Recent Trends of Stabilisation Methods: A Case Study for Rural Roads by Councils in the New England Region of NSW

A dissertation submitted by

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ENG4111 and ENG4112 Research Project

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Abstract

Local gravel materials are used by councils in the New England Region of NSW for pavement construction as they are readily available and keep the construction cost down. The issue of using these materials is they may not meet the specification requirements. This can have impacts on the performance and safety of the road. Therefore these materials need to be improved through the process of stabilisation to make the material more suitable for use.

This report compares a selection of stabilisation agents that can be used to improve the properties of a not suitable material. This is done by conducting a questionnaire for councils in the New England Region to obtain some knowledge of what stabilisation agents they use and their local materials. It also contains some questions on maintenance. The responses from the questionnaire reveal that there is different stabilisation agents used in the area. Therefore this project aims to investigate these agents through laboratory testing and compare these with a more innovative agent such as bitumen emulsion.

Laboratory tests include the Particle Size Distribution, California Bearing Ratio and Capillary Rise and Water Absorption tests. Results from the Particle Size Distribution indicate that the sample material is quite a coarse material and is outside the limits when compared with the RMS DGB20 specifications. The California Bearing Ratio test results were as expected. The cement and tri-blend of slag/lime/fly-ash both increased the CBR greatly whereas the bitumen emulsion did not increase nor decrease the CBR. The bitumen emulsion did however stand up very well in the capillary rise test and it was shown that the bitumen emulsion can reduce the rate of water absorption greatly. The natural material sample fell apart and the cement and tri-blend samples became fully saturated in a very short time.

Theoretical pavement designs were trialled using the empirical design method but the mechanistic method would have been a more appropriate method. This was outside the scope. A sensitivity analysis was also part of this project, but the cost analysis which was outside this scope was required to conduct this properly.

Finally it can be said that natural materials that are not suitable for road pavement construction can be improved through the process of stabilisation and it was found that different stabilisation agents have different effects on the material. Therefore the correct stabilisation agent or a combination of can be determined for the pavement and its environment.
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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.

Matthew Mepham

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1. Introduction

1.1 Brief Introduction

Councils in the New England Region of NSW like to use locally available materials in the construction of rural roads where possible. However, these materials are not always suitable to use in their natural state. Therefore the material properties need to be improved to make them suitable for use. This can be done through the process of stabilisation.

Materials that are not suitable for use or do not meet the requirements of the pavement specification can have many impacts on the pavement performance and the safety of the road if they are used. The materials used in rural road pavements are required to meet certain specifications to construct a pavement that will be capable of providing a safe and long lasting structure for vehicles to utilise. To improve the properties of these unsuitable materials, the process of stabilisation can be used as a cost effective way to improve the quality of the materials and make them suitable for use. There are many different types of stabilisation of which a selection of these will be researched and compared with one another.

1.2 Idea Initiation

As my work consists of consulting with Local Government that require pavement designs, I have learnt that many of our local councils like to use readily available materials where possible. These materials are usually sourced from the councils local gravel pits as this keeps the development cost down. However, these local materials in their natural state are not always suitable or do not meet the specification requirements for the pavement being constructed. Therefore the material properties need to be modified to improve their performance which can be done using stabilisation. The main focus of this research project is to investigate the currently used methods of stabilisation on local materials used in rural roads within the New England Region of NSW, and compare these to an innovative method such as bitumen emulsion to determine the most suitable but cost effective solution.

Regional councils commonly use locally available materials where possible but due to the very high costs and legislative and environmental requirements involved in opening up new gravel pits, there is a shortage of good quality natural gravels that are suitable for use without the need for material modification. This research topic was considered to be worthwhile as it would be a benefit to the local councils in maximising the use of locally available materials.
1.3 Aims

There are many types of stabilisation methods currently used throughout the world in pavement design but not all of these methods are considered when designing rural roads. The aim of the project is to provide a comparison of a selection of current stabilisation methods used for rural road pavements by councils in the New England area of NSW with another innovative stabilisation method such as bitumen emulsion. To give councils a better knowledge base regarding stabilisation methods and agents the following aims will be followed.

- Determine what stabilisation method is mostly used in the New England Area
- Investigate stabilisation methods through means of laboratory testing on natural gravel
- Compare currently used methods of stabilisation with an innovative alternative available method such as bitumen emulsion
- Compare stabilisation agents in theoretical pavement designs

Due to the nature of this project topic and the vast available stabilisation methods, it was decided to constrain the study area to that of the New England Region of NSW and to use two or three alternative methods of stabilisation. This would ensure the project would be manageable but still have enough depth and research to be conducted for the case study.

1.4 Objectives

For the project to be successful there are some objectives that will need to be met. These objectives are used to keep the project on track and to make sure everything is covered. The objectives are shown below.

- Conduct research into the background of stabilisation methods and agents to gain an insight on what is currently available and used in industry.
- Collect and compare data from different councils in the New England Area by way of a questionnaire regarding materials and stabilisation agents they have typically used to ensure my research can be meaningfully compared to current practice.
- Analyse the effects of different stabilisation agents on material properties through laboratory testing. Evaluation of the different agents will determine which agent increases the quality of the material being tested and incorporated into pavement design.
• Conduct theoretical pavement designs using the test data. This will provide a comparison of stabilised pavement materials to traditional materials that are used in rural road pavement design.
• Conduct a sensitivity analysis on pavement design calculations to highlight the degree to which various stabilisation agents improve performance of road building materials typically used.

1.5 Expected Outcome

The expected outcome of this project is that the material properties of local gravels that are not up to specification will increase through the use of stabilisation agents. It may also be the case that the material properties are not changed and could potentially decrease in quality through the use of stabilisation, depending on the type of material being used.

Typically, stabilisation increases the quality of the material therefore it is also expected that the pavement will have thinner layers of material and an increased lifetime and strength.

For the sensitivity analysis, it is expected that certain stabilisation methods will have more of an impact on the pavement design than others as different stabilisation methods have different effects on the properties of the particular material.
2. Literature Review and Background

2.1 Pavement Stabilisation and Agents

Pavement Stabilisation has been used in Australia for more than half a century and has become more widely used due to its effectiveness in both cost and performance.

There are many stabilisation agents available for use on rural roads. The most common agents include lime, fly ash and slag, cement, granular and foamed bitumen. One of the more recent stabilisation agents is bitumen emulsion. As previously discussed, bitumen emulsion will be the main agent used for this project and compared with some more common agents.

2.1.1 Lime

Lime stabilisation consists of introducing a specified amount of lime into the subgrade or base course materials. This process has many benefits of which some of these are listed below:

- Improved Strength
- Improved Workability
- Elimination of Swelling
- Improved Grading
- Greatly improved water resistance

Auststab (2011)

Due to the improvement in the properties of the pavement materials or subgrade there are many advantages to using this process. These can include the following:

- Subgrades are stronger therefore reduce the pavement thickness as stabilised material can be treated as lower subbase layer
- Improved water resistance of overall pavement
- Creates a working platform that allows construction to proceed in wet weather
- Unsealed roads require less maintenance
- Greatly reduced dust generation
- Far safer driving surface especially in wet weather

Auststab (2011)
2.1.2 Fly Ash & Slag

Fly ash is a by-product of burning black coal and has good stabilisation properties as it contains silica and alumina but is low in calcium and carbon. These properties improve the strength in both compression and shear as it has cementitious characteristics. Fly ash can also help with the shrink-swell properties of a soil. Fly ash bonds the material particles together to form a strong bond that cannot expand hence reducing the shrink-swell of the soil.

The benefits of fly ash as a stabilisation agent include the following:

- Cementitious Properties
- Reduction in shrink-swell
- Increased strength and stiffness
- Increased workability

Slag is another stabilisation agent that has cementitious characteristics. However, only one type of slag is utilised for material stabilisation which is known as Blast Furnace slag or BF slag. This type of slag is readily available commercially and the supply is high whereas other types of slag such as Basic Oxygen slag and Electric Arc slag are not as readily available. Slag is quite often blended with lime as it reacts well together and is commercially available as a pre-blended mix.

The benefits of slag stabilisation include:

- Cementitious properties
- Increased strength
- Can be blended with other stabilisation agents such as lime to improve certain properties

2.1.3 Cement

Cement stabilisation consists of adding cement to the pavement material. In addition to cement, other products such as slag, fly-ash or lime can be added to the mix. This helps to reduce cracking through reduction in shrinkage and increase in strength. The addition of cement alone reacts with the water content in the pavement material to form a modified pavement that could be classified as a lightly bound or heavily bound pavement, depending on the amount of cement added to the pavement materials. This stabilisation method has similar characteristics to that of lime stabilisation but has an advantage of being suitable for use with low cohesion soils whereas lime does not.

The main advantages of cement stabilisation include:
• Increase in strength
• Increase in water resistance
• Reduced pavement thickness
• Improves quality of unsuitable materials to make them suitable for use in pavements

2.1.4 Granular
Granular stabilisation is the process of adding higher quality granular material to the poor quality materials to improve its performance and its grading. The process can be performed on multiple layers of the pavement depending on the required specifications the pavement has been designed in accordance with. This method can be performed either on site or at a mixing plant depending on the size of the job. Granular materials can be added to improve the quality of the material as a whole. The following types of material can be granular stabilised to improve their quality:

• Poorly graded products
• River deposited products
• Silty, sandy or clay soils
• Crusher runs
• Highly plastic materials

Auststab (2011)

2.1.5 Foamed Bitumen
Foamed bitumen is a stabilisation method comprising of three main ingredients which include bitumen, water and air. The process involves mixing hot bitumen with cold water to make the bitumen expand and create a foam like substance. Hence the title foamed bitumen. This foamed bitumen is then injected into a mixing drum that blends the bitumen into the pavement gravels. The bitumen sticks to the fine particles in the gravel to create a resin that binds the gravel mix together.

Foamed bitumen stabilisation has many advantages of which include the following:

• Increased shear strength in granular pavements
• Fatigue resistant and flexible but has similar strength characteristics to that of cement stabilised gravels
2.1.6 Bitumen Emulsion

Bitumen Emulsion is a stabilisation agent that is starting to become more popular with improving pavement performance. This process bitumen emulsion stabilisation involves the dispersion of bitumen into water using fine droplets. When this is mixed in with the poor gravel material, the process of ‘Breaking’ is performed to remove the water from the mix, leaving hard bitumen which improves the performance of the material. There are two types of bitumen emulsion setting. They are rapid setting and slow setting of which the latter is used for stabilisation. The bitumen emulsion mix is generally a 60/40 mix comprising of 60% bitumen and 40% water. To break down the bitumen component of the mix an emulsifier is put into the mix. A stabilising agent is also put into the mix to keep the bitumen as droplets.

![Figure 1: Bitumen Emulsion Manufacturing Process (Akzo Nobel)](image)

The advantages of using bitumen emulsion as a stabilisation agent includes the following:

- The ability to handle with minimal or no heating required
- The absence or significant reduction of cutter in the binder
- Decreases the water absorption or permeability
- Is a dust suppressor

GeoPave (2006)

2.2 Material Properties

Material properties are important when selecting a material for construction of a pavement. A pavement is designed with certain properties to ensure that it will withstand the require traffic loads and last for the designed lifetime. Without material properties, the quality of pavements may not be suitable for the required traffic and lifespan and end up costing much more than it would if the material properties were known.
There are many different properties that need to be known to design pavements and these will be discussed below.

### 2.2.1 Grading/Particle Size Distribution
Grading or Particle size distribution is performed by means of sieving a material through a set of different size sieves. This is done to determine the percentage by mass of different size particles in the material by measuring the mass retained on each sieve. The particle size distribution can help to determine if the material will have good strength or load bearing properties and be graded into their corresponding grade.

The current Australian Standard for sieve sizes include 75mm, 63mm, 37.5mm, 19.0mm, 9.5mm, 4.75mm, 2.36mm, 0.425mm and 0.075mm.

There are also certain requirements for performing the sieve testing when conducting other tests such as California Bearing Ratios. In this test there is a requirement to pass the material sample through a 19mm sieve in order to gain an accurate result from testing.

### 2.2.2 Atterberg Limits
Atterberg limits are a set of limits or properties that describe the performance of the change in moisture content in soil. The limits include the Shrinkage Limit (SL), Plastic Limit (PL) and Liquid Limit (LL). The PL and LL are used to determine the Plasticity Index (PI) which describes the amount of plasticity in a soil as a percentage of the dry weight of the soil sample. A high PI represents clay content and a low PI represents a silty soil.

### 2.2.3 Optimum Moisture Content
According to Dictionaryofconstruction.com (2016), the Optimum Moisture Content (OMC) is defined as the amount of moisture in a soil upon being compacted to its greatest density. Similarly, it’s the moisture content in the soil when it reaches maximum achievable dry density during testing. A compaction curve can be generated from a maximum dry density test which denotes the OMC in the particular soil being tested. However there are two different types of compaction that can be performed during the test of which includes Modified and Standard. Depending on the test being used will determine where the curve lies on the graph. An example of this compaction curve is shown in Figure 2.
2.2.4 California Bearing Ratio

California Bearing Ratio or CBR is a test developed many years ago by the California Highways Department and performed on a soil sample to determine the load to penetration ratio as a percentage. This percentage value is used as part of the classification of gravel material for pavement design where a high percentage represents a quality material and vice-versa. 100% CBR was adopted to be the standard value for fine crushed rock and is used as a starting point to determine the ratio of load to penetration for each sample being tested. In simple terms, the test is used to compare the bearing strength of a material and compares it to that of high quality gravel that has a CBR standard of 100%.

CBR values are required in pavement design to ensure that pavements will stand up to the required traffic loads and perform to their designed lifetime. Therefore testing is paramount of the material being used in construction to make sure these requirements are met.

2.3 Material Testing

Material Testing is vital for determining the properties of materials used for construction. This is to ensure that the correct standard of material as specified by the designer are used when construction takes place. If the wrong type of material is used, this could have huge impacts on the strength and lifetime of the pavement. Material testing will help to prevent these impacts from occurring as the materials specified during design have been designed to withstand the required traffic loads and lifetime. The material testing that will be performed as part of my case study includes the Grading/ Particle Size Distribution test,
Water Absorption Test and the California Bearing Ratio Test. The two latter tests will incorporate the testing of different stabilisation agents to compare the changes that are made by the reaction of the agent in the soil. The three main stabilisation agents that will be tested and compared include a Lime-Fly Ash-Slag mix, Cement and Bitumen Emulsion.

These tests will be performed in accordance to the appropriate Australian Standards or RMS and Main Roads standards.

2.3.1 Grading/Particle Size Distribution

As previously described, the Grading or Particle Size Distribution test involves placing a sample material through a set of Australian Standard compliant sieves to determine the particle sizes contained in that material. The retained material on each sieve is measured and the material can be classified accordingly. A material grading graph can be produced on a semi-logarithmic chart to display the results if required.

Generally councils would have certain specifications they follow when determining if the materials particle size distribution falls within the requirements. For councils in the NSW New England Area, the Roads and Maritime Services (RMS) specifications have been adopted. The RMS specifications for Particle Size Distribution requirements for Base and Subbase gravels are shown in Figure 3.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unbound Materials/Material To Be Modified</th>
<th>Materials To Be Bound</th>
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<tr>
<td></td>
<td>DGR20(%)</td>
<td>DGE20(%)</td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>Subbase</td>
</tr>
<tr>
<td>75.0 mm</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>53.0 mm</td>
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<td>–</td>
</tr>
<tr>
<td>37.5 mm</td>
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<td>–</td>
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<tr>
<td>26.5 mm</td>
<td>100</td>
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<td>2.36 mm</td>
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</tr>
<tr>
<td>0.125 mm</td>
<td>14–23</td>
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</tr>
<tr>
<td>0.075 mm</td>
<td>7–14</td>
<td>7–14</td>
</tr>
<tr>
<td>0.038 mm</td>
<td>3–7</td>
<td>3–7</td>
</tr>
<tr>
<td>0.028 mm</td>
<td>3–7</td>
<td>3–7</td>
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Figure 3: RMS Particle Size Distribution Specs (RMS 3051)
2.3.2 Capillary Rise/Water Absorption

Capillary rise or water absorption test is used to visually see how much a particular gravel absorbs water through its capillaries or voids. The test shows how water is absorbed upwards through the gravel sample over a period of time and can be used as a means of determining if a gravel will have good water repellent properties and suitable for use.

