapping.

Figure 4.2: GoPro mounted on the car with tethering system

A phone application called Endomondo was used in conjunction with the video recording process to determine that exact position of the camera during the recording. Eudomondo is an application which is often used for tracker fitness activities like running and cycling. Eudomondo uses the phone’s GPS to calculate and track the position of the device. A phone GPS system is usually accurate 1 to 10m and is dependent on satellites available and clear line of sight to said satellites. During the experiment, the application started tracking the location of the vehicle at the same time as the video recording commenced. From this, the time from the tracker data and the time from the recording can be used to find the extract position of the camera at any stage of the recording. This enabled the location of the defects identified in the video to be determined accurately with ease.

The defects in the road will be recorded in10m segments with the segment given a ranking based on the severity and type of the defect or defects found in that 10m segment of road. The ranked system proposed for use can be found below in table 3.1. The ranking system will start at 0, being no defects, and end with 5 being for the most severe defects. The number and type of each defect in each segment will be recorded in an excel spreadsheet along with a ranking and any notes regarding the segment. This will allow the data to be graphed and/or compared to other data sets.

Table 4.1: Ranking system for defect mapping

Ranking	***Severity***	***Failure types***
0	No failure in the segment	
1	Minor structural failure	Minor pot hole – Minor Shove – Minor cracking – Minor undulations
2	Medium structural failure	Major pot hole – Major Shove – Major cracking – Major undulations
3	Major structure failure	Heavy patching – Major repair work

Figure 4.3: Image from the video used for the defect mapping of a section of road with no defects.

Figure 4.4: Image from the video used for the defect mapping, heavy patch can be seen of the left side of the image.

Original, it was planned to identify areas of flushing and rutting in the defect mapping but due to the nature of video recording it was found hard to do this with consistency. As a result, these failure types were not recorded as part of the analysis of the pavement with an aim to keep collected data consentient and make the mythology more repeatable.

The final video used for the project was recorded on the 11th of September, 2016 between 12 noon and 1pm. Weather during this period was clear and sunny with no to very little cloud cover. The GPS system in the phone was turned on and left to sit for 5 minutes to acquire as many satellites as possible. The phone's GPS system was recording Horizontal and vertical accuracy of less 5 meters with a GPS status rating of very good before and after the recordings were undertaken.

4.3 Pavement performance RAMS data

The pavement performance data used this section of the project is from the RMS RAMS data base. A range of pavement condition and performance data is collect by the ARRB group on behalf of RMS and entered into RAMS database. ARRB collects the data with the use of one of its dedicated pavement survey vehicles. The vehicle uses a range of sensors, monitors and cameras to take a measurements and calculation which make up the data (ARRB Group 2014). An example of the type of vehicle used to collect this data can be seen below in the figure.

(ARRB Group 2014)

Figure 4.5:ARRB Group pavement survey cars

Roughness, rut depth and cracking data was extracted from the RMS RAMS database. These three performance indicators were chosen for the following reasons:

- Roughness - is a key indicator of how the public perceive the condition of the road. A high roughness value will generally lead to a less comfortable ride for the occupants of the vehicle. Vehicle operating and maintenance costs can also be affected by the roughness of roads with the costs increasing as the roughness increases. A road being comfortable and minimising operation cost for the user are key functions for high quality roads

- Rutting – is an indicator of the structural integrity of the pavement. High or excessive rutting can identify areas with structural weaknesses in a section of pavement. Granular pavement ability to resist rutting is a key structural function of a quality road.
- Cracking - The extent of cracking indicates the risk of exposure to rapid deterioration of the pavement due to water ingress. High or excessive cracking can identify areas with ingress of water which may have an effect on structural capacity of a section of pavement. A pavement's ability to resist cracking is a key structural function of a quality road.

This data was used to examine the functional and structural performance of the pavement at the present time. This was done in line with RMS Performance Measures and Indicators Manual. For the proposed analysis of the highway at Glenugie, the customer level of service will be considered to be class A due the section of highway having a high traffic levels, freight demands and a posted speed limit of 100km/h. This is as per the pavement level assessment in appendix C of the manual (RMS 2016). The sections below explain how the raw data was analysed and interoperated.

4.3.1 Rutting

Rutting measures the extent of permanent pavement deformation in the wheel paths. High levels of rutting require investigation to ascertain the structural integrity of the pavement and potential risk to safety. The measure of rutting used for the project is the depth of the wheel ruts in mm. Using this measured value, the average rutting is calculated based on a 100 metre interval using the highest value from inner or outer wheel paths. Then the results were used to determine the condition of the pavement based on the rutting average indicator values. The level of rutting that corresponds to each condition can be found in table below under customer level of service A(RMS 2016). The results for the 100m interval were also graphed so they could examined for abnormally rutted sections and the presents of that patterns in pavement rutting results.

Table 4.2: Rutting in mm values and there corresponding pavement condition.

CLoS	1 – VERY GOOD	2 – GOOD	3 – FAIR	4 – POOR	5 – VERY POOR
A	≤ 3.5	> 3.5 to ≤ 5.5	> 5.5 to ≤ 7.5	> 7.5 to ≤ 9.5	> 9.5
B	≤ 5.0	> 5.0 to ≤ 7.0	> 7.0 to ≤ 9.0	> 9.0 to ≤ 11.0	> 11.0
C	≤ 6.5	> 6.5 to ≤ 8.5	> 8.5 to ≤ 10.5	> 10.5 to ≤ 12.5	> 12.5
D	≤ 8.0	> 8.0 to ≤ 10.0	> 10.0 to ≤ 12.0	> 12.0 to ≤ 14.0	> 14.0
E	≤ 9.5	> 9.5 to ≤ 11.5	> 11.5 to ≤ 13.5	> 13.5 to ≤ 15.5	> 15.5

(RMS 2016)

4.3.2 Roughness

Pavement roughness is a measure of the evenness or irregularity of the pavement surface. It is an important measure because it affects comfort, vehicle operating costs and maintenance costs. The international roughness index (IRI) was used for the measurement of roughness for the project. The highest IRI values from the inner or outer lane were taken as the relevant IRI value for each direction of carriageway. From this, the IRI roughness values for each carriageway were calculated by taking the average of each 100 metre interval result. Then the results were used to determine the condition of the pavement based on the roughness indicator value. The level of roughness that corresponds to each condition can be found in table below under customer level of service A(RMS 2016). The results for the 100m interval were also graphed so they could examined for abnormally rough sections and the presents of that patterns in pavement roughness results.

Table 4.3: IRI roughness values and there corresponding pavement condition.

CLoS	1 – VERY GOOD	2 – GOOD	3 – FAIR	4 – POOR	5 – VERY POOR
A	≤ 1.8	> 1.8 to ≤ 2.6	> 2.6 to ≤ 3.4	> 3.4 to ≤ 4.2	> 4.2
B	≤ 2.2	> 2.2 to ≤ 3.0	> 3.0 to ≤ 3.8	> 3.8 to ≤ 4.6	> 4.6
C	≤ 2.6	> 2.6 to ≤ 3.4	> 3.4 to ≤ 4.2	> 4.2 to ≤ 5.0	> 5.0
D	≤ 3.0	> 3.0 to ≤ 3.8	> 3.8 to ≤ 4.6	> 4.6 to ≤ 5.4	> 5.4
E	≤ 3.4	> 3.4 to ≤ 4.2	> 4.2 to ≤ 5.0	> 5.0 to ≤ 5.8	> 5.8

(RMS 2016)

4.3.3 Cracking

The extent of cracking indicates the risk exposure to rapid deterioration of the pavement due to water ingress. Cracking is measured in number of cracked frames in a 100m interval of carriageway with 200 frames taken in each interval. Where cracking within a frame is identified, the whole area of the frame is deemed to be cracked. For the project total number of cracked frames will be used, meaning the number of frames with transverse, longitudinal, crocodile or straight cracking will be added together to give the total. Then the results were used to determine the condition of the pavement based on the cracking indicator value. The level of cracking that corresponds to each condition can be found in table below under customer level of service A(RMS 2016). The results for the 100m interval were also graphed so they could examined for excessive cracking in sections and the presents of that patterns in pavement roughness results.

Table 4.4: Cracking values and there corresponding pavement condition.

CLoS	1 – VERY GOOD	2 – GOOD	3 – FAIR	4 – POOR	5 – VERY POOR
A	≤ 0	> 0 to ≤ 1.33	> 1.33 to ≤ 2.67	> 2.67 to ≤ 4.0	> 4.0
B	≤ 0.5	> 0.5 to ≤ 1.83	> 1.83 to ≤ 3.17	> 3.17 to ≤ 4.5	> 4.5
C	≤ 1.0	> 1.0 to ≤ 2.33	> 2.33 to ≤ 3.67	> 3.67 to ≤ 5.0	> 5.0
D	≤ 1.5	> 1.5 to ≤ 2.83	> 2.83 to ≤ 4.17	> 4.17 to ≤ 5.5	> 5.5
E	≤ 2.0	> 2.0 to ≤ 3.33	> 3.33 to ≤ 4.67	> 4.67 to ≤ 6.0	> 6.0

(RMS 2016)

4.4 Soil testing data and construction documentation

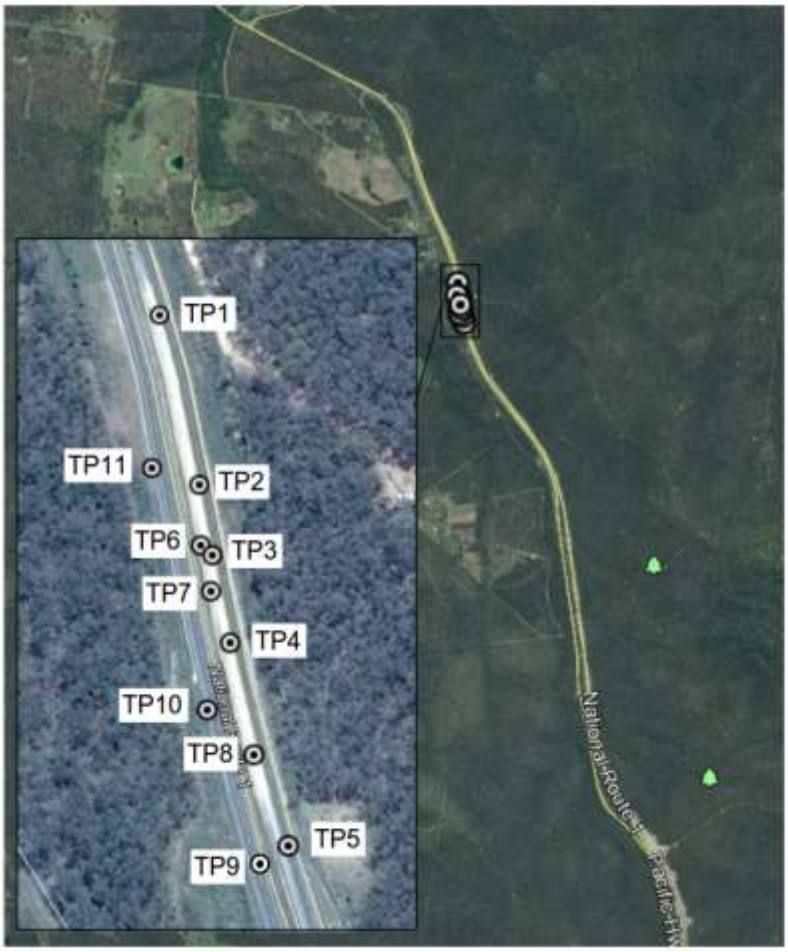
Samples of the pavement materials for the project were collected by RMS staff and the author of this report over a three-day period from 4/3/2015 to 6/3/2015. During the sampling, 11 test holes were excavated at areas identified by the defect mapping to be of interest for the project, predominantly within an area where pavement failures had occurred. The pavement layers were sampled at each test hole so a range of soil testing could be carried out. Some test pits were sampled in two sections: pavement material under the outer wheel path and under the shoulder of the road. Below, in table 3.2, is the Roadloc location of each of the test pits. Surface and pavement condition for each test pit were recorded by Dale Morgan in the sampling log as listed below.

Table 4.5: Test pit locations with surface and pavement conditions

Test pit	*Roadloc*	*Surface condition*	*Pavement condition*
TP1	R[10,2661,C1,5.223]	Good – slight flushing adjacent to both inside and outside edge line	Good – some slight seal flushing but no other signs of distress
TP2	R[10,2661,C1,5.102]	Fair – some cracking on the edge line	Fair – Small failure beginning to appear on edge line
TP3	R[10,2661,C1,5.055]	Poor – patched, slightly flushed	Poor - deformation and failure along edge line. Some flushing appearing in wheel paths, both lanes
TP4	R[10,2661,C1,4.998]	Poor – flushing in OWP of slow lane & IWP of fast lane	Poor – OWP rutted, numerous edge line failure
TP5	R[10,2661,C1,4.871]	Poor – some flushing in OWP, cracking and patching	Poor – OWP rutted, numerous edge line failure, pit at topside of AC patch
TP6	R[10,2661,C1,5.063]	Fair – fine cracks	Fair – Some slight rutting, fine cracks in seal in IWP leaching fines
TP7	R[10,2661,C1,5.032]	Fair – some flushing. More pronounce around failure	Fair – pit adjacent to small shoving failure along inner edge line
TP8	R[10,2661,C1,4.927]	Fair - Some slight flushing in wheel paths	Fair – Outer lane failing. Inner lane generally good

TP9	R[10,2661,B1,4.920]	Fair – slight flushing	
TP10	R[10,2661,B1,5.014]	Poor – Flushing in both wheel paths	Poor – Shoving along edge line. Previous AC patch immediately above test pit.
TP11	R[10,2661,B1,5.171]	Good	Good – Pit in good area towards top of hill

Sampling was carried out with the assistance of the 5 ton rubber tracked excavator. Traffic control closed the relevant lane to be sampled and the excavator dug the test pits at areas of interest. The excavator operator carefully excavated the test pits one layer at a time with the help of a spotter, placing the pavement material from each layer separately. The said material was then shovelled into 2 to 4, 15 litre sampling containers and labelled based on the test pit and pavement layer. In addition to this, smaller moisture content samples of approximately 500g were taken from each sample and placed in sealed plastic bags with the relevant label written on them. All samples were then loaded into utility vehicles and transported to RMS Grafton laboratory for testing. A map of the test pits can be seen below. It can be seen that the test pits focus on a small area of overall pavement which was identified in the defect mapping to be the area where most of the major pavement defects had occurred. As such, the test pitting has focused on this area with the aim of identifying the cause of these defects.



(Google earth 2016)

Figure 4.6: Maps of the test pit locations

The weather leading up to sampling was relatively average for the given time of year. The two previous month's rainfall had been very slightly above average with the month before below average. This has resulted in what could be considered a typical moisture content in the surrounding environment.

The soil testing was predominantly carried out by RMS staff with some assistance by the author of this report. Soil testing included tests on 57 field moisture samples, 18 particle sizes grading samples, 6 Atterberg limits samples and a CBR sample. The results from this testing along with information regarding how the failure mode occurred in the pavement and the test result from the construction of the project were used to determine mechanisms causing the pavement failures.

The testing and sampling was carried out in line with the following standards and specification:

- Sampling method – AS1289.1.2.1 cl 6.4b
- Field moisture – RMS T120
- Particle size grading method – pre-treatment RMS T102, Grading 75mm to 2.36mm RMS T107, Grading 2.36mm to 13.5µm RMS T106
- Atterberg Limits Method – Moisture content RMS T120, Liquid limit RMS T108, Plastic Limit RMS T107
- CBR Method – RMS T117, Maximum dry density RMS T111, Moisture RMS T120

4.4.1 Moisture content results

As outlined in the background information of this report, high moisture content in pavement material can be a major factor in pavement deformation. This is true, particularly of rutting and shoving which has been identified in the defect mapping and performance section of analysis as being present in the area where the moisture content sampling has occurred. As a result, the moisture content testing may provide important evidence to cause of this deformation. The moisture content results are analysis in three ways as a part of the project. These include:

- The percentage of optimum moisture content in the sample tested from the pavement layers;
- The relationship between moisture levels in different sample relative to their physical location in the pavement;

- The relationship between the moisture content of the samples and the condition of the pavement at the location that was sampled.

The analysis of the percentage of the optimum moisture content was carried out to examine if the moisture levels in at the time of the sample were high enough to result in the significant loss of strength/modulus of the pavement material. Austroads indicates that moisture content in pavement material for a major road generally should not exceed 70% of the material optimum moisture content as it will experience significant loss of strength/modulus (Bodin & Kraft 2015; Hubner & Jameson 2012). This section focuses on this and examines if any of the samples exceed this 70% of optimum moisture content suggested by Austroads. Density testing on samples of mixed base layer from test pits 5, 6 and 7 show the optimum moisture content for the base material ranges from 7.9% to 8.7% with an average of 8.3%. This average was used in the analysis to calculate the percentage of the optimum moisture content by dividing the moisture content results for each sample by this average and multiplying the answer by 100 to get a percentage. From this, it could be determined if the moisture in the sample was at a level which may significantly affect the pavement material's strength/modulus.

The relationship between moisture levels in the different sample relative to their physical location in the pavement were examined as a part of the analysis to identify if any patterns exist which may identify how the moisture may be entering the pavement material. Water in pavement generally enters in a pattern with higher moisture contents at the point of entry and moisture content decreasing as the ingress further from the point (Hubner & Jameson 2012). An example of patterns the analysis may identify is moisture content in the top layers being consistently higher than the lower layers and decreasing as the depth increases. This indicates the moisture is entering the pavement through the seal and the seal is somewhat permeable. Another example of pattern would be if the opposite was occurring. It could indicate that water enters the pavement through a rising water table or saturated subgrade. Understanding how moisture may be entering the pavement is of interest to the project because it will need to be addressed if high moisture is identified as one of the causes of the failures.

The relationship between the moisture content of the samples and the condition of the pavement at the location that was sampled was investigated. The analysis looks to establish if there is a connection between the level of moisture content in pavement material and the condition of the pavement. If this relationship in confirmed, it would indicate that moisture in the pavement is playing a role in causing failure in the pavement. The style of analysis is useful as clear relationships between the two factors indicates that the moisture content level in the pavement may have fluctuated from the levels observed during sampling and result in increased deterioration of the pavement. The analysis for the section of the report, graph the pavement condition against the moisture content the base material, upper sub-base and lower sub-base material. Furthermore it examined if any relationships exists .

Figure 4.7: Moisture content sample being dried back in the soil oven.

4.4.2 Particle sizes distribution results

The sample tested for particle sizes distribution are all from test pits 3, 4 and 5. These test pit were chosen as they were in the location of the biggest failure identified in the defect mapping. As these was the location of the largest failure the author of this report this was the most likely locator to find evidence of the cause of the failure in the heavy duty pavement.

As outline in the background information of this report particle sizes distribution can play an important role in the strength properties of a pavement material. The grading curves and mass of the material retained between sieves can affect the shear strength and the modulus of a pavement material. This in turn can affect the performance of a pavement and as these material strength property reduce the likelihood pavement deformation increases. The first section of the analysis compares the result of the test to result from testing carried out on stock piles during construction. Which stock piles result are relevant to which sample examining construction documentation in the form of lot conformance documents. The documentation shows that the base material for all three test pits came from stock pile, 15 similarly all test pits for the upper sub-base were from 13 and all test pits for the lower sub-base were from stock pile 9 (original construction documentation is in appendices. Be comparing the particle sizes distribution and the mass retained between the sieves for the material in its current state to the state it was in before construction started it can be determined if any changes have occur. This is important as change may represent a change in the material strength properties.

As the breakdown in the material was identified in the previous section of analysis, the result of particle sizes distribution the mass retained between the sieves will be compared RMS materials specification unbound granular material, RMS3051. This is significant to the project because the in design of the pavement assumptions have been made regarding the strength of the material base of the material being used in the project meeting specification. If the breakdown material has occurred at such a rate that the material was now outside the limits of the specification it would indicate that the assumption made in design process would be incorrect and the strength of the material may be less than that used in the pavement design process. In the was found to be the case it likely the pavement would deteriorate at a faster rate than expected and lead to premature failures occurring in the pavement.

The analysis attempts to identify the cause of the breakdown of the material by examining to two relationships. The pavement material has been exposed to 2 major loading since stock pile testing has occurred in the construction process. Firstly the loading as a result of the compactive effort apply to the pavement material increase the density of the pavement and the design requirements. Secondly the traffic loading vehicle using the road since it was constructed. This study will examine either of these two factor are related to the material breakdown experienced test pits 3, 4 and 5.

To exaimine if traffic loading has played a role in the material break down a comparison of the breakdown of the material between samples taken for the shoulder of the pavement and the outer wheel path of the lane will carried out. This is of interest to the study, as these to section of the road are exposed to very different traffic loading. Naturally a very small number of the vehicle tyres travel of the shoulder of the pavement with most vehicle only using it in the event of an emergency when a vehicle needs to pull over quickly. This is very different wheel paths of the lane where most of the vehicles tyres travel. As a result a large difference in the traffic loading is experienced between two areas of pavement with the shoulder exposed all no loading and the outer wheel path generally being the area of highest loading. Therefore it could be expected that if the material is breaking down as result of traffic loading acting on the pavement that higher level of breakdown would be expected in the sample from the wheel path. For this section of analysis only the base layer is analysed as this is the layer most exposed to the traffic loading and therefore most likely to display sign of the relationship if it existed.

To examine if the compative effort applied to the pavement material has played a role in breakdown on the material the study will compare the level of break in the top 2 layers of pavement against bottom lower sub-base pavement layer. This is of interest to the study, as the top 2 pavement layers were exposed to a higher level of compactive effort in construction compare to the lower sub-base layer. The base and upper sub-base were required to be compacted 100% of modified compact where the lower sub-base only required 98% of modified compact. Therefore if compactive effort used on the pavement material in construction was the cause of the material breakdown it would be expected to see higher levels of material breakdown in the base and upper sub-base layer compared lower sub-base. As part of the analysis of grading curves and mass of the material retained between sieves, the relationship between the levels of breakdown in the different pavement layers will investigation to identify if a relationship exists that could indicate that compative effort is the cause of the breakdown.

4.4.3 Atterberg limits

As plasticity of a pavement material increase over the specified limits of a material, so does the moisture susceptibility of the material, weakening the pavement under traffic during wet periods which can lead to distress reflecting through the sprayed seal surfacing. This can result in accelerated deterioration of a road pavement and plastic deformation of the road pavement over time. This section of the report examine plasticity of the pavement material. Given that material break down has occur it likely that increase in materials plasticity has also occurred. This of interest to the study as an increase in the material plasticity mean the material well be more susceptibility to reduce in strength due to moisture ingress. This analysis will focus on plastic index of the material as it is a good overall indicator of the plasticity in the pavement material. The plastic index will be compared with original testing from the construction of the project to identify any changes in the material. In addition to this I will also be compared with Atterberg limits requirements stipulated in RMS materials specification for unbound granular material, RMS3051. Similarly to particle size distribution tests this is significant to the project because the in design of the pavement, assumptions have been made regarding the strength of the material based on the material meeting specification. If these assumption are incorrect and the strength of the material may be less than that used in the pavement design process.

Figure 4.8: Moisture contents sample from Atterberg tests after being oven dried

4.5 Travel Speed Deflection Data

Travel speed deflection data was extracted from the RMS RAMS database. The data was collected by ARRB Group's TSD truck on RMS' behalf. As discussed in the literature review, the TSD is a rolling wheel deflectometer which uses a 10 tonne load applied on a single rear axle. Doppler laser sensors are used to measure the pavement deflect as the load moves over the pavement (Rabe 2012). Testing for the project was carried out on the 25/8/2015 for the south bound lane. The weather and rainfall leading up to this, was slightly below average with August historically been a dryer month in the region. This is important as deflection testing can be affected by the moisture level in the underlining material. This is most prevalent when subgrade material is clayey in nature such as at Glenugie.

For the project, TSD data is used to identify weak areas in the pavement. This is generally indicated by high deflection. Given that composition of the pavement through the test area is known to be of the same design, it is expected that deflection along the segment should be of similar value if no weak spots exist.

Figure 4.9: ARRB Groups TSD truck which was used to collect TSD data

(ARRB Group 2014)

TSD data was chosen over more traditional methods of deflection testing due to data being already available without cost to the project. Benkelman beam testing was examined as an option but at a cost of close to $40 000, it was well out of the budget of the project. TSD testing also provides data that can be compared with FWD and offers a deflection bowl for a more in-depth analysis.

The association of the various deflection bowl parameters with the pavement structure and structural elements has been identified in several studies. This report will look used these relationships to focus on the defection data relevant to lower road formation and subgrade. Up to now little analysis has been carried assess if weakness in the earthworks upper zone of the formation or the subgrade are related to the failures in the pavement. This section of the study utilises defection bowl data from the TSD and two simple formula to investigate the structural condition of the earthworks upper zone and subgrade. The equations used to do this are as follows:

- Middle Layer Index (MLI) MLI=D300-D600

  MLI gives an indication of the probably earthworks upper zone structural condition

- Lower Layer Index (LLI) LLI=D600-D900

  LLI gives an indication of the lower structural layer or subgrade.

(Horak & Khumalo 2006)

The values for Middle Layer Index and Lower Layer Index will be calculated and compare with the rutting and defect data collect in the earlier analysis carried out for the project. By analysing these factors together it is hoped that it can be established if weaknesses or abnormally in the lower formation layers have played a role in the development of the failure or rutting in the pavement. Due to time and resources restriction the section of analysis is only going to focus of the outer southbound lane as it as the most failures to be compare with the Middle Layer Index and Lower Layer Index values.

