University of Southern Queensland

Faculty of Engineering and Surveying

Determination of Insitu Flexible Moduli of Modified Pavement Materials.

A dissertation submitted by

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Abstract

The aim of this project is to determine the flexible moduli for cement, lime and bituminous modified pavement materials for use in future mechanistic pavement design in North Queensland by back analysis using ‘CIRCLY’ which is a mechanistic pavement design computer software program.

Three trial pavement areas throughout the Far North Queensland area have been monitored over the past years and will be analysed on their performance over this time. The three trial sections chosen are all in extremely wet areas of Far North Queensland’s wet tropics, near the small town of Innisfail, which is approximately 100 km’s south of Cairns. The rainfall in the Innisfail area has been known to exceed 7 metres for a year.

A secondary aim is to attempt to determine a correlation between the actual rutting of three trial road sections by using existing traffic volumes and a ‘cumulative damage factor’ computed by ‘CIRCLY’. This inturn allows a theoretical rut calculation to be compared with the actual rut in the field. The goal is to verify whether the input parameters that are being used in the ‘CIRCLY ‘program are representative of what is actually happening in the field.

Presently in Far North Queensland, mechanistic pavement designers are using what are considered to be conservative moduli for the purpose of designing insitu-modified pavements. By collecting data and performing back analysis using ‘CIRCLY’, a more accurate moduli can be determined with the intent to aid in designing a more economical road network.

Thus, the overriding aim of this project is to identify different moduli for the different binder-material combinations encounted in Far North Queensland so as to develop a more economical pavement with predictable performance when rehabilitating roads in the region.

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ENG4111 & ENG4112 *Research Project*

Limitations of Use

Certification

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

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

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Signature

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Date

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C. GORDON

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Chapter 1

Introduction

Determining how pavements behave is an important part of understanding pavement materials and how to get the most economical pavement designs for road rehabilitation. As costs are increasing, materials are becoming scarcer, and the public expectation is for engineers to employ sound economical and environmental practices in the reuse of resources, it is imperative that pavements are designed with the above in mind. To better maintain the nation's road network, rehabilitation of pavements with insitu stabilisation of pavements is increasing. This study has been done to attempt to achieve a correlation between the pavement failure mechanisms and the information gathered onsite and whether the initial design modulus that has been used in the 'CIRCLY' software mechanistic pavement designs are too conservative. Far Northern District Department of Main Roads is provided with parameters that are generalised for the State as a whole. These parameters are then used for the respective areas when using the soft ware program 'CIRCLY', which is a mechanistic pavement design tool used to design rehabilitated road pavements. It is considered that the moduli used for the three main pavement modifiers, cement, lime and foamed bitumen are too conservative. This study will show the reader that the set parameters are indeed too conservative for cement and foamed bitumen modified pavements.

Initially, the study was to use data from six locations, however due to a lack of existing data being available for some of the sections the decision was made to concentrate on three sections. The three sections are Deeral lime stabilisation, Cowley Cement modified and Palmerston foamed bitumen stabilised.

1.1 Far North Queensland

Tropical Far North Queensland is situated in the far north eastern end of Australia above latitude 19^0 and below latitude 16^0. The major centre in Far North Queensland is Cairns, which services its major industry of tourism, which is characterised by rainforest and easy access to the Great Barrier Reef.

The Cairns Harbour is the largest fishing port in Australia, and supports the commercial trawlers, tuna long liners, reef fin fisheries and marlin recreational fishing. The sugar industry in the Far North encompasses vast tracts of land, thus is a major industry throughout the Far North, both as an export crop and a major employer. Banana growing and harvesting also generates employment, though smaller in extent than the sugar industry. Further inland the industries comprise agriculture and dairy on the Atherton Tablelands, horticulture in the Mareeba area, and the beef industry that comprises the majority of the inland of Far North Queensland. A map of Queensland is shown below in figure 1.0.