The test consists of placing a compacted gravel sample into a water bath that is 10mm deep for at least five (5) days. The water level should stay consistently at 10mm depth for the entire time of the test and a continuous video or still shots at intervals should be taken to record the results.

2.3.3 California Bearing Ratio

The California Bearing Ratio test is the main test of concern in this project as it is a fundamental property used in pavement design. The CBR test consists of firstly passing the sample material through a 19mm sieve to ensure the accuracy of results. Once this is completed the material shall be placed into a standard size mould in accordance with the current Australian Standards. The material should be placed into the mould in 3 equal layers and compacted with a slide hammer at each layer. If the test is conducted using standard compaction, each layer needs to be compacted with 53 blows of the slide hammer of which is 2.7kg in weight and dropped from a 300mm height. Alternatively, if the test is for modified compaction the material should be placed and compacted in the mould in 5 layers with a slide hammer of 4.9kg and dropped from 450mm for 53 blows.

A summary of compaction requirements from the RMS test procedure can be seen in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Standard Compaction</th>
<th>Modified Compaction</th>
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</thead>
<tbody>
<tr>
<td>No. of equal layers</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Rammer drop mass (kg)</td>
<td>2.7 ± 0.01</td>
<td>4.9 ± 0.01</td>
</tr>
<tr>
<td>Height of drop (mm)</td>
<td>300 ± 2.0</td>
<td>450 ± 2.0</td>
</tr>
<tr>
<td>No. of uniformly distributed blows per layer</td>
<td>53 where ( LDR_e = 100% )</td>
<td>53 where ( LDR_e = 100% )</td>
</tr>
</tbody>
</table>

Table 1: CBR Compaction Specifications (RMS T117)

The compacted material, while remaining in its mould is fully submerged in a water bath with a weight on top for a period of 4 days. This is done to simulate the worst case environment to give more accurate and realistic results. Once the sample has been submerged for the 4 days it is removed from the water bath and allowed to drain before testing the specimen in the CBR machine.
To test the specimen a penetration piston machine is used to penetrate the surface of the specimen. As the piston penetrates the surface the load required to penetrate the specimen by 2.5mm and 5mm is recorded. From these recordings the CBR value can be calculated.

2.4 Pavement Design

There are different types of pavements of which each have their own uses. These include flexible pavement and rigid pavement. This project only looks at the flexible pavement design as this is the most typically used pavement in the New England Region.

2.4.1 Materials

There are many types of material that can be used for pavement construction and these materials can be split up into five different categories. As stated in the Austroads Guide to Pavement Technology: Part 2 – Pavement Structural Design; these five categories include the following:

1. Unbound Granular Materials
2. Modified Granular Materials
3. Cemented Materials
4. Asphalt
5. Concrete

Austroads (2012)

The first three material categories are the main materials used for a flexible pavement. As described in the Austroads Guide (2012), Unbound Granular materials include crushed rock, gravel, soil aggregate and granular stabilised materials. Modified granular materials consist of bitumen stabilised materials, chemically modified materials and cement, lime, lime/flyash or slag modified materials. Finally Cemented materials consist of lime stabilised materials, cement stabilised materials, lime/flyash stabilised materials, slag stabilised materials and slag/lime stabilised materials.

These materials need to have suitable properties for construction and are dependent on a number of factors including the traffic loading, intended use of the material whether it be for subbase or base, the climate etc. These are all outlined in the Austroads Guide (2012) as well.

2.4.2 Methodology

There are two different methods used for pavement design. These include the Empirical method and the Mechanistic Method. The Empirical method is the more basic method and is used for flexible pavement design. This method is the method of choice for the
councils in the New England region. The Mechanistic method requires much more detail regarding the properties of materials in each of the pavement layers and subgrade.

2.4.2.1 Empirical

The Empirical design method is mainly used where standard traffic loadings will occur and where a bitumen seal or asphalt less than 40mm thick will be used coat the gravel material. This method is based on the use of a design chart that specifies the required thickness of materials with certain CBR values and traffic loadings.

To use the design chart, some parameters need to be determined including the traffic loads, subgrade properties and pavement material properties. These parameters will be discussed in the Specifications section further in the report.

The procedure for conducting the Empirical design method is as follows:

1. Select or determine the subgrade CBR value
2. Determine the design traffic
3. Calculate a pavement thickness from the design chart
4. Using the available pavement material properties, determine a tentative pavement structure
5. Using the selected pavement material CBR values, check that sufficient cover occurs for each material
6. Check the minimum base material thickness has been satisfied
7. Adopt final pavement design

Transport Engineering Study Book (USQ 2014)

A design procedure from Austroads Guide to Pavement Technology: Part 2 – Pavement Structural Design is shown in Figure 4.
2.4.2.2 Mechanistic

The Mechanistic design method is a more detailed method as it is based on analysing the structural components of the pavement layers subjected to a particular traffic loading. To complete this analysis a computer program such as CIRCLY needs to be used. The Austroads Guide (2012) gives a summary of the procedure that is used to perform the mechanistic design. The procedure consists of the input parameters required and evaluating these. This could include the materials being used, the predicted or known traffic and the environment of which the road will be built. Once these have been evaluated a trial pavement should be selected. Using this trial pavement an allowable traffic should be determined and compared to the design traffic to see if the trial pavement is meeting the requirements. If this is the case then the pavement may be used, otherwise a new trial pavement needs to be selected and run through the process again until the correct pavement is determined. Within this procedure there are affiliated design inputs that are needed in order to do an analysis. These inputs include the desired project reliability depending on the type of road class being analysed. The influence of construction and maintenance policy will need to be assessed to determine the correct use of material for construction and maintenance purposes. The environment of which the road is located will influence the type of construction also. Subgrade materials will need to be analysed to know what soils are going to be built upon and how thick pavement layers need to be. The materials and performance criteria will also need to be analysed in
the design of the pavement. Finally the design traffic loading is a key component to the
design and analysis of the pavement as this is the component that is used to analyse the
structural loadings on the pavement.

It should be noted that this design method is outside the scope of this project.

### 2.4.3 Specifications

Specifications are an important aspect of pavement design. As previously mentioned, the
specifications for designing a pavement include the following:

- Traffic loads
- Subgrade Material Properties
- Pavement Material Properties

To begin a pavement design we need to know how much traffic we are expecting to travel
on this pavement. The amount of traffic will depend on the type of road that is being
designed whether it is a residential network road or a major rural road. Traffic counts on
similar roads can also be used to determine an estimate for the amount of traffic that
needs to be designed for. From this traffic estimation the equivalent standard axles or
ESA can be calculated. The ESA represents how many standard axle loads will be
travelling on the pavement as there is a variety of different traffic. The equivalent
standard axles are calculated using a particular formula which is shown below.

\[
No.\ of\ ESA = \left(\frac{Axle\ Load}{Standard\ Axle\ Load}\right)^4
\]

Where: Standard axle load = 5.4t for a single axle consisting of single tyres
- 8.2t for a single axle consisting of dual tyres
- 13.6t for a tandem axle consisting of dual tyres

The subgrade material properties are also needed for pavement design. The subgrade
CBR is an important property as it is used to determine the required total thickness of the
pavement in conjunction with the traffic loads. Once the total thickness has been
determined, the pavement can be split up into the subbase and base layers and checked
for correct pavement thickness using the properties of each material. The design chart
used for the Empirical Design method is shown in Figure 5.
Figure 5: Design Chart for Pavements (Austroads 2012)
2.5 Risk Assessment

There will be potential risks involved with this research project and this risk assessment aims to identify these risks and evaluate the level of harm it may pose. A risk assessment table has been created to evaluate each of the risks that may be encountered during the project and how these could be minimised. This is shown in Table 2.1 below.

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Risk Level</th>
<th>Minimisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy machinery at gravel pits</td>
<td>Medium</td>
<td>- Supervision&lt;br&gt; - Induction to worksite&lt;br&gt; - PPE&lt;br&gt; - Time Separation&lt;br&gt; - Spatial Separation</td>
</tr>
<tr>
<td>Lack of information from Councils</td>
<td>Medium</td>
<td>- Collect gravel samples&lt;br&gt; - Get samples tested at nearby geotechnical lab</td>
</tr>
<tr>
<td>Inconsistency of types of information available from councils or other companies</td>
<td>Medium</td>
<td>- Conduct own tests to gather appropriate information</td>
</tr>
<tr>
<td>Council Laboratory Unavailable</td>
<td>Low</td>
<td>- Send samples to an external laboratory</td>
</tr>
<tr>
<td>Burns from hot oven</td>
<td>Low</td>
<td>- Wear appropriate PPE</td>
</tr>
<tr>
<td>Dust from stabilisation agents such as lime, flyash and cement</td>
<td>Low</td>
<td>- Wear a mask when handling agents</td>
</tr>
<tr>
<td>Confidentiality of information collected from councils and other companies</td>
<td>Low</td>
<td>- Sign a confidentiality agreement&lt;br&gt; - Notify USQ supervisor of requirement</td>
</tr>
</tbody>
</table>

Table 2: Risk Assessment Table
3. Methodology

3.1 Overview

To fulfil the objectives as stated in the first chapter of this report, the methodology that will be followed will be as follows:

- Gather the information required
- Conduct Questionnaire for a number of Councils in the New England Region
- Collect natural gravel samples from a nominated pit
- Conduct material testing
- Analyse the results from testing
- Conduct a theoretical pavement design using the test data
- Conduct a sensitivity analysis on pavement design calculations

3.2 Information Gathering

The information required to conduct this project needs to be gathered from many sources to ensure the research is accurate and feasible. There is a lot of useful information regarding this project on the internet, books and technical notes and needs to be thoroughly reviewed to make sure the information is of good quality and value. Information that is required for this project include the background literature of stabilisation methods and agents, material properties, material testing and pavement design as previously seen in this report. Other information that needs to be researched includes testing procedures that are required for this project. Many of the councils or traffic authorities have their own testing procedures but may be very similar to each other.

Another part of this project is to gather information from various councils in the New England Region by means of a questionnaire. This questionnaire will contain particular questions regarding the stabilisation methods they currently use and the effectiveness of these methods. It will also contain some questions about maintenance and the use of local gravel materials.

3.3 Material Collection

As part of this project testing will be conducted in a local council laboratory. To do this, samples of material will need to be collected from a local pit. As the project needs to be a manageable size, one sample of material will be used for testing. This material will be
natural gravel from North’s Pit located on the Old Grafton Road, east of Glen Innes. The gravel will be collected in plastic sample bags and sealed to keep the moisture level the same as it came out of the stockpile. To make sure there is enough material to test, at least five large samples bags will be collected.

Other materials that need to be collected include a bitumen emulsion, lime-flyash-slag mix and cement. These will be used as the stabilisation agents to be tested with the gravel samples. Three stabilisation agents will be selected of which some of the councils in the New England region are already using. These include the lime-flyash-slag mix and cement. As this study is a comparison of these to bitumen, this will give those councils some knowledge on the effects of bitumen emulsion.

### 3.4 Material Testing

As previously discussed, I will be performing my own testing on materials and stabilisation agents. To do this I will need to follow certain procedures to ensure the accuracy of results. The tests that will be undertaken include the following:

- Atterberg Limits
- Grading/Particle Size Distribution
- Capillary Rise/Water Absorption
- California Bearing Ratio

In order to properly perform these tests some initial testing will be required and include:

- Optimum Moisture Content
- Maximum Dry Density

These tests will be performed by following the procedures as set out in Roads and Maritime Services standard test procedures. These are as follows:

- RMS T105, Preparation of Samples for Testing (Soils)
- RMS T108/T109, Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index)
- RMS T106, Particle Size Distribution
- RMS T111, Max Dry Density & Optimum Moisture Content
- RMS T117, California Bearing Ratio
- RMS T172 Capillary Rise/ Water Absorption

*Note: All formulas used for calculations during testing can be found in the RMS Test Procedures located in Appendix E*
3.5 Testing Equipment and Resources

The testing that will be performed will require a fair bit of testing equipment and resources. Thankfully, the local council, being Inverell Shire Council, has a laboratory that they have agreed to let me use for my project testing. They have all of the testing equipment that is required such as a CBR testing machine and a set of Australian Standard sieves. They also have the required compaction moulds and hammers for preparation of the CBR test. An oven is also available for drying the samples for the max dry density testing and curing of samples.

3.6 Theoretical Pavement Design

To put the testing into practice some theoretical pavement designs will be conducted. To do this the Empirical Design method as discussed previously will be used as this is the method mainly used by councils in the New England Region.

To conduct a theoretical pavement design a set of subgrade CBR values that are typical for the New England Region will be selected and the Empirical Design method will be used to determine a pavement thickness. Once this has been done the results from the CBR testing conducted previously will be used to determine the required thickness of each layer in the pavement. This will show how the different stabilised materials can be incorporated into the pavement design and the effects that they have on the required thickness.

To finish the theoretical pavement design a table of results will be written up to give a comparison of the different layer thicknesses required using the different stabilised materials.

3.7 Sensitivity Analysis

The aim of the sensitivity analysis is to test what happens when certain parameters of the pavement design calculations are changed. For instance if the CBR is changed for a particular pavement design but the subgrade and traffic loads are held, what happens to the thickness of the pavement. By doing this sensitivity analysis, it may be determined which parameters have the most effect on the pavement design and why.
4. Questionnaire

To begin my research a questionnaire was sent out to council in the New England Region of NSW to gather information about their stabilisation methods/agents and maintenance methods. Template of the questionnaire is shown below.

4.1 Questionnaire Template

The following is a questionnaire I am conducting as part of my University Thesis on the topic of “Recent Trends of Stabilisation Methods: A Case Study for Rural Roads by Councils in the New England Region of NSW”. The aim of this case study is to find out what stabilisation methods are being used in our area and the effectiveness of those methods. The questionnaire responses can be found in Appendix B.

Question 1

Of the gravel used in road construction, what is the proportion of local (within 30km of site) to Imported?

☐ 20% Local/80% Import  ☐ 40% Local/60% Import  ☐ 50% Local/50% Import

☐ 60% Local/40% Import  ☐ 80% Local/20% Import

Any Comments:…………………………………………………………………………….

Question 2

Of the local gravel materials used, what are the typical CBR values and is stabilisation used to improve the material properties?

<table>
<thead>
<tr>
<th>Percentage of Local Gravel</th>
<th>CBR Value</th>
<th>Stabilised (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Any Comments:…………………………………………………………………………….
Question 3
What are the main stabilisation methods/agents used by council? (ie: Cement, Lime, Slag, Flyash, Bitumen Emulsion etc.)

Comment:……………………………………………………………………………………………

Question 4
Is Stabilisation only used for road maintenance purposes or for new road construction as well?

□ Road Maintenance Only    □ New Road Construction Only    □ Both

Any Comments:…………………………………………………………………………………………

Question 5
Does Council find stabilisation to be cost effective?

□ Very Cost Effective    □ Somewhat Cost Effective    □ Not Very Cost Effective

Any Comments:…………………………………………………………………………………………

Question 6
Are decisions regarding maintenance methods made onsite or planned for with design and testing?