Chapter 5 : Results, Analysis & Discussion

5.1 Defect mapping

5.1.1 Results

The result from the southbound defect mapping can be seen in the figure below. The ranking for the defect is on the y axis and has been determined by the ranking system outline in the methodology section of the report. Along the x axis is the chainage relative to Road Loc position. The mapping shows that a considerable number of defects were identified along the southbound lanes.

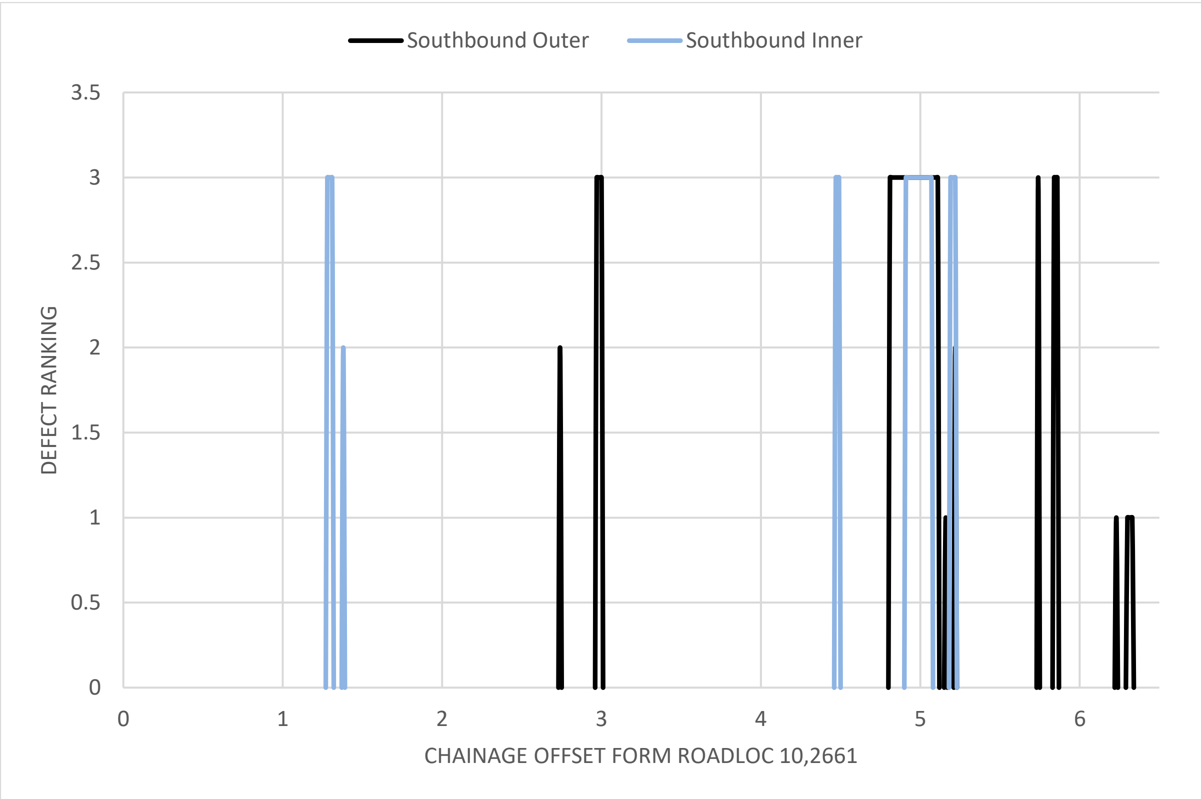


Figure 5.1: Defect mapping of the south bound lanes.

In the figure above, it can be seen that the largest and longest failures occur around the 5km chainage mark. Outside of this, 4 other areas can be identified as areas where structural failures have occurred. These include around 1.3km, 2.9km, 4.5km and 5.8km chainages.

Around the 5km mark, two large failures have been identified in the mapping in both the outer and inner lane. The failure in the outer lane is the longer of the two and is 300m in length, running from chainage 4.81 to 5.11. The failure in the inner lane runs from chainage 4.91 to 5.08 and is 170m in length. Furthermore, the defect mapping of the southbound lanes showed that 4.5% of the inner lane and 7.2% of the outer lane were affected by structural pavement defects. These are both higher than the average of 4.0% calculated for the 4 lanes combined. This indicates higher levels of structural defects in southbound lanes when compared the northbound. This can also be seen by comparing the southbound figure above with the northbound figure below.

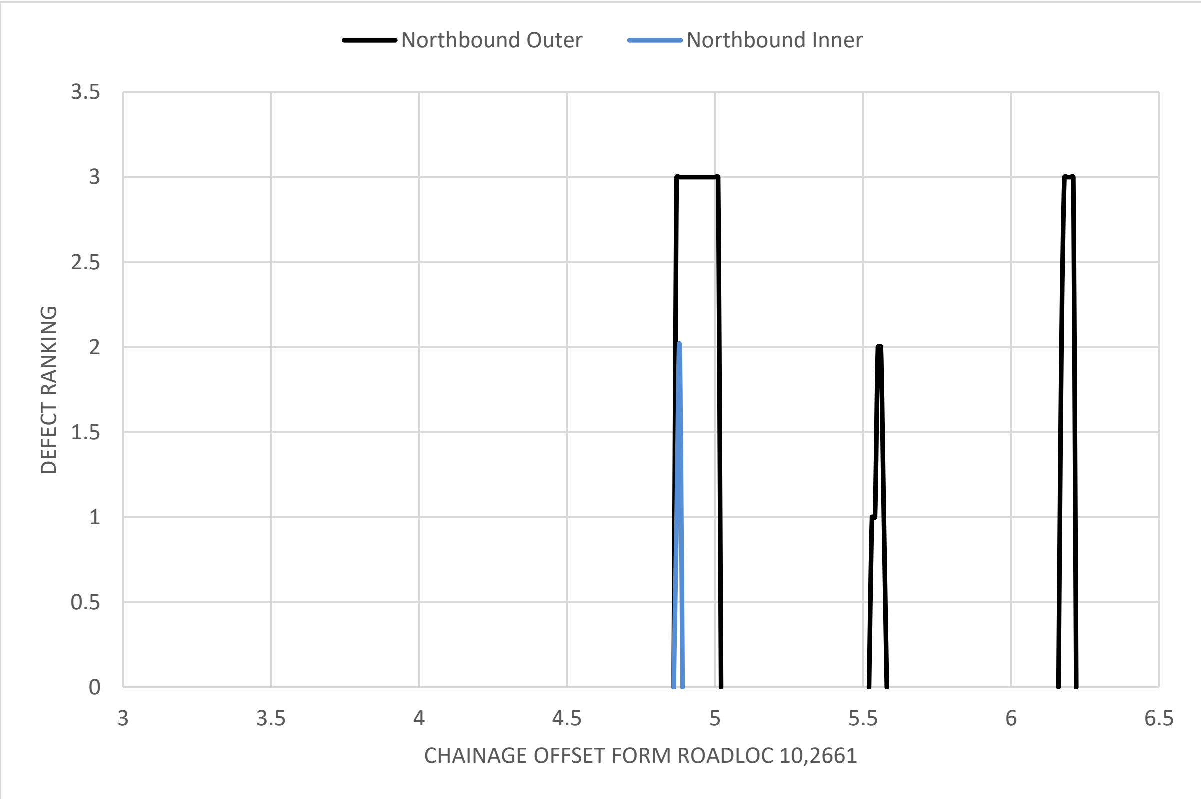


Figure 5.2: Defect mapping of the northbound lanes

The results from the northbound defect mapping can be seen above. Like the southbound figure, the ranking for the defect is on the y axis and the chainage relative to Road Loc position is on the x axis. The mapping shows fewer pavement defects when compared to the southbound mapping. This is most evident in the inner lane where only 0.3% of the lane had been affected by pavement defects. This is well below the average of 4.0% calculated for the 4 lanes combined. Similarly, the outer lane was slightly less than the average with 3.9% of the lane affected by pavement defects. Similarly, in the southbound lanes the largest and longest failures along the northbound carriageway are also around the 5 km chainage and in the outer lane there is a large failure 140m in length starting at chainage 4.87 and finishing at 5.01.

5.1.2 Major failure area description

The area of pavement where that major failure that occurred seem to follow no pattern. The some of the failure occurring in pavement on a 15m fill and others in large cut areas. Some of the biggest failure cover the transition zone between cut and fill. This suggest that the cause of the failures is not associated with changes occurring in the lower formation.

5.1.3 Inner and outer lanes

The results indicate that the outer lane has considerably more defects identified than the inner lane for both the northbound and southbound carriageway. This is evident in the difference between the percent of pavement affected by structural pavement defects in the inner and outer lanes. For the southbound carriageway this is a difference of 2.8% and for the northbound this difference is bigger at 3.5%. This result is expected and can be explained by the heavier traffic loading the outer lanes are generally under. Generally, heavier vehicles travel in the outer lanes due to slower travelling nature when compared to lighter vehicles. This results in the outer lane carrying a considerably heavier traffic load when compared to the inner lane. It is likely that this difference in traffic loading is the cause of the differences in the failures between the inner and outer lanes.

5.1.4 Limitation of method used

The method of using a video recording to identify and record defects did have some limitation when compared with carrying it out in person and walking over the road. The major limitation is the ability to identify some of the more minor defects like flushing and rutting using the video. In the case of flushing, it was found that the video recording did not pick up the flush very consistently, often varying because of the position of camera relative to the sun. This generally occurred as the road changed direction and/or grade, resulting in it being extremely difficult to identify flushing in a consistent manner.

Rutting was not visible on the video recording. It is believed this is a result of the whole road being a very similar colour in the recording, making it difficult to perceive small differences in the surface. As a result of these challenges, the discussion was made to not include these defects in the defect mapping as originally planned. This was done to improve the consistency of the data recorded from the defect mapping.

Although the class for each defect was defined in the methodology, it is acknowledged that using this approach in the project to identify defects is very subjective in nature. This style of the assessment lacks repeatability when carried out by a different person. Potentially, this could be problematic if this research is built upon in the future as the same assessment carried out by different people may produce different results.

5.2 Pavement performance RAMS data

5.2.1 Pavement rutting results

The graph of the rutting data for the north and southbound lanes is shown below. The graphs show that the rutting ranges from 4.5mm to 9mm across the length of pavement examined. The rutting of the pavement is not consistent with peaks and troughs occurring along the section of pavement. In the southbound lane, two large peaks occur at the chainage 1.5km mark and around the 5km mark. In the northbound, the most notable peak in the data occurs at the 6.2km mark. It is clear from the data that rutting has occurred along the length of the pavement examined with higher depth of rutting in some areas.

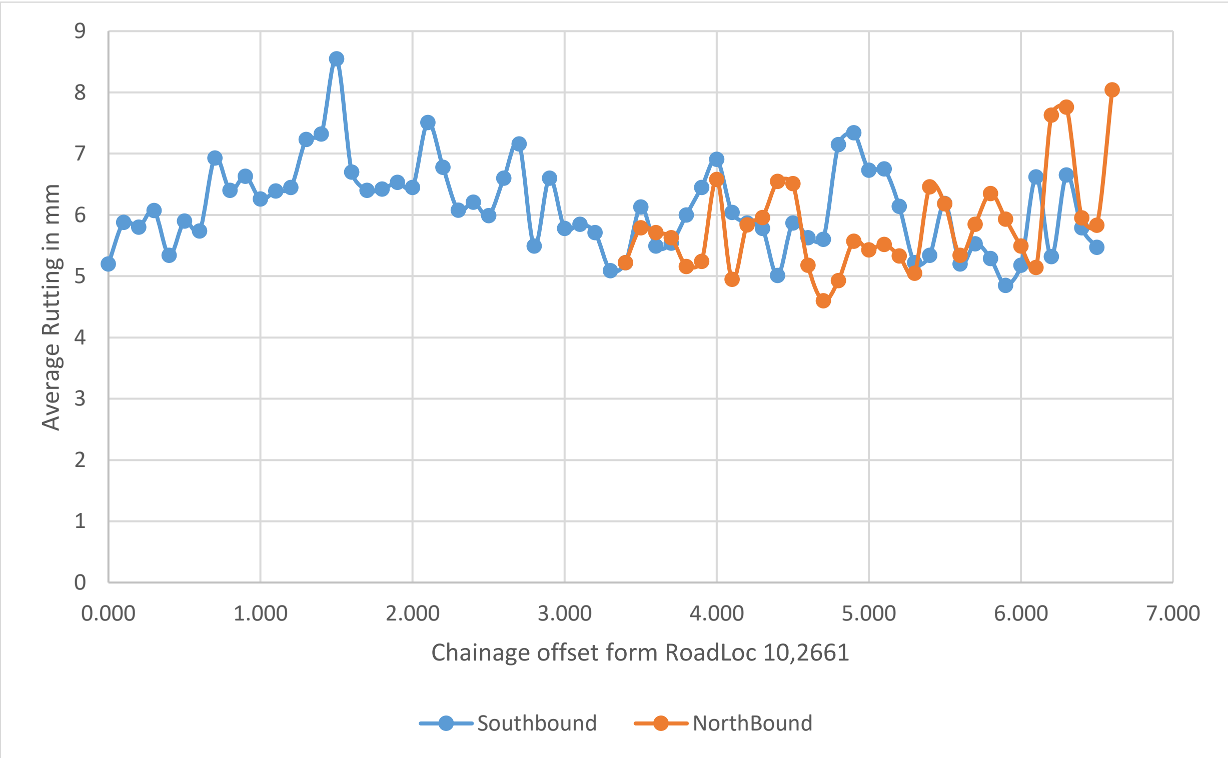


Figure 5.3: Average Rutting in mm graphed against the chainage of the pavement examined

Below are the results from the analysis of the rutting data using the RMS Pavement Performance and Indicator Manual (RMS 2016). The analysis shows that 67% of the pavement examined is considered to be of fair condition with 28% considered good condition and 5% considered to be of poor condition. The condition of the pavement based on the rutting indicator is much poorer than expected for a class A pavement of 5 years old. If the pavement was to continue to deteriorate at this rate, it is expected, based on the rutting performance indicator, that pavement would need to be rehabilitated in the next 5 years (RMS 2016). Based on the analysis that pavement has performed well below expectation and the level of rutting in the pavement examined is much higher than that of a class A pavement of 5 years old.

Table 5.1: Results from the pavement condition analysis based of rutting data

Condition	***Very Good***	***Good***	***Fair***	***Poor***	***Very Poor***
Condition parameter	< 3.5	3.5 to 5.5	5.5 to 7.5	7.5 to 9.5	> 9.5
% of road in each condition	0	28	67	5	0

Rutting measures the extent of permanent pavement deformation in the wheel paths. The high rate of deformation in the wheel paths indicates investigation is required to ascertain the structural integrity of the pavement and potential risk to safety. It is likely that the accelerated rutting identified in the condition analysis indicates structural instability in the flexible pavement (RMS 2016).

5.2.2 Pavement roughness

Below is a graph of the roughness data for the north and southbound lanes. The graphs show that the IRI ranges from 1m/km to 3.5m/km across the length of pavement examined. The roughness data for the section of pavement examined varies with serval peaks and troughs. The data indicates there is some roughness along the section of the pavement. When looking at the figure, it is important to keep in mind that some roughness is expected and no road has a perfectly flat surface.

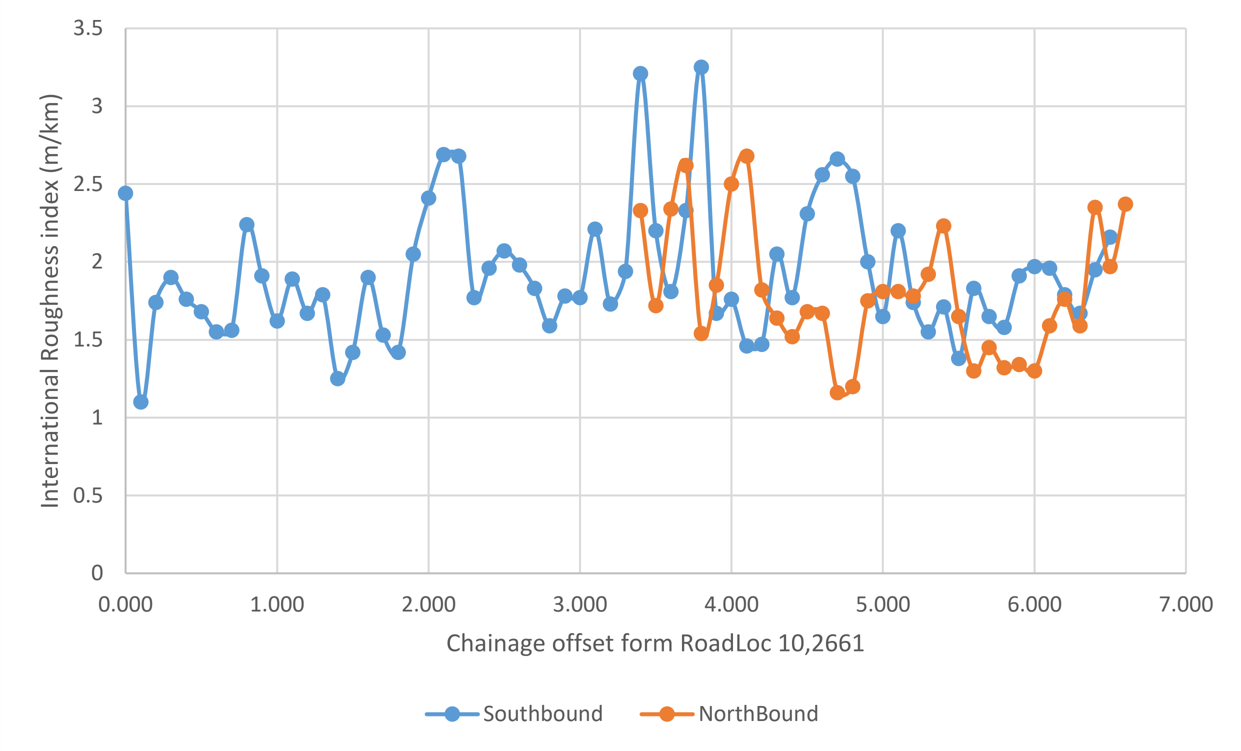


Figure 5.4 : Average international roughness index in m/km graphed against the chainage of the pavement examined.

Below are the results from the analysis of the roughness data using the RMS Pavement Performance and Indicator Manual (RMS 2016). The analysis shows that 52% of the pavement examined is considered to be of very good condition with 41% considered good condition and 7% consider to be of fair condition. The condition of the pavement based on the roughness indicator is as expected for a class A pavement of 5 years of age. If the pavement was to continue to deteriorate at this rate, it is expected, based on the roughness performance indicator, that pavement would be close to meeting the required design life (RMS 2016). Based on this analysis the pavement has performed as expectation or very slightly below the expectations. The analysis of the roughness data shows very little other than that the pavement is behaving in line with the expected design life for the project.

Table 5.2: Results from the pavement condition analysis based of roughness data

Condition	***Very Good***	***Good***	***Fair***	***Poor***	***Very Poor***

Condition parameter	≤ 1.8	1.8 to 2.6	2.6 to 3.4	3.4 to 4.2	> 4.2
% of road in each condition	52	41	7	0	2

5.2.3 Pavement cracking

Below is a graph of the cracking data for the north and southbound lanes. The graphs show that the cracking ranges from 0 to 8 cracked frames per 100m across the length of pavement examined with a lot of sections showing 0 cracked frames. Two peaks in the cracking can be seen around the 1km chainage in the southbound lane. The data indicates that there is little cracking along the section of the pavement.

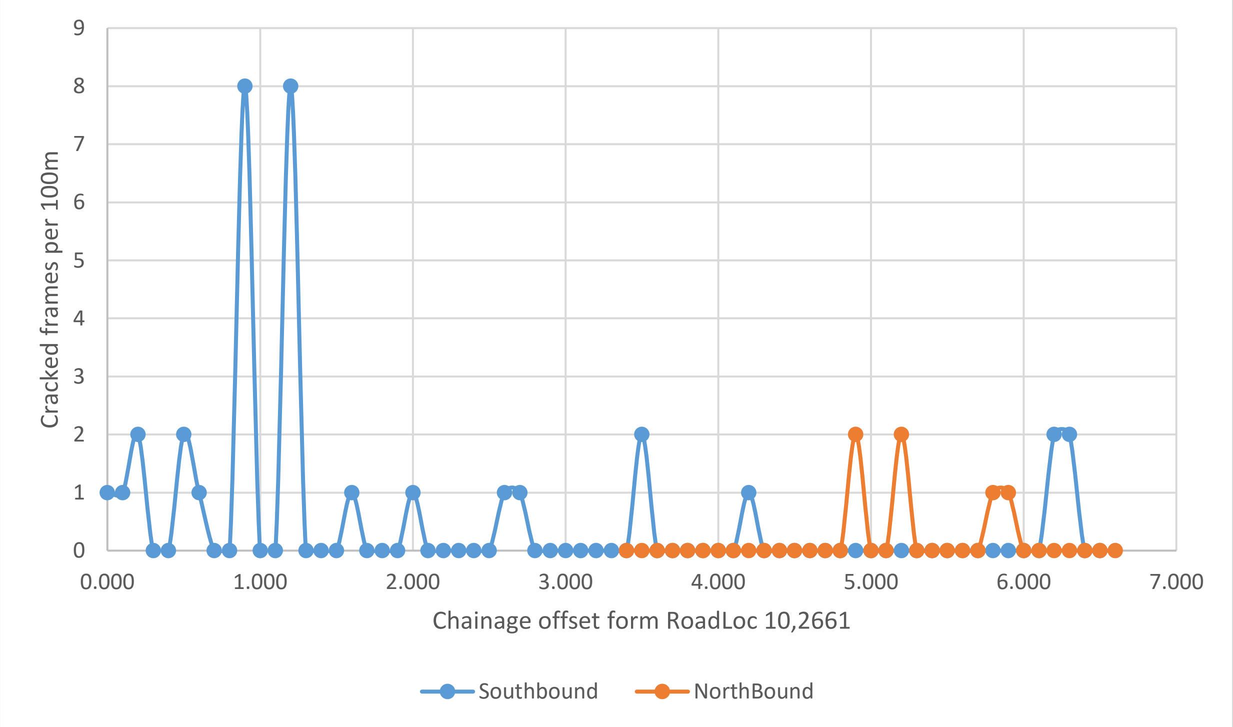


Figure 5.5: Average cracking in cracked frames per 100m graphed against the chainage of the pavement examined.

Below in the table are the results from the analysis of the cracking data using the RMS Pavement Performance and Indicator Manual (RMS 2016). The analysis shows that 81% of the pavement examined is considered to be of very good condition with 10% considered good condition and 7% consider to be of fair condition. 2% of the pavement is considered to be in very poor condition. This is a result of the two areas in the southbound lane around the 1km chainage, both with 8 cracked frames in the 100m. One of the areas seems to correspond with a defect area identified in the defect mapping. Overall, looking at the section of pavement as a whole, the condition of the pavement, based on the cracking indicator, is behaving better than expected for a class A pavement of 5 years of age. If the pavement was to continue to deteriorate at this rate, it is expected that, based on the cracking performance indicator, the pavement would exceed the required design life (RMS 2016). Based on the analysis that pavement has performed above expectation. The analysis of the cracking data pavement is performing better expected regarding cracking.

Table 5.3: Results from the pavement condition analysis based of cracking data

Condition	***Very Good***	***Good***	***Fair***	***Poor***	***Very Poor***
Condition parameter	0	0 to 1.33	1.33 to 2.67	2.67 to 4.0	> 4.0
% of road in each condition	81	10	7	0	2

5.2.4 Overall results from the performance data

The analysis of the performance indicator data has shown the following key information:

- Rutting has occurred at an accelerated rate along the section examined and extent of rutting is higher than expected;
- The pavement roughness is slightly higher than expected but still at a very acceptable rate;
- Overall, looking at the section of pavement as a whole, the condition of the pavement, based on the cracking indicator, is behaving better than expected.

The accelerated rate of rutting is the most important information as it indicates structural instability in the flexible pavement. As the rutting is associated with shoving, which has been identified as occurring at the start of the of the failure process in the sections of highway, it is indicative that the shear strength in the upper pavement layers may be inadequate to withstand the applied traffic loads. In this case, there will be a poor correlation between the severity of rut depth and measured deflections. Laboratory testing of the affected materials sampled from the pavement will further assist in evaluating whether the shear deformation is related to deficiencies in the specification for that material or to the use of non-conforming material (Jameson & Harrison 2011). Laboratory testing and defection data are analysed in the later stages of the project with the intention of examining these relationships.

Two areas of the southbound lanes show high levels of cracking around 1km chainage. A review of the corresponding section of the defect mapping video and visual inspection of the area showed little to no cracking in this area. As a result, the project spends little time examining this anomaly and suggests it may be a result of a recording error by ARRB during the data collection.

5.3 Soil testing results

5.3.1 A graphical representation of the test pit

A graphical representation of the test pit can be found in figures below. The figures show all samples taken for the project grouped by the test pits with the depth of the sample shown running down the page. The results of any field moisture, Atterberg and CBR testing undertaken for the project are shown in the figures with it, indicating which samples have had particle size gradings completed on them. The road Loc location for each of the tests can be seen at the top of each figure along with offsets from the test pits to the centre line of the road. A very brief description of each sample is also given along with a legend which indicates which layer of the pavement structure the test was taken from. Moisture content in all of the base and sub-base material sampled ranges from 2.4% at test pit 7 to 5.8% at test pit 3. The majority of the sample moisture contents sit within the range of 3.5% to 4.5%. The bulk of the testing has been carried out of the southbound outer lane which had the most severe failures at the time of sampling.

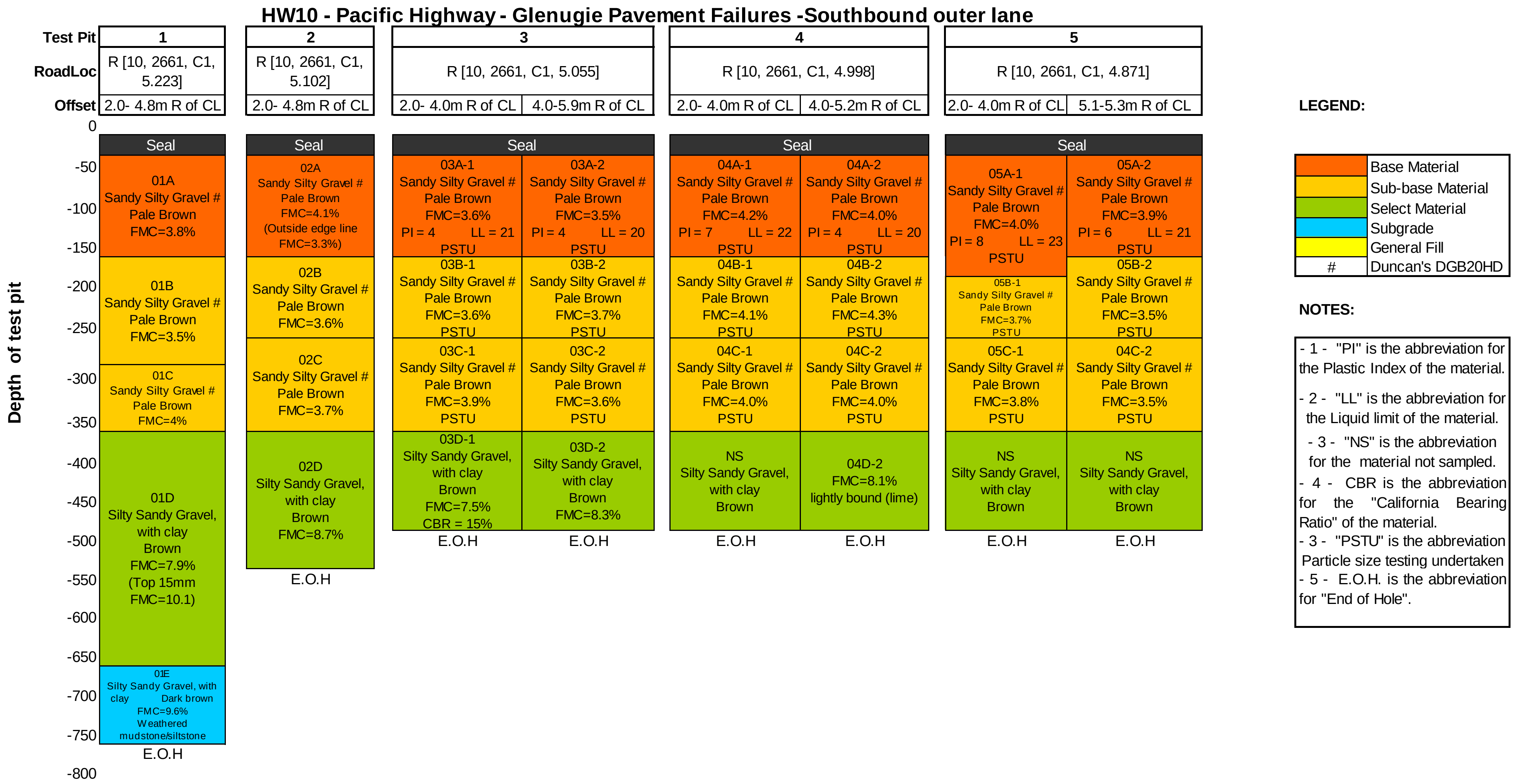


Figure 5.6: Graphical representation of the test pit 1, 2, 3, 4 and 5 in the southbound outer lane.

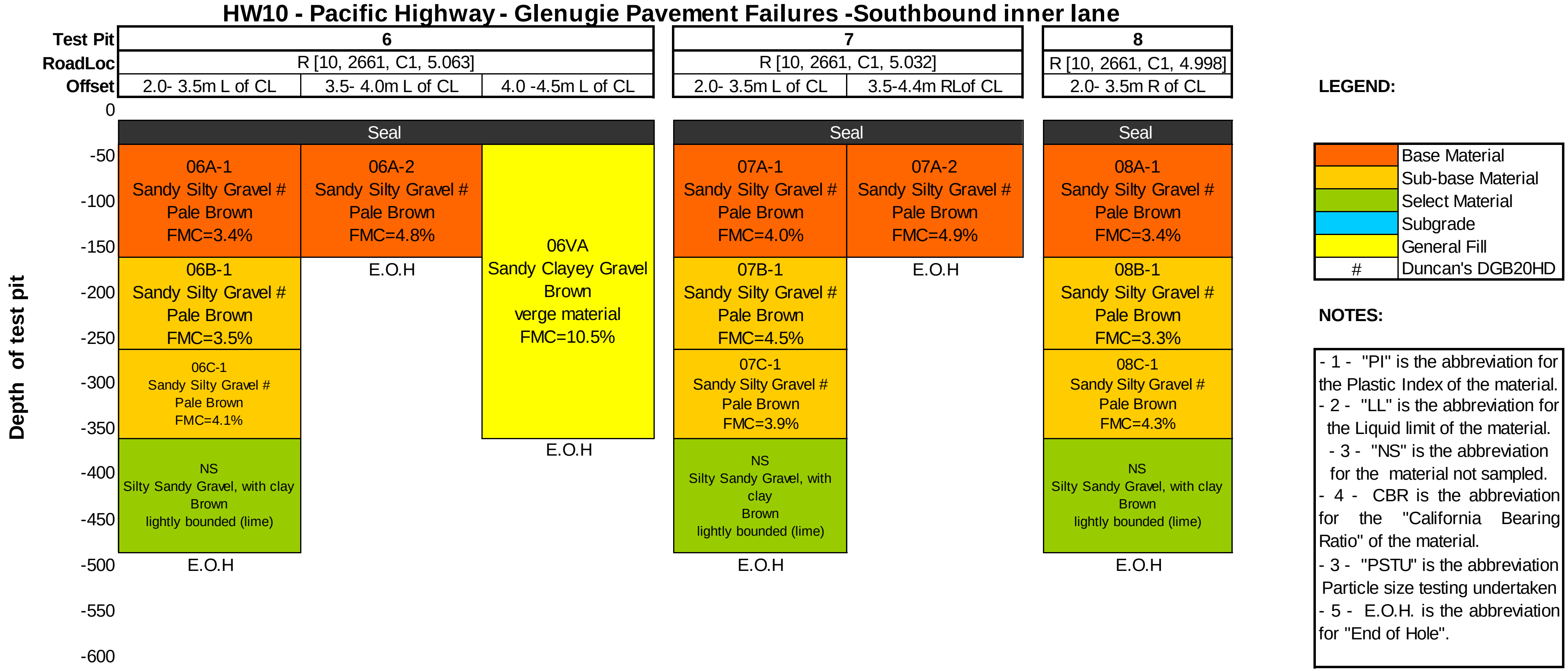


Figure 5.7: Graphical representation of the test pit 7, 8 and 9 in the southbound inner lane.

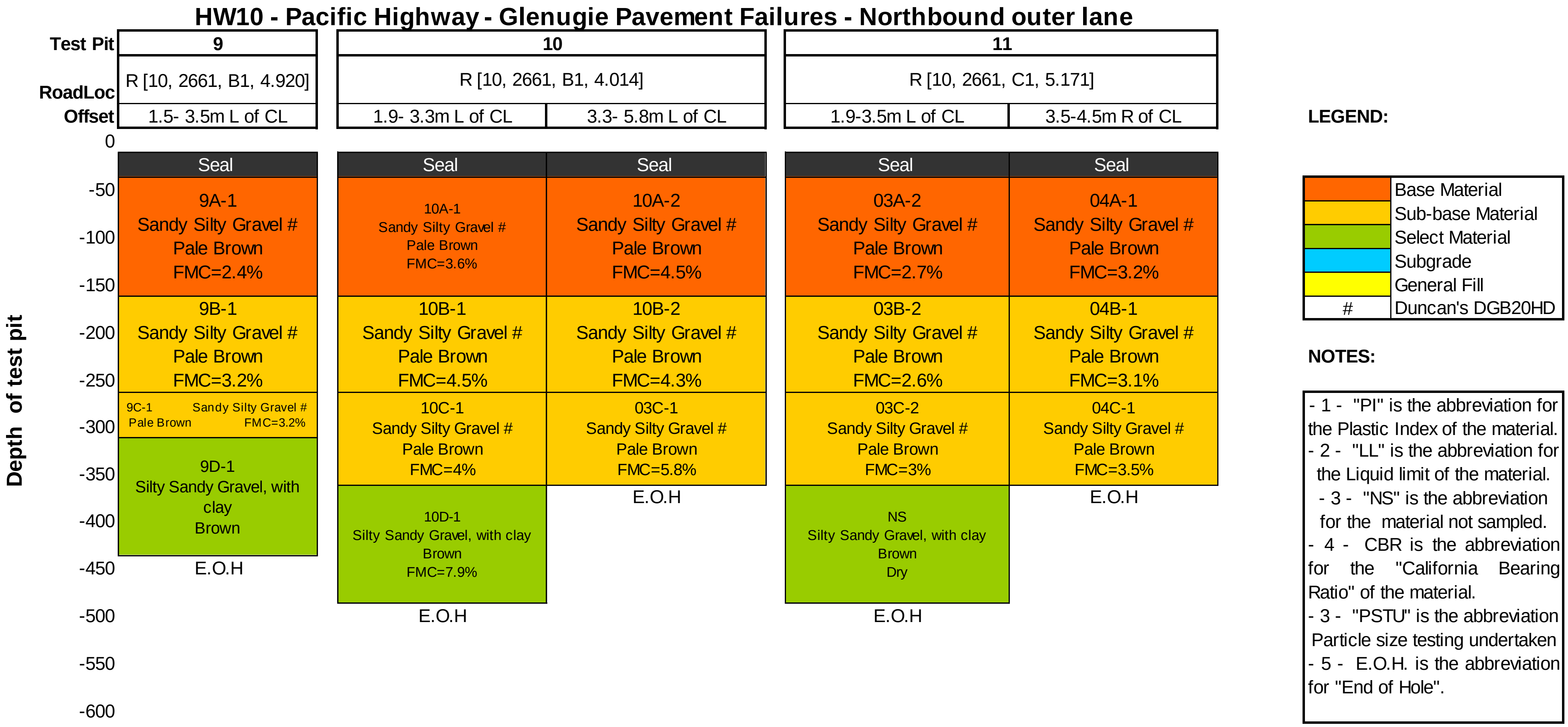


Figure 5.8: Graphical representation of the test pit 9, 10 and 11 in the northbound outer lane.

5.3.2 Optimum Moisture Content

Density testing was carried out on samples of mixed base layer from test pit 5, 6 and 7 shows the optimum moisture content for the base material ranges from 7.9% to 8.7% with an average of 8.3%. Austroads indicates that moisture content in pavement material for a major road generally should not exceed 70% of the material optimum moisture content as it will experience significant loss of strength/modulus (Bodin & Kraft 2015; Hubner & Jameson 2012). In the table below is the percentage of the optimum moisture content for the base and sub-base samples. The percentage is calculated by dividing the moisture content for the samples by the average optimum moisture content derived from test pits 5, 6 and 7.

Table 5.4: Percentage of optimum moisture for the base and sub-base material.

Pavement layer			3		4		5		6		7				10		11	
	1	2	1	2	1	2	1	2	1	2	1	2	8	9	1	2	1	2
Base	46%	49%	43%	42%	51%	48%	48%	47%	41%	58%	48%	59%	41%	29%	43%	54%	33%	39%
Upper Subase	42%	43%	43%	45%	49%	52%	45%	42%	42%		54%		40%	39%	54%	52%	31%	37%
Lower Subase	48%	45%	47%	43%	48%	48%	46%	42%	49%		47%		52%	39%	48%	70%	36%	42%

Look at the results in the table above it seen that there considerable change in percentage between test pits. The highest percentages can be found at test pit 6, 7 and 10. In the sub-base material in shoulder of the road pavement at test pit 10 is at 70% percent of the optimum and is likely to be effecting materials structural properties. The shoulder base material at test pit 6 and 7 also has relatively high percentage of optimum moisture content at 58% and 59% respectively. This would indicate a small fluctuation in moisture content in these areas may result in the significant reduction on the pavement capabilities.

In the test pits associated with the outer northbound and southbound inner lane where the wheel path and shoulder has be sampled, it can be seen that generally the samples from the shoulder has a higher moisture content. This can be seen in test pits 6, 7, 10 and 11. This indicates the moisture ingress is likely occurring through the shoulder of the pavement on the on the west edge of both the north and southbound lanes. This would make sense given the cross fall of the road in the area of all the test pits, except test pit 1, falling from west to east due to the nature of the curvature of the section of road.

5.3.1 Verge material

At test pit 6, some verge material was sampled from beyond the edge of the pavement shoulder. During the sampling, it could be seen by the ease with which the excavator dug into the material that is was loosely packed and had a relatively high moisture content. After further inspection of the material after excavation it could be seen that the material was clayey in nature and appears to be have high plasticity properties. The moisture content testing of the sample confirmed the material at a high moisture content at 10.5%. The sampling log describes the material as a sandy clayey gravel. The clayey nature of the soil combined with low length of compact that has been applied to the verge material has helped to make material susceptible to hold higher amounts of water when compared to the pavement material. This has resulted in the verge material consistently being wetter than the pavement material, effectively meaning the pavement is surrounded by a strip of wetter material along it edges most of the time.

It likely that this has resulted in moisture ingress from the wetter verge martial into the dryer pavement material as the water equalises and moves under gravitational forces. This is also supported by the finding in the analysis of the percentage of optimum moisture in the previous section that shows the moisture ingress is likely occurring through the shoulder of the pavement on the west edge of both the north and southbound lanes. The use of the low quality, poorly compacted material as verge is likely to have contributed to the ingress of the water into the pavement material.

5.3.2 Relationship between pavement condition and moisture content

The condition of the pavement as recorded in the test pit logs has been graphed against the moisture content of the sample for the base, lower and sub-base material to examine if a relationship exists between them and the moisture content. The condition of the pavement has been given a number value 1, 2 or 3 based on the condition of the pavement at the time of sampling being good, fair or poor.

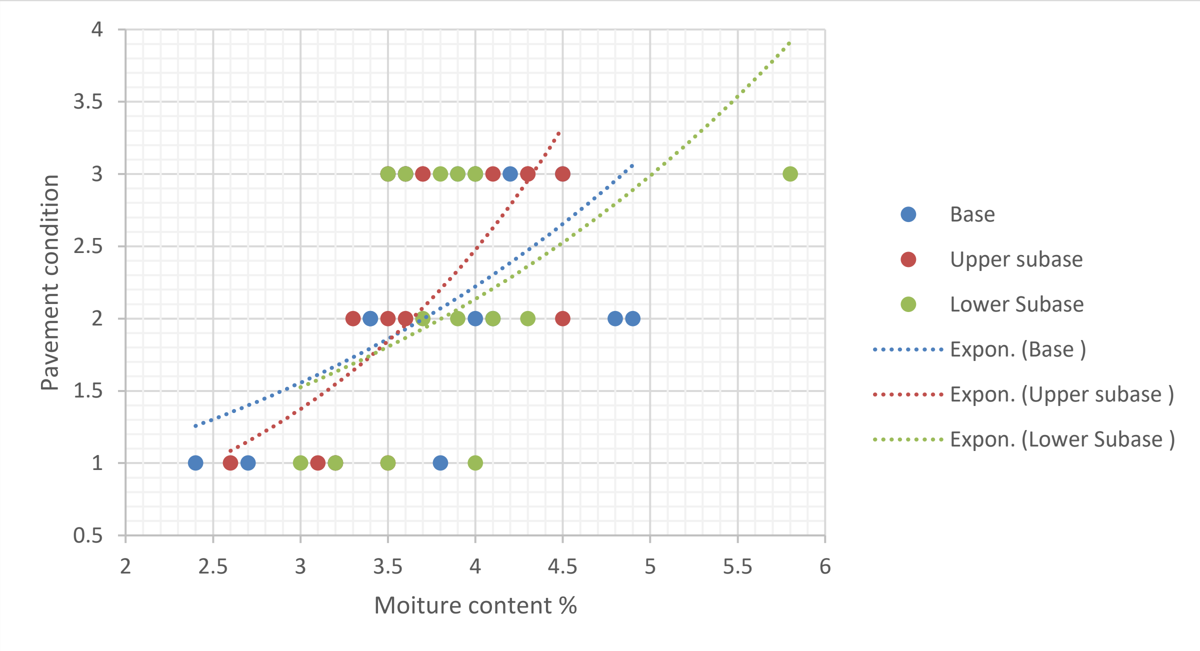


Figure 5.9: Shows pavement condition vs moisture content for the base, lower base and sub-base with linear lines of best fit.

It can be seen above in the figure that a relationship exists between the pavement condition and the moisture content found in the pavement material. The relationships for the base, lower base and sub-base material are of a similar nature with the pavement condition deteriorating as the moisture content in the pavement material increases. This was the expected result with several studies showing this relationship to exist in granular pavements as well. It can be seen in the figure that when the pavement is in good condition moisture is generally at lower levels that the fair condition. When moisture level for the fair condition is compared with the poor condition, it can be seen that the difference in the moisture level is smaller then was experienced between the good to fair condition.

A major challenge of the analysis of the moisture content against the pavement condition is that it is difficult to determine if the increase in moisture content is a result of the pavement seal being damaged or if the damage to the pavement is a result of the high moisture content in the pavement. The author of this report believes that it is most likely that in the case of Glenugie that as moisture content in the pavement increases so does the likelihood of failures occurring. The evidence which supports this is as follows:

- This mechanism has been identified in several studies conducted with granular pavements in controlled environments (Hussain et al. 2011; Saad 2014; Soliman & Shalaby 2015);
- If the failure were the cause of the increase in moisture levels, it would be expected that a pattern of higher moisture content in the top layer of the pavement with it decreasing with depth. Such a pattern cannot be seen in the moisture content data.
- In the case that the failure was the cause of the increase in moisture levels, it would be expected there would be a more substantial difference in the moisture levels between the pavement in fair condition and the pavement in good condition. This expectation is due to the pavement areas in poor condition generally having a larger area of exposed pavement for water to enter through when compare to the areas in fair condition. Therefore, it can be expected that moisture content of the material in the pavement in poor condition would be considerably greater than that observed in the pavement of fair condition. This is not the case in the data collect for the project.

This shows that is most likely that in the case of Glenugie pavement where soil testing occurred that as moisture content in the pavement increases so does the likelihood of failures occurring.

5.3.3 Limitations of analysis of moisture content data

The moisture content testing carried out for the project only represents a very small section of the overall heavy duty pavement constructed for the project, with most of the test occurring in areas where failure are present. As a result, only 3 of the test pits were from areas that were considered to be in good condition. The limited nature and small sample size of this data may mean that conclusions drawn from the data may only be relevant to a small section of the overall pavement section and may be somewhat limited in nature.

The results of the moisture content testing only give a snap shot of the moisture content at a particular point in time in a complex system with many contributing factors. Fluctuations in the moisture content of the material are expected over time. Given that the sampling was carried out after a period of what could be considered relatively average weather, I could expect that during a time of prolonged or high rainfall, some increase may occur in the moisture content of the pavement material. These fluctuations are hard to predict or model due to the complex nature of water movement in pavements and would be dependent on a range of the factors including:

- Rainfall and rainfall events in the area;
- Water table movements;
- Seal condition;
- Effectiveness of subsoil drainage and surface drainage;
- Subgrade saturation;
- Seasonal weather patterns.

Given the complexity of the system and limited nature of the testing, any conclusions made for the analysis would be presumptive and should be treated as such. Further testing and analysis would be required to get a fuller understand of the complex system.

5.3.4 Overall finding from the moisture content testing

The analysis of the percentage of the optimum moisture content of the samples shows that moisture content of most samples are within a range that would be expected to have little effect on the pavement material. The exception to this is test pit 10 where one of the pavement layers has a moisture content which is high enough to result in significant loss of strength/modulus in the pavement material. Furthermore, the results indicate the moisture ingress is likely occurring through the shoulder of the pavement on the western edge of both the north and southbound lanes. The use of the low quality, poorly compacted material as verge is likely to have contributed to the ingress of the water into the pavement material. It is important to remember the moisture contest results are only a snapshot of a dynamic system and it is likely that moisture content may fluctuate beyond that of the results recorded in the study. This has the potential to result in increase in the area where high moisture content results in a significant loss of strength/modulus in the pavement material.

The analysis of the relationship between the pavement condition and the moisture content of the material showed that a relationship exists between them. It showed that in the case of Glenugie pavement where soil testing occurred that as moisture content in the pavement increases so does the likelihood of failures occurring. This would suggest that high moisture content may have played a role in the failures which have occurred at Glenugie but does little to identify how large of role it has played. This does contradict some of the results for analysis of the percentage of the optimum moisture content suggesting at some stage in the pavement life, moisture content in the pavement may have been higher than the levels at the time of testing.

5.3.5 Particle size grading

Particle size grading were carried out on 18 samples of DGB20 material, sample 3A-1, 3A-2, 3B-1, 3B-2, 3C-1, 3C-2, 4A-1, 4A-2, 4B-1, 4B-2, 4C-1, 4C-2, 5A-1, 5A-2, 5B-1, 5B-2, 5C-1, and 5C-2. The results show the percentage of material tested passing through the sieves by mass. The particle size distribution results for the samples mentioned above can be found below figures. Also included in the figure is the average grading result for the gravel stock pile that corresponds to the area sampled along with the upper and lower limits which are stipulated by RMS 3051 materials standard.

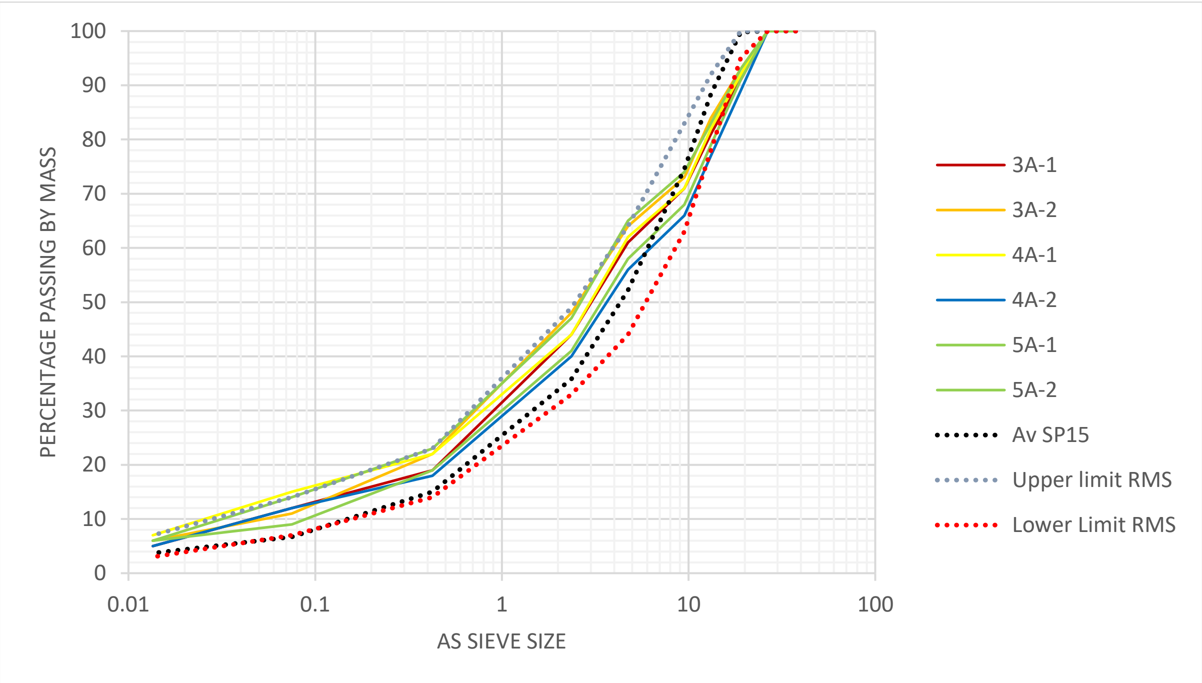


Figure 5.10: Particle size distribution results from the base material for the 3 test pits sampled

The grading results for the base material at test pit 3, 4 and 5 can be seen above. In the construction of the project, the base material for these test pits were all part of pavement lot 47 and the material was sourced from stock pile 15. The average of the 5 five particle size distribution tests carried on the stock pile during construction can be seen in the figure as the black dotted line along with the upper and lower limit from the RMS materials specifications in red and blue dotted lines. Examining the results of the samples tested, it can be seen that material has broken down considerably since it was tested in the stock pile. From around the 10mm size and below, all samples showed increase in the amount of the finer material when compared to the stock pile test. It can be seen that samples 3A-2, 4A-1 and 5A -2 have broken down to the point that they are outside the specified RMS limits for the material. Above the 10mm particle, the grading curve shows that less material is passing through the sieves. This is an unusual result and suggests the material above 10mm is generally larger in size than when the stock pile was sampled.