□ Onsite
Comment:…………………………………………………………………………………………
…………………………………………………………………………………………

□ Design and Testing
Comment:…………………………………………………………………………………………
…………………………………………………………………………………………

Completed by:………………………………………..
Signature:……………………………………………
Position:……………………………………………
Council:……………………………………………...
4.2 Questionnaire Results

From conducting the questionnaire it was found that councils generally like to use 100% of their local materials. Of this local material most councils participating in the questionnaire use stabilisation to improve the quality of the material for use in road construction. It was found that councils use a few different methods of stabilisation which include a tri-blend of slag, lime and fly-ash, slag and lime mix, granular stabilisation with better materials and bitumen emulsion. When asked if they use stabilisation in new road construction, maintenance only or both, there were mixed results. Some Council’s seem to use stabilisation in both new road construction and maintenance of existing roads and others only use it for existing road maintenance. Even though there were mixed results, all councils say that stabilisation is very cost effective to use.

Some comments from one of the councils regarding the use of stabilisation stated that they use stabilisation as it is great for increasing the longevity and strength of pavements.

The final question of the questionnaire was just to get an idea of how councils make a decision with maintenance methods. Whether they decide how the road maintenance will be conducted by just an onsite visit and decision made on the spot or whether they have testing done to see exactly what the issue is and design for the maintenance before construction. It was found that most council’s do some kind of testing before they perform maintenance on their roads. There are some council that at times where the work isn’t major, they will make a decision onsite and conduct the maintenance without a formal design.
5. Laboratory Material Testing

Material testing was conducted in a local council laboratory to compare the different stabilisation agents and the effects they may have on unsuitable materials for pavement construction.

*Note: All Excel spreadsheets are located in Appendix C if not in the main text of this report.*

5.1 Material Collection

As previously stated, the material that was used for testing came from North’s Pit in Glen Innes Severn Council. This material was stockpiled at the councils quarry. To obtain samples of the material a particular method is required. The method used to sample the material from the stockpile was the Australian Standard 1141.3.1. This standard contains the correct procedure for sampling materials for testing from a stockpile and is outlined under clause 6.9.3.

The procedure entails the use of a board pushed into the side of the stockpile to prevent other material spilling into the sample area. The top 200mm of gravel is then removed from the surface and then samples are taken with a shovel from the exposed material. These samples were as previously noted, placed into plastic sampling bags to keep the moisture content constant and as per is was in the stockpile.

5.2 Sample Preparation

According to the RMS Test Methods Volume 1 there are certain requirements regarding sample preparation for each of the tests that are conducted. These requirements are set out in Materials Test Method T105 – Preparation of Samples for Testing (Soils). This test method consists of all the different tests that RMS conduct and how the materials need to be prepared for each of these tests. This is done to ensure consistency and quality control when performing testing. It was aimed to follow this procedure during the testing phase for this reason.

5.3 Maximum Dry Density

The maximum dry density test was conducted first to determine the optimum moisture content and the maximum dry density of the material sample. The results from this test were used in further tests such as the CBR test.
To conduct the maximum dry density (MDD) test, the material needs to be sieved through a 19mm sieve as per the RMS procedure. Once the material has been sieved, it was split up into four equal size samples to conduct four separate tests. The mould that was used for this test was a one litre mould which was measured to determine its mass and recorded. The first sample was then moulded using standard compaction in 3 layers with each layer compacted by 25 blows of the rammer. After compaction the collar was removed from the mould and the top of the sample was levelled using a straightedge. The base plate was then removed and the sample was weighed in the mould and recorded.

The next step was to eject the sample and collect a portion of it to determine the moisture content.

All other samples were moulded in the same way as described above but with added moisture prior to moulding. The moisture added into these samples increased by 2% for each sample. Sample 2 had 2%, Sample 3 had 4% and Sample 4 had 6% moisture added to the material. This was to make sure that the optimum moisture content value was straddled and the MDD can be determined accordingly.

The results from this test can be seen in Figure 6 where it can be seen that the optimum moisture content has been straddled and the MDD was determined to be 2.0t/m³ with an Optimum Moisture Content of 8.6%.

![Maximum Dry Density - Optimum Moisture Content](image)

**Figure 6: Maximum Dry Density - Optimum Moisture Content Curve**
5.4 Particle Size Distribution/Grading

To determine the type of material being worked with a particle size distribution or material grading test was performed. This was done to see the range of particle sizes in the material which can be recorded and plotted on a grading chart to compare with specifications set by RMS. To perform this particular test a set of Australian Standard sieves were required to be used. These sieves come in a range of sizes but the sizes selected for this test corresponded with the RMS testing procedure. As the test was only performed for the coarse particle distribution, the following sieves were used.

Sieve Sizes – 26.5mm, 19.0mm, 13.2mm, 9.5mm, 6.70mm, 4.75mm & 2.36mm

These sieves can be seen in Figure 7

![Figure 7: Australian Standard Set of Sieves](image)

Before the sieving can be conducted, the sample material needed to be dried in an oven at 50 degrees to ensure the material could be easily passed through the sieves. Once the sample was dry the set of sieves were placed together from largest to smallest and the sample material placed on the largest sieve while ensuring that the sieves were not overloaded. The loading specifications from the RMS procedure can be seen in Table 3.
Table 3: Maximum loads on each sieve

Once the material was placed onto the largest sieve, the material was sieved through each of the sieves by using lateral and vertical shaking. When the majority of material has passed through the sieves, each sieve was hand shaken individually to ensure that less than 1% of the material was passing through that particular sieve.

Following the sieving, the material retained on each sieve was measured and recorded. The material left in the pan was also measured and recorded. Table 4 shows the results of percentage passing each sieve.

Table 4: Particle Size Distribution - Percentage Passing Results

From this table of results a grading curve can be generated. This grading curve is compared to the RMS DGB20 grading specifications to give an idea of where this material lies. It can be seen in Figure 8 that the material lies outside the RMS specification and represents a coarse material.
5.5 Atterberg Limits

The Atterberg limits test was conducted to gain some knowledge about the plasticity index, meaning how plastic the material is. To do this a couple of separate test are conducted. These are the Liquid Limit and the Plastic Limit which are in turn used to determine the Plasticity Index.

The first test that was conducted was the liquid limit test. This consisted of sieving the material left in the pan from the particle size distribution test previously conducted through a 425μm sieve and mixing it with water until the material becomes a thick paste. This paste was then allowed to cure in air temperature for at least 12 hours before conducting the test.

Once the sample had cured, the paste was placed into a liquid limit testing cup and levelled off. The grooving tool was then used to create a groove in the middle of the sample for the full depth, dividing the sample into two. The handle on the testing apparatus was then turned 25 times making the cup hit the base plate. As the cup hit the base, the sample groove started to close but there was slippage in the cup.

The test was repeated to see if a liquid limit could be determined but the same result occurred with slippage in the cup. It was therefore recorded that a liquid limit could not be determined as a result.
Figure 9 shows the liquid limit testing apparatus and grooving tool with the sieves used for this test.

![Liquid Limit Apparatus and Test Sieves](image)

**Figure 9: Liquid Limit Apparatus and Test Sieves**

Figure 10 shows the material in the testing apparatus for the liquid limit.

![Material in Liquid Limit Testing Apparatus](image)

**Figure 10: Material in Liquid Limit Testing Apparatus**

The second test for the Atterberg Limits was the plastic limit test. To conduct this test a sample of the thick paste from the liquid limit test was used and attempted to roll a thread. The thread was required to be rolled to 3mm in diameter but the material was not plastic enough to roll. It was therefore recorded that the plastic limit could not be determined. Figure 11 shows the attempted rolling of the material into a thread.
5.6 California Bearing Ratio

The California Bearing Ratio is the main test for this project as it determined the strength of the pavement material. The CBR is one of the parameters used to design a pavement. The aim of this test is to test the effects of adding different stabilisation agents to the natural material to see how it changes the strength properties of the material. The test consisted of four different samples being the natural for control, 3% portland cement, 3% slag/lime/fly-ash mix and 3% bitumen emulsion. Each of these agents were mixed into the natural material and soaked for a period of time before testing them in a load-penetration machine to calculate the CBR of that particular sample.

The following steps were taken in order to conduct this test.

Firstly the sample material was passed through a 19mm sieve as per the RMS sample preparation requirements. As none of the sample was retained on the sieve, no recording was needed which meant the sample was great to use for the test. Water was then added to the material to bring it up to the optimum moisture content and the laboratory moisture ratio was kept within the tolerances as specified by RMS. If the sample was one that required the stabilisation agent, then this was mixed in thoroughly before moulding the sample.
Next the mass of the mould was determined and recorded. After this the material was ready to be moulded. The material was split into equal thirds to ensure the 3 layers were consistent when moulding. Each layer was placed into the mould and compacted before the next layer was placed into the mould. The compaction used was Standard compaction with 53 blows per layer. The aim of compacting the material in three layers is to try to achieve the target laboratory density ratio. An extract from the RMS test method for CBR is shown in Table 5. Table 5 shows the compaction requirements for both Standard and Modified compaction. Standard compaction was the method adopted for this project.

<table>
<thead>
<tr>
<th>Item</th>
<th>Standard Compaction</th>
<th>Modified Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of equal layers</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Rammer drop mass (kg)</td>
<td>2.7 ± 0.01</td>
<td>4.9 ± 0.01</td>
</tr>
<tr>
<td>Height of drop (mm)</td>
<td>300 ± 2.0</td>
<td>450 ± 2.0</td>
</tr>
<tr>
<td>No. of uniformly distributed blows per layer</td>
<td>53 where LDR_0 = 100%</td>
<td>53 where LDR_0 = 100%</td>
</tr>
</tbody>
</table>

Table 5: CBR Compaction Specifications (RMS T117)

Once the sample was compacted, the collar was removed and the sample levelled off with a straightedge. The base plate was removed and the spacer disc was taken out ready for the sample to be weighed in the mould. The mass was recorded on the record sheet.

Next, a filter paper was placed on the bottom of the base plate and the mould clamped back in place. The stem and a 4.5kg weight was placed on top of the moulded sample and immersed in a water bath. This was done for each of the samples being tested. Once all samples were immersed in the water bath, the initial swell measurement was taken and recorded. The samples were then left to soak for 4 to 10 days.

A photo of the samples in the water bath can be seen in Figure 12.
After 7 days, the final swell readings were measured and recorded. These results can be seen in Figure 13.

The samples were then removed from the water bath and allowed to drain for 15 minutes before conducting the load-penetration testing. The surcharge weights were removed prior to testing as well.

Now that the samples had been drained of any excess water, the testing could be conducted on the load-penetration machine. The machine was setup to have a displacement meter and a load meter reader to allow for recording the particular displacements at the required loading. The surcharges were placed on the surface of the sample and the sample was placed in the machine. The penetration piston was then seated.
at the required load limits of 0kN to 250kN as the CBR was expected to exceed the 30% value. A slotted surcharge was then placed on the sample to make up the 4.5kg surcharge load. The displacement meter was set to zero and the machine turned on to start the penetration. As the displacement meter reached certain readings, the load was recorded. The displacement readings used for recording were as follows.

Displacement (mm): 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, 12.0

At each of these readings the load was recorded so that the equivalent CBR value could be calculated.

A photo of the load-penetration machine can be seen in Figure 14.

![Figure 14: CBR Testing Machine (Right) - Load and Displacement Meters (Left)](image)

Once the readings are recorded they can be reproduced into graph form to create the load-penetration curve. This curve gives a representation of what load was required to penetrate the sample to a certain depth. The load-penetration record tables can be found in Appendix C.
Figure 15: Natural Material Load-Penetration Curve

Figure 15 above shows the load-penetration curve for Sample 1. This sample was the natural material and was used to create a base line or control for each of the tests carried out with different stabilisation agents added. The chart needs to be adjusted at the start of the curve to make it linear. This would mean that the actual start of the line would move to 0.4mm on the penetration axis and this would become the corrected zero point. It can be seen on the chart that the load did not reach its maximum allowable limit of 50kN before the penetration reached 12mm. Therefore the test was stopped.

The second sample to be tested was the Portland cement stabilised material. This sample contained 3% Portland cement. Figure 16 shows the load-penetration curve for this sample and it can be seen that the curve does not need any adjustment; therefore the zero point is correct. It can also be seen that the curve stops at 50kN and 4mm penetration. This is due to the limitation of the machine only being capable of a 50kN load. This meant that the cement had a huge effect on the materials strength properties and created a hard material to penetrate.
The next sample to be tested was the slag/lime/fly-ash stabilised material. Again, 3% of the stabilisation agent was added to the material prior to moulding to keep consistent. Figure 17 shows the load-penetration curve for this material and it can be seen that the curve needs a slight adjustment. The new zero point should be adjusted to be at 0.1mm on the penetration axis. It was also seen that the test had to be stopped at 7.5mm penetration as the maximum allowable load of 50kN was reached. This meant that the slag/lime/fly-ash mix also had a good effect on the material strength but not as good as the cement stabilised material as per the previous sample.

The final sample to be tested was the bitumen emulsion stabilised material. As per the last 2 samples 3% bitumen emulsion was mixed into the material before moulding. The load-penetration curve for this sample can be seen in Figure 18. This curve requires a slight adjustment to the curve which means the new zero point would be located at 0.1mm on
the penetration axis similar to that of the previous sample. The chart shows that the load did not reach the maximum allowable limit of 50kN similar to the first sample tested. This meant that the 12mm penetration limit was reached before the maximum load and hence the test was stopped. The test results came out to be very similar for the bitumen emulsion stabilisation and the natural material meaning that the CBR would not have changed much with the added bitumen emulsion stabiliser.

![Force vs Penetration Sample 4 - 3% Bitumen Emulsion](image)

**Figure 18: Bitumen Emulsion Stabilised Material Load-Penetration Curve**

Upon completion of the CBR testing, the results were used to calculate the CBR value at both the 2mm and 5mm penetration displacements. Of these two CBR values, the highest value is adopted as the final CBR.

The final CBR values can be seen in Figure 19.

![CBR Results](image)

**Figure 19: CBR Results Graph**
Following the CBR test, the samples were required to be ejected from the moulds to conduct some further testing on the samples. These further tests included determining the moisture content of the top 30mm of each sample and the moisture content of the remaining part of the sample respectively. To simplify the test, 500 grams of material was taken from the top 30mm of each sample and 500 grams from the remaining part of each sample was also taken and the moisture content tested. The results can be seen in Table 6.

<table>
<thead>
<tr>
<th>Moisture Content - Top 30mm (After Test)</th>
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<tbody>
<tr>
<td>Mass of Wet Soil (g)</td>
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<tr>
<td>Mass of Dry Soil (g)</td>
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<td>Moisture Content %</td>
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<table>
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<tr>
<th>Moisture Content - Whole Sample (After Test)</th>
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<tbody>
<tr>
<td>Mass of Wet Soil (g)</td>
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<tr>
<td>Mass of Dry Soil (g)</td>
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<td>Moisture Content %</td>
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Table 6: CBR Moisture Content Results after Testing

5.7 Capillary Rise and Water Absorption

The capillary rise and water absorption test was conducted to determine how much moisture would be absorbed into the sample which has been stabilised with different agents. This was compared with a control sample of natural material with no stabilisation agents added into the sample to give a good comparison. To conduct this test there were a number of initial setup steps need to be undertaken.

Firstly a water bath that was capable of maintaining a consistent water depth of 10mm for 72hrs, and large enough to hold at least 6 samples was constructed. This water bath can be seen in Figure 20.
Secondly a material sample of 7kg as per the RMS requirements needed to be collected and prepared for mixing by sieving the entire sample through a 19mm sieve. Once the sample material was prepared the stabilisation agents were able to be mixed into the samples and moulded as per the Maximum Dry Density test procedure. 3 layers each compacted with 25 blows.