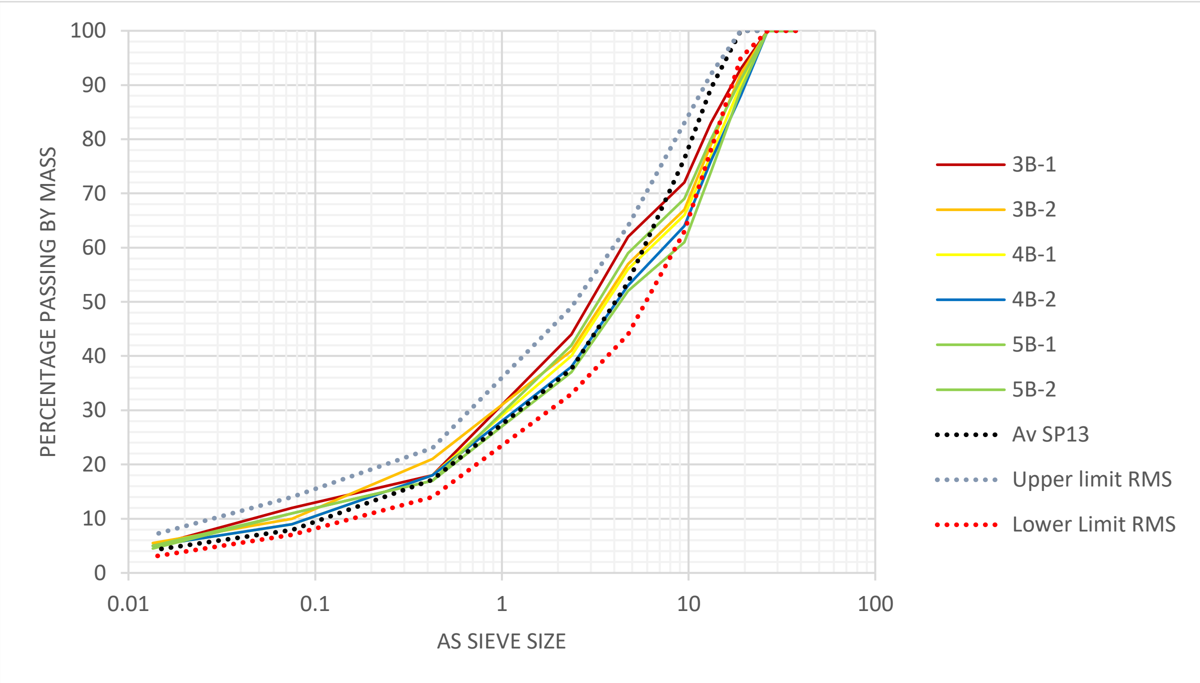


Figure 5.11: Particle size distribution results from the upper sub-base material for the 3 test pits sampled

The grading results for the upper sub-base material at test pit 3, 4 and 5 can be seen above. In the construction of the project, the upper sub-base material for these test pits were all part of pavement lot 39 and the material was sourced from stock pile 13. Similar to above results, the average of the 5 five particle size distribution test carried out on the stock during construction is represented as a black dotted line along with the upper and lower RMS limits which are the red and blue dotted lines. Examining the results of the samples tested, it can be seen that most of the samples have broken down considerably since testing was carried out on the stock pile. From around the 8mm size and below, all samples showed increase in the amount of the finer material when compared to the stock pile tests average. Similar to the base material the results for the upper sub-base show that above the 8mm particle size the grading curve shows that less material is passing through the sieves. This is an unusual result and suggests the material above 8mm is generally larger in size then when the stock pile was sampled in construction of the Glenugie project.

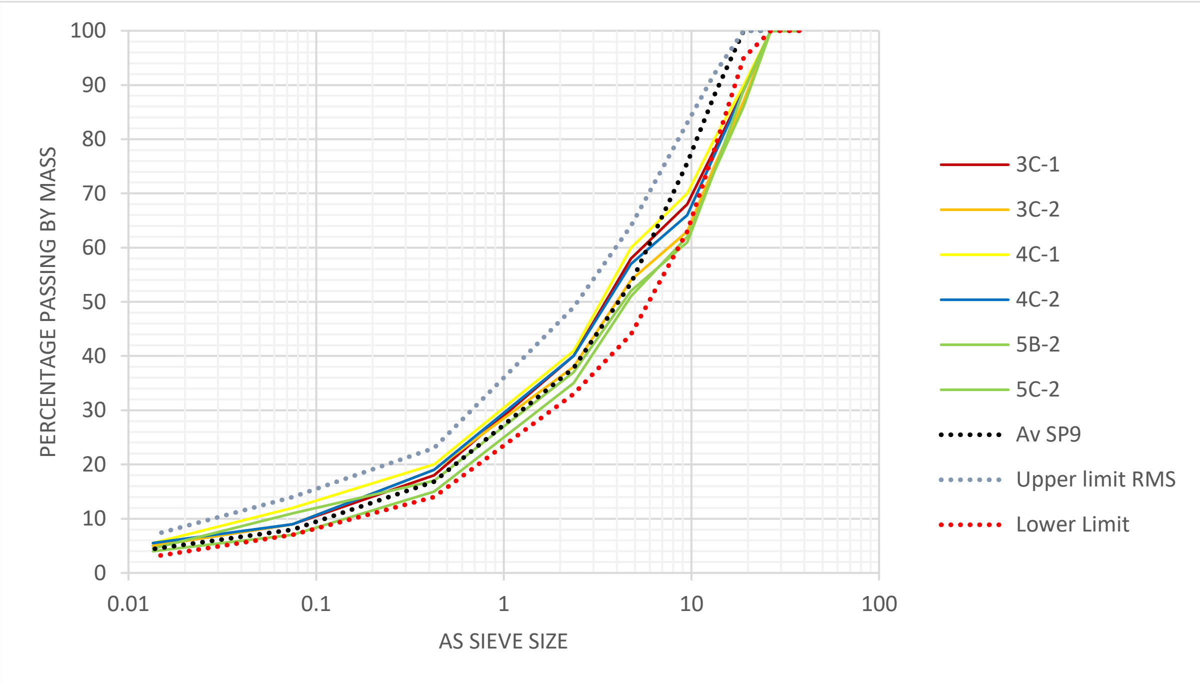


Figure 5.12: Particle size distribution results from the lower sub-base material for the 3 test pits sampled

The grading results for the lower sub-base material at test pit 3, 4 and 5 can be seen above. In the construction of the project, the lower sub-base material for these test pits were all part of pavement lot 24 and the material was sourced from stock pile 9. Similarly, the above results, the average of the 5 five particle size distribution test carried out on the stock during construction, are represented by the black dotted line along with the upper and lower limits which are the red and blue dotted lines. Examining the results of the samples tested, it can be seen that material has broken down in some of the samples since testing was carried out on the stock pile. From around the 8mm size and below, most of the samples showed increase in the amount of the finer material when compared to the stock pile tests. Similar to the base and upper sub-base material, the results for the upper sub-base show that above the 8mm particle size, the grading curve shows that less material is passing through the sieves. This is an unusual result and suggests the material above 8mm is generally larger in size than when the stock pile was sampled in construction of the Glenugie project.

Comparing the result from the base, upper sub-base and lower sub-base, it can be seen that all three sets of results show similar patterns with an increase in the finer material in the bottom 2/3 of the grading curve. This increase is most clear in the base material where it is largest. The breakdown in the base material is so large that 3 of the samples are outside the RMS specification. The upper sub-base shows similar results to the base material with all samples breaking down to some extent when compared with the stock pile results. The amount of material breakdown in the upper sub-base is less than the base but still substantial. The lower sub-base results do show in most of the samples that the material has broken down to some degree but it is much less than the two top pavement layers. Some of the samples show little or no breakdown and this indicates that the likely cause of the breakdown is less prevalent in the pavement layer.

In all 3 sets of results, the top 1/3 of the grading curve shows that there is less particle passing through the sieves when compared with the stock pile testing which occurred in construction. This would suggest that some of the particles are larger than approximately 10mm have increased in size. This is an unexpected result and likely indicates a potential abnormality or error, as rocks in pavement material generally do not increase in size.

This report puts forward two possible cause for this. Firstly, a material has some naturally occurring cementing properties and this has caused some cementing of the material during compaction and resulted in some larger size material. Secondly, during the particle size testing process, insufficient effort was used to make sure there was no lumps in the samples before sieving. During testing, a mortar and pestle were used to separate any clumped material after drying in the oven had been completed. If this had been carried out poorly, it could lead to results similar to the ones observed. Problems of this nature are more likely when the material being sampled is in a compacted state like the sample taken for the project when compared with samples taken when the material is in a loose state like the stock pile samples carried out in construction. The author of the report believes the abnormal result is likely a combination of both of these factors and small clumps of the material have been mistaken for larger size particles than they should have been. If this is the case, it means it is likely that there is more fines material in these clumps which has not been allowed for the grading.

5.3.6 Particle mass retained on the sieve compared RMS material specification

The section examines the particle mass retained on the different sieve sizes and compares them with RMS material specification. The analysis looks at the requirement of the material to be retain between sieves requirements. In the tables below, the cell in green represent where the material is lower than the requirement and the red shows where it is higher than the requirement. The results have been grouped by layers and includes the construction data from the stock pile testing.

Retained between AS Sieve Size (mm)	***Percentage by mass***						
	3A-1	3A-2	4A-1	4A-2	5A-1	5A-2	Av SP15
19-13.2	10	9	10	12	12	10	11.4
13.2-9.5	10	11	11	11	11	9	13.8
9.5-4.75	10	9	9	10	10	9	22.4
4.75-2.36	17	16	18	16	17	18	16.4
2.36-0.425	25	26	22	22	22	24	20.8
0.425-0.075	7	11	7	6	10	9	8.3
0.075-.0135	7	5	8	7	3	8	3

In the above table, all the samples of the base material do not meet requirements of the specification. This is most clear in the material retained between the 9.5-4.75 mm sieves sizes where the specified requirement is between 14 to 24% mass retained and all of the samples are 10% or lower. Furthermore, this material size has seen the largest breakdown of material with approximately 55% of the material which was caught on the sieve in the construction testing now passing through the sieve. This extra material has been retained on the sieves below, with almost all of the results below showing an increase when compared with the averages from the stock piles tests. This is most evident between sieve sizes 0.075 to 0.0135mm where 5 of the samples have almost doubled in mass. In addition to this sample 4A-1 and 5A-2 at 8% mass are over the maximum requirement of the material of 7%. These results show that most of the material breakdown has occurred between 9.5-4.75 mm sieve sizes and resulted in an increase in material in the lower sieve sizes.

Retained between AS Sieve Size (mm)	***Percentage by mass***						
	3B-1	3B-2	4B-1	4B-2	5B-1	5B-2	Av SP15
19-13.2	10	13	13	12	11	15	10.6
13.2-9.5	11	12	11	12	11	13	13
9.5-4.75	10	10	10	11	10	9	22.8
4.75-2.36	18	16	16	15	17	15	16
2.36-0.425	26	20	22	20	25	20	20.4
0.425-0.075	6	11	9	9	6	6	9.3
0.075-.0135	7	4.5	4	4	6	6.5	3.7

In the table above, the results from the upper sub-base can be seen. All the sample materials do not meet requirement of the specification. This is due to the material retained between the 9.5-4.75 mm sieves sizes where the specified requirement is to be between 14 to 24% mass retained and all of the samples are 11% or lower. Furthermore, this material size has seen the largest break down of material with approximately 51% of the material which was caught on the sieve in the construction testing now passing through the sieve. This extra material has been retained on the sieves below, with most of the results below this size showing an increase when compared with the averages from the stock piles tests. These results show that most of the material breakdown has occurred between 9.5-4.75 mm sieve sizes and resulted in an increase in material in the lower sieve sizes.

Retained between AS Sieve Size (mm)	***Percentage by mass***						
	3C-1	3C-2	4C-1	4C-2	5C-1	5C-2	Av SP15
19-13.2	11	12	10	12	12	12	12
13.2-9.5	10	12	10	11	12	12	12.4
9.5-4.75	10	9	10	9	10	11	22.2
4.75-2.36	18	16	19	17	15	16	15.6
2.36-0.425	22	19	21	21	24	20	21
0.425-0.075	9	10	8	10	7.5	8	8.8
0.075-.0135	4	4	6.5	3.5	3.5	3	3.6

In the table above, the results from the lower sub-base can be seen. All the samples do not meet requirements of the specification. This is due to the material retained between the 9.5-4.75 mm sieves sizes where the specified requirement is to be between 14 to 24% mass retained and all of the samples are 11% or lower. Furthermore, this material size has seen the largest break down of material with approximately 49% of the material which was caught on the sieve in the construction testing now passing through the sieve. This extra material has been retained on the sieves below, with most of the results below this size showing an increase when compared with the averages from the stock piles tests. This evident in sample

4C-1 between sieve sizes 4.75 to 2.36mm where 19% of the mass was retained which is above the maximum limit 18%. These results show that most of the material breakdown has occurred between 9.5-4.75 mm sieves sizes and resulted in some increase in material in the lower sieve sizes.

All the samples which have undertaken particle size distribution are outside the required limit for the mass retained of the sieves set out in RMS 3051 unbound granular materials specification. Comparing the result from the base, upper sub-base and lower sub-base it can be seen that all three sets of results show a similar distinct pattern of material breakdown occurring between 9.5-4.75mm sieve sizes and resulted in an increase in material in the lower sieve sizes. This indicates a weakness in the material at this particular size and most likely can be explained by the makeup of that material blend used. Given the larger size material above 10mm have been shown in the testing to be undergoing little to no breakdown, it is unlikely that the -22.5mm Granite or -20mm Argillite which make 85% of the material is the part of the breaking down. The -10mm Argillite Scalps which make up 15% of the blend given their size are the most likely part of the gravel blend to breaking down. This is supported by the distinct pattern of material breakdown occurring between 9.5-4.75mm sieve sizes which would be majority -10mm Argillite Scalps would be in particle size distribution. This is a little unusual given it is likely that the Argillite for the 20mm and 10mm scalp are from the same source rock. This could be explained by a couple of the factors including:

- It is possible that the although they are from the same rock that the scalp are from a section of rock which is more weathered than the 20m Argillite;
- It possible that scalp has undergone greater weathering since crushing due to their smaller nature when compare the 20mm Argillite;
- It possible that particle shape size factors like flakiness have a role in making the scalp material more susceptible to breakage than larger 20mm Argillite.

All the samples which have undertaken particle size distribution are outside the required limit for the mass retained of the sieves set out in RMS 3051 unbound granular materials specification. This is of interest to the project as this requirement in the specification directly relates to the shear strength of the material as stated in section 8.2.1. The specification indicates that material outside these requirements would not be suitable for high traffic applications due to its lower shear strength. Therefore the assumption made of the materials shear strength based on it meeting the materials specification are incorrect and the actual shear strength of the material is lower than the values used in the pavement design process. This has resulted in a difference in the expected performance and the actual performance of the material. This would explain the accelerated deterioration identified by the defect mapping in the area surrounding test pit 3, 4 and 5.

The reduction in the materials strength is due to the changing the in the particles which make up the material. As can be seen figure 2.5 in the background information granitic base material is susceptible to change in modulus as a result of a change grading curve. It is likely that if the pavement material was still in the same state as it was in when it was stock piled more of the traffic load carried by the road would be transferred through point-to-point contact of aggregate, resulting in higher modulus and lower moisture sensitivity. As the material has broken down and the content fine has increased it is likely the material relies more on the strength of the fine matrix material surrounding the aggregate to achieve modulus. This most likely lead to the reduction in the materials strength qualities. Furthermore, the effects of moisture are more significant on materials with a high proportion of fines then the influence of water on coarse granular materials. As the material has broken down the increase of fines content has also made it more susceptible to a substantial decrease in the modulus as the water content increased. This effetely means that the material is more susceptible in a reduction of strength due to moisture ingress in to the pavement.

5.3.1 Investigate of the cause of the breakdown of the material

The change in mass retained on the sieve between the stock pile testing and the test carried out for this project are graphed below for samples from the shoulder and the outer wheel path. This section of analysis looks to examining if more material breakdown occurred in the sample from the outer wheel path when compared to the shoulder. This will help to determine if traffic loading has played a role in the in the beak down of the pavement material.

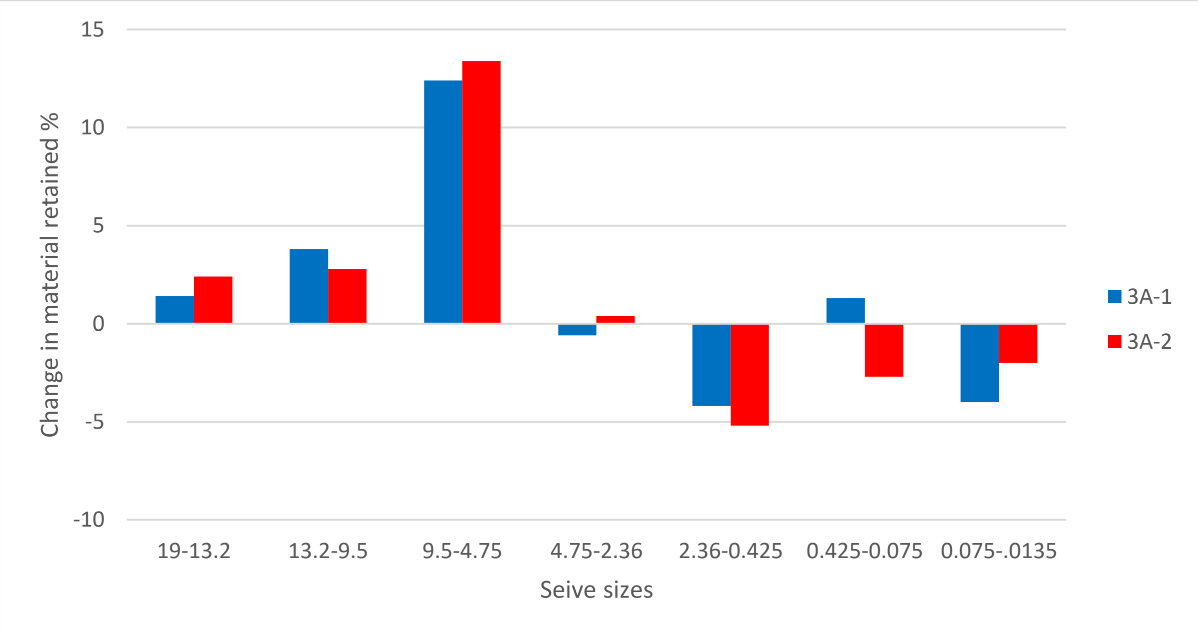


Figure 5.13: Change in material retain on the sieves for the base material at test pit 3

The figure above shows the result for both the shoulder material and material from the outer wheel path for the base layer at test pit 3. It can be seen that similar levels of break down are occurring in both samples, if anything the martial from the shoulder may have broken down more. This would suggest that it is unlikely that traffic loading is the cause of the break down base on these samples.

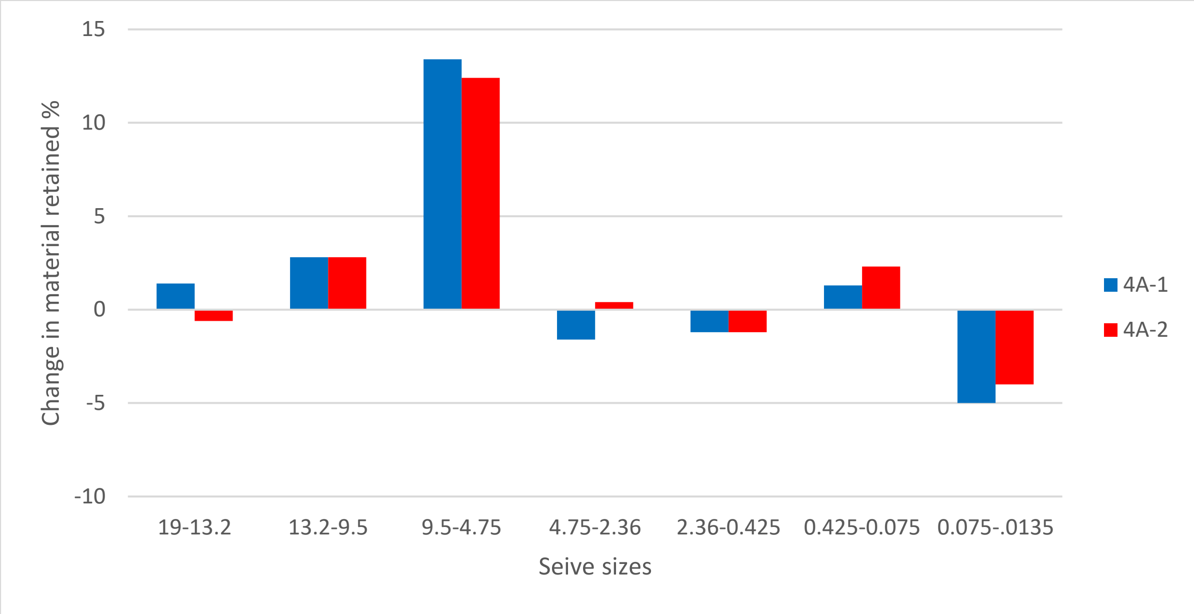


Figure 5.14: Change in material retain on the sieves for the base material at test pit 4

The figure above shows the results for both the shoulder material and material from the outer wheel path for the base layer at test pit 3. It can be seen that similar levels of break down are occurring in both samples. This would suggest that it is unlikely that traffic loading is the cause of the break down base on these samples.

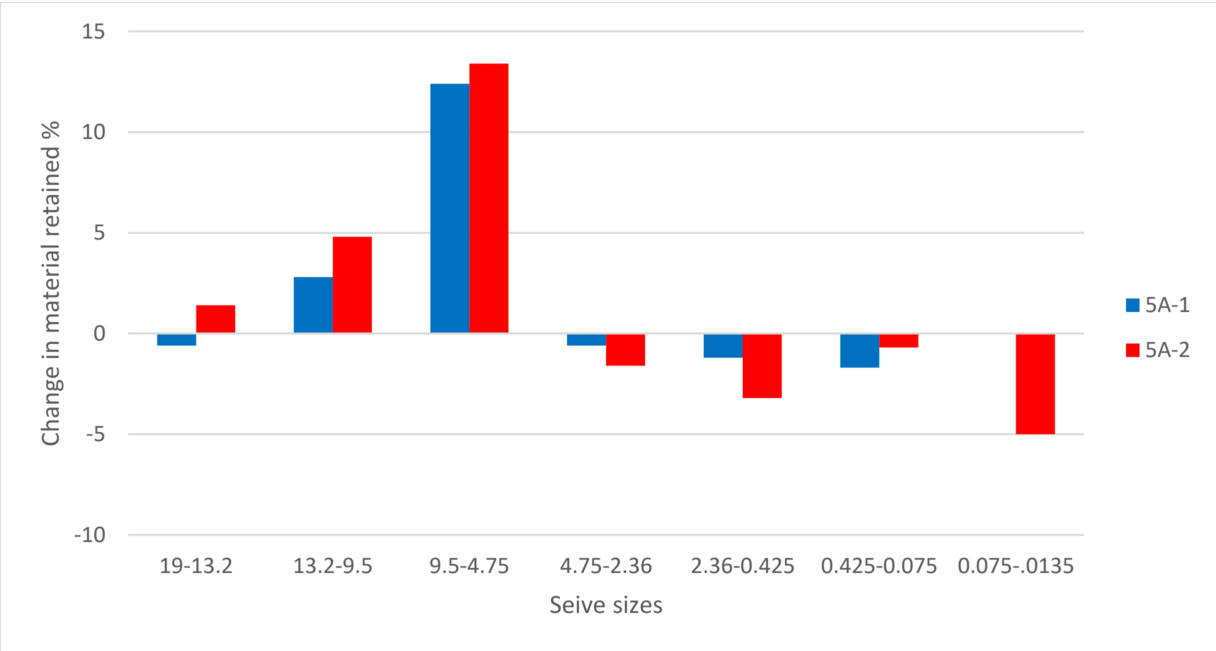


Figure 5.15: Change in material retain on the sieves for the base material at test pit 5

The figure above shows the result for both the shoulder material and material from the outer wheel path for the base layer at test pit 5. It can be seen that more material break down in the sample from the shoulder of the pavement. This would suggest that it is unlikely that traffic loading at is the cause of the break down base on these samples.

The results suggest that the break down in the pavement material surround test pits 3, 4 and 5 is unlikely to be related the traffic load of vehicle using the road. Given the small and limited sample size used in this section of analysis, it is hard to say with any certainty that this is the case for the overall pavement. Despite this it does indicate it is unlikely in the area of the major failure that encompasses test pit 3, 4 and 5 that traffic loading has caused the pavement material to break down.