After the samples have been moulded with the stabilisation agents mixed into the sample, the sample was ejected from the mould and prepared for curing.

Table 7 shows the different requirements for curing the sample. The accelerated method was used for all samples due to time restrictions in the laboratory and use of the oven. This consisted of wrapping the samples in wet newspaper and foil and either curing in an oven at 65 degrees for 7 days or in air at 23 degrees for 7 days depending on the stabilisation agent.

<table>
<thead>
<tr>
<th>Material</th>
<th>Curing</th>
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<tbody>
<tr>
<td>Cementitious binders</td>
<td>Wrap specimens and cure for 7 days accelerated curing or 28 days normal curing.</td>
</tr>
<tr>
<td>Self-cementing material</td>
<td>Wrap specimens and cure for 7 days accelerated curing or 28 days normal curing.</td>
</tr>
<tr>
<td>Bituminous binder</td>
<td>Cure in air at a temperature of 23 ± 2°C for 7 days.</td>
</tr>
<tr>
<td>Proprietary additives</td>
<td>As per manufacturer's recommendations.</td>
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**Table 7: Curing Specifications for the Capillary Rise Test**

The samples were taken out of the oven after 7 days of curing and unwrapped. The samples were then placed back into the oven to dry the sample to constant mass. This was done with an oven temperature of 50 degrees. Once constant mass was reached, the mass of each sample was taken. The average height of each sample was also recorded. The sample was then placed into the water bath with the compacted face upwards. A time lapse was recorded during the whole period of the test at half hour intervals. This would be used to give a visual of the water absorption for each sample and the stabilisation agents added.

A snapshot of a few different times during the test is shown in Figures 21–25.
Figure 21: Capillary Rise at 30 Seconds

It can be seen in Figure 21 that the first three samples being the Natural, Cement Stabilised and Slag/Lime/Fly-Ash Stabilised, the water is really starting to be sucked in right from the time it is placed into the water bath. After only 30 seconds of sitting in the bath the capillary rise is approximately a quarter of the total height of the sample. The three bitumen samples have no capillary rise whatsoever.

Figure 22: Capillary Rise at 30 Minutes

At 30 minutes (Figure 22) it can be seen that the first three samples are still rapidly sucking up the water and are now approximately two-thirds soaked. The natural material sample can also be seen to be breaking away at the base as the water is obviously taking away its strength and bonding of materials. The three bitumen samples still have no sign of a capillary rise at this time.
After two hours (Figure 23) it can be seen that the first three samples are basically fully saturated. The natural material sample is still collapsing at the base as more water is penetrating the surface. The cement and tri-blend samples were holding together even though they were fully saturated at this time. All bitumen samples have no visible capillary rise.

It’s not until 11 hours (Figure 24) that the 0.5% bitumen sample starts to see a capillary rise occurring. Even at this point in time the capillary rise is only about 5mm above the water level. The other two bitumen samples still have no visible capillary rise, the natural sample is still collapsing slowly and the cement and tri-blend samples have no visible change as they are fully saturated.
Figure 25: Capillary Rise at 72 Hours/3 Days

At the final hour of the test (Figure 25), it can be seen that the natural sample has collapsed about a third of the way up the sample and is fully saturated. The Cement stabilised sample is fully saturated but is holding together well as is the tri-blend sample. The 0.5% Bitumen Emulsion sample can be seen to have a 40mm capillary rise, the 1.5% sample has a 15mm rise and the 3% sample has only an 8mm capillary rise.
6. Theoretical Pavement Design

Part of this project included using the results from the laboratory testing to conduct some theoretical pavement design. The aim of this theoretical pavement design was to test how different stabilisation methods impacted on the pavement thickness. It was decided that a fixed design traffic and fixed subbase CBR with multiple thicknesses would be adopted so that the design only relied on the changing subgrade CBR to determine the Base thickness using the stabilised materials.

The results of the theoretical pavement designs can be seen in Tables 8-10.

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<tr>
<th>Subgrade CBR</th>
<th>Design Traffic</th>
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Table 8: Natural Material or Bitumen Emulsion Pavements

Table 9: Portland Cement Stabilised Pavements
It became apparent that the theoretical designs were turning up to all be the same. This was due to the empirical method only relying on the subgrade CBR value to calculate a total pavement thickness. This meant that the theoretical pavement designs for each of the stabilisation agents used in testing returned the same values for the base thickness required as the subbase CBR would always be over the minimum CBR of 30.

After further investigation it was determined that to improve the theoretical pavement design experiment, the mechanistic approach could be utilised. This approach would account for the loads in each layer of the pavement, giving a better understanding of the stabilised pavement effects. The mechanistic approach would consist of using software to model the pavement using the different stabilised materials.

A cost analysis could also be conducted to see which stabilisation method was going to be the most cost effective. A cost analysis was only going to be conducted if time permitted but unfortunately this was not the case. Therefore it is recommended that this be done as further research.

### Table 10: Slag/Lime/Fly-Ash Stabilised Pavements

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<tr>
<th>Subgrade CBR</th>
<th>Design Traffic</th>
<th>Required Pavement Thickness</th>
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7. Sensitivity Analysis

A sensitivity analysis was going to be a part of this thesis but after further investigation into what the sensitivity analysis was going to achieve, it was found that it would only be investigating different pavement designs similar to what has already been done in the theoretical pavement design section above. For a sensitivity analysis to be more appropriate in this thesis, some cost analysis would be required. From this cost analysis, a sensitivity analysis would be performed by analysing the effects to the costs from using different materials and stabilisations agents in different pavement designs.

It was therefore decided that the sensitivity analysis would be omitted due to the lack of time for a cost analysis to be performed. This could be an area for future research and would definitely be a worthwhile resource for councils in the New England Region.
8. Discussion

From conducting the questionnaire for this project it was found that many council’s in the New England Region of NSW try to use 100% of their local gravel materials wherever possible and that they use stabilisation as a method to improve their gravels for pavement construction. This was a great result as it meant that this project would have some validity and meaning to the real world use of stabilisation.

It was found that there was a variety of stabilisation methods used including slag/lime mix, tri-blend mix of slag/lime/fly-ash and bitumen emulsion. It was also found that these councils use stabilisation as it is a very cost effective solution for them to use. Whether it is for maintenance of existing roads or construction of new roads or both, all councils that were surveyed seemed to use it one way or another.

After conducting the questionnaire and collecting the responses, the laboratory testing was used to confirm and compare the effect of different stabilisation methods in a few different tests.

The first major test was the Particle Size Distribution which was used to find out what sort of grading the sample material had. From sieving the materials and obtaining the results, it was found that the material was a fairly coarse material when compared to the RMS DGB20 specifications. This may be due to the sample material not being pre-treated before conducting the test but it was decided that this would not be needed as the test was only used to gain a general idea of the material grading.

The next test was the CBR test. This was conducted using four different samples of material. These included a natural material sample, Portland cement stabilised material, tri-blend stabilised material and bitumen emulsion stabilised material. This test was used to gain some knowledge on how each stabilisation agent changed the strength properties of the unsuitable natural material. The test results were as expected with the natural material having a CBR that was not ideal for a material used in pavement construction but when this material was stabilised with either cement or a tri-blend of slag/lime/fly-ash, the CBR was increased hugely. The cement stabilisation improved the strength of the material over four times its natural strength and the tri-blend improved the strength by over 3 times. However the bitumen emulsion did not improve the material nor did it decrease in strength. This may not be a bad result as the bitumen emulsion was found to have other improving properties in the capillary rise test.
The capillary rise and water absorption test was conducted to see how the stabilised materials stood up to the water compared to the natural material. Again, as expected the cement and tri-blend stabilised materials absorbed water really quickly as did the natural material. The cement and tri-blend stabilised material did however hold its integrity compared to the natural material. But in the end these three samples were all fully saturated. Remarkably, the three bitumen stabilised samples each with different applied rates of bitumen emulsion, all stood up to the test. The 0.5% bitumen emulsion sample only had a capillary rise of 40mm from the total height of 117mm sample. The 1.5% sample had a capillary rise of 15mm and the 3% sample had only an 8mm rise, less than the water bath depth. This was amazing to see how such a small amount of the bitumen emulsion can keep the water absorption rate down to a very slow rate.

To put this testing into perspective, if a pavement was constructed in an area where drainage was hard to design for than the bitumen emulsion would be a great solution to help keep the water out of the pavement and hence a longer pavement life and less maintenance. This would reduce costs for councils which is always a positive. Even though the bitumen emulsion doesn’t increase the strength of the material, it could still be utilised with good materials to give them that “waterproofing” advantage.

Theoretical pavements were conducted using the Empirical Method but it was found that this method was not suitable for calculating the pavement thickness of each layer. It was therefore determined that the Mechanistic approach would be a better solution but this would be something required in the future research. The sensitivity analysis had the same outcome where there was not enough information for the analysis to be conducted properly. Further investigation recognised the need for a cost analysis to be done which could be incorporated into the sensitivity analysis. This would also be a future research item.
9. Conclusion

This project aimed to compare different stabilisation agents used by councils in the New England Region of NSW. As these councils favour the use of locally available materials that are not always ideal for use in pavement construction, stabilisation is a known method of improving the properties of these materials to make them suitable for use.

From conducting a questionnaire, it was found that councils are trying to use 100% of their local materials in pavements and they are using stabilisation to improve the properties of these materials. The questionnaire revealed the types of stabilisation agents that councils use on their materials and so these were utilised in the testing. The aim to compare these agents to an innovative agent such as bitumen emulsion was able to be fulfilled. Laboratory testing showed that the commonly used stabilisation agents improved the strength greatly whereas the bitumen emulsion had no effect on the strength. The bitumen emulsion was however very good at reducing the rate of water absorption compared to the commonly used stabilisation agents which absorbed the water very quickly. Therefore even though the bitumen emulsion didn’t increase the strength of the materials, it would still be a great agents to use in pavements where drainage is an issue as it would increase the life of the pavement due to the “waterproofing” advantage.

Theoretical pavement designs were trialled but could have been improved using the mechanistic approach and modelling the pavement in a software package to obtain a better understanding of the effects of stabilisation in pavements. The sensitivity analysis could have also been improved through conducting a cost analysis.

In conclusion, this project has shown that materials not ideal for use in pavements can be improved by the use of stabilisation. Councils in the New England Region of NSW are doing this with commonly used stabilisation agents but can now consider whether bitumen emulsion would be a more appropriate solution in some cases.
10. Future Research

To improve or follow on from this project, materials from other councils could be tested in the same way as done in this project to compare results or to give that particular council a better idea of what effects stabilisation has on their materials. As this project was only conducted on materials from one council, a broad overview of what effects were encountered are reported and are not specifically going to be the same for other materials.

Another area of future research would be to conduct the theoretical pavement design using the Mechanistic approach and utilising the appropriate software to model each pavement layer for the required traffic loading. This would give a much more accurate representation of pavement requirements and effects that stabilisation has on the pavement design.

A cost analysis would be very useful in order to show the different costs that stabilisation has on pavement construction. This may help to determine if a particular stabilisation method is more cost effective than another while still constructing a suitable pavement.

Finally, trial runs on real life pavements with the different stabilisation agents and variations of these agents would be a great way to see how they actually perform under real traffic loads and real weather conditions.
11. References


CIV3703 Transport Engineering: Study Book 2014, University of Southern Queensland


Appendix A
University of Southern Queensland

Faculty of Engineering and Surveying

Project Specification

For: Matthew Mepham

Title: Recent Trend of Stabilisation Methods: A case study for Rural Roads by Councils in the New England Region of NSW.

Major: Civil Engineering

Supervisors: Jim Shiau

Sponsorship: No Official sponsorship but support in-kind from Glen Innes Severn Council, Inverell Shire Council and Local Government Engineering Services.

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

Project Aim: The aim of this case study is to provide councils with an information resource to assist them in their consideration of available stabilisation methods.

Programme: Issue B, October 2016

1. Conduct research into the background of stabilisation methods and agents.
2. Collect and compare data from different councils in the New England Area by way of a questionnaire regarding materials and stabilisation agents they have typically used to ensure my research can be meaningfully compared to current practice.
3. Analyse the effects of different stabilisation agents on material properties through laboratory testing.
4. Conduct theoretical pavement designs using the test data.

If Time Permits

5. Conduct a sensitivity analysis on pavement design calculations to highlight the degree to which various stabilisation agents improve performance of road building materials typically used.
6. Conduct a cost analysis for different stabilisation methods.
Appendix B
Questionnaire Responses
Inverell Shire Council

Questionnaire

The following is a questionnaire I am conducting as part of my University Thesis on the topic of “Recent Trends of Stabilisation Methods: A Case Study for Rural Roads by Councils in the New England Region of NSW”. The aim of this case study is to find out what stabilisation methods are being used in our area and the effectiveness of those methods.

Question 1

Of the gravel used in road construction, what is the proportion of local (within 30km of site) to Imported?

☐ 20% Local/80% Import  ☐ 40% Local/60% Import  ☐ 50% Local/50% Import

☐ 60% Local/40% Import  ☑ 80% Local/20% Import

Any Comments: We try to use 100% Local

Question 2

Of the local gravel materials used, what are the typical CBR values and is stabilisation used to improve the material properties?

<table>
<thead>
<tr>
<th>Percentage of Local Gravel</th>
<th>CBR Value</th>
<th>Stabilised (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>40-100%</td>
<td>Y</td>
</tr>
</tbody>
</table>

Any Comments: Stabilised materials typically improve engineering properties of local soil close to within required parameters.

54 | Page
Question 3

What are the main stabilisation methods/agents used by council? (ie: Cement, Lime, Slag, Flyash, Bitumen Emulsion etc.)

Comment: \text{blend} \text{ either} \text{ E22 or E52} \text{ (Slag | Lime | Fly Ash)}

Question 4

Is Stabilisation only used for road maintenance purposes or for new road construction as well?

\square \text{ Road Maintenance Only} \quad \square \text{ New Road Construction Only} \quad \square \text{ Both}

Any Comments: ............................................................................................................................

Question 5

Does Council find stabilisation to be cost effective?

\checkmark \text{ Very Cost Effective} \quad \square \text{ Somewhat Cost Effective} \quad \square \text{ Not Very Cost Effective}

Any Comments: \text{ Extends Pavement Longevity / Strength}

Question 6

Are decisions regarding maintenance methods made onsite or planned for with design and testing?

\square \text{ Onsite}

Comment: \text{ Geotechnical Investigation including sampling Pavement Materials, Inspection of Road Pavement Faults}

\checkmark \text{ Design and Testing}

Comment: \text{ Laboratory Testing + Pavement Investigation}


Completed by: \text{ G.V. Merchant}
Signature: \text{ G.V. Merchant}
Position: \text{ Materials Testing Technician}
Council: \text{ Indebell Shire Council}
Questionnaire

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☐ 60% Local/40% Import ☐ 80% Local/20% Import

Any Comments: .................................

Question 2

Of the local gravel materials used, what are the typical CBR values and is stabilisation used to improve the material properties?

<table>
<thead>
<tr>
<th>Percentage of Local Gravel</th>
<th>CBR Value</th>
<th>Stabilised (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>50</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Any Comments: .................................

Stabilised if used as a base course
Question 3

What are the main stabilisation methods/agents used by council? (ie: Cement, Lime, Slag, Flyash, Bitumen Emulsion etc.)

Comment: stabiliment - slag/lime mix 85:15

Question 4

Is Stabilisation only used for road maintenance purposes or for new road construction as well?

☐ Road Maintenance Only  ☑ New Road Construction Only  ☐ Both

Any Comments: including rehabilitation on existing roads

Question 5

Does Council find stabilisation to be cost effective?

☑ Very Cost Effective  ☐ Somewhat Cost Effective  ☐ Not Very Cost Effective

Any Comments: ........................................................................................................

Question 6

Are decisions regarding maintenance methods made onsite or planned for with design and testing?

☐ Onsite

Comment: Testing is essential

..........................................................................................................................

☐ Design and Testing

Comment: ........................................................................................................

Completed by: Ralf Stockler

Signature: [Signature]

Position: Director of Engineering

Council: Benebilla Regional Council
Questionnaire

The following is a questionnaire I am conducting as part of my University Thesis on the topic of "Recent Trends of Stabilisation Methods: A Case Study for Rural Roads by Councils in the New England Region of NSW". The aim of this case study is to find out what stabilisation methods are being used in our area and the effectiveness of those methods.

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☐ 60% Local/40% Import  ☐ 80% Local/20% Import

Any Comments: New construction 100% DGB20 pavement recycled where possible.

Question 2

Of the local gravel materials used, what are the typical CBR values and is stabilisation used to improve the material properties?

<table>
<thead>
<tr>
<th>Percentage of Local Gravel</th>
<th>CBR Value</th>
<th>Stabilised (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Any Comments: Existing pavement...only...blended with DGB20 to increase CBR and/or pavement thickness. Standard treatment is to add 75mm of DGB20 (or M820) and mix to 200mm with base binder.
Question 3
What are the main stabilisation methods/agents used by council? (ie: Cement, Lime, Slag, Flyash, Bitumen Emulsion etc.)
Comment: Bitumen

Question 4
Is Stabilisation only used for road maintenance purposes or for new road construction as well?
☐ Road Maintenance Only   ☐ New Road Construction Only   ☐ Both
Any Comments: Trialled for maintenance but not economical.

Question 5
Does Council find stabilisation to be cost effective?
☐ Very Cost Effective   ☐ Somewhat Cost Effective   ☐ Not Very Cost Effective
Any Comments: Rehabilitation cost can be as low as $80,000 per km.

Question 6
Are decisions regarding maintenance methods made onsite or planned for with design and testing?
☐ Onsite
Comment: Depending on individual site, some projects are completed only using observation of the performance of an existing pavement.
☐ Design and Testing
Comment: If subgrade failure is apparent, pavements thickness plus subbase layer are tested.

Completed by: [Signature]
Signature: [Signature]
Position: Director Infrastructure
Council: [Signature]
Questionnaire

The following is a questionnaire I am conducting as part of my University Thesis on the topic of “Recent Trends of Stabilisation Methods: A Case Study for Rural Roads by Councils in the New England Region of NSW”. The aim of this case study is to find out what stabilisation methods are being used in our area and the effectiveness of those methods.

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☐ 20% Local/80% Import  ☐ 40% Local/60% Import  ☐ 50% Local/50% Import

☐ 60% Local/40% Import  ☑ 80% Local/20% Import

Any Comments: ........................................................................................................

Question 2

Of the local gravel materials used, what are the typical CBR values and is stabilisation used to improve the material properties?

<table>
<thead>
<tr>
<th>Percentage of Local Gravel</th>
<th>CBR Value</th>
<th>Stabilised (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80%</td>
<td>&gt; 70</td>
<td>N</td>
</tr>
</tbody>
</table>

Any Comments: ........................................................................................................
Question 3

What are the main stabilisation methods/agents used by council? (i.e. Cement, Lime, Slag, Flyash, Bitumen Emulsion etc.)

Comment: Slag/Lime

Question 4

Is Stabilisation only used for road maintenance purposes or for new road construction as well?

☐ Road Maintenance Only  ☐ New Road Construction Only  ☐ Both

Any Comments: Has been used on one new construction that consisted of an overlay of 100mm and kerb stabilised to 200mm deep. Most other stabilisation is for maintenance at 100mm deep.

Question 5

Does Council find stabilisation to be cost effective?

☐ Very Cost Effective  ☐ Somewhat Cost Effective  ☐ Not Very Cost Effective

Any Comments: 

Question 6

Are decisions regarding maintenance methods made on site or planned for with design and testing?

☐ Onsite

Comment: On some sites, during maintenance patching, the application rate may be varied where the base material is exposed.

☐ Design and Testing

Comment: 

Completed by: A. Harvey
Signature: A. Harvey
Position: Works Manager
Council: Uluru Shire Council
Appendix C
## Excel Spreadsheet Data

### Maximum Dry Density & Optimum Moisture Content

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Added %</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Mass of Mould + Wet Soil (g)</td>
<td>5902</td>
<td>5987</td>
<td>6028</td>
<td>6048</td>
</tr>
<tr>
<td>Mass of Mould (g)</td>
<td>3831</td>
<td>3831</td>
<td>3831</td>
<td>3831</td>
</tr>
<tr>
<td>Mass of Wet Soil (g)</td>
<td>2071</td>
<td>2156</td>
<td>2197</td>
<td>2217</td>
</tr>
<tr>
<td>Wet Soil (g)</td>
<td>500.0</td>
<td>500.0</td>
<td>500.0</td>
<td>500.0</td>
</tr>
<tr>
<td>Dry Soil (g)</td>
<td>472.9</td>
<td>464.2</td>
<td>455.6</td>
<td>448.1</td>
</tr>
<tr>
<td>Moisture (g)</td>
<td>27.1</td>
<td>35.8</td>
<td>44.4</td>
<td>51.9</td>
</tr>
<tr>
<td>Moisture Content %</td>
<td>5.73</td>
<td>7.71</td>
<td>9.75</td>
<td>11.58</td>
</tr>
<tr>
<td>Dry Density t/m³</td>
<td>1.96</td>
<td>2.00</td>
<td>2.00</td>
<td>1.99</td>
</tr>
</tbody>
</table>

| Maximum Dry Density t/m³ | 2.00 |
| Optimum Moisture Content % | 8.6 |

### Particle Size Distribution

<table>
<thead>
<tr>
<th>Initial Mass (g)</th>
<th>1216</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td>Mass Retained (g)</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>37.5</td>
<td>0</td>
</tr>
<tr>
<td>26.5</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>13.2</td>
<td>9</td>
</tr>
<tr>
<td>9.5</td>
<td>36</td>
</tr>
<tr>
<td>6.7</td>
<td>86</td>
</tr>
<tr>
<td>4.75</td>
<td>135</td>
</tr>
<tr>
<td>2.36</td>
<td>288</td>
</tr>
<tr>
<td>PAN</td>
<td>662</td>
</tr>
</tbody>
</table>
### California Bearing Ratio

#### Compaction Data

<table>
<thead>
<tr>
<th></th>
<th>Sample No. 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Of Rammer (t)</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Number of Layers</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Blows Per Layer</td>
<td>53</td>
<td>53</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Compaction Effort</td>
<td>Standard</td>
<td>Standard</td>
<td>Standard</td>
<td>Standard</td>
</tr>
<tr>
<td>Max Dry Density (t/m³)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Moisture Content %</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
</tbody>
</table>

#### Moulding Data

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilisation Agent</td>
<td>NIL</td>
<td>3% Portland Cement</td>
<td>3% S/L/FA (532 Mix)</td>
<td>3% Bitumen</td>
</tr>
<tr>
<td>Mould Volume (ml)</td>
<td>3229</td>
<td>3228</td>
<td>3227</td>
<td>3204</td>
</tr>
<tr>
<td>Mass of Mould (g)</td>
<td>7662</td>
<td>7816</td>
<td>7727</td>
<td>7913</td>
</tr>
<tr>
<td>Mass of Mould + Wet Soil (g)</td>
<td>12273</td>
<td>12453</td>
<td>12347</td>
<td>12504</td>
</tr>
<tr>
<td>Mass of Wet Soil (g)</td>
<td>4611</td>
<td>4637</td>
<td>4620</td>
<td>4591</td>
</tr>
<tr>
<td>Wet Density (t/m³)</td>
<td>1.43</td>
<td>1.44</td>
<td>1.43</td>
<td>1.43</td>
</tr>
<tr>
<td>Moisture Content before soak %</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Dry Density (t/m³)</td>
<td>2.00</td>
<td>2.01</td>
<td>2.00</td>
<td>1.99</td>
</tr>
<tr>
<td>Base Plate &amp; Mould (before soak) (g)</td>
<td>12273</td>
<td>12453</td>
<td>12347</td>
<td>12504</td>
</tr>
<tr>
<td>Days Soaked</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Base Plate &amp; Mould (after soak) (g)</td>
<td>12429</td>
<td>12556</td>
<td>12471</td>
<td>12642</td>
</tr>
</tbody>
</table>

#### Moisture Content - Top 30mm (After Test)

| Mass of Wet Soil (g) | 500 | 500 | 500 | 500 |
| Mass of Dry Soil (g) | 450.029 | 458.984 | 450.2 | 467.249 |
| Moisture Content %  | 11.6% | 10.2% | 11.3% | 9.0% |

#### Moisture Content - Whole Sample (After Test)

| Mass of Wet Soil (g) | 500 | 500 | 500 | 500 |
| Mass of Dry Soil (g) | 463.481 | 461.984 | 462.732 | 467.249 |
| Moisture Content %  | 9.5% | 9.7% | 9.6% | 9.0% |

#### Swell

| Initial Reading (mm) | 1.52 | 0.03 | 0.32 | 0.04 |
| Final Reading (mm)  | 1.55 | 0.05 | 0.36 | 0.06 |
| Height Increase (mm) | 0.03 | 0.02 | 0.04 | 0.02 |
| Height of Specimen (mm) | 117.00 | 117.00 | 117.00 | 117.00 |
| Swell %             | 0.0256% | 0.0171% | 0.0342% | 0.0171% |

#### CBR Results

| CBR @ 2.5mm (%) | 54.7 | 266 | 171.3 | 56.7 |
| CBR @ 5mm (%)   | 64.8 | N/A | 193 | 64.7 |
| Corrected CBR (%) | 60 | 270 | 190 | 60 |

### CBR Load-Penetration Tables

<table>
<thead>
<tr>
<th>Sample 1 - Natural</th>
<th>Sample 2 - 3% Portland Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration (mm)</td>
<td>Reading</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.50</td>
<td>752</td>
</tr>
<tr>
<td>1.00</td>
<td>1962</td>
</tr>
<tr>
<td>1.50</td>
<td>3500</td>
</tr>
<tr>
<td>2.00</td>
<td>5022</td>
</tr>
<tr>
<td>2.50</td>
<td>6400</td>
</tr>
<tr>
<td>3.00</td>
<td>7750</td>
</tr>
<tr>
<td>4.00</td>
<td>10170</td>
</tr>
<tr>
<td>5.00</td>
<td>12300</td>
</tr>
<tr>
<td>7.50</td>
<td>16800</td>
</tr>
<tr>
<td>10.00</td>
<td>20550</td>
</tr>
<tr>
<td>12.00</td>
<td>23740</td>
</tr>
<tr>
<td>Penetration (mm)</td>
<td>Reading</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.50</td>
<td>4436</td>
</tr>
<tr>
<td>1.00</td>
<td>9500</td>
</tr>
<tr>
<td>1.50</td>
<td>14370</td>
</tr>
<tr>
<td>2.00</td>
<td>18585</td>
</tr>
<tr>
<td>2.50</td>
<td>22680</td>
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</tr>
<tr>
<td>7.50</td>
<td>50238</td>
</tr>
<tr>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>12.00</td>
<td>12.00</td>
</tr>
</tbody>
</table>

### Capillary Rise and Water Absorption

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage by Mass Retained in 19mm Sieve (%)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Stabilisation Agent</td>
<td>NIL</td>
<td>3% Portland Cement</td>
<td>3% S/L/FA(532 Mix)</td>
<td>0.5% Bitumen</td>
<td>1.5% Bitumen</td>
<td>3% Bitumen</td>
</tr>
<tr>
<td>Weight in Mould (g)</td>
<td>5998</td>
<td>5998</td>
<td>5971</td>
<td>6628</td>
<td>6001</td>
<td>5995</td>
</tr>
<tr>
<td>Weight of Mould (g)</td>
<td>3831</td>
<td>3831</td>
<td>3831</td>
<td>3831</td>
<td>3831</td>
<td>3831</td>
</tr>
<tr>
<td>Weight of Sample before soak (g)</td>
<td>2167</td>
<td>2167</td>
<td>2140</td>
<td>2197</td>
<td>2169</td>
<td>2164</td>
</tr>
<tr>
<td>Height of Mould (mm)</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Height Of Sample (mm)</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td>40</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Moisture Content (%)</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Moisture Rise in Sample (mm)</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td>40</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Capillary Rise (%)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>35%</td>
<td>13%</td>
<td>7%</td>
</tr>
<tr>
<td>Weight of Sample at Constant Mass (g)</td>
<td>1999</td>
<td>2019</td>
<td>2001</td>
<td>2030</td>
<td>2018</td>
<td>2033</td>
</tr>
<tr>
<td>Weight of Sample after soak (g)</td>
<td>1782</td>
<td>2188</td>
<td>2171</td>
<td>2059</td>
<td>2024</td>
<td>2033</td>
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<td>-8.63%</td>
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Appendix D
Capillary Rise Time Lapse Photos
Appendix E
RMS Test Procedure – T106 Particle Size Distribution

Test method T106
Coarse particle size distribution of road construction materials (By dry sieving)

OCTOBER 2012
## Revision Summary

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Note that Roads and Maritime Services is hereafter referred to as "RMS".

The most recent revision to Test method T106 (other than minor editorial changes) are indicated by a vertical line in the margin as shown here.
Test method T106

Coarse particle size distribution of road construction materials (By dry sieving)

1. Scope
This Test Method sets out the procedure for determining the coarse particle size distribution by dry sieve analysis of road construction materials greater than 2.36 mm.

NOTE: The procedure is similar to AS 1289.3.6.1 'Standard method of analysis by sieving' except that only dry sieving is used and sieving stages are not defined.

2. General
(a) This method is used to determine the coarse particle size distribution. The sieves are defined in Step 3(a).
(b) Required pre-treatment’s are carried out on the sample before using T106 unless otherwise specified.
(c) This method may be used in conjunction with T107 to determine a complete particle size distribution of the material. When both tests are required, T106 is carried out first.

NOTE: T107 is for determining the particle size distribution of material passing the 2.36 mm AS sieve.
(d) If required, the test portions for other tests may be prepared from the material passing the 2.36 mm AS sieve as described in T105.
(e) Reference to ‘Constant Mass’ is according to the procedure described in T120 or AS 1289.2.1.1 Clause 1 to (g) except at the temperature stated in the test method.
(f) A large sample (i.e. over 40 kg) is time-consuming to dry to Constant Mass. Therefore, the method sieves:

(i) +19 mm material without further drying, except if porous and very moist
(ii) 19 mm material to be dried to Constant Mass

(g) The following documents are referred to in this Test Method:
(i) T105 Preparation of Samples for Testing (Soils)
(ii) T107 Fine Particle Size Distribution of Road Construction Materials
(iii) T120 Moisture Content of Road Construction Materials (Standard Method)
(iv) AS 1152 Test Sieves.
(v) AS 1289.2.1.1 Soil moisture content tests – Determination of the moisture content of a soil – Oven Drying method (standard method).

3. Apparatus
(a) Sieves of the following sizes or as required that conform to AS 1152:

(i) Coarse Sieves: 75.0 mm, 53.0 mm, 37.5 mm, 26.5 mm, 19.0 mm
(ii) Intermediate sieves: 13.2 mm, 9.5 mm, 4.75 mm, 2.36 mm.

NOTE: While the 6.70 mm sieve is not normally reported, it may be used to prevent overloading sieves.
Where other sieve sizes are specified, amend the sizes referred to in this method accordingly.
(b) A receiver and lid of suitable diameter
(c) Mechanical shaker (optional)
(d) An area with good air circulation with a temperature that does not exceed 50°C
(e) Dishes of suitable size to hold test portions
(f) A porcelain mortar with rubber pestle

(g) Brushes (wire or stiff bristle) and scoops as required

(h) A balance of suitable capacity with a limit of performance of not greater than ± 0.5 g

4. **Preparation**

Prepare samples in accordance with T105.