Examining the results for the grading curves and the retained mass on the sieve in figure 5.10, 5.11, 5.12 and tables 5.5, 5.6 and 5.7 a general pattern can be seen. This pattern is the base and upper sub-base layers that have shown greater level of material break down then the lower sub-base layer. The two top pavement layers were exposed to higher comapactive effort in the construction to achieve 100% modified compaction specified for them compared with the 98% modified compaction specified for the lower sub-base layer. This difference in the compactive effort between the layers may explain the increase in material break down in the higher two layers of the pavement material when compared with the lower sub-base layer. Although this is not conclusive, the evidence indicates the amount of break down occurring in the material is relative to the amount of compactive effort the pavement material has been exposed too. It suggests that the material is breaking down as a result of the compaction in the construction of the road. The theory is also more plausible given the compaction requirements for the project are higher most normal granular road project. The general requirement of 100% standard compaction for base and upper sub-base with 98% standard compaction lower sub-base used on most road project. This higher compact was used to help the material meet the lower permeability requirement of the HD specification.

5.3.2 Overall findings from the particle size grading tests

The major finding from this section of analysis is that the pavement material underwent substantial break down since testing of the stock pile occurred in the construction of the project. This breakdown of the pavement material is likely to have reduced the shear strength and modulus of the material below that of which the original design values used for the project. As result the pavement has performed below expectations as identified in the first two sections of the results of this report. The breakdown of the material and the increase in the amount of fines in the materials make up are likely to increase the material susceptibility to strength reduce due to moisture ingress. All samples show a distinct pattern of material breakdown occurring between 9.5-4.75mm sieves sizes indicating that the 15% -10mm Argillite Scalps is mostly likely part of the material blend to be breakdown. A relationship between compactive effect and the amount of the breakdown occurring in the sample suggest that breakdown is occurring as a result of the campactive effort applied to that material in construction. Furthermore results show no evidence of a relationship between traffic loading and the material breakdown, this indication it is unlikely that the material break is a result of the traffic loading.

5.3.3 Atterberg Limits

All 6 base layer sample are from the same stock pile, stock pile 15. The construction testing for this stock pile showed that the originally the plastic index for the material conformed to the RMS specification with the stock piles plastic index ranging from 4% to 5% with an average of 4.4% across the five test carried on the stock pile.

Table 5.5: Test results for the Atterberg limits tests carried out on test pit 3, 4 and 5.

	3A-1	*3A-2*	*4A-1*	*4A-2*	*5A-1*	*5A-2*
Liquid limit (%)	21	20	22	20	23	21
Plastic limit (%)	17	16	15	16	15	15
Plasticity index (%)	4	4	7	4	8	6

The results from the Atterberg limits testing carried out on the base sample as a part of this study can been seen above in the table. It can been seen that sample 4A-1, 5A-1 and 5A-2 have a higher plastic index then the stock pile, suggesting change has occur in the material since construction test was carried out. This is likely to have increase the material susceptibility to a reduction in strength due to moisture ingress in to the pavement.

For heavy duty granular material RMS 3051 specifies that plastic index should between 2 and 6%. It can been seen that sample 4A-1 and 5A-1 are outer side the specified limit set by RMS. This indicates that the base material at these 2 test pits are more susceptible to water related strength reduction then that value assumed in the design process . This is likely to have contributed to the failure in the areas surrounding the test pit 4 and 5.

5.4 Travel Speed Deflection results

In the figures below the values for Middle Layer Index and Lower Layer Index area graphed with the rutting data collected in the earlier stages of the study. By analysing these factors together the study will be able to identify if weaknesses or abnormally in the lower formation layers have played a role in the development of the failure or rutting in the pavement. Due to time and resource restriction this section of analysis in only going to focus of the outer southbound lane as it has the most failures to be compare with the Middle Layer Index and Lower Layer Index values. The southbound defect mapping showed major defects at approximant chainages 3, 4.8 to 5.2 and at 5.7. The indexes value surround these areas will also be examined be examined aim identify if the underling structure in these areas has some sort of weakness.

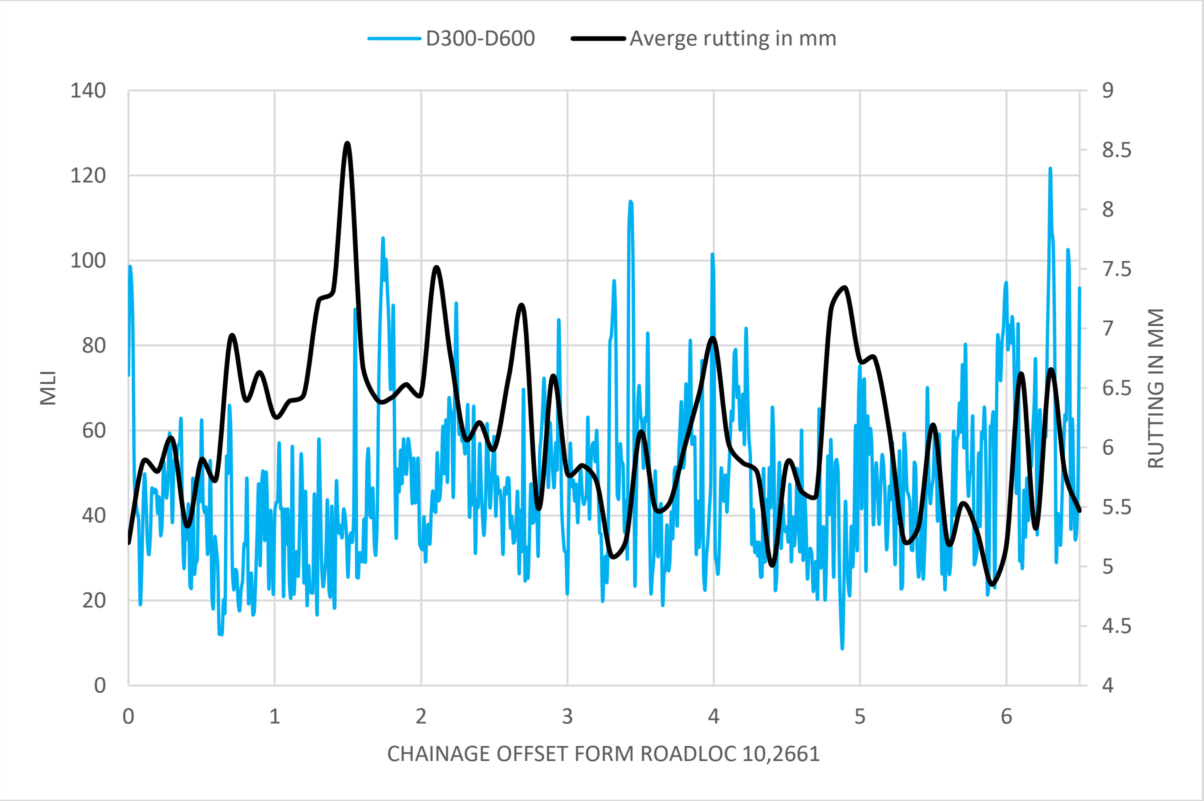


Figure 5.16: Middle Layer Index value vs rutting data

In the figure above it can be seen that the Middle Layer Index has no correlation with the rutting value. The two values act independently of each other with no pattern. At chainage 3, 4.8 to 5.2 and at 5.7 again no evidence of the weak or soft underlining material can be identified from the Middle Layer Index. The Middle Layer Index show that structural condition of the earthworks upper zone is unlikely to have been a cause of the high rutting and failure found in the southbound pavement. This is indicated by the lack of correlation between the Middle Layer Index, the rutting data and failures in the pavement.

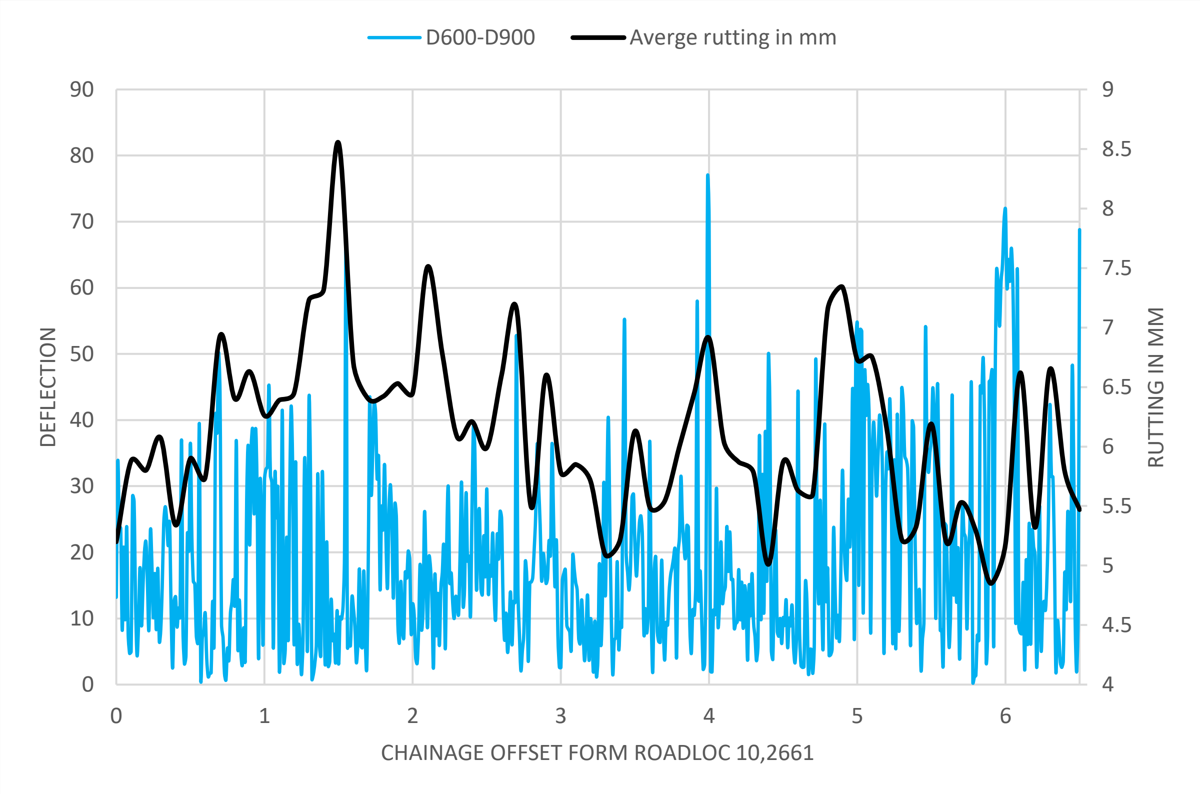


Figure 5.17: Lower Layer Index value vs rutting data

Similar to the Middle Layer Index it can be seen that the Lower Layer Index has no correlation with the rutting values as well. The two value act independent of each other with no pattern. At chainage 3, 4.8 to 5.2 and at 5.7 again no evidence of the weak or soft underlining material can be identified from the Lower Layer Index. The Lower Layer Index shows that the structural condition of the subgrade material is unlikely to have been a cause of the high rutting or failures found in the outer southbound pavement. This is indicated by the lack of correlation between the lower Layer Index, the rutting values and failures in the pavement.

A major limitation of this style of analysis is that structural condition of the earthworks upper zone or subgrade material this related to the moisture content in the material at the time of testing. As the period leading up to the TSD test was relatively dry and the underlining material in the formation is clayey in nature it likely to have given better reading then if it was after a large rainfall event. So if there is a subgrade weakness which is related to an area of the subgrade, losing strength due it saturation cause by intermittent issue like a fluctuating water table this style of analysis would not picked it up unless the area was saturated at the time of testing.

5.4.1 Findings from Travel Speed Deflection results

The results show that the rutting and failures experienced in the southbound outer lane are not a result of the structural condition of the earthworks upper zone or subgrade material at the time that TSD test was carried out. This supports the theory that the failures and rutting are a result of weak base material resulting it a shearing failure of the pavement. Furthermore it supports earlier finding in the report that suggest that pavement material’s lower shear strength and modulus are the likely cause of the failures.

Chapter 6 : Key Finding and Recommendations

6.1 Key findings

The analysis of the performance indicators and defect mapping data has shown the following;

- Rutting has occurred at an accelerated rate along the section examined and extent of rutting is higher than expected;
- The pavement roughness is slightly higher than expected but still at a very acceptable rate;
- A substantial number of failures are present in the areas where heavy duty granular has been used in the Glenugie project, this number is beyond that expect of a Class A pavement of 5 years of age;
- Failure have been identified at higher rates in the outer lanes of the carriageway this is likely due to the higher traffic loading.

The accelerated rate of rutting is the most important information as it indicates structural instability in the flexible pavement. As the rutting is associated with shoving, which has been identified as occurring at the start of the failure process in the section of highway, it is indicative that the shear strength in the upper pavement layers may be inadequate to withstand the applied traffic loads. The poor correlation between the severity of rut depth and measured deflections confirms that this is the likely cause of the failure and rutting. The flushing, rutting and shoving observed at the start of the failure modes would would also support the theory that the shear strength and modulus of the pavement material may not meet the needs of the road.

One of the major finding from this report is that the pavement material has undergone substantial break down since testing of the stock piles occurred in the construction of the project. This breakdown of the pavement material is likely to have reduced the shear strength and modulus of the material below that of which the original design values used for the project. As result the pavement has performed below expectations as identified in the first two sections of the results from the performance indicator and defect mapping data. The study indicating that the 15% -10mm Argillite Scalps is the mostly likely part of the material blend to have broken down. The load applied to the material due to compactive effort during construction is likely to be the cause of this material breakdown. Furthermore results show no evidence of a relationship between traffic loading and the material breakdown, this indicates it is unlikely that the material break down is a result of the traffic loading.

The analysis of the percentage of the optimum moisture content of the samples shows that moisture content of most samples are within a range that would be expected to have little effect on the pavement material, exception for test pit 10. Furthermore, the results indicate the moisture ingress is likely occurring through the shoulder of the pavement on the western edge of both the north and southbound lanes. The use of the low quality, poorly compacted material as verge is likely to have contributed to the ingress of the water into the pavement material through the shoulder of the pavement.

The analysis of the relationship between the pavement condition and the moisture content of the material showed that a relationship exists between them. It showed that as the moisture content in the pavement increases so does the likelihood of failures occurring. This would suggest that high moisture content may have played a role in the failures which have occurred at Glenugie but does little to identify how large of role it has played. The breakdown of the material has resulted in an increase in the amount of fines and the plasticity of the pavement materials and are likely to increase the material susceptibility to strength reduce due to moisture ingress. It is expect that is has also played a role in the existence of the relationship between the pavement condition and the moisture content.

The results show that the rutting and failure experienced in the southbound outer lane are not a result of the structural condition of the earthworks upper zone or subgrade material at the time that TSD test was carried out. This supports the theory that failures and rutting are a result of weak base material resulting it a shearing failure of the pavement. Furthermore it supports earlier finding in the report that suggest that pavement material's lower shear strength and modulus are the likely cause of the failure.

Overall the study shows that pavement at Glenugie is performing below expectations. With the primary cause of the rutting and failures being the breakdown of material and associated reduction in shear strength and modulus of the material. The evidence presented in the report supports that the secondary cause of failures is likely to be due to moisture content of the pavement material. This is supported be the defection data which indicates that earthworks upper zone or subgrade material are unlikely to be the cause of the failures.

6.2 Recommendations and Further Research

6.2.1 Recommendations

Further development work needs to be carried out on the pavement material and construction techniques before using heavy duty granular pavement on future Pacific Highway upgrade projects. The report show the pavement material at Glenugie has performed below expectation and it is likely that pavement material, construction techniques and design have all contributed in some way to is poor performance. In future heavy duty projects in northern NSW the author of this report would suggest the following factors need to be look at:

- The use of scalps material in the pavement material blend and if an additive like fly ash could be used instead to help achieve workability and permeability requirements.
- Are pre-treatment requirement in the testing specification adequate for the higher level of compaction used in Glengue project.
- If the higher compaction requirement are needed or if the permeability requirement of the specification can be met by other means like the use of an additives.
- If the saving from using boxed construction is worth the increase in risk of moisture ingress problem, as seen in the poor quality verge material.

These are just some of the areas that need to be looked and address in detail before heavy duty granular pavement could used in future Pacific Highway projects in northern NSW.

The results show that the accelerated deterioration occurring at Glenugie is likely to continue. If the deterioration continue at this rate it is likely the pavement will need an early rehabilitation. The author of the report suggest that Option B from the maintenance plan be brought forward. This rehabilitation option is an insitu stabilisation to 350mm, then 40mm AC and 7mm sprayed. This style of rehabilitation would address several of pavements issue include:

- High plasticity, by reducing the plasticity index
- Low shear strength, by increase the shear strength
- Susceptibility to moisture induced strength reduction, reducing moisture ingress.

It is likely this type of rehab have a design life of 20 years and may be a good option for extending the life of the pavement.

Although the pavement at Glenugie has performed below expectations, some areas of the pavement are performing at a level that could be expected. This would indicate it is possible for heavy duty granular pavement to meet the expectation in the conditions prevalent in northern NSW. With further development and testing it is likely that an effective heavy duty granular pavement can be developed for use in northern NSW.

6.2.2 Further research

Replicating breakdown of the material in laboratory to confirm the theory developed in the study, that the breakdown of material is caused by the compactive effort applied to the pavement material during construction of the Glenugie project. The experiment would use samples of HD DGB20 from the same quarry and of the same make up as the material used at Glenugie. The samples would be expose to a range of different compactive effort before undergoing particle size testing. This would show if compactive effort was the sole cause of the material breakdown or if there was other factors involved. The result of the experiment could also be used to examine if pre-treatment specified in the RMS testing procedures was adequate given the higher levels of compaction used on the project. Furthermore this kind of study could also confirm if it is the -10mm Argillite Scalps breaking down in the material blend.

The results of the study have shown that it is likely that moisture ingress into the pavement material have played a role in the failure in the pavement at Glenugie. The area of Glenugie is a high rainfall area when compared other areas in NSW, with a subtropical climate similar to that experience in south east Queensland. The RMS specification make no differentiation for the requirements for high and low rainfall areas. This is very different to the specification used in Queensland which make a clear distinction between high rainfall and low rainfall areas and acknowledge different approaches are need in these different areas. A study comparing the performance of the two different approaches used by NSW and Qld may indicate areas where both specification can be improved and have a positive impact on RMS specifications in northern NSW.

This study uses a limit sample size most of it analysis. With almost all of the samples focusing on areas where major failure have occur and little comparison has been done with areas of pavement in good condition. An extension of the study to include more testing in these "good" pavement area would make for an interesting comparison and would help to identify the difference between the two area which contributing to better performance. This would help to produce more useful results which would paint a fuller picture of the pavement at Glunugie.

References

Aktaş, B, Karaşahin, M, Saltan, M, Gürer, C & Uz, VE 2013, 'Effect of aggregate surface properties on chip seal retention performance', *Construction and Building Materials*, vol. 44, pp. 639-44.

ARRB Group 2014, *Road Inventory and Condition Assessments*, viewed 11th September, 2016, <https://www.arrb.com.au/admin/file/content2/c7/Services_1459292489618.pdf>.

Austrailian standards 2009, *AS 1289.3.6.1-2009 Methods of testing soils for engineering purposes - Soil classification tests - Determination of the particle size distribution of a soil - Standard method of analysis by sieving*.

Austrailian Standards 2014, *AS 1289.6.1.1:2014 : Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the California Bearing Ratio of a soil - Standard laboratory method for a remoulded specimen*.

Austroads 2011, *Austroads Test Method AG:AM/T006 Pavement Deflection Measurement With A Falling Weight Deflectometer (FWD)*, viewed 18th July, 2016, <http://austroads.com.au.tmp.anchor.net.au/images/stories/AG_AM_T006__Deflection-FWD_survey__2011.pdf>.

Baltzer, S, Pratt, D, Weligamage, J, Adamsen, J & Hildebrand, G 2010, 'Continuous bearing capacity profile of 18,000 km Australian road network in 5 months', in 24th ARRB Conference, Melbourne, Australia: *proceedings of the24th ARRB Conference, Melbourne, Australia*.

Bodin, D & Kraft, J 2015, *Effect of moisture content and laboratory preparation conditions on the permanent deformation of unbound granular materials*, 192529403X.

BOM 2016, *Climate statistics for Australian locations*, viewed 28th September, 2016, <http://www.bom.gov.au/climate/averages/tables/cw_058130.shtml>.

CPEE 2012, *Mechanistic Pavement Design – Faster and Better with CIRCLY 6.0*, viewed 29th , October <https://www.pavementeducation.edu.au/industry-and-partners/industry/mincad-systems/70-industry-partners/mincad-systems/mincad-news/111-mechanistic-pavement-design-faster-and-better-with-circly-6-0>.

Das, BM 2006, *Principles of geotechnical engineering*, 6th ed. edn, Nelson, Canada.

Das, BM 2010, *Geotechnical Engineering Handbook*, J. Ross Pub.

Department of Transport and Main Roads 2013, *Pavement Design Supplement : Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology* Department of Transport and Main Roads, viewed 25th of August, 2016, <http://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Pavement-design-supplement>.

Department of Transport and Main Roads 2015, *Technical Specification :Transport and Main Roads Specifications MRTS05 Unbound Pavements*, Transport and Main Roads Specifications, viewed 27th of August, 2016, <http://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Specifications/5-Pavements-Subgrade-and-Surfacing#MRTS05>.

Engineers Australia 2010, *Our Code OF Ethics* viewed 9th January, 2014, <http://www.engineersaustralia.org.au/sites/default/files/shado/About%20Us/Overview/Governance/codeofethics2010.pdf>.

A comparison between austroads pavement structural design and AASHTO design in flexible pavement, Key Subjects <http://www.scopus.com/inward/record.url?eid=2-s2.0-84884745497&partnerID=40&md5=3b6c52cf5fe208f74d2d3e3d200ba07d>.

Haigh, SK & Vardanega, PJ 2014, 'Fundamental basis of single-point liquid limit measurement approaches', *Applied Clay Science*, vol. 102, pp. 8-14.

Horak, E & Khumalo, T 2006, 'Deflection Bowl Parameters Correlation Pilot Study Of A Light And Standard Falling Weight Deflectometer '.

Huang, YH 2004, *Pavement analysis and design*, 2nd ed. edn, Pearson Prentice Hall, Upper Saddle River NJ.

Hubner, D & Jameson, GW 2012, *Guide to pavement technology. Part 2, Pavement structural design / Austroads*, Austroads, Sydney.

Hussain, J, Wilson, DJ, Henning, TFP & Alabaster, D 2011, 'What happens when it rains? Performance of unbound flexible pavements in accelerated pavement testing', *Road and Transport Research*, vol. 20, no. 4, pp. 3-15, Scopus.

IPWEA 2006, *Condition Assessment and Asset Performance Guidelines* viewed 20th July, 2016, <https://higherlogicdownload.s3.amazonaws.com/IPWEA/e5f045c3-43de-4e66-b9ad-8af5523dc4e2/UploadedImages/Bookshop/PN%20Preamble_lp_v2.pdf>.

Jameson, G 2013, *Technical basis of Austroads guide to pavement technology. Part 2, Pavement structural design / prepared by Geoff Jameson*, ARRB Group Ltd, Vermont South, Vic.

Jameson, G & Harrison, C 2011, *Guide to pavement technology. Part 5, Pavement evaluation and treatment design*, Austroads, Sydney.

Kelley, J & Moffat, M 2012, *Review of the Traffic Speed Deflectograph – Final Project Report*, Austroads Ltd, Sydney NSW Australia.

Liddle, G 2005, *Technical basis of Austroads pavement design charts for light traffic / [project manager, Gary Liddle]*, Austroads, Sydney.

Magnan, J-P & Ndiaye, M 2015, 'Determination and assessment of deformation moduli of compacted lateritic gravels, using soaked CBR tests', *Transportation Geotechnics*.

Maji, A & Das, A 2008, 'Reliability considerations of bituminous pavement design by mechanistic-empirical approach', *International Journal of Pavement Engineering*, vol. 9, no. 1, pp. 19-31, EBSCOhost, a9h, item: 27777641.

Midgley, L 2009, *Ingredients of an unbound granular pavement for a successful sprayed seal*, VicRoads.

Millichamp, S, Nash, G, Donnelly, J & Gamble, S 2012, *Heavy Duty Flexible Granular Pavement ; Glenugie Upgrade Alliance Legacy Paper*

Moffatt, M 2006, *Guide to asset management. Part 5C, Rutting / [prepared by Michael Moffatt and Rayya Hassan]*, Austroads, Sydney.

Moffatt, M 2007, *Guide to asset management: part 5B: roughness*.

Moffatt, M & Hassan, R 2006, *Guide to asset management: part 5E: cracking*.

Moss, J 2009, *Guide to pavement technology. Part 4C, Materials for concrete road pavements / [prepared by Justin Moss ... [et al.]. ; project manager Ken Porter]*, Austroads, Sydney.

Nash, G, Donnelly, J, Gamble, S, Morgan, D, Kearns, G & Millichamp, S 2011, 'Development of a heavy duty flexible granular pavement for the Pacific Highway upgrade at Glenugie ', in RTA Pavements Conference 2011: *proceedings of theRTA Pavements Conference 2011* Darling Harbour, Sydney

Nikolaides, A 2014, *Highway Engineering: Pavements, Materials and Control of Quality*, CRC Press.

Rabe, R 2012, 'Structural Pavement Monitoring with Non-Destructive Measuring Devices at Traffic Speed–Current Research and Experience in Germany', in German Federal Highway

Research Institute BASt. 4th European Pavement and Asset Management Conference EPAM4: *proceedings of theGerman Federal Highway Research Institute BASt. 4th European Pavement and Asset Management Conference EPAM4*.

RMS 2015, *Pacific Highway upgrade*, viewed 29, October, <http://www.rms.nsw.gov.au/projects/key-build-program/pacific-highway/index.html>.