5. **Procedure**

5.1 **General**

(a) The sample is sieved through the required sieves by hand or with a mechanical shaker.

**NOTE:** Sieves are fitted together in order of size with the coarsest sieve uppermost, and may be used at the same time provided the assembly is not too heavy.

(i) When sieving by hand, use a lateral and vertical motion of the sieve accompanied by a jarring action.

**NOTE:** Pause the motion periodically to assist the process.

(ii) When using a mechanical shaker, set the timer to an appropriate time.

**NOTE:** Estimate the minimum sieving time based on the slope of time for the first sample or from experience. Generally about 12 to 15 minutes sieving is required. Periodically stop and then starting the equipment after a pause may help the process.

(b) At the end of sieving, hand sieve each portion retained for about 1 min until the mass passing each sieve is less than 1% of the mass of material retained on that sieve.

(c) Take care not to overload the sieve(s). Check that the charge and mass retained complies with Table A.4 in T105.

**NOTE:** Overloading of sieves may affect the accuracy of results and damage the sieves. To overcome:

(i) Use sieves with a larger capacity, or

(ii) Use additional sieves, or

(iii) Divide the fraction retained on the sieve into two or more portions and pass separate portions through the sieve that was originally overloaded and the sieve that are finer.

5.2 **Coarse Sieving**

(a) Dry the sample at a temperature not to exceed 50°C so that aggregations of material can be easily separated when crumbled according to Procedure A1 in T105 to the extent required to pass the 19.0 mm sieve.

(b) Crumble the sample into aggregations smaller than about 19 mm.

(c) Determine the mass of the sample (M) to the nearest 1 g.

(d) Assemble the required coarse sieves in order from largest to smallest size with receiver at the bottom.

(e) Sieve the portion through the coarse sieves and continue sieving until the mass passing each sieve in one minute is less than 1% of the mass of material retained on that sieve.

**NOTE:** A wire or stiff bristle brush may be used to remove adhering particles.

(f) Determine the mass of the following fractions to the nearest 1 g:

(i) Material retained on each coarse sieve (M_i).

(ii) Material in the receiver (M_d) (i.e. passing the 19.0 mm sieve)

5.3 **Intermediate Sieving**

(a) Dry the material in the receiver to 'Constant Mass' at a temperature not to exceed 50°C according to Step 2(c).

(b) Determine the dry mass of the intermediate sample (M_i) to the nearest 1 g.
(c) Assemble the required intermediate sieves in order from largest to smallest size with a clean receiver at the bottom.

(d) Sieve the portion through the intermediate sieves and continue sieving until the mass passing each sieve in one minute is less than 1% of the mass of material retained on that sieve.

(e) Determine the mass of the following fractions to the nearest 1 g:
   (i) Material retained on each sieve (Mi).
   (ii) Material in the receiver (Mf) (i.e. passing the 2.36 mm sieve).

6. Calculations

6.1 Adjusted mass of sample

(a) Calculate the adjusted mass of sample (Ma) to the nearest 1 g as follows:

\[ M_a = \sum M_i + M_f \]

Where:
- \( M_a \) = Adjusted mass of sample to allow for drying (g).
- \( M_i \) = Mass of portion retained on each coarse sieve (g).
- \( M_f \) = Dry mass of portion for intermediate sieving (g).

NOTE: The original mass of the sample is not used as drying the -19 mm portion during the test changes the mass.

6.2 Particle Size Distribution

(a) Calculate the percentage retained on each coarse sieve as follows:

\[ R_i = \left( \frac{M_i}{M_{a1}} \right) \times 100 \]

Where:
- \( R_i \) = Percentage retained on sieve \( i \) (%) [i.e. \( R_{2.36}, R_{4.76}, R_{11.18}, R_{22.66}, R_{45.78} \)].
- \( M_i \) = Mass of fraction retained on coarse sieve \( i \) (g).
- \( M_{a1} \) = Adjusted mass of sample (g).
- \( i \) = The coarse sieve.

(b) Calculate the percentage passing each coarse sieve as follows:

\[ P_i = \left( 100 - \sum R_i \right) \]

Where:
- \( P_i \) = Percentage passing coarse sieve \( i \) (%) [i.e. \( P_{2.36}, P_{4.76}, P_{11.18}, P_{22.66}, P_{45.78} \)].
- \( \sum R_i \) = Cumulative percentage retained on coarse sieves \( i \) and coarser (%).
- \( i \) = The coarse sieve.
(c) Calculate the percentage retained in each intermediate sieve as follows:

\[ R_i = \frac{M_i}{M_i} \times 100 \]

Where:
- \( R_i \) = Percentage retained on sieve \( \gamma \) (%) (i.e., \( R_{10}, R_{20}, R_{30}, R_{50}, R_{75} \)).
- \( M_i \) = Mass of fraction retained on sieve \( \gamma \) (g).
- \( M_i \) = Adjusted mass of sample (g).
- \( \gamma \) = The intermediate sieve.

(d) Calculate the percentage passing each intermediate sieve as follows:

\[ P_i = \left( P_n - \sum R_i \right) \]

Where:
- \( P_i \) = Percentage passing the particular sieve (%) (i.e., \( P_{10}, P_{20}, P_{30}, P_{50}, P_{75} \)).
- \( P_n \) = The percentage passing the 19.0 mm sieve (%).
  (If the whole sample passes the 19.0 mm sieve \( P_n = 100 \), otherwise from Calculation (b)).
- \( \sum R_i \) = Cumulative percentage retained on intermediate sieve \( \gamma \) and coarser (\( P_n \)).
- \( \gamma \) = The intermediate sieve.

(e) Calculate the percentage in the intermediate receiver (\( P_r \)) as follows and check that this is within \( \pm 0.5\% \) of \( P_{20} \):

\[ P_r = \frac{M_r}{M_r} \times 100 \]

Where:
- \( P_r \) = Percentage in the intermediate receiver (%)\( P_r \).
- \( M_r \) = Mass of the fraction in the receiver (g).
- \( M_r \) = Adjusted mass of sample (g).

7. Reporting

(a) Where the material is also to be tested using T107, the results from this test are to be reported according to T107.

(b) Where only the coarse particle size distribution is required, include the following results in the report:

(i) The percentages passing (\( P \) and \( P_r \)) each sieve used to the nearest 1\% commencing with the smallest sieve size through which 100\% of the material passes or the largest sieve size specified.
<table>
<thead>
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<td>75.0 mm</td>
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</tr>
<tr>
<td>53.0 mm</td>
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<td>37.5 mm</td>
<td></td>
</tr>
<tr>
<td>26.5 mm</td>
<td></td>
</tr>
<tr>
<td>19.0 mm</td>
<td></td>
</tr>
<tr>
<td>13.2 mm</td>
<td></td>
</tr>
<tr>
<td>9.5 mm</td>
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</tr>
<tr>
<td>4.75 mm</td>
<td></td>
</tr>
<tr>
<td>2.36 mm</td>
<td></td>
</tr>
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</table>

(ii) Where required, plot the results on semi-logarithmic axes with particle size as the 'x' axis and percentage passing as the 'y' axis.

(iii) Reference to this Test Method.
RMS Test Procedure – T108 Liquid Limit

Test method T108
Liquid limit of road materials
OCTOBER 2012
## Revision Summary

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The most recent revision to Test method T108 (other than minor editorial changes) are indicated by a vertical line in the margin as shown here.
Test method T108

Liquid limit of road materials

1. Scope
This test method sets out the procedure for the routine determination of the liquid limit for soils, gravels and crushed rock, materials that are encountered or used in road and bridge construction.

2. Test Requirements, Procedure and Reporting
This Test Method is identical to AS 1289.3.1.1, except that:

Clause 5 (c) is amended as follows:

(c) Palette knives of convenient size (e.g., having a blade 200 mm long and 30 mm wide), having sufficient flexibility to avoid crushing of intact rock or mineral grains, while still allowing adequate pressure to be exerted on the soil during mixing and placement into the liquid limit apparatus.

Clause 5 (a) is replaced by the following:

(a) Obtain at least 250 g of the material passing the 425 μm sieve and prepared in accordance with AS1289.1.1 (see AS1289.3.1.1 Note 5). Alternatively, when practically all soil passes a 425 μm sieve the material may be used in the natural state without further preparation. Then proceed as follows:

(i) Record the method of preparation (see AS1289.3.1.1 Note 1)

(ii) Place the sample in the mixing bowl or on the glass plate and add water in increments, mixing thoroughly with the palette knives for not less than 5 min after each increment of water (see Notes A, B, C and D below).

(iii) Continue adding water and mixing the soil until the soil becomes a thick homogeneous paste (see AS1289.3.1.1 Note 6). Cover the soil in a bowl and allow to cure for at least 12 h at room temperature (see AS1289.3.1.1 Note 7). Record the start and finish times of the curing period.

Notes:

(i) Soils of medium to high plasticity will require mixing times of more than 3 min. Mixing times of over 5 min may be required for high plasticity clays to obtain uniform distribution of moisture.

(ii) Inadequate mixing may result in an erroneous value being obtained for the liquid limit (usually below the true value). This is due to the time necessary for water to penetrate into absorptive particles and into the internal structure of some clays, and for mechanical disturbance to break up aggregations of finer particles, particularly clays. The sample should be mixed as a paste, using firm pressure with the palette knives, against the surface of the bowl or glass plate. In the case of highly plastic clay other techniques may be needed, in the initial stages of water addition, to bring the material to a suitable consistency.

(iii) If there is evidence that the liquid limit of the sample increases with additional and/or finer mixing, the mixing times and/or pressure from the palette knives shall be increased until no further changes occur. Any such tendency should be noted in the report.

(iv) In soils containing a high proportion of mica (particularly muscovite, commonly known as white mica), such as some granite sands, an increase in liquid limit may also be recorded after prolonged mixing. This may be due to mechanical attrition of the mica particles, which are soft, flexible and highly fissile. The presence of mica and any such behaviour arising from it should be noted in the report.

Clause 5 (c) (i) is amended as follows:

(i) Level off the mixture parallel to the base, using sufficient downward pressure from the palette knife to prevent the formation of air voids within the soil cake, to give a depth of soil in the cup of about, but not greater than, 10mm (Note E). Hold the grooving tool normal to the surface of the cup, with the chamfered edge facing in the direction of movement and divide the soil by drawing the grooving tool along the diameter through the centre-line of the hinge in one continuous motion (Note F). If at any time during these operations the soil cake slides in the cup start the procedure again, first following the requirements of Clause 5 (d).
Notes:

c) Placement of soil in the cup in a loose condition substantially changes the behaviour of the material in the test and leads to determination of a falsely low liquid limit.

d) Repeatedly drawing the tool backwards and forwards to form the groove may, in lower plasticity soils, redistribute moisture in the soil cake and lead to an incorrect determination of the liquid limit.

Clause 5 (g) 1st paragraph is amended as follows:

Replace “mixing for at least 1 min after each addition of water” with “mixing for at least 3 mins after each addition of water”

Clause 7 is amended by the insertion of an additional paragraph, as follows:

(g) Note any tendency for the liquid limit to increase with increased or finer mixing of the sample, beyond the minimum requirements of the method, together with any evidence for the cause(s) of the behaviour.
Test method T109
Plastic limit and plasticity index of road construction materials
OCTOBER 2012
## Revision Summary

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The most recent revision to Test method T109 (other than minor editorial changes) are indicated by a vertical line in the margin as shown here.

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Test method T109 - Plastic limit and plasticity index of road construction materials
Test method T109

Plastic limit and plasticity index of road construction materials

1. **Scope**
   This test method sets out the procedure to determine the Plastic Limit and the Plasticity Index of road construction materials.

2. **General**
   (a) This test method is generally applicable to soils, gravels, crushed rock and recycled materials.
   (b) This test method is not applicable to materials containing bituminous materials (e.g. Reclaimed Asphalt Pavement materials [RAP]).

3. **Apparatus, Preparation, Procedure, Calculations and Reporting**
   This test method is identical to AS 1289.3.2.1 and AS 1289.3.3.1 except for the following amendments:
   (i) Sample preparation shall be carried out in accordance with T105, and
   (ii) The Liquid Limit shall be determined in accordance with T108, and
   (iii) Moisture content shall be determined in accordance with T120.
   (iv) Include reference to this test method in the report.
Test method T111
Dry density/moisture relationship of road construction materials

OCTOBER 2012
## Revision Summary

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Test method T111

Dry density/moisture relationship of road construction materials

1. Scope
This Test Method sets out the procedure to determine the relationship between moisture content and dry density of road construction materials.

The method uses Standard or Modified compaction on independent sub-samples having different moisture contents.

2. General
(a) Standard compaction is to be used unless otherwise specified.
(b) The sample is the portion passing the 19 mm AS sieve except where a larger maximum sieve size is specified (e.g. the 37.5 mm portion that is applicable to T171). Separate testing of different portions from the sample may be required.

NOTE: The OMC and MDD may differ for different portions and cannot be interchanged.
(c) For road construction materials blended in the laboratory with cementitious binders, this test is amended in accordance with T130.
(d) The following documents are referred to in this Test Method:
   (i) T105 Preparation of Samples for Testing (Soils)
   (ii) T120 Moisture Content of Road Construction Materials (Standard Method)
   (iii) T171 Modified Texas Triaxial Compression Test for Pavement Materials.
   (iv) AS 1289.5.1.1 Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using standard compactive effort.
   (v) AS 1289.5.2.1 Soil compaction and density tests - Determination of the dry density/moisture content relation of a soil using modified compactive effort.

3. Apparatus
(a) A cylindrical metal mould with an internal diameter and volume as specified below. A detachable base plate and a collar assembly, approximately 60 mm high, both of which can be firmly attached to and removed from the mould.
   (i) An internal diameter of 105 ± 0.5 mm and a volume of 1000 ± 15 ml. (i.e. one litre mould)

NOTE: A suitable design is shown in Figure 1 of AS 1289.5.1.1.

OR
(i) An internal diameter of 148.5 ± 1.0 mm and a volume of 2000 ± 30 ml. (i.e. two litre mould)

(b) A metal rammer with a 50 ± 0.4 mm face diameter and the requirements as specified below.
   (i) For Standard compaction, a drop mass of 2.7 ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 300 ± 2.0 mm.

OR
(ii) For Modified compaction, a drop mass of 4.9 ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 450 ± 2.0 mm.

NOTE: A suitable form of hand apparatus is shown in Figure 2 of AS 1289.5.1.1 or AS 1289.5.2.1. Provided the essential dimensions are adhered to, mechanical forms of the apparatus may be used.

(c) A rigid foundation to compact the specimen on (e.g. a concrete floor or a concrete block of at least 100 kg) with suitable attachments for firmly holding the mould base plate assembly during compaction.

Test method T111 - Dry density/moisture relationship of road construction materials
(d) A balance of suitable capacity with a limit of performance not greater than ± 5 g
(e) A jack, lever and frame or other device suitable for extruding compacted specimens from the mould
(f) A bowl and trowel, or mixing machine suitable for thoroughly mixing increments of water with the sub-sample
(g) A suitable measuring cylinder
(h) A steel straightedge, about 300 mm long, about 25 mm wide and about 3 mm thick, preferably with a bevelled edge
(i) A 300 mm ruler marked in mm or a suitable depth gauge
(j) Dishes of suitable size
(k) Suitable brushware

4. Preparation
Prepare samples in accordance with T108. Ensure that the curing requirements for the sample have been achieved.

5. Procedure

5.1 General

(a) Use a one or two litre mould. However, a two litre mould must be used if the sample has < 95% passing 19 mm sieve (i.e. more than 5% is retained on a 19.0 mm sieve).
(b) Determine the mass of the mould and record the mass (M).

NOTE: In some cases, the mass of the mould (M) is to include the mass of the base plate and liner. The base plate may be retained to prevent some materials (e.g. fine crushed rock) slipping from the mould. This plastic wrap may be installed as a liner to retain moisture.

(c) Assemble the mould, collar and base plate, and secure the assembly to the rigid foundation.
(d) Carry out testing of the sub-samples as described in Step (e), 5.3 and 5.4 until at least three test results “straddle” the Optimum Moisture Content (OMC). Straddling has been achieved when:
   (i) Three moisture contents lie between OMC - 2.5% and OMC + 2% with one result below OMC and one result exceeding OMC;
   (ii) The increments between the moisture contents in ascending order lie between 1% and 2.5%.

NOTE: Preferably results should be approximately 2% below, at OMC and 2% above OMC.
(e) After moisture adjustments have been made, protect the sub-samples from moisture loss.

5.2 Sub-sample 1

(i) Remove the sub-sample 1 from the sealed container.
(b) Adjust the moisture content, if required, to approximate OMC.
(c) Thoroughly mix the sub-sample.
(d) Compact the sub-sample in the mould using the compaction specified in the following table (i.e. number of equal layers and each layer subject to a uniformly distributed number of blows from the required rammer falling freely from the height). Do not vary the compacted thickness of each layer by more than 5 mm.
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<thead>
<tr>
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<tbody>
<tr>
<td>No. of layers</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Runner drop mass (kg)</td>
<td>2.7 ± 0.01</td>
<td>4.9 ± 0.01</td>
</tr>
<tr>
<td>Height of drop (mm)</td>
<td>300 ± 2.0</td>
<td>450 ± 2.0</td>
</tr>
<tr>
<td>No. of uniformly distributed blows per layer</td>
<td>25 for the one litre mould; or 50 for the two litre mould</td>
<td>25 for the one litre mould; or 50 for the two litre mould</td>
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</table>

**NOTE:** Use only sufficient material to slightly overfill the mould leaving not more than 5 mm to be struck off after removing the collar. If overfilled by more than 5 mm or underfilled, the sample is to be replaced by a new sub-sample.

(e) Free the material from around the collar and then carefully remove the collar.

(f) Level the specimen to the top of the mould by means of the straightedge. Patch any holes developed in the surface by replacing coarse material with smaller sized material.

(g) Remove the mould plus specimen from the base plate and determine the mass \( (M_1) \).

**NOTE:** When the base plate is retained and/or a liner used, \( M_0 \) is to include the mass of the base plate and/or liner.

(h) Eject the specimen from the mould.

(i) Obtain a representative portion from the specimen and determine the moisture content \( (w) \) in accordance with T120.

5.3 **Sub-sample 2**

(a) Remove sub-sample 2 from the sealed container and adjust to appropriate moisture content.

**NOTE:** If the first sub-sample was obviously above OMC, compact the remaining sub-samples at lower moisture contents. Suitable increments of moisture content range from 1% for gravel up to 3% for clay.

(b) Repeat Steps 5.2(e) to (i).

5.4 **Sub-sample 3 and additional sub-samples**

(a) Remove the next sub-sample from the sealed container and adjust to appropriate moisture content.

**NOTE:** If the second sub-sample was obviously above OMC, compact the remaining sub-sample(s) at lower moisture contents.

(b) Repeat Steps 5.2(e) to (i).

(c) Where the OMC has been straddled as required in Step 5.1(b), proceed to Calculations. Otherwise, repeat Step 5.4 using additional sub-samples.

6. **Calculations**

(a) Calculate the Dry Density \( (\rho_D) \) of each compacted specimen as follows:

\[
\rho_D = \frac{(M_1 - M_0)}{V} \times \frac{100}{(100 + w)}
\]

Where:

- \( \rho_D \) = Dry Density \( (\text{kg/m}^3) \)
- \( M_1 \) = Mass of mould and compacted specimen \( (g) \)
- \( M_0 \) = Mass of mould \( (g) \)

**NOTE:** \( \rho_D \) can also be designated as ‘DD’. \( M_0 \) and \( M_1 \) are to include the mass of the base plate and/or liner if retained.
\( V' \) = Volume of the mould (mL)

\( w' \) = Moisture content at time of moulding (%)

(b) Plot the dry densities obtained in the series of compaction tests against the corresponding moisture contents.

c) Using one of the procedures described in the Appendix A, determine the following:
   (i) The Maximum Dry Density (MDD)
   (ii) The Optimum Moisture Content (OMC), which is the moisture content corresponding to the Maximum Dry Density (MDD)

7. Reporting

Include the following data and results in the report:

(a) **The percentage by mass of material retained on the 37.5 mm and 19 mm AS sieves determined while preparing the sample according to T106**

(b) **The nominal mould size and the fraction used for testing**

(c) **The compaction used (i.e., Standard or Modified)**

(d) **The method used from the Appendix for determining the OMC and Maximum Dry Density**

(e) **The Maximum Dry Density (MDD) to the nearest 0.01 t/m³**

**NOTE:** When the result is to be used in subsequent calculations, report the MDD to the nearest 0.001 t/m³

(f) **The OMC to the nearest 0.1%**

(g) **Reference to this test method**
Appendix A: Determination of Maximum Dry Density and Optimum Moisture Content

Determine MDD and OMC using either a mathematical or graphical procedure as described below.

A.1 Mathematical solution

The MDD and OMC may be determined by one of the following mathematical procedures: (i) Non-linear regression plot; (ii) Cubic spline function; or (iii) Solution for vertex of a parabola with vertical axis, given 3 points closest to the OMC.

A.2 Graphical Solution - Vertex of a Parabola with Vertical Axis Given 3 Points

(a) From the available results, denote point B as the result with greatest density (closest to the MDD).

(b) Denote point A as the result with moisture content just lower than that of point B.

(c) Denote point C as the result with moisture content just higher than that of point B.

(d) Draw a horizontal base line through point A.

(e) If points A, B and C are equally spaced horizontally (i.e., equal increments of ρ0):

(i) Point F coincides with point B.
(ii) Point G is halfway between the baseline and point C.
(iii) Draw line BG to intersect the base line at H.

(f) If points A, B and C are not equally spaced horizontally.

(i) Draw vertical lines through points B and C. Point D lies at the intersection of the horizontal line through A and the vertical line through B.

(ii) Draw a line DE parallel to AB. Point E lies on a vertical line through point C.
(iii) Draw a line DG parallel to AC. Point G lies on a vertical line through C.
(iv) Draw line FG to intersect the base line at H.

(g) Bisect base line AH to form the axis of the parabola. This defines the OMC.

(h) Draw line AB to intersect axis of parabola at J. Project J horizontally to K, which lies on the vertical line through B.

(i) Line KH intersects the axis at O, the vertex. This defines the MDD.

Figure 1—Graphical Solution for Peak Point of Parabola

Test method T111 - Dry density/moisture relationship of road construction materials
Test method T117
California bearing ratio of remoulded specimens of road construction material
OCTOBER 2012
## Revision Summary

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<th>Clause Number</th>
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<td>All</td>
<td>Generally Revised Title changed Amalgamation of T117 and T117a T117a withdrawn.</td>
<td>G. Donald</td>
<td>November 2007</td>
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<td>Ed 2/Rev 1</td>
<td>2(b), 2(c), 5.1(c), 7(e)</td>
<td>New Revision Summary. Clause 2(c) specifies the parameters and adds LMR and LDR. Changed LMR tolerance in Clause 5.1(e) &amp; edited 7(e).</td>
<td>David Hazell</td>
<td>February 2008</td>
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<td>1; 2(e), 5, 6, (g); 3(d); 3(f); 4.5.1, 5.2(c), 6(i), 6(j), 5.3(a), 5.4(d); 6(a), (e), 7(c)</td>
<td>Reference to dynamic deleted. Term ‘Static’ not used, combined mass with tolerance specified, list test methods. Number of perforations. More detail provided to adjust moisture, moisture content, no. blows, surcharge. Symbol for DD. Symbols added for clanity.</td>
<td>D Hazell</td>
<td>May 2011</td>
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<td>J Friedrich</td>
<td>October 2012</td>
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Note that Roads and Maritime Services is hereafter referred to as ‘RMS’.

The most recent revision to Test method T117 (other than minor editorial changes) are indicated by a vertical line in the margin as shown here.

Test method T117 - California bearing ratio of remoulded specimen of road construction material
Test method T117

California bearing ratio of remoulded specimens of road construction material

1. Scope
This test method sets out the procedure to determine the California Bearing Ratio (CBR) of road construction materials. The specimens are compacted and tested in a laboratory.

NOTE: This method is adapted from AS 1289.6.1.1.

2. General

(i) This method is performed on the portion passing the 19.0 mm AS sieve.

NOTE: The removal of small amounts of material retained on the 19.0 mm AS sieve will have a minor effect on the CBR obtained. However, the removal of a large proportion of material retained on the 19.0 mm AS sieve may have a major effect on the CBR obtained compared with that obtainable with the material as a whole. There is no generally accepted method of testing or of calculation that deals with this difficulty.

(ii) This method is used on either unsoked specimens or specimens that have been soaked for a specified period (e.g. 4 days, 10 days).

(iii) Do not use static compaction for this test.

(iv) Where an electronic data acquisition system is used to directly capture and record test data, it must have a precision at least equivalent to the apparatus replaced.

(v) The following terms and definitions are used in this Test Method:

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Laboratory Moisture Ratio</td>
<td>The ratio of the moisture content of the specimen to the Optimum Moisture Content (OMC) of the material as determined by T111 or T112 and expressed as a percentage (refer to Calculations).</td>
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<tr>
<td>Laboratory Density Ratio</td>
<td>The ratio of the Dry Density of the specimen to the Maximum Dry Density (MDD) of the material as determined by T111 or T112 and expressed as a percentage (refer to Calculations).</td>
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</tbody>
</table>

(f) Use the following unless otherwise specified:

(i) LMR = 100% with a tolerance of −3%/+2% at moulding

(ii) LDR = 100% with a tolerance of ±1% for the moulded specimen

(iii) Standard compaction

(iv) The number of days for soaking is 10 days

(g) The following documents are referred to in this Test Method:

(i) T111: Dry Density/Moisture Relationship of Road Construction Materials

(ii) T112: Dry Density/Moisture Relationship of Road Construction Materials

(iii) AS 1289.6.1.1 Soil strength and consolidation tests - Determination of the California Bearing Ratio of a soil - Standard laboratory method for a remoulded specimen

(iv) AS 2103: dial gauges and dial test indicators (metric series)

(v) AS 2193: Calibration & classification of force-measuring systems

3. Apparatus

(i) A loading machine equipped with the following:

(a) A moveable head or base capable of controlled travel at a uniform (not pulsating) rate of 1 ± 0.2 mm/min
(ii) A force-measuring device that meets the accuracy and repeatability requirements of AS 2193
Grade C testing machines for the range of forces used in the test. The force-measuring device also is to be capable of indicating seating loads of approximately 50 N and approximately 250 N.

NOTE: The force-measuring device is to be calibrated over an appropriate range e.g. calibration of the force-measuring device from 0.1 kN to 1.25 kN would allow reporting of CBR values ranging from 0.75% to 9% at 2.5 mm penetration, and from 0.9% to 6% at 5.0 mm penetration.

(b) A metal penetration piston of 49.6 ± 0.1 mm diameter and approximately 190 mm long.

(c) A cylindrical metal mould with an internal diameter of 152 ± 1 mm and internal height of 178 ± 1 mm.

(d) A metal extension collar approximately 50 mm high and a perforated metal base plate approximately 10 mm high, both of which can be firmly attached to and removed from the mould. Evenly distributed over the base plate is to be a minimum of 20 perforations approximately 3.0 mm in diameter.

(e) A metal spacer disc of 150 ± 0.5 mm diameter and 61 ± 0.25 mm thickness.

(f) A metal perforated plate of 150 ± 0.5 mm diameter fitted with a metal stem. The total mass of the perforated plate and stem is to be 1.0 ± 0.025 kg, evenly distributed over the perforated plate is to be a minimum of 42 perforations of approximately 3.0 mm diameter.

(g) One annular metal surcharge and one slotted metal surcharge, each having a mass of about 2.25 kg and a diameter of 150 ± 0.5 mm with central hole diameter of 55 ± 1.0 mm, and a combined mass of 4.5 ± 0.05 kg.

(h) Two displacement measuring devices for measurement of swell and penetration, each capable of measuring the expected range of travel, graduated to 0.01 mm and meeting the accuracy and repeatability requirements of AS 2103.

(i) A rigid support frame, such as a tripod, for mounting the displacement measurement device (e.g. dial gauge) for measuring the amount of swell during soaking.

(j) A setting piece (only required when the rigid support frame is to be removed from the mould during the test).

NOTE: The setting piece is used to set the reading on the displacement measuring device attached to the rigid support frame prior to each reading in the swell test.

(k) A metal tammer with a 50 ± 0.4 mm face diameter and the requirements as specified below.

(i) For Standard compaction, a drop mass of 2.7 ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 300 ± 20 mm.

(ii) For Modified compaction, a drop mass of 4.9 ± 0.01 kg and equipped with a suitable device to control the height of drop to a free fall of 450 ± 20 mm.

NOTE: A suitable form of hand apparatus is shown in Figure 2 of AS 1289.5.1, or AS 1289.5.2.1. Provided the essential dimensions are adhered to, mechanical forms of the apparatus may be used.

(l) A rigid foundation to compact the specimen on (e.g. a concrete floor or a concrete block of at least 100 kg) with suitable attachments for firmly holding the mould base plate assembly during compaction.

(m) A jack, lever and frame or other device suitable for extacting compacted specimens from the mould.

(n) A balance of at least 15 kg capacity with a limit of performance of not greater than ± 5g.

(o) Timer readable in seconds.

(p) Soaking tank of sufficient depth to immerse the mould in water.

(q) Filter papers, coarse, nominal 150 mm diameter.

(r) Mixing apparatus such as a trowel and quartzing apparatus such as metal plates approximately 400 mm by 125 mm and 200 mm by 125 mm.
A bowl suitable for thoroughly mixing increments of water with the sample. A mixing machine (approximately 11 litre capacity) may be used

(i) A graduated measuring cylinder

(ii) A steel straightedge, about 300 mm long, about 25 mm wide and about 3 mm thick, preferably with a bevelled edge

(iii) A 300 mm ruler

(iv) Sealed airtight containers suitable for curing moist samples

(v) Dishes of suitable size

4. Preparation

Prepare the test samples in accordance with T105.

*NOTE:* A second or third sample of -19 mm may be required in Step 5.1.

5. Procedure

5.1 Moisture Adjustment

*NOTE:* Adjusting the moisture content to the required LMR and providing curing is important for this test.

(a) Use a sub-sample (-19 mm) to determine the following:

- The moisture content (\(m\)) according to T120
- OMC according to T111 but using a -19 mm portion

(b) Calculate the LMR according to Step 6(b)

- Where the LMR is within the specified tolerance, proceed to Step 5.2
- Where the LMR is outside the specified tolerance, adjust the moisture content of the portion to be moulded

*NOTE:* The moisture should not be too high or too low as T105 requires the sample to be crumbled before sieving.

*Process A.10 in T105 can be used to estimate the water that needs to be added (\(M_W\)) based on \(W = \text{OMC} - m\):

- Add the required quantity of water and thoroughly mix the sample to ensure uniform distribution of moisture

*NOTE:* A check on moisture content may be required to ensure LMR is met.