RMS 2016, *Performance Measures and Indicators Manual: Asset Strategy Section, Network Optimisation*, NSW Goverment

Roberts, J, Ai, U, Toole, T & Martin, T 2014, *Traffic speed deflectometer: data review and lessons learnt*, 1925037916.

Saad, B 2014, 'Analysis of excess water impact on the structural performance of flexible pavements', *International Journal of Pavement Engineering*, vol. 15, no. 5, pp. 409-26.

Saevarsdottir, T & Erlingsson, S 2013, 'Water impact on the behaviour of flexible pavement structures in an accelerated test', *Road Materials and Pavement Design*, vol. 14, no. 2, pp. 256-77.

Sharp, KG 2005, *Guide to pavement technology. Part 1, Introduction to pavement technology / [author Kieran Sharp]*, Austroads, Sydney.

Siripun, K, Jitsangiam, P & Nikraz, H 2012, 'The design model of unbound granular materials for flexible pavement', *Australian Journal of Civil Engineering*, vol. 10, no. 1, pp. 1-10, Scopus.

Soliman, H & Shalaby, A 2015, 'Permanent deformation behavior of unbound granular base materials with varying moisture and fines content', *Transportation Geotechnics*.

Song, D & Chen, B 2016, 'Extended Exergy Accounting For Energy Consumption and CO2 Emissions of Cement Industry—A Basic Framework', *Energy Procedia*, vol. 88, pp. 305-8.

Tamsett, P 2015, *RMS Austroads Supplement for Guide to Pavement Technology - Part 2: Pavement Structural Design* RMS

Thom, N 2014, *Principles of pavement engineering*, Second edition. edn, ICE Publishing, London.

Vic Roads 2011, *Section 812 - Crushed Rock for Pavement Base and Subbase*, Vortorian Goverment <http://www.alexfraser.com.au/params/img/product/downloads/Vicroads%20Specification%20812%20Crushed%20Rock.pdf>.

Vic Roads 2013, *Code of Practice:Selection and Design of Pavements and Surfacings RC500.22*, Victorian Goverment <https://www.vicroads.vic.gov.au/~/media/files/technicaldocuments/codes-of-practice/code-of-practice-rc-50022--selection-and-design-of-pavements-and-surfacings.pdf>.

Vuong, B, JAMESON, G, Sharp, KG & FIELDING, B 2008, *Guide to pavement technology part 4A: granular base and subbase materials*.

Wang, H & Al-Qadi, IL 2010, 'Evaluation of Surface-Related Pavement Damage due to Tire Braking', *Road Materials and Pavement Design*, vol. 11, no. 1, pp. 101-21.

Yang, R, Kang, S, Ozer, H & Al-Qadi, IL 2015, 'Environmental and economic analyses of recycled asphalt concrete mixtures based on material production and potential performance', *Resources, Conservation and Recycling*, vol. 104, Part A, pp. 141-51.

Appendix A

Project Specification

ENG4111/4112 Research Project

Project Specification

For: Matthew Beaumont

Title: Pacific Highway Glenugie; Case study of the use of Heavy duty Granular Pavement in Northern NSW

Major: Civil Engineering

Supervisor: Jo Devine

Industry Supervisor: John Howell, Ben Churton

Enrolment: ENG4111 – EXT S1, 2016
ENG4112 – EXT S2, 2016

Project Aim: To evaluate the pavement performance thus far and determine the mechanism which is the cause of any failure in the pavement. Examination of the root cause of the failure mechanism, with the aim of improving performance and maintenance of heavy duty granular pavements in Northern NSW in future.

Programme: Issue B, 19th April 2016

1. Research non-destructive methods for testing pavement performance and evaluate their suitability for the project.

2. Map failures and performance indicator along the segment of road.

3. Gather construction, design and testing documentation from the original road construction.

4. Review destructive pavement testing techniques that could be used to help evaluate the cause of the pavement failures.

5. Gather and analysis test result data relating to pavement failures to identify failure mechanism or mechanisms.

6. Identify potential shortfalls in design, construction techniques or materials used in the project to make recommendations on how heavy duty granular pavements could be improved for future use in NSW.

If time and resources permit:

7. Analysis the adequacy of the current maintenance plan given the information gain in earlier sections and development of a new maintenance if deemed necessary.

8. A whole life cost analysis of a section of road for both the original and new maintenance for comparison.

Appendix B

Test logs

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

Field Moisture Content Data Sheet

Project Details

Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failure

Equipment

Balance Number	
Oven Number	

Tested By and Date	
Checked By and Date	

Sample ID	Drying Tin Number	Mass of Tin (g)	Mass of Wet Sample and Tin (g)	Mass of Dry Sample and Tin (g)	Repeat Mass of Dry Sample and Tin (g)	Moisture Content in Percent (%)

Remarks

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.80965	E 153.03362	Road Loc	R[10,2661,C1,5.223]	Offset (m)	In 2.0	out 4.8	
Road / Segment					Road Description	4 Lane Dual Carriage (Nth/Sth)		
Lane / Section	Southbound Outer				Direction of Test Pit	Transverse		

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Good ---	Some slight seal flushing but no other signs of distress
Features	Large Cutting ---	Approx 7m high at this point
Drainage	Good ---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Good - slight flushing adjacent to both I & O edgelines

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
01A	*Top* 30 *Bottom* 155	2.0 4.8	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.8 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
01B	*Top* 155 *Bottom* 270	2.0 4.8	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
01C	*Top* 270 *Bottom* 355	2.0 4.8	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularVery Dense.	Duncan's DGB20HD
01D	*Top* 355 *Bottom* 645	2.0 4.8	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Dry , FMC = 7.9 % Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Top 15mm is more moist (FMC = 10.1%)
01E	*Top* 645 *Bottom* 750+	2.0 4.8	***Subgrade*** ***Flexible***	**Clayey Gravel - Dark Brown** Of medium plasticity LL > 35 ≤ 50 , Slightly moist , FMC = 9.6 % Gap graded to 60 mm, Sub-Angular Low strength Distinctly weathered rock, Medium Dense.	Weathered mudstone/siltstone ex cutting

There are no DCP results attached for this schedule.

Remarks

Test pit located in good area.

Logged By	*DM, JW*	Date	4/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS N -29.81073	E 153.03382	Road Loc	R[10,2661,C1,5.102]	Offset (m)	In 2.0 out 4.8
Road / Segment	Sg 3855	Road Description	4 Lane Dual Carriage (Nth/Sth)		
Lane / Section	Southbound Outer	Direction of Test Pit	Transverse		

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.6m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Fair ---	Small failure beginning to appear on edgeline
Features	Large cutting ---	Approx. 7m at this point
Drainage	Good ---	SO kerb 2.4 m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	25	Surface Condition	Fair - Some cracking on edge line

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
02A	*Top* 25 *Bottom* 150	2.0 4.8	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.1 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Moisture content outside edgeline FMC = 3.3%
02B	*Top* 150 *Bottom* 250	2.0 4.8	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.6 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
02C	*Top* 250 *Bottom* 350	2.0 4.8	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.7 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
02D	*Top* 350 *Bottom* 500+	2.0 4.8	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 8.7 % Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone

There are no DCP results attached for this schedule.

Remarks

Pit in area just starting to fail

Logged By	*DM, JW*	Date	4/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP3-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81115	E 153.03388	Road Loc R[10,2661,C1,5.055]	Offset (m)	In 2.0 out 4.0
Road / Segment	Sg 3855			Road Description	4 Lane Dual Carriage (Nth/Sth)
Lane / Section	Southbound Outer			Direction of Test Pit	Transverse

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor ---	Deformation and failures along edgeline. Some flushing appearing in wheelpaths - both lanes
Features	Large cutting ---	Approx. 4m at this point
Drainage	Good ---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Poor - patched, slightly flushed

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
03A-1	*Top* 30 *Bottom* 155	2.0 4.0	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.6 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
03B-1	*Top* 155 *Bottom* 260	2.0 4.0	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.6 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
03C-1	*Top* 260 *Bottom* 355	2.0 4.0	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.9 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
03D-1	*Top* 355 *Bottom* 400+	2.0 4.0	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 7.5 % Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone

There are no DCP results attached for this schedule.

Remarks

Test pit in failed area

Logged By	*DM, JW*	Date	4/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP3-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81115	E 153.03388	Road Loc R[10,2661,C1,5.055]	Offset (m)	In 4.0 out 5.9
Road / Segment	Sg 3855			Road Description	4 Lane Dual Carriage (Nth/Sth)
Lane / Section	Southbound Shoulder			Direction of Test Pit	Transverse

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor ---	Deformation and failures along edgeline. Some flushing appearing in wheelpaths - both lanes
Features	Large cutting ---	Approx. 4m at this point
Drainage	Good ---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Poor - patched, slightly flushed

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
03A-2	*Top* 30 *Bottom* 155	4.0 5.9	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
03B-2	*Top* 155 *Bottom* 260	4.0 5.9	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.7 % Well graded to 50 mm, AngularDense.	Duncan's DGB20HD
03C-2	*Top* 260 *Bottom* 355	4.0 5.9	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.6 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
03D-2	*Top* 355 *Bottom* 450+	4.0 5.9	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 8.3 % Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Outside 0.5m adjacent to kerb unstabilised and moister. FMC taken from here

There are no DCP results attached for this schedule.

Remarks

Pit is an extension of Test Pit 3-1. Shoulder area (0.5m outside edgeline to kerb).
Sub-soil drain under kerb OK. Not holding water. Some clayey fines under fabric on top of aggregate - possibly from construction.

Logged By	*DM, JW*	Date	4/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP4-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81166	E 153.03396	Road Loc	R[10,2661,C1,4.998]	Offset (m)	In 2.0	out 4.0
Road / Segment	Sg 3855			Road Description	4 Lane Dual Carriage (Nth/Sth)		
Lane / Section	Southbound Outer			Direction of Test Pit	Transverse		

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor	---	OWP rutted, numerous edgeline failures
Features	Large cutting	---	Approx. 4m at this point
Drainage	Good	---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Poor - flushing in OWP of slow lane & IWP of fast lane

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
04A-1	*Top* 30 *Bottom* 155	2.0 4.0	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.2 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
04B-1	*Top* 155 *Bottom* 255	2.0 4.0	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.1 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
04C-1	*Top* 255 *Bottom* 350	2.0 4.0	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 350 *Bottom* 425+	2.0 4.0	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone - not sampled

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	4/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP4-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81166	E 153.03396	Road Loc	R[10,2661,C1,4.998]	Offset (m)	In 4.0	out 5.2	
Road / Segment	Sg 3855				Road Description	4 Lane Dual Carriage (Nth/Sth)		
Lane / Section	Southbound Outer				Direction of Test Pit	Transverse		

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor	---	OWP rutted, numerous edgeline failures
Features	Large cutting	---	Approx. 4m at this point
Drainage	Good	---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Poor - flushing in OWP of slow lane & IWP of fast lane

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
04A-2	*Top* 30 *Bottom* 155	4.0 5.2	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
04B-2	*Top* 155 *Bottom* 255	4.0 5.2	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.3 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
04C-2	*Top* 255 *Bottom* 350	4.0 5.2	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
04D-2	*Top* 350 *Bottom* 400+	4.0 5.2	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 8.1 % Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	4/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP5-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81278	E 153.03423	Road Loc	R[10,2661,C1,4.871]		Offset (m)	In 2.0	out 4.0	
Road / Segment	Sg 3855					Road Description	4 Lane Dual Carriage (Nth/Sth)		
Lane / Section	Southbound Outer					Direction of Test Pit	Transverse		
Lane / Shoulder Widths (metres)	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---				
	I SB Lane 3.5m	O SB Lane 3.6m	East Sh 2.4m	---	---				

Pavement Description and Distress Mechanisms

Pavement Condition	Poor ---	OWP rutted, numerous edgeline failures, pit at topside of AC patch
Features	Fill ---	Just below cut/fill line at bottom of big cut
Drainage	Good ---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	25	Surface Condition	Poor - some flushing in OWP, cracking, patched

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
05A-1	*Top* 25 *Bottom* 150	2.0 4.0	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
05B-1	*Top* 150 *Bottom* 255	2.0 4.0	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.7 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
05C-1	*Top* 255 *Bottom* 350	2.0 4.0	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.8 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 350+	2.0 4.0	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Not sampled

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP5-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81278	E 153.03423	Road Loc R[10,2661,C1,4.871]	Offset (m) In 5.1	out 5.4
Road / Segment	Sg 3855		Road Description	4 Lane Dual Carriage (Nth/Sth)	
Lane / Section	Southbound Outer		Direction of Test Pit	Longitudinal	

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh ---
	I SB Lane 3.5m	O SB Lane 3.6m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor ---	OWP rutted, numerous edgeline failures, pit at topside of AC patch
Features	Fill ---	Just below cut/fill line at bottom of big cut
Drainage	Good ---	SO kerb 2.4m outside edgeline, on downhill grade

Log, Material Description

Surface Type	Seal	Thickness (mm)	25	Surface Condition	Poor - some flushing in OWP, cracking, patched

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
05A-2	*Top* 25 *Bottom* 165	5.1 5.4	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.9 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
05B-2	*Top* 165 *Bottom* 260	5.1 5.4	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
05C-2	*Top* 260 *Bottom* 350	5.1 5.4	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 350+	5.1 5.4	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Not sampled.

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP6-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81109	E 153.03381	Road Loc	R[10,2661,C1,5.063]	Offset (m)	In 2.0	out 3.5
Road / Segment	Sg 3855				Road Description	4 Lane Dual Carriage (Nth/Sth)	
Lane / Section	Southbound Inner				Direction of Test Pit	Transverse	

Lane / Shoulder Widths (metres)	West Sh	O NB Lane	I NB Lane	I West Sh	I East Sh 0.5m
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Fair ---	Some slight rutting, fine cracks in seal in IWP leaching fines
Features	Large cutting ---	Approx. 4m at this point
Drainage	Good ---	On downhill grade. Wide dished centre median. Crossfall runs to outside edge. SO kerb on outside edge

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Fair - fine cracks

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
06A-1	*Top* 30 *Bottom* 155	2.0 3.5	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.4 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
06B-1	*Top* 155 *Bottom* 260	2.0 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
06C-1	*Top* 260 *Bottom* 355	2.0 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.1 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 355+	2.0 3.5	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Not sampled.

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP6-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS N -29.81109	E 153.03381	Road Loc R[10,2661,C1,5.063]	Offset (m) In 3.5 out 4.5
Road / Segment	Sg 3855	Road Description	4 Lane Dual Carriage (Nth/Sth)
Lane / Section	Southbound Inner Shoulder	Direction of Test Pit	Transverse

Lane / Shoulder Widths (metres)					
	West Sh ---	O NB Lane ---	I NB Lane ---	I West Sh ---	I East Sh 0.5m
	I SB Lane 3.5m	O SB Lane 3.5m	East Sh 2.4m	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Fair ---	Some slight rutting, fine cracks in seal in IWP leaching fines
Features	Large cutting ---	Approx. 4m at this point
Drainage	Good ---	On downhill grade. Wide dished centre median. Crossfall runs to outside edge. SO kerb on outside edge

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Fair - fine cracks

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
06A-2	*Top* 30 *Bottom* 155	3.5 4.0	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Moist , FMC = 4.8 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Only moisture content taken
06VA	*Top* 30 *Bottom* 360	4.0 4.5		**Sandy Clayey Gravel - Brown** Of medium plasticity LL > 35 ≤ 50 , Moist , FMC = 10.5 % Gap graded to 50 mm, Sub-AngularMedium Dense.	Verge material

There are no DCP results attached for this schedule.

Remarks

Sub-soil drain at inside edge of pavement. Working okay. Not holding water.

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP7-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81136	E 153.03386	Road Loc	R[10,2661,C1,5.032]	Offset (m)	In	2.0	out	3.5
Road / Segment	Sg 3855				Road Description	4 Lane Dual Carriage (Nth/Sth)			
Lane / Section	Southbound Inner				Direction of Test Pit	Transverse			

Lane / Shoulder Widths (metres)	West Sh	---	O NB Lane	---	I NB Lane	---	I West Sh	---	I East Sh	0.7m
	I SB Lane	3.4m	O SB Lane	3.5m	East Sh	2.4m	---		---	

Pavement Description and Distress Mechanisms

Pavement Condition	Fair ---	Pit adjacent to small shoving failure along inner edgeline
Features	Large Cutting ---	Approx. 4m at this point
Drainage	Good ---	On downhill grade. Wide dished centre median. Crossfall runs to outside edge. SO kerb on outside edge

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Some slight flushing. More pronounced around failure

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
07A-1	*Top* 30 *Bottom* 155	2.0 3.5	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
07B-1	*Top* 155 *Bottom* 255	2.0 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
07C-1	*Top* 255 *Bottom* 360	2.0 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.9 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 360 *Bottom* 480+	2.0 3.5	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Not sampled.

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP7-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81136	E 153.03386	Road Loc	R[10,2661,C1,5.032]	Offset (m)	In 3.5	out 4.4
Road / Segment	Sg 3855				Road Description	4 Lane Dual Carriage (Nth/Sth)	
Lane / Section	Southbound Inner Shoulder				Direction of Test Pit	Transverse	

Lane / Shoulder Widths (metres)										
	West Sh	---	O NB Lane	---	I NB Lane	---	I West Sh	---	I East Sh	1.1m
	I SB Lane	3.4m	O SB Lane	3.5m	East Sh	2.4m	---		---	

Pavement Description and Distress Mechanisms

Pavement Condition	Fair ---	Pit adjacent to small shoving failure along inner edgeline
Features	Large Cutting ---	Approx. 4m at this point
Drainage	Good ---	On downhill grade. Wide dished centre median. Crossfall runs to outside edge. SO kerb on outside edge

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Some slight flushing. More pronounced around failure

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
07A-2	*Top* 30 *Bottom* 155	3.5 4.4	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Moist , FMC = 4.9 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Moisture content only

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP8	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81229	E 153.03406	Road Loc	R[10,2661,C1,4.927]	Offset (m)	In	2.0	out	4.4
Road / Segment	Sg 3855				Road Description	4 Lane Dual Carriage (Nth/Sth)			
Lane / Section	Southbound Inner				Direction of Test Pit	Transverse			

Lane / Shoulder Widths (metres)										
	West Sh	---	O NB Lane	---	I NB Lane	---	I West Sh	---	I East Sh	1.1m
	I SB Lane	3.4m	O SB Lane	3.5m	East Sh	2.4m	---		---	

Pavement Description and Distress Mechanisms

Pavement Condition	Fair ---	Outer lane failing. Inner lane generally good
Features	Large Cutting ---	Approx. 2.5m at this point
Drainage	Good ---	On downhill grade. Wide dished centre median. Crossfall runs to outside edge. SO kerb on outside edge

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Some slight flushing in wheelpaths.

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
08A-1	*Top* 30 *Bottom* 155	2.0 3.5	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.4 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Moisture content outside edgeline FMC = 4.9%
08B-1	*Top* 155 *Bottom* 255	2.0 4.4	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.3 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
08C-1	*Top* 255 *Bottom* 360	2.0 4.4	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.3 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 360+	2.0 4.4	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Not sampled

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	5/03/2015

Roads and Maritime Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP9	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81284	E 153.03403	Road Loc R[10,2661,B1,4.920]	Offset (m)	In 1.5 out 3.5
Road / Segment	Sg 3850			Road Description	4 Lane Dual Carriage (Nth/Sth)
Lane / Section	Northbound Outer			Direction of Test Pit	Transverse

Lane / Shoulder Widths (metres)					
	West Sh 3.1m	O NB Lane 3.6m	I NB Lane 3.4m	I West Sh 1.3m	I East Sh ---
	I SB Lane ---	O SB Lane ---	East Sh ---	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Good ---	
Features	Fill ---	Approx. 2.- 2.5m high. Wire rope guard fence along outside edge.
Drainage	Good ---	On uphill grade. Crossfall runs to centre median

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Fair - slight flushing

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
09A-1	*Top* 30 *Bottom* 155	1.5 3.5	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 2.4 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
09B-1	*Top* 155 *Bottom* 255	1.5 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 3.2 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
09C-1	*Top* 250 *Bottom* 300	1.5 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 3.2 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 300+	1.5 3.5	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. No sample taken.

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	6/03/2015

Roads and Maritime Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP10-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS N -29.81204	E 153.03365	Road Loc R[10,2661,B1,5.014]		Offset (m) In 1.9 out 3.3
Road / Segment	Sg 3850	Road Description	4 Lane Dual Carriage (Nth/Sth)	
Lane / Section	Northbound Outer	Direction of Test Pit	Diagonal	

Lane / Shoulder Widths (metres)					
	West Sh 2.4m	O NB Lane 3.4m	I NB Lane 3.4m	I West Sh 1.4m	I East Sh ---
	I SB Lane ---	O SB Lane ---	East Sh ---	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor ---	Shoving along edgeline. Previous AC patch immediately above test pit.
Features	Fill ---	Approx. 2.- 2.5m high. Wire rope guard fence along outside edge.
Drainage	Good ---	On uphill grade. Crossfall runs to centre median

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Poor - Flushing in both wheelpaths

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
10A-1	*Top* 30 *Bottom* 150	1.9 3.3	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 3.6 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
10A-2	*Top* 150 *Bottom* 250	1.9 3.3	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
10C-1	*Top* 250 *Bottom* 340	1.9 3.3	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
10D-1	*Top* 340 *Bottom* 360+	1.9 3.3	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 7.9 % Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Moisture content only

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	6/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP10-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81204	E 153.03365	Road Loc R[10,2661,B1,5.014]	Offset (m)	In 3.3 out 5.8
Road / Segment	Sg 3850		Road Description	4 Lane Dual Carriage (Nth/Sth)	
Lane / Section	Northbound Outer Shoulder		Direction of Test Pit	Diagonal	

Lane / Shoulder Widths (metres)					
	West Sh 2.4m	O NB Lane 3.4m	I NB Lane 3.4m	I West Sh 1.4m	I East Sh ---
	I SB Lane ---	O SB Lane ---	East Sh ---	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Poor ---	Shoving along edgeline. Previous AC patch immediately above test pit.
Features	Fill ---	Approx. 2.- 2.5m high. Wire rope guard fence along outside edge.
Drainage	Good ---	On uphill grade. Crossfall runs to centre median

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Poor - Flushing in both wheelpaths

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
10A-2	*Top* 30 *Bottom* 100	3.3 5.8	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Moisture content taken directly under edgeline.
10B-2	*Top* 100 *Bottom* 240	3.3 5.8	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 4.3 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Moisture content only.
10C-2	*Top* 240 *Bottom* 330	3.3 5.8	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Slightly moist , FMC = 5.8 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD. Moisture content taken from 1.8m outside edgeline.

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	6/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP11-1	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81062	E 153.03352	Road Loc	R[10,2661,B1,5.171]	Offset (m)	In 1.9 out 3.5
Road / Segment	Sg 3850				Road Description	4 Lane Dual Carriage (Nth/Sth)
Lane / Section	Northbound Outer				Direction of Test Pit	Transverse

Lane / Shoulder Widths (metres)	West Sh	2.6m	O NB Lane	3.5m	I NB Lane	3.4m	I West Sh	1.4m	I East Sh	---
	I SB Lane	---	O SB Lane	---	East Sh	---	---		---	

Pavement Description and Distress Mechanisms

Pavement Condition	Good ---	Pit in good area towards top of hill
Features	Cutting ---	Approx. 3m high.
Drainage	Good ---	On uphill grade. SO kerb on outside edge.

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Good

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
11A-1	*Top* 30 *Bottom* 155	1.9 3.5	***Base*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 2.7 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
11B-1	*Top* 155 *Bottom* 255	1.9 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 2.6 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
11C-1	*Top* 255 *Bottom* 360	1.9 3.5	***Subbase*** ***Flexible***	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 3.0 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
NS	*Top* 360 *Bottom* 400+	1.9 3.5	***Select*** ***Lightly Bound***	**Silty Sandy Gravel , with Clay - Brown** PI at the lower end of specification for this course , Dry Gap graded to 50 mm, Sub-Angular Low strength Distinctly weathered rock, Dense.	Lime modified weathered sandstone. Not sampled

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date	6/03/2015

Roads and Maritme Services, NSW : Engineering Technology

Northern Laboratory - Grafton - 34 Heber St , South Grafton, 2460

SCHEDULE OF PAVEMENT AND SUBGRADE INVESTIGATION

Project Details

ETN Project No.	N2015021	Registration Number	GR 2015012
Project / Job Name:	HW10 - Pacific Highway - Glenugie Pavement Failures		

Site ID and Sampling Method

Test Pit Number / Identification	TP11-2	Sampling Method	AS1289.1.2.1 cl 6.4b

Site Location and Road details

GPS	N -29.81062	E 153.03352	Road Loc	R[10,2661,B1,5.171]	Offset (m)	In 3.5	out	4.5

Road / Segment	Sg 3850	Road Description	4 Lane Dual Carriage (Nth/Sth)
Lane / Section	Northbound Outer Shoulder	Direction of Test Pit	Transverse

Lane / Shoulder Widths (metres)	West Sh	O NB Lane	I NB Lane	I West Sh	I East Sh
	I SB Lane	O SB Lane	East Sh	---	---

Pavement Description and Distress Mechanisms

Pavement Condition	Good ---	Pit in good area towards top of hill
Features	Cutting ---	Approx. 3m high.
Drainage	Good ---	On uphill grade. SO kerb on outside edge.