(b) Return the sample to the same container and seal

(c) Cure the sample according to Process A.6 Curing (b) and (c) in T105

5.2 Moulding

*NOTE:* Plan testing so that CBR penetration testing falls due on a normal working day, unless other arrangements are made.

(a) Determine the mass of the mould (\(M\)) in grams

(b) Clamp the mould, with extension collar attached, to the base plate. Insert the spacer disc and place a coarse filter paper on top of the spacer disc

(c) Remove the cured sample from the container. Either immediately before, during or immediately after compaction, obtain a representative portion and use T120 to determine the moisture content at moulding (\(m\)). Ensure minimal moisture loss from the portion or sample

*NOTE:* The sample is assumed to be within the specified tolerance for LMR.

(d) Compact the sample in the mould to achieve the target LDR. Compact in layers using the appropriate compaction specified in the following table (i.e. number of equal layers and each layer subject to a uniformly distributed number of blows from the required rammer falling freely from the height). Do not vary the compacted thickness of each layer by more than 5 mm
NOTE: Compaction to achieve a LDR similar to the in situ density, or anticipated service density, may be required for the material being tested.

<table>
<thead>
<tr>
<th>Item</th>
<th>Standard Compaction</th>
<th>Modified Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of equal layers</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Ramsden drop mass (kg)</td>
<td>2.7 ± 0.01</td>
<td>4.9 ± 0.01</td>
</tr>
<tr>
<td>Height of drop (mm)</td>
<td>300 ± 2.0</td>
<td>450 ± 2.0</td>
</tr>
<tr>
<td>No. of uniformly distributed blows per layer</td>
<td>55 where LDR = 100%</td>
<td>55 where LDR = 100%</td>
</tr>
</tbody>
</table>

NOTE: Use only sufficient material to slightly overfill the mould leaving just more than 5 mm to be struck off after removing the collar. If overfilled by more than 5 mm or underfilled, the sample is to be replaced by a new sample. Record the number of blows per layer.

(c) Free the material from around the collar and then carefully remove the collar

(f) Level the specimen to the top of the mould by means of the straightedge. Patch any holes developed in the surface by replacing coarse material with smaller sized material

(i) Remove the perforated base plate and spacer disc. Determine the mass of the mould plus compacted specimen and record the mass (M) in grams

NOTE: Take care when inserting the specimen sliding in the mould (sands & gravels).

(b) Place a coarse filter paper on the perforated base plate, invert the mould plus compacted specimen and clamp the perforated base plate to the mould with the compacted specimen in contact with the filter paper

(i) For soaked samples go to Step 5.3. Should soaking be delayed, cover the specimen to avoid moisture loss

(l) Where the sample is not to be soaked:

   (ii) Place the filter paper, perforated plate and surcharge weights on the compacted specimen in the mould

   (ii) Cover the assembly to avoid moisture loss. Allow to stand for at least 4 hours to allow pore pressures to dissipate prior to testing

   (iii) After standing, go to Step 5.4

5.3 Preparation of soaked sample

(a) Place the filter paper, perforated plate and stem of 1 kg, and surcharge weights of 4.5 kg on the compacted specimen

(b) Immerse the surcharged specimen in water allowing free access of water to the top and bottom of the specimen

(c) Determine the initial reading for swell using either of the following procedures:

   (i) Set the displacement-measuring device to be in contact with the top of the metal stem and record the initial displacement reading (h1)

   OR

   (ii) Where the rigid support frame is to be removed from the mould during soaking, use the setting piece. Set the reading on the displacement measuring device against the setting piece before placing the frame on top of the mould and take the initial reading (h1)

   NOTE: Ensure that the frame can be accurately relocated in the same positions on the setting piece and the mould for subsequent readings.

(d) Allow the specimen to soak for the specified number of days, maintaining the water level above the mould during this period
(e) Record the displacement reading (h) after the specified number of days of soaking. Where the test piece was used in Step (g), accurately relocate the frame in the same positions as for the initial readings on the test piece and mould.

(f) Remove the rigid support frame and displacement measuring device.

(g) Remove the specimen from the water. Tilt the specimen to remove water. Return the mould to the vertical position and allow the specimen to drain downwards for approximately 15 minutes. Take care not to disturb the surface of the specimen during removal of the water.

(h) Remove the 5.5 kg surcharge masses (i.e., perforated plate, stem and surcharge).

5.4 Testing

(i) Ensure that the loading machine is fitted with a suitable force-measuring device as specified in the Apparatus for the anticipated CBR value.

(j) Uncover the compacted specimen.

(k) Without delay, place the annular surcharge on the surface of the specimen and then place the mould assembly in position beneath the penetration piston. Seat the penetration piston at the smallest possible load not exceeding:

(i) 50 N for expected CBR values equal to or less than 30%

OR

(ii) 250 N for expected CBR values exceeding 30%

NOTE: The load is required to ensure satisfactory seating of the penetration piston and is considered as the zero load when plotting the load-penetration curve.

(d) If unsouked, uncover the specimen.

(e) Place the stored surcharge to provide a total surcharge mass of 4.5 kg. Read, or reset to zero, the force-measuring device and displacement measuring device.

NOTE: The displacement measuring device is to be mounted such that no other displacements in the equipment can influence the actual measured penetration.

(f) Apply the load uniformly so that the rate of penetration is $1 \pm 0.2$ mm/min. Record the load readings at consecutive penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5 mm as required below.

NOTE: Where data is captured electronically, ensure that recording commences prior to applying the load.

(i) Stop the test when a penetration cannot be achieved without damaging the apparatus (e.g., exceeding proving ring capacity or mechanical limits) and record the maximum penetration obtained.

(ii) Where a penetration of at least 2.5 mm cannot be achieved, stop further testing and report the maximum penetration achieved.

(iii) Where the load-penetration curve continues to be concave upwards at 7.5 mm penetration, additional readings at 10 mm and 12.5 mm are to be taken.

(g) Remove the mould assembly from the machine and eject the specimen from the mould.

(h) Determine moisture contents in accordance with T120 of both the following portions:

(i) A vertical slice of at least 1000 g over the full depth of the specimen ($m_1$)

(ii) Approximately the top 30 mm layer from the remainder of the specimen ($m_2$)
6. Calculations

(i) Calculate the Dry Density ($\rho_d$) of the sample before soaking as follows:

NOTE: $\rho_d$ can also be designated as ‘DD’.

\[
\rho_d = \frac{(M_s - M_p)}{V'} \times \frac{100}{(100 + w)}
\]

\[
V' = \frac{\pi D_a^2}{4 \times 1000} \times (h_s - h_i)
\]

Where:

- $\rho_d$ = Dry Density (t/m³)
- $M_s$ = Mass of mould and compacted specimen (g)
- $M_p$ = Mass of mould (g)
- $V'$ = Effective volume of the mould (mL)
- $w$ = Moisture content at time of moulding (% from T120)
- $D_a$ = Average internal diameter of the mould (mm)
- $h_s$ = Height of the mould (mm)
- $h_i$ = Height of the metal spacer disk (mm)

(ii) Calculate the Laboratory Moisture Ratio (expressed as a percentage) as follows:

\[
LMR = \frac{w}{OMC} \times 100
\]

Where:

- LMR = Laboratory Moisture Ratio (%)
- $w$ = Moisture content at time of moulding (%)
- OMC = Optimum Moisture Content of the material as determined by T111 or T112 as appropriate (%)

(iii) Calculate the Laboratory Density Ratio (expressed as a percentage) as follows:

\[
LDR = \frac{\rho_{ps}}{MDD} \times 100
\]

Where:

- LDR = Laboratory Density Ratio (%)
- $\rho_{ps}$ = Dry Density of the sample (t/m³)
- MDD = Maximum Dry Density of the material as determined by T111 or T112 as appropriate (t/m³)

(iv) Calculate the Swell as follows:

\[
S = \frac{(b_f - b_i)}{T117} \times 100
\]

Where:

- S = Swell (%)
- $b_i$ = The initial displacement reading for swell (mm)
- $b_f$ = The displacement reading for swell after the soaking period (mm)
(c) Plot the load-penetration curve at a suitable scale, which allows the force value (kN) to be determined for the calculation of the CBR value as specified in the table of Clause 7(f). Where the load-penetration curve concaves upwards initially, because of surface irregularities or other causes, adjust the zero point. Draw a tangent through the steepest part of the curve to intersect the horizontal scale. This point is the corrected zero point.

**NOTE:** The load-penetration curve may be plotted by automatic means. Examples of typical load-penetration curves and corrected zero points are shown in AS 1289.6.1 Figure 6.

(f) Using the corrected values, determine the loads corresponding to penetrations of 2.5 mm and 5.0 mm ($P_{25}$ and $P_{50}$ respectively)

(g) Calculate the CBR as follows:

$$CBR = \text{Greater of } \frac{P_{25}}{13.2} \times 100 \text{ OR } \frac{P_{50}}{19.8} \times 100$$

Where:

- $CBR$ = California Bearing Ratio (%)
- $P_{25}$ = Load corresponding to penetration of 2.5 mm (kN)
- $P_{50}$ = Load corresponding to penetration of 5.0 mm (kN)

(b) Record the greater calculated value as the CBR value of the sample.

7. **Reporting**

Include the following data and results in the report:

(a) The percentage by mass of material retained on the 19 mm AS sieve from T105 (to the nearest 1%)

(b) The compaction hammer used (i.e. Standard or Modified)

(c) The period of soaking in days

(d) The MDD and OMC of the material as determined by T111 or T112 as appropriate

(e) The target and the sample Laboratory Density Ratios (LDR and LDR) and the target and the sample Laboratory Moisture Ratios (LMR and LMR) to the nearest 1%

(f) The Moisture Content of the top 50 mm layer after penetration (to the nearest 0.1%)

(g) The Moisture Content of the full depth of the specimen after penetration (to the nearest 0.1%)

(h) The Swell as a percentage of the initial height (to the nearest 0.1%)

(i) Where the load-penetration curve is corrected by more than 2 mm, attach a plot of the Load-penetration Curve

(j) The California Bearing Ratio of the sample according to the table below, and the penetration at which it was determined

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<th>Report CBR value to the nearest (%)</th>
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<td>0.5</td>
</tr>
<tr>
<td>5 - 20</td>
<td>1</td>
</tr>
<tr>
<td>20 - 50</td>
<td>5</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>10</td>
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(k) Reference to this test method.
Test method T172
Capillary rise and absorption of modified or bound road construction materials
OCTOBER 2012
# Revision Summary

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</tbody>
</table>

Note that Roads and Maritime Services is hereafter referred to as ‘RMS’.

The most recent revision to Test method T172 (other than minor editorial changes) are indicated by a vertical line in the margin as shown here.
Test method T172

Capillary rise and absorption of modified or bound road construction materials

1. Scope
This test method sets out the procedure for determining the capillary rise and absorption of modified, bound or self-cementing road construction materials.

2. General
(a) The method is applicable to road construction materials that gain tensile strength with time (e.g. material blended in the field with a cementitious or bituminous binder, or self-cementing materials such as slag).
(b) The method is applicable to road construction materials that are modified using proprietary additives.
(c) The method is applicable to that portion passing a 19.0 mm AS sieve.

3. Apparatus
(a) A balance of suitable capacity and a limit of performance of 5g.
(b) A thermostatically controlled oven with good air circulation, which can be maintained within temperature ranges of 23 ± 2°C and 65 ± 5°C.
(c) A 300 mm rule marked in mm.
(d) Sealed airtight containers.
(e) Dishes of suitable size.

4. Preparation
(a) Specimens are prepared as follows:
(i) For materials modified or bound using cementitious binders, prepare the specimen according to T116 Step 3(i) except that the specimen must be hand compacted.
(ii) For self-cementing materials, prepare the specimen according to T116 Step 5.1 Moulding except that the specimen must be hand compacted.
(iii) For materials bound using bituminous binders according to T105 Appendix C except that the specimen must be hand compacted.
(iv) For materials combined with proprietary additives according to the manufacturer's recommendations provided that the specimen must be hand compacted.

NOTE: Machine compaction does not sufficiently compact material around the perimeter of the mould.
(b) Determine the Dry Density (D) of the specimen in t/m³ according to the relevant test method.

5. Procedure
5.1 Curing of Specimen
(a) Place the specimens into the specified curing environment and cure based on the requirements in Table 1:
(i) Where required, wrap each specimen in wet newspaper and seal in foil to keep the specimen moist during curing.
(ii) For accelerated curing, store the specimens in an oven within a temperature range of 65 ± 5°C and cure for 7 days ± 6 hours.
For normal curing, store the specimens in an apparatus capable of maintaining a temperature of 23 ± 2°C and cure for 28 days ± 6 hours

**NOTE:** When specimens are cured in a water bath, they must be sealed in waterproof containers to prevent water ingress.

<table>
<thead>
<tr>
<th>Material</th>
<th>Curing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cementitious binders</td>
<td>Wrap specimens and cure for 7 days accelerated curing or 28 days normal curing.</td>
</tr>
<tr>
<td>Self-cementing material</td>
<td>Wrap specimens and cure for 7 days accelerated curing or 28 days normal curing.</td>
</tr>
<tr>
<td>Bituminous binder</td>
<td>Cured in air at a temperature of 23 ± 2°C for 7 days.</td>
</tr>
<tr>
<td>Proprietary additives</td>
<td>As per manufacturer’s recommendations.</td>
</tr>
</tbody>
</table>

**Table 1 – Specimen Curing**

5.2 Capillary rise and absorption

(a) Remove the specimen from the curing environment and remove any covering. If necessary, allow the specimen to cool

(b) Dry the specimen to constant mass at a temperature not exceeding 50°C. Determine the mass \( M_1 \) at constant mass

(c) Determine the average height \( H \) of the specimen from two heights taken opposite each other to the nearest 1 mm

(d) Place the specimen with the compacted face upwards in water to a depth of 19+2/-5 mm for 72±6 hours.

**NOTE:** Periodically top up the water to maintain the water depth.

(e) Remove the specimen from the water, dry the surface to saturated surface dry condition and determine the following:

(i) The mass \( M_2 \) of the moist specimen

(ii) Note any break down of the specimen

(f) Carefully split the specimen longitudinally into halves. Measure the rise of moisture in the middle of each half and average the height \( h \) to the nearest 1 mm.

6. Calculations

6.1 Capillary rise

Calculate the capillary rise \( CR \) as a percentage of specimen height as follows:

\[
CR = \left( \frac{h}{H} \right) \times 100\%
\]

Where:

- \( CR \) = Capillary Rise (mm)
- \( h \) = Moisture rise in the specimen (mm)
- \( H \) = Height of specimen (mm)
6.2 Water Absorption

Calculate the water absorption (A) as a percentage by mass as follows:

\[ A = \frac{(M_4 - M_3)}{DD \times V} \times 100\% \]

Where:
- \( A \) = Water absorption (\%)
- \( M_4 \) = Mass of specimen after standing in water (g)
- \( M_3 \) = Mass of specimen dried to constant mass (g)
- \( DD \) = Dry Density of specimen (g/mL)
- \( V \) = Volume of the mould (mL)

7. Reporting

Include the following results in the report:
(a) Source of sample (i.e. location)
(b) The percentage by mass of material retained on the 19 mm sieve from T105 (to the nearest 1%) (c) Type, source and percentage of binder or additive where applicable (d) Where binder or additive has been incorporated in the field, the time between initial mixing of binder and completion of moulding in hours and minutes (e) Standard or Modified compaction (f) Moisture content at which specimens were compacted (to nearest 0.5%) (g) Dry density (DD) of specimens as moulded (to the nearest 0.01 t/m³) (h) Capillary rise (CR) of water (i) Water absorption (A) as a percentage of mass (j) Notes on any break down of the specimen (Step 5.2(c)) (k) Reference to this Test Method