Log, Material Description

Surface Type	Seal	Thickness (mm)	30	Surface Condition	Good

Sample / Layer ID	Depth (mm)	Offsets (m) *From Centre*	Course	Soil Description	Remarks
11A-2	Top 30 Bottom 155	3.5 4.5	Base Flexible	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 3.2 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
11B-2	Top 155 Bottom 255	3.5 4.5	Base Flexible	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 3.1 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD
11C-2	Top 255 Bottom 360	3.5 4.5	Base Flexible	**Sandy Silty Gravel - Pale Brown** PI at the lower end of specification for this course , Dry , FMC = 3.5 % Well graded to 20 mm, AngularDense.	Duncan's DGB20HD

There are no DCP results attached for this schedule.

Remarks

Logged By	*DM, JW*	Date

Appendix C

Soil testing results

ROADS AND MARITIME SERVICES

California Bearing Ratio of Soils and Gravel

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

CBR Record No: 17

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: Select

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Sample Name:	**03D-1**	
Date Sampled:	04/03/2015	
Lot Distance Start:	*	
Lot Distance End:	*	
Lot Number:	R[10,2661,	
Sample Chainage (km) or Location:	C1,5.055]	
Lane:	SB Outer	
Offset (M):	2.0m - 4.0m	
Depth (mm):	355 - 400	
Specimen No.	**1**	
(%) Retained on 19mm sieve:	1	
Test Method:	T117	
Additive Type:	*	
Percentage of Additive(%):	*	
Period of Soaking (Days):	10	
Compactive Effort:	Standard	
Maximum Dry Density Test Method:	T111	
Maximum Dry Density (t/m^3):	1.934	
Optimum Moisture (%):	13.0	
LDR Target and LMR Target (%):	100	100
Moisture Content Test Method:	T120	
Moisture Content (%):	12.9	
Dry Density of Specimen (t/m^3):	1.94	
Swell (%):	0.0	
Moisture Content Test Method:	T120	
Moisture Content Top 30mm (%):	14.4	
Moisture Content Whole (%):	12.9	
% of Maximum Dry Density (LDR):	100	
% of Optimum Moisture (LMR):	99	
California Bearing Ratio (%):	**15**	
At Penetration (mm):	5.0	
Max Penetration (if terminated) (mm):	12.5	

Report Comments:-

Offsets measured from lane separation line.
Material was previously lime modified at time of construction.

NATA
ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for Compliance with ISO/IEC 17025

Accreditation Number: **2606**

Dale Morgan
Laboratory Supervisor
Date: 19/06/2015

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils - Percentage Retained

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

SPECIFIED LIMITS:	RMS3051/DGB20HD	Sample:	03A-1	03A-2	03B-1	03B-2
	Date Sampled:		04/03/2015	04/03/2015	04/03/2015	04/03/2015
	Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
	Sample Chainage (km) or Location:		C1,5.055]	C1,5.055]	C1,5.055]	C1,5.055]
	Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
	Offset (m):		2.0m - 4.0m	4.0m - 5.9m	2.0m - 4.0m	4.0m - 5.9m
	Depth (mm):		30 - 155	30 - 155	155 - 260	155 - 260
	Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	Pretreatment:		*	*	*	*
T106 and T107	Pass. 37.5mm, Retained 26.5mm Sieve(%		*	*	*	*
	Pass. 26.5mm, Retained 19.0mm Sieve(%		0	0	0	0
	Pass. 19.0mm, Retained 13.2mm Sieve(%	7 - 17	9	6	6	8
	Pass. 13.2mm, Retained 9.5mm Sieve(%	8 - 16	10	10	10	13
	Pass. 9.5mm, Retained 4.75mm Sieve(%	14 - 24	20	20	22	22
	Pass. 4.75mm, Retained 2.36mm Sieve(%	8 - 18	17	16	18	16
	Pass. 2.36mm, Retained 425µm Sieve(%	14 - 28	25	27	26	20
	Pass. 425µm, Retained 75µm Sieve(%	6 - 13	7	10	6	11
	Pass. 75µm, Retained 13.5µm Sieve(%	3 - 7	7	5	7	5

Report Comments:-

Offsets taken from inner and outer lane separation line.

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for Compliance with ISO/IEC 17025

Accreditation Number: **2606**

Dale Morgan
Laboratory Supervisor
Date: 19/06/2015

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils - Percentage Retained

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Laboratory Test Report

Report: **GR2015012** Part 1

SPECIFIED LIMITS:	RMS3051/DGB20HD	Sample:	03C-1	03C-2	04A-1	04A-2
	Date Sampled:		04/03/2015	04/03/2015	04/03/2015	04/03/2015
	Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
	Sample Chainage (km) or Location:		C1,5.055]	C1,5.055]	C1,4.998]	C1,4.998]
	Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
	Offset (m):		2.0m - 4.0m	4m - 5.9m	2.0m - 4.0m	4.0m - 5.2m
	Depth (mm):		260 - 355	260 - 355	30 - 155	30 - 155
	Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	**Pretreatment:**		*	*	*	*
T106 and T107	Pass. 37.5mm, Retained 26.5mm Sieve(%		*	*	*	*
	Pass. 26.5mm, Retained 19.0mm Sieve(%		0	0	0	0
	Pass. 19.0mm, Retained 13.2mm Sieve(%	7 - 17	10	13	8	11
	Pass. 13.2mm, Retained 9.5mm Sieve(%	8 - 16	11	12	10	12
	Pass. 9.5mm, Retained 4.75mm Sieve(%	14 - 24	21	21	20	21
	Pass. 4.75mm, Retained 2.36mm Sieve(%	8 - 18	17	16	17	16
	Pass. 2.36mm, Retained 425µm Sieve(%	14 - 28	21	19	22	22
	Pass. 425µm, Retained 75µm Sieve(%	6 - 13	7	10	7	6
	Pass. 75µm, Retained 13.5µm Sieve(%	3 - 7	7	4	8	7

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils - Percentage Retained

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Laboratory Test Report

Report: **GR2015012** Part 1

SPECIFIED LIMITS:	RMS3051/DGB20HD	Sample:	04B-1	04B-2	04C-1	04C-2
	Date Sampled:		04/03/2015	04/03/2015	04/03/2015	04/03/2015
	Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
	Sample Chainage (km) or Location:		C1,4.998]	C1,4.998]	C1,4.998]	C1,4.998]
	Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
	Offset (m):		2m - 4m	4m - 5.2m	2m - 4m	4m - 5.2m
	Depth (mm):		155 - 255	155 - 255	255 - 350	255 - 350
	Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	**Pretreatment:**		*	*	*	*
T106 and T107	Pass. 37.5mm, Retained 26.5mm Sieve(%		*	*	*	*
	Pass. 26.5mm, Retained 19.0mm Sieve(%		0	0	0	0
	Pass. 19.0mm, Retained 13.2mm Sieve(%	7 - 17	10	12	10	11
	Pass. 13.2mm, Retained 9.5mm Sieve(%	8 - 16	13	12	9	12
	Pass. 9.5mm, Retained 4.75mm Sieve(%	14 - 24	21	22	20	20
	Pass. 4.75mm, Retained 2.36mm Sieve(%	8 - 18	16	16	19	17
	Pass. 2.36mm, Retained 425µm Sieve(%	14 - 28	22	20	21	21
	Pass. 425µm, Retained 75µm Sieve(%	6 - 13	9	9	8	10
	Pass. 75µm, Retained 13.5µm Sieve(%	3 - 7	4	4	7	4

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils - Percentage Retained

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

SPECIFIED LIMITS:	RMS3051/DGB20HD	Sample:	05A-1	05A-2	05B-1	05B-2
	Date Sampled:		05/03/2015	05/03/2015	05/03/2015	05/03/2015
	Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
	Sample Chainage (km) or Location:		C1,4.871]	C1,4.871]	C1,4.871]	C1,4.871]
	Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
	Offset (m):		2.0m - 4.0m	5.1m - 5.4m	2m - 4m	5.1m - 5.4m
	Depth (mm):		25 - 150	25 - 165	150 - 255	165 - 260
	Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	**Pretreatment:**		*	*	*	*
T106 and T107	Pass. 37.5mm, Retained 26.5mm Sieve(%		*	*	*	*
	Pass. 26.5mm, Retained 19.0mm Sieve(%		0	0	0	0
	Pass. 19.0mm, Retained 13.2mm Sieve(%	7 - 17	9	7	9	11
	Pass. 13.2mm, Retained 9.5mm Sieve(%	8 - 16	12	10	11	15
	Pass. 9.5mm, Retained 4.75mm Sieve(%	14 - 24	20	18	22	22
	Pass. 4.75mm, Retained 2.36mm Sieve(%	8 - 18	17	17	17	15
	Pass. 2.36mm, Retained 425µm Sieve(%	14 - 28	22	24	25	20
	Pass. 425µm, Retained 75µm Sieve(%	6 - 13	10	9	6	6
	Pass. 75µm, Retained 13.5µm Sieve(%	3 - 7	4	8	6	7

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils - Percentage Retained

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Laboratory Test Report

Report: **GR2015012** Part 1

SPECIFIED LIMITS:	RMS3051/DGB20HD	Sample:	05C-1	05C-2
	Date Sampled:		05/03/2015	05/03/2015
	Lot Number:		R[10,2661,	R[10,2661,
	Sample Chainage (km) or Location:		C1,4.871]	C1,4.871]
	Lane:		SB Outer	SB Shldr
	Offset (m):		2m - 4m	5.1m - 5.4m
	Depth (mm):		255 - 350	260 - 350
	Material Type:		DGB20	DGB20
TESTS	**Pretreatment:**		*	*
T106 and T107	Pass. 37.5mm, Retained 26.5mm Sieve(%		*	*
	Pass. 26.5mm, Retained 19.0mm Sieve(%		1	1
	Pass. 19.0mm, Retained 13.2mm Sieve(%	7 - 17	12	13
	Pass. 13.2mm, Retained 9.5mm Sieve(%	8 - 16	12	12
	Pass. 9.5mm, Retained 4.75mm Sieve(%	14 - 24	21	23
	Pass. 4.75mm, Retained 2.36mm Sieve(%	8 - 18	16	15
	Pass. 2.36mm, Retained 425µm Sieve(%	14 - 28	24	20
	Pass. 425µm, Retained 75µm Sieve(%	6 - 13	8	8
	Pass. 75µm, Retained 13.5µm Sieve(%	3 - 7	4	3

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Laboratory Test Report

Report: **GR2015012** Part 1

SPECIFIED LIMITS:		RMS3051/DGB20HD	Sample:	03A-1	03A-2	03B-1	03B-2
		Date Sampled:		04/03/2015	04/03/2015	04/03/2015	04/03/2015
		Lot Number:					
		Sample Chainage (km) or Location:		R[10,2661, C1,5.055]	R[10,2661, C1,5.055]	R[10,2661, C1,5.055]	R[10,2661, C1,5.055]
		Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
		Offset (m):		2.0m - 4.0m	4.0m - 5.9m	2.0m - 4.0m	4.0m - 5.9m
		Depth (mm):		30 - 155	30 - 155	155 - 260	155 - 260
		Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	PORTION	Pretreatment:		*	*	*	*
T106	WHOLE SAMPLE	Passing 75.0mm Sieve(%):		*	*	*	*
		Passing 53.0mm Sieve(%):		*	*	*	*
		Passing 37.5mm Sieve(%):		*	*	*	*
		Passing 26.5mm Sieve(%):	100	100	100	100	100
		Passing 19.0mm Sieve(%):	95-100	100	100	100	100
		Passing 13.2mm Sieve(%):	78-92	91	93	93	92
		Passing 9.50mm Sieve(%):	63-83	81	84	83	79
		Passing 6.70mm Sieve(%):		71	73	72	67
		Passing 4.75mm Sieve(%):	44-64	61	64	62	57
		Passing 2.36mm Sieve(%):	33-49	44	48	44	41
T107	WHOLE SAMPLE	Passing 425µm Sieve(%):	14-23	19	22	18	21
		Passing 75µm Sieve(%):	7-14	12	11	12	10
		Passing 13.5µm Sieve(%):	3-7	5.0	6.0	5.0	5.5
T107	-2.36mm	Passing 425µm Sieve(%):		42.0	45.0	40.0	50.0
		Passing 75µm Sieve(%):		26.0	23.0	26.0	25.0
		Passing 13.5µm Sieve(%):		11.5	13.0	12.0	13.5
	*	A Ratio:		42	45	40	50
		B Ratio:		63	50	66	49
		C Ratio:		44	57	45	55
		Observation:		*	*	*	*
AS1289.3.1.2	-425um	Liquid Limit (%):	Max 20	21	20	*	*
AS1289.3.2.1		Plastic Limit (%):	Max 20	17	16	*	*
		Moisture Content Method:		AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1
AS1289.3.3.1		Plasticity Index (%):	2 - 6	4	4	*	*
		Samp. Hist. / Preparation*:		OD/DRY	OD/DRY	OD/DRY	OD/DRY
*	-19mm	Maximum Dry Density (t/m^3)		*	*	*	*
		Moist. Cont. Method (MDD)		*	*	*	*
		Optimum Moist. Content (%		*	*	*	*
*	-2.36mm	Linear Shrinkage (%):		*	*	*	*
*	-19mm	MDCS Moist. Cont. (%):		*	*	*	*
		M. D. C. S. (MPa):	Min 1.7	*	*	*	*
		Straddling:		*	*	*	*
*	*	Moisture Content (%):		*	*	*	*

Report Comments:-

*: NS - Natural State; OD - Oven Dried; UK - Unknown; WET - Wet Sieved; DRY - Dry Sieved

Offsets taken from inner and outer lane separation line.

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for Compliance with ISO/IEC 17025

Accreditation Number: **2606**

This document shall not be reproduced, except in full.

Dale Morgan
Laboratory Supervisor
Date: 19/06/2015

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils

SOIL Record No: 33	Client: Asset Northern - Journey Management - Ross Gersekowski	Transport Roads & Maritime Services
Recieved: 4/03/2015	Address: 76 Victoria St Grafton	**Grafton Laboratory**
Sampled By: DM, JW	Client Ref: A/13262/01/D Lab Ref (Project): N2015021	34 Heber Street South Grafton NSW 2460
Sampling Method: AS1289.1.2.1 cl 6.4b	Project Description: HW10 Pacific Highway - Glenugie Pavement Failures	T: (02) 6642 9930 F: (02) 6642 9997
Material: DGB20	Work Details: Pavement & Subgrade Investigation	
Request Id:	Work Distance: *	***Laboratory Test Report***
	Supplier: Ex Pavement Test Pits	Report: **GR2015012** Part 1

SPECIFIED LIMITS:	RMS3051/DGB20HD		Sample:	03C-1	03C-2	04A-1	04A-2
		Date Sampled:		04/03/2015	04/03/2015	04/03/2015	04/03/2015
		Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
		Sample Chainage (km) or Location:		C1,5.055]	C1,5.055]	C1,4.998]	C1,4.998]
		Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
		Offset (m):		2.0m - 4.0m	4m - 5.9m	2.0m - 4.0m	4.0m - 5.2m
		Depth (mm):		260 - 355	260 - 355	30 - 155	30 - 155
		Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	**PORTION**	**Pretreatment:**		*	*	*	*
T106	WHOLE SAMPLE	Passing 75.0mm Sieve(%):		*	*	*	*
		Passing 53.0mm Sieve(%):		*	*	*	*
		Passing 37.5mm Sieve(%):		*	*	*	*
		Passing 26.5mm Sieve(%):	100	100	100	100	100
		Passing 19.0mm Sieve(%):	95-100	100	100	100	100
		Passing 13.2mm Sieve(%):	78-92	89	87	92	89
		Passing 9.50mm Sieve(%):	63-83	78	75	82	77
		Passing 6.70mm Sieve(%):		68	63	71	66
		Passing 4.75mm Sieve(%):	44-64	58	54	62	56
		Passing 2.36mm Sieve(%):	33-49	40	38	44	40
T107	WHOLE SAMPLE	Passing 425µm Sieve(%):	14-23	19	19	22	18
		Passing 75µm Sieve(%):	7-14	12	9.0	15	12
		Passing 13.5µm Sieve(%):	3-7	5.0	5.0	7.0	5.0
T107	-2.36mm	Passing 425µm Sieve(%):		46.0	49.0	50.0	45.0
		Passing 75µm Sieve(%):		29.0	24.0	33.0	29.0
		Passing 13.5µm Sieve(%):		12.5	13.5	15.5	12.5
	*	A Ratio:		46	49	50	45
		B Ratio:		62	48	67	65
		C Ratio:		43	57	47	43
		Observation:		*	*	*	*
AS1289.3.1.2	-425um	Liquid Limit (%):	Max 20	*	*	22	20
AS1289.3.2.1		Plastic Limit (%):	Max 20	*	*	15	16
		Moisture Content Method:		AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1
AS1289.3.3.1		Plasticity Index (%):	2 - 6	*	*	7	4
		Samp. Hist. / Preparation*:		OD/DRY	OD/DRY	OD/DRY	OD/DRY
*	-19mm	Maximum Dry Density (t/m³		*	*	*	*
		Moist. Cont. Method (MDD		*	*	*	*
		Optimum Moist. Content (%		*	*	*	*
*	-2.36mm	Linear Shrinkage (%):		*	*	*	*
*	-19mm	MDCS Moist. Cont. (%):		*	*	*	*
		M. D. C. S. (MPa):	Min 1.7	*	*	*	*
		Straddling:		*	*	*	*
*	*	Moisture Content (%):		*	*	*	*

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D　Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Laboratory Test Report

Report: **GR2015012** Part 1

SPECIFIED LIMITS:	RMS3051/DGB20HD		Sample:	04B-1	04B-2	04C-1	04C-2
		Date Sampled:		04/03/2015	04/03/2015	04/03/2015	04/03/2015
		Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
		Sample Chainage (km) or Location:		C1,4.998]	C1,4.998]	C1,4.998]	C1,4.998]
		Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
		Offset (m):		2m - 4m	4m - 5.2m	2m - 4m	4m - 5.2m
		Depth (mm):		155 - 255	155 - 255	255 - 350	255 - 350
		Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	**PORTION**	**Pretreatment:**		*	*	*	*
T106	WHOLE SAMPLE	Passing 75.0mm Sieve(%):		*	*	*	*
		Passing 53.0mm Sieve(%):		*	*	*	*
		Passing 37.5mm Sieve(%):		*	*	*	*
		Passing 26.5mm Sieve(%):	100	100	100	100	100
		Passing 19.0mm Sieve(%):	95-100	100	100	100	100
		Passing 13.2mm Sieve(%):	78-92	90	88	90	89
		Passing 9.50mm Sieve(%):	63-83	77	76	80	77
		Passing 6.70mm Sieve(%):		66	64	70	66
		Passing 4.75mm Sieve(%):	44-64	56	53	60	57
		Passing 2.36mm Sieve(%):	33-49	40	38	41	40
T107	WHOLE SAMPLE	Passing 425µm Sieve(%):	14-23	18	18	20	19
		Passing 75µm Sieve(%):	7-14	9.0	9.0	12	9.0
		Passing 13.5µm Sieve(%):	3-7	5.0	5.0	5.5	5.5
T107	-2.36mm	Passing 425µm Sieve(%):		45.0	47.0	48.0	48.0
		Passing 75µm Sieve(%):		22.0	24.0	30.0	23.0
		Passing 13.5µm Sieve(%):		13.0	13.5	13.0	13.5
	*	A Ratio:		45	47	48	48
		B Ratio:		49	51	61	48
		C Ratio:		57	57	45	60
		Observation:		*	*	*	*
AS1289.3.1.2	-425um	Liquid Limit (%):	Max 20	*	*	*	*
AS1289.3.2.1		Plastic Limit (%):	Max 20	*	*	*	*
		Moisture Content Method:		AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1
AS1289.3.3.1		Plasticity Index (%):	2 - 6	*	*	*	*
		Samp. Hist. / Preparation*:		OD/DRY	OD/DRY	OD/DRY	OD/DRY
*	-19mm	Maximum Dry Density (t/m^3		*	*	*	*
		Moist. Cont. Method (MDD		*	*	*	*
		Optimum Moist. Content (%		*	*	*	*
*	-2.36mm	Linear Shrinkage (%):		*	*	*	*
*	-19mm	MDCS Moist. Cont. (%):		*	*	*	*
		M. D. C. S. (MPa):	Min 1.7	*	*	*	*
		Straddling:		*	*	*	*
*	*	Moisture Content (%):		*	*	*	*

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

SOIL Record No: 33

Recieved: 4/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

SPECIFIED LIMITS:	RMS3051/DGB20HD		Sample:	05A-1	05A-2	05B-1	05B-2
		Date Sampled:		05/03/2015	05/03/2015	05/03/2015	05/03/2015
		Lot Number:		R[10,2661,	R[10,2661,	R[10,2661,	R[10,2661,
		Sample Chainage (km) or Location:		C1,4.871]	C1,4.871]	C1,4.871]	C1,4.871]
		Lane:		SB Outer	SB Shldr	SB Outer	SB Shldr
		Offset (m):		2.0m - 4.0m	5.1m - 5.4m	2m - 4m	5.1m - 5.4m
		Depth (mm):		25 - 150	25 - 165	150 - 255	165 - 260
		Material Type:		DGB20	DGB20	DGB20	DGB20
TESTS	**PORTION**	**Pretreatment:**		*	*	*	*
T106	WHOLE SAMPLE	Passing 75.0mm Sieve(%):		*	*	*	*
		Passing 53.0mm Sieve(%):		*	*	*	*
		Passing 37.5mm Sieve(%):		*	*	*	*
		Passing 26.5mm Sieve(%):	100	100	100	100	100
		Passing 19.0mm Sieve(%):	95-100	100	100	100	100
		Passing 13.2mm Sieve(%):	78-92	91	93	91	89
		Passing 9.50mm Sieve(%):	63-83	79	83	80	74
		Passing 6.70mm Sieve(%):		68	74	69	61
		Passing 4.75mm Sieve(%):	44-64	58	65	59	52
		Passing 2.36mm Sieve(%):	33-49	41	47	42	37
T107	WHOLE SAMPLE	Passing 425µm Sieve(%):	14-23	19	23	17	17
		Passing 75µm Sieve(%):	7-14	9.0	14	11	11
		Passing 13.5µm Sieve(%):	3-7	6.0	6.0	5.0	4.5
T107	-2.36mm	Passing 425µm Sieve(%):		46.0	48.0	40.0	46.0
		Passing 75µm Sieve(%):		22.0	30.0	25.0	28.0
		Passing 13.5µm Sieve(%):		14.5	12.5	11.5	12.0
	*	A Ratio:		45	48	40	46
		B Ratio:		49	63	64	61
		C Ratio:		64	42	45	42
		Observation:		*	*	*	*
AS1289.3.1.2	-425um	Liquid Limit (%):	Max 20	23	21	*	*
AS1289.3.2.1		Plastic Limit (%):	Max 20	15	15	*	*
		Moisture Content Method:		AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1	AS1289.2.1.1
AS1289.3.3.1		Plasticity Index (%):	2 - 6	8	6	*	*
		Samp. Hist. / Preparation*:		OD/DRY	OD/DRY	OD/DRY	OD/DRY
*	-19mm	Maximum Dry Density (t/m3		*	*	*	*
		Moist. Cont. Method (MDD		*	*	*	*
		Optimum Moist. Content (%		*	*	*	*
*	-2.36mm	Linear Shrinkage (%):		*	*	*	*
*	-19mm	MDCS Moist. Cont. (%):		*	*	*	*
		M. D. C. S. (MPa):	Min 1.7	*	*	*	*
		Straddling:		*	*	*	*
*	*	Moisture Content (%):		*	*	*	*

ROADS AND MARITIME SERVICES

Pavement Materials, Fill, Subgrade and Soils

Transport Roads & Maritime Services (NSW Government)

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

SOIL Record No: 33	Client:	Asset Northern - Journey Management - Ross Gersekowski	
Recieved: 4/03/2015	Address:	76 Victoria St Grafton	
Sampled By: DM, JW	Client Ref:	A/13262/01/D	Lab Ref (Project): N2015021
Sampling Method: AS1289.1.2.1 cl 6.4b	Project Description:	HW10 Pacific Highway - Glenugie Pavement Failures	
Material: DGB20	Work Details:	Pavement & Subgrade Investigation	
	Work Distance:	*	
Request Id:	Supplier:	Ex Pavement Test Pits	

SPECIFIED LIMITS:	RMS3051/DGB20HD		Sample:	05C-1	05C-2
		Date Sampled:		05/03/2015	05/03/2015
		Lot Number:		R[10,2661,	R[10,2661,
		Sample Chainage (km) or Location:		C1,4.871]	C1,4.871]
		Lane:		SB Outer	SB Shldr
		Offset (m):		2m - 4m	5.1m - 5.4m
		Depth (mm):		255 - 350	260 - 350
		Material Type:		DGB20	DGB20
TESTS	**PORTION**	**Pretreatment:**		*	*
T106	WHOLE SAMPLE	Passing 75.0mm Sieve(%):		*	*
		Passing 53.0mm Sieve(%):		*	*
		Passing 37.5mm Sieve(%):		*	*
		Passing 26.5mm Sieve(%):	100	100	100
		Passing 19.0mm Sieve(%):	95-100	100	99
		Passing 13.2mm Sieve(%):	78-92	88	86
		Passing 9.50mm Sieve(%):	63-83	76	74
		Passing 6.70mm Sieve(%):		64	62
		Passing 4.75mm Sieve(%):	44-64	54	51
		Passing 2.36mm Sieve(%):	33-49	39	35
T107	WHOLE SAMPLE	Passing 425µm Sieve(%):	14-23	15	15
		Passing 75µm Sieve(%):	7-14	7.5	7.0
		Passing 13.5µm Sieve(%):	3-7	4.0	4.0
T107	-2.36mm	Passing 425µm Sieve(%):		38.0	42.0
		Passing 75µm Sieve(%):		19.0	20.0
		Passing 13.5µm Sieve(%):		10.5	11.0
	*	A Ratio:		38	42
		B Ratio:		50	47
		C Ratio:		55	56
		Observation:		*	*
AS1289.3.1.2	-425um	Liquid Limit (%):	Max 20	*	*
AS1289.3.2.1		Plastic Limit (%):	Max 20	*	*
		Moisture Content Method:		AS1289.2.1.1	AS1289.2.1.1
AS1289.3.3.1		Plasticity Index (%):	2 - 6	*	*
		Samp. Hist. / Preparation*:		OD/DRY	OD/DRY
*	-19mm	Maximum Dry Density (t/m³		*	*
		Moist. Cont. Method (MDD		*	*
		Optimum Moist. Content (%		*	*
*	-2.36mm	Linear Shrinkage (%):		*	*
*	-19mm	MDCS Moist. Cont. (%):		*	*
		M. D. C. S. (MPa):	Min 1.7	*	*
		Straddling:		*	*
*	*	Moisture Content (%):		*	*

ROADS AND MARITIME SERVICES

Unconfined Compressive Strength of Soils and Gravel

NSW GOVERNMENT | Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

UCS Record No: 34

Recieved: 5/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20+Lime

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Sample Name:	05U		05U		06U		06U	
Date Sampled:	05/03/2015		05/03/2015		05/03/2015		05/03/2015	
Lot Distance Start:	*		*		*		*	
Lot Distance End:	*		*		*		*	
Lot Number:	R[10,2661,		R[10,2661,		R[10,2661,		R[10,2661,	
Sample Chainage (km) / Location:	C1,4.871]		C1,4.871]		C1,5.063]		C1,5.063]	
Lane:	SB Outer		SB Outer		SB Inner		SB Inner	
Offset (M):	2.0m - 4.0m		2.0m - 4.0m		2.0m - 3.5m		2.0m - 3.5m	
Depth (mm):	25 - 350		25 - 350		30 - 355		30 - 355	
Specimen No.	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**
Retained on 37.5mm sieve (%):	*		*		*		*	
Retained on 19mm sieve (%):	0.0		0.0		0.0		0.0	
Test Method:	T131		T131		T131		T131	
Additive Type:	70% Slag / 30% Hydrated Lime		70% Slag / 30% Hydrated Lime		70% Slag / 30% Hydrated Lime		70% Slag / 30% Hydrated Lime	
Percentage of Additive(%):	1.5		3.5		2.0		4.0	
Days of Curing:	7		7		7		7	
Condition of Curing:	Accelerated		Accelerated		Accelerated		Accelerated	
Period of Soaking (Hours):	4		4		4		4	
Standing Time:	1 Hrs 0 Mins		1 Hrs 0 Mins		1 Hrs 0 Mins		1 Hrs 0 Mins	
Compaction Type:	Standard		Standard		Standard		Standard	
Max. Dry Density Test Method:	T130		T130		T130		T130	
Maximum Dry Density (t/m_3):	2.113		2.132		2.120		2.101	
Optimum Moisture (%):	7.9		8.7		8.1		8.4	
Moisture Content Test Method:	T120		T120		T120		T120	
Moisture Content (%):	7.3	7.4	8.1	8.3	8.0	7.8	8.3	7.8
Dry Density of Specimen (t/m_3):	2.13	2.10	2.15	2.15	2.15	2.10	2.13	2.14
Condition after curing:	Moist	Moist	Moist	Moist	Moist	Moist	Moist	Moist
UCS (Mpa):	3.05	2.90	4.25	4.50	3.95	3.70	4.80	4.95
Average per pair (MPa):	**3.0**		**4.4**		**3.8**		**4.9**	

Report Comments:-

Samples underwent three cycles of pretreatment by compaction prior to testing.
Offsets measured from lane separation line.

NATA ACCREDITED FOR TECHNICAL COMPETENCE

Accredited for Compliance with ISO/IEC 17025

Accreditation Number: **2606**

Dale Morgan
Laboratory Supervisor
Date: 18/06/2015

ROADS AND MARITIME SERVICES

Unconfined Compressive Strength of Soils and Gravel

UCS Record No: 34

Recieved: 5/03/2015

Sampled By: DM, JW

Sampling Method: AS1289.1.2.1 cl 6.4b

Material: DGB20+Lime

Request Id:

Client: Asset Northern - Journey Management - Ross Gersekowski

Address: 76 Victoria St Grafton

Client Ref: A/13262/01/D   Lab Ref (Project): N2015021

Project Description: HW10 Pacific Highway - Glenugie Pavement Failures

Work Details: Pavement & Subgrade Investigation

Work Distance: *

Supplier: Ex Pavement Test Pits

Transport Roads & Maritime Services

Grafton Laboratory
34 Heber Street
South Grafton NSW 2460
T: (02) 6642 9930
F: (02) 6642 9997

Laboratory Test Report

Report: **GR2015012** Part 1

Sample Name:	07U		07U	
Date Sampled:	05/03/2015		05/03/2015	
Lot Distance Start:	*		*	
Lot Distance End:	*		*	
Lot Number:	R[10,2661,		R[10,2661,	
Sample Chainage (km) / Location:	C1,5.032]		C1,5.032]	
Lane:	SB Inner		SB Inner	
Offset (M):	2m - 3.5m		2m - 3.5m	
Depth (mm):	30 - 360		30 - 360	
Specimen No.	**09**	**10**	**11**	**12**
Retained on 37.5mm sieve (%):	*		*	
Retained on 19mm sieve (%):	0.0		0.0	
Test Method:	T131		T131	
Additive Type:	70% Slag / 30% Hydrated Lime		70% Slag / 30% Hydrated Lime	
Percentage of Additive(%):	1.5		3.5	
Days of Curing:	7		7	
Condition of Curing:	Accelerated		Accelerated	
Period of Soaking (Hours):	4		4	
Standing Time:	1 Hrs 0 Mins		1 Hrs 0 Mins	
Compaction Type:	Standard		Standard	
Max. Dry Density Test Method:	T130		T130	
Maximum Dry Density (t/m_3):	2.120		2.135	
Optimum Moisture (%):	8.1		8.5	
Moisture Content Test Method:	T120		T120	
Moisture Content (%):	8.4	8.5	8.9	8.8
Dry Density of Specimen (t/m_3):	2.11	2.12	2.12	2.12
Condition after curing:	Moist	Moist	Moist	Moist
UCS (Mpa):	3.25	3.30	3.90	3.90
Average per pair (MPa):	**3.3**		**3.9**	

Appendix D

Project plan

3.4 Project Strategy

The project strategy will be conducted in 5 phases;

- **Start-up Phase** – involve obtaining agreement to use RMS data and RMS resources and gather specialist information
- **Gathering data phase** – Gather a range of data that may be used in the research project. The data is broken up into 2 categories Primary and secondary, with the primary data being most important to be gather first.

  Primary data;

  1. Sampling logs and test results for test pit sampling that was carried out at Glenugie in 2015.
  2. Construction testing that was carried out during road construction (Impractically grading and Atterberg testing carried out on stock piles)
  3. RMS RAMS data which includes Travel speed deflection, roughness data, cracking data

  Secondary data;

  4. Test results from material development carried out in the development of a suitable gravel for the Glenugie project.
  5. Construction testing that was carried out during road construction (deflection testing carried out at top SMZ layer)
  6. NCR register from road construction
- **Data collecting phase** – collect quality video record of the both lanes of the of the road section of interest, collect anecdotal evidence from the follow people:
  1. Greg Nash – Senior project engineer for project
  2. Mitch Ingram – Project engineer for project

3. Steve Gamble – Geotechnical scientist that help with material development
4. Rick Jones – Surveillance officer

- **Data organisation Phase** –compile all data and organise data in a presentable form so it can be clearly understood and compared. Use videos to produce road mapping of failure along section for comparison.
- **Data Analysis Phase** – Analysis compiled data to determine failure mechanism and develop theory to root cause failure. Examine how the root cause could be avoided in the future and what it mean for Glenugie maintenance program moving forward.
- **Write up Phase** – involves the drafting and final writing of the project dissertation

Further detail of the methodology are outline in table 3.1 with individual tasks described.

Table 3.1: Project individual task description

Phase 1	**Start-up Phase**
1a	Resources agreement – obtain agreement with RMS data and test results to be to be used in project
1b	Background information – start carrying out background research in specialty areas where my knowledge is limited.
1c	Start writing up background – start writing up background information including basic and specialty information
Phase 2	**Gathering data phase**
2a	Primary data; Tests and logs - Sampling logs and test results for test pit sampling that was carried out at Glenugie in 2015. Contact: Ben Churton, Dale Morgan
2b	Primary data;

	Construction testing - that was carried out during road construction (Impractically grading and Atterberg testing carried out on stock piles). Contact: Greg Nash, Mitch Ingram
2c	Primary data; RMS RAMS data - which includes Travel speed deflection, roughness data, cracking data. Contact: John Howell
2d	Secondary data; Material development testing - Test results from material development carried out in the development of a suitable gravel for the Glenugie project. Contact: Steve Gamble
2e	Construction testing - that was carried out during road construction (deflection testing carried out at top UFZ layer) Contact: Greg Nash, Mitch Ingram
2f	NCR register - from road construction Contact: Greg Nash, Mitch Ingram
Phase 3	**Data collecting phase**
3a	Interview - Greg Nash – Senior project engineer for project
3b	Interview - Mitch Ingram – Project engineer for project
3c	Interview - Steve Gamble – Geotechnical scientist that help with material development
3d	Interview - Rick Jones – Surveillance officer
3e	Video - Collect quality video record of the both lanes of the of the road section of interest
Phase 4	**Data organisation Phase**

4a	Compile all data and organise data in a presentable form so it can be clearly understood and compared.
4b	Use videos of road to produce road mapping of failure along section for comparison with other data sets.
4c	Convert TSD – attempted to covert TSD data in to a data set comparable with other deflection tests
4d	Start writing up result section
Phase 5	**Data Analysis**
5a	Soil testing results – compare test results with RMS 3501 specification, construction testing and optimum moisture content determine if material breakdown or moisture ingress had occurred in the pavement.
5b	TSD data – compare test results with construction testing, RMS guidelines, scientific literature and failure mapping. Determine extent of the expected failure in the near future
5c	Identify design weaknesses – Identify root causes of the failures and whether these are related to issues in design, construction, specifications or materials
5d	Recommendation – make recommendations based on the information gathered and the testing on areas where heavy duty granular pavements in Northern NSW can be improved
5e	Start writing up discussion
Phase 6	**Write up Phase**
6a	Draft dissertation - write a draft dissertation so supervisor and others can review and provide feedback
6b	Final dissertation – make final alteration based on the feedback received from review and double check it conforms formal writing guide provided by USQ.

3.5 Resource Requirements

The analysis of the resources and equipment need to complete the project can be found in in table 3.2 below. The majority of the resources for the project will be supplied by RMS. Currently an agreement has been reach between the student and RMS. The agreement is that RMS will provide testing results and data of the Glenugie pavement at no cost.

Table 3.4: Project resource analysis

Task	Items	Amount	Source	Cost
1b	Assess to RMS and USQ library	1	Student & RMS	Nil
1c	Laptop & word processing software	1	Student	Nil
2a, 2b, 2c, 2d, 2e, 2f	Assess to RMS data systems and record keeping	1	Student & RMS	Nil
3a, 3b, 3c, 3d	Recording device Access to relevant person	1 1	Student RMS	Nil
3e	Video recording device & mount Motor vehicle	1 1	Student	Nil
4a, 4b, 4c	Excel software Matlab software	1 1	Student	Nil
6a -6b	Word software Endnote software	1 1	Student	Nil

4. Project Planning

4.1 Risk Assessments

The risk assessment for this project aims to analyse the project from two angles, personal risk to the student, colleagues and resources and risks that pose a threat to the project's completion. The risk assessment is based on the Work Cover HAZPAK (Work Cover NSW 1996) where the likelihood and consequence matrix has been adapted both personal and project risk, table 4.1 and 4.2 respectively . The Primary focus of the risk assessment will be to scrutinise activity undertaken by the student throughout project, these include the mapping failures conduction interviews. The assessment will briefly touch on some of the risks involved in the RMS testing and sampling work without expanding into too much detail, as RMS will go through their own risk assessment for work carried out by them. The risk matrix will examine perceived risk for the length of the project, ranking the risk a low, high or medium. This will be listed in table 4.3 (personal) and 4.4 (project) along with the actions to minimise the risks.

Table 4.1Personal risk - likelihood and consequence matrix

How severely could the project timeline be effected (1,2,3,4)	***Likelihood of incident occurring (A,B,C,D)***			
	Very likely could happen any time	**Likely** could happen sometime	**Unlikely** could happen but very rarely	**Very unlikely** could happen but probably never will
Kill or cause permanent disability or ill health	A1	B1	C1	D1
Long term illness or serious injury	A2	B2	C2	D2
Medical attention and several days off work	A3	B3	C3	D3

first aid needed	A4	B4	C4	D4

Risk legend

Catistofic	high	medium	low	minor

Table reference (Work Cover NSW 1996)

Table 4.2: Project risk - likelihood and consequence matrix

How severely could the project timeline be effected (1,2,3,4)	***Likelihood of incident occurring (A,B,C,D)***			
	Very likely could happen any time	**Likely** could happen sometime	**Unlikely** could happen but very rarely	**Very unlikely** could happen but probably never will
Prevent the completion of the project	A1	B1	C1	D1
Major delay of months	A2	B2	C2	D2
Major delay of weeks	A3	B3	C3	D3
Minor delay of days	A4	B4	C4	D4

Risk legend

Catistofic	high	medium	low	minor

Table reference (Work Cover NSW 1996)

Table 4.3: Personal risk assessment

Task	Hazard	Risk	Minimisation

2a	being a car accident or being struck by a car	C2	1. Used designated parking area fit camera to car and tether camera to car 2. Adhere to all road regulations and traffic rules 3. Make sure U-turns and any stopping is carried out in designated areas 4. Drive at speed limit to prevent being a hazard to other road users 5. Wear high-vis vest to improve visibility to other when setting up
2a	Over exposer to the sun	C4	1. Use adequate sun protection (long sleeve shirt, long pants, broad breamed hat, sun glass and sunscreen
1c	Injury of laboratory technician by traffic	C2	1. Design the test plan with mindfulness of how the test pitting will be carried out and choose areas with sufficient shoulder for machinery
3c	Injury in laboratory eg oven burn and crushing injury from compaction machine	C3	1. Carried safety induction for laboratory 2. Carried necessary training on all laboratory equipment before using it 3. Follow direction from laboratory manger and technicians
4a-4d 5a-5b	Injury due to prolonged office work	C4	1. Take regular breaks 2. Set office space with best ergonomic practices 3. Manage time well to allow for breaks

Table 4.4: Project risk assessment

Task	Hazard	Risk	Minimisation
2b, 2e	Construction data not being available	C2	1. Start the process for obtaining data as early as possible 2. Contact Greg Nash and Mitch Ingram early in the project 3. Develop project in a manner that means it can be completed without data
1c, 4d, 5e, 6a, 6b	Report writing not being completed on time	B4	1. Start the process of writing the report as early as possible 2. Follow schedule 3. Take some time off work in July to complete majority of the writing.

4.2 Communication Plan

Communication is one of the key areas of any large project and a clear line of communication can very beneficial to the project (Schermerhorn 2010). The communication plan for this project can be viewed schematically in figure 4.1 with the detail of the links outline in table 4.5. These show the links between the key people involved and their relationships as well as the median generally used for communication.

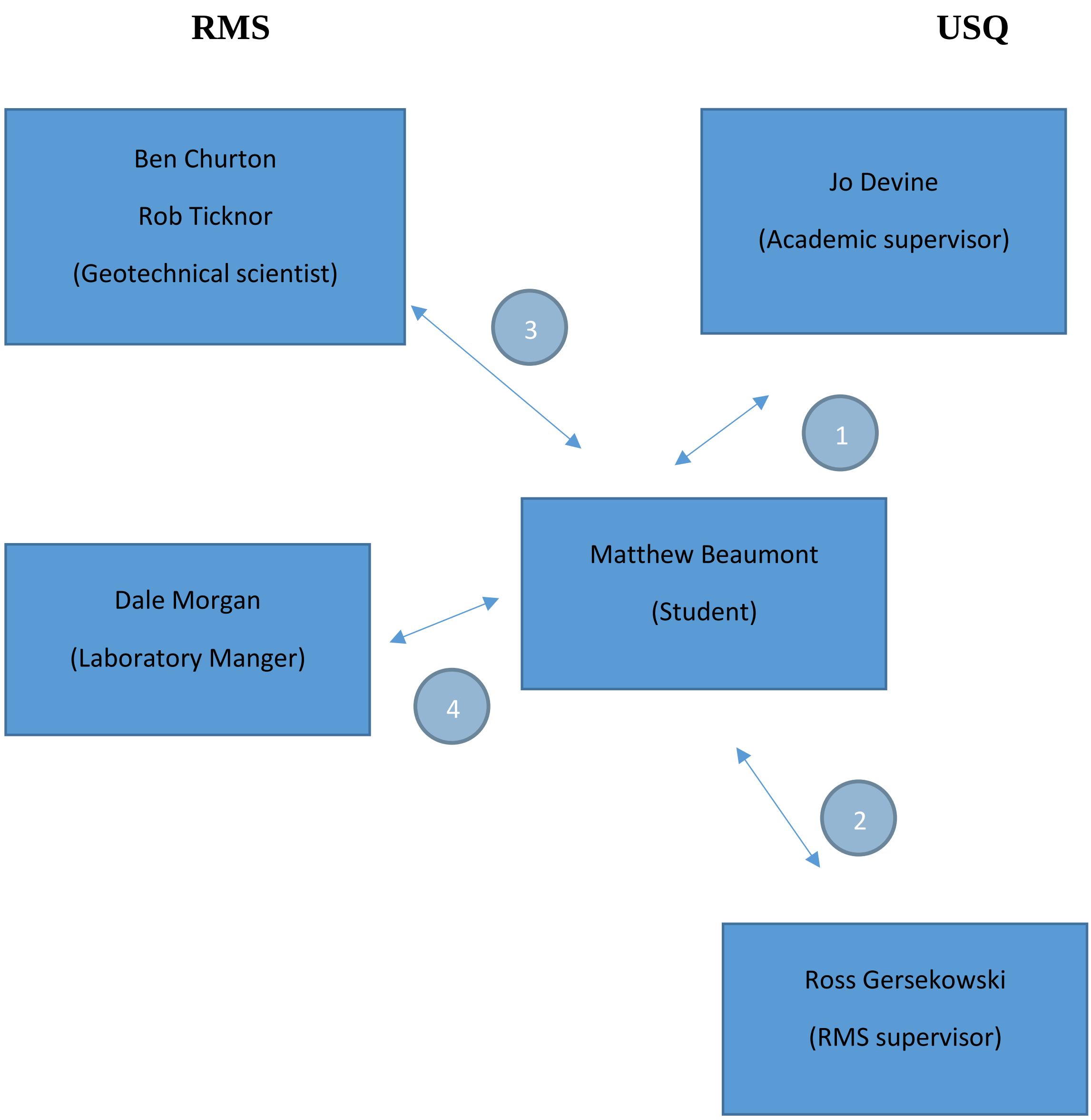


Figure 4.1: Schematic of the communication plan for key people involved in the project

Table 4.5: Description of communication links

Link	Description
1	Supervisor provides student support and feedback on project and queries. Student updates supervisor regularly of progress and issues that they may need help to solve. Monthly meeting in the form of progress emails with follow up phone calls. Face to face meeting at USQ during practice course (3 weeks over the course of the project). Primary median for communication: email secondary: phone & face to face
2	Help provide advice on technical matters and RMS expectation of the research. To confirm RMS money in being spent in the correct testing areas. Primary median for communication: email secondary: phone & face to face
3	Help provide advice on technical matters. Primary median for communication: email secondary: phone & face to face
4	Provide advice testing and test results Primary median for communication: email secondary: phone & face to face

4.3 Special Requirements

At this stage of the project there are no special requirements but it is worth noting that if the study was to find that RMS or the contactor did something toward in the design or construction, a confidentiality restriction may be need. This outcome is unexpected and not likely to occur. Any data provided by RMS throughout the study would remain the property RMS with approval required before supplying to a third party.

4.4 Project Schedule

The project schedule has several features which will help the project achieve the outcomes and aims. The feature list below can be observed in the planned schedule in figure 4.2.

- Student review point. Point at which project will be dropped if formal agreement with RMS has not been reached. (review point achieved)
- Review point 1. Point which the supervisor and RMS representatives can provide feedback on the and alignment with objectives
- Review point 2. Point which the supervisor and RMS representatives can provide feedback on data analysis and alignment with objectives
- Draft dissertation starts early allow for much of the literature review to write in the holiday period and developed during the length of the project. This means there will always be work to be done on the draft if other areas of the project stall at time.

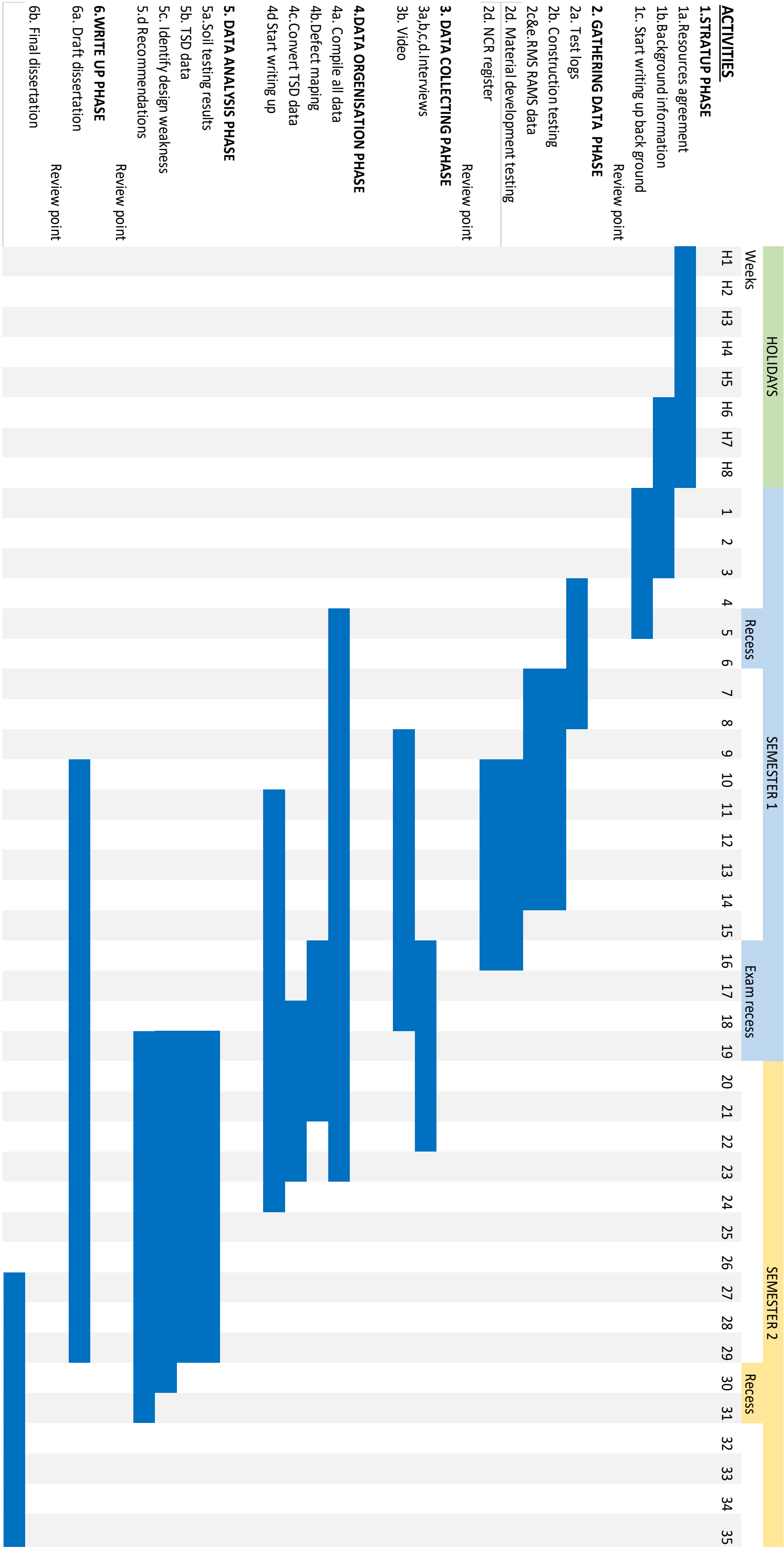


Figure 4.2: planned project schedule

4.5 Quality Assurance plan

Laboratory would primarily be carried out by RMS Grafton laboratory. The laboratory NATA accredited assuring the quality of their testing. Testing will be completed to the RMS soil testing standards. These standards are based on Australian standards for soil testing with small modifications to improve the tests repeatability. As a part the NATA accreditation the laboratory equipment at RMS's Grafton Laboratory is regularly calibrated and tested.