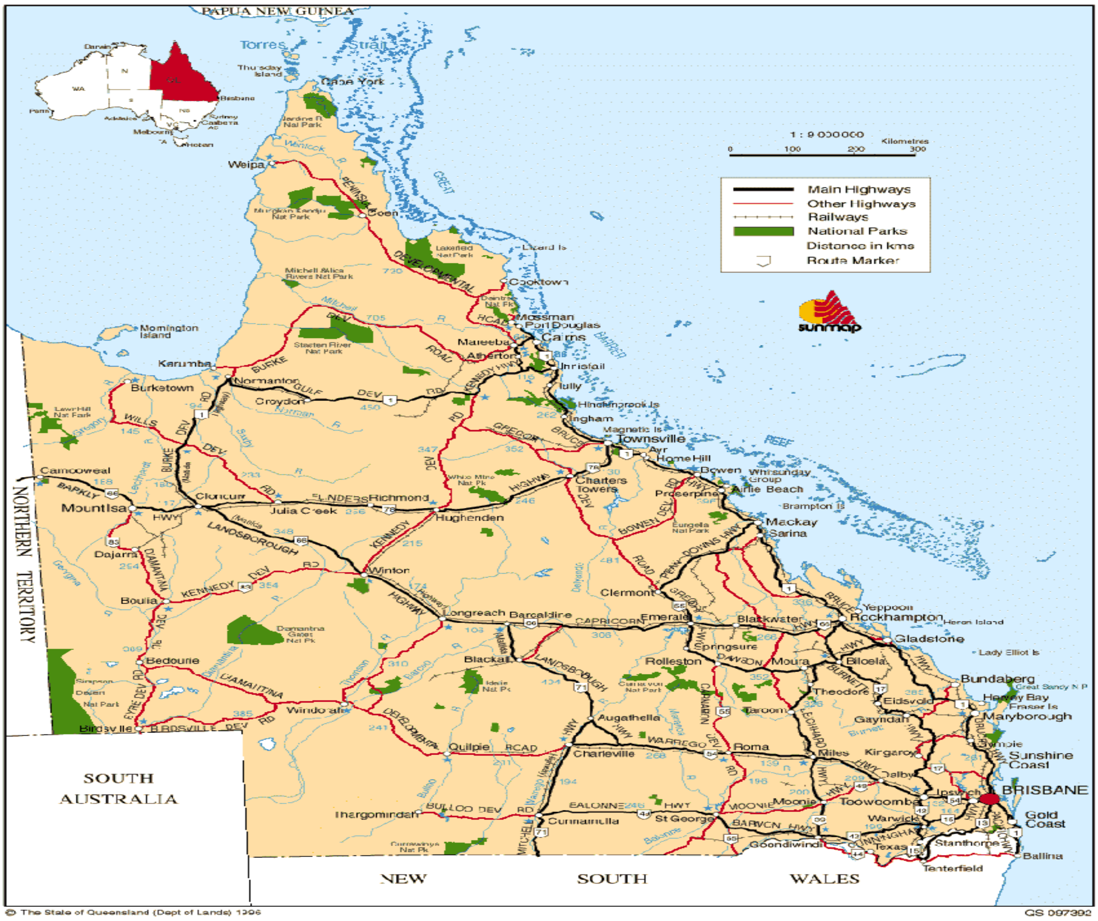


Figure 1.0 Queensland Map

Source: Sunmap

1.2 Weather

The coast of Far North Queensland has a tropical climate, with generally hot and humid summers and milder dryer winters. The average annual rainfall is 1992mm for the Cairns area with peak annual rainfall as high as 7 metres in some years. The majority of the rainfall in Cairns occurs during summer between December and April.

The monsoon trough is close to Cairns from December to April bringing with it warm to hot, humid conditions and the possibility of thunderstorms and tropical cyclones. Thunderstorms regularly develop over the ranges inland from Cairns, but seldom move off the ranges to cross the city.

The sub-tropical ridge dominates the months from May to October, with the Far North under the influence of the southeast trade stream. These moist onshore winds often produce diurnal showers, peaking overnight and morning and weakening during the afternoon. The tropics have uniform temperatures throughout the year. Typical daytime min/max temperature ranges in are 23^0C/31^0C in mid-Summer and 18^0C/26^0C in mid-Winter.

The prevailing winds are east to south easterly with strongest winds (cyclones excluded) usually occurring during April and August. During the summer months, north to north easterly sea breezes dominate the winds along the coast.

In the wet season, the quantity of rain can be impressive, however the natural geological and drainage characteristics of the region allow heavy rainfall events to drain into the Coral sea in a relatively short time period.

In the wet season tropical cyclones often influence the weather. Whilst they can be quite destructive, cities like Cairns are built to withstand the strong winds. The cyclone season is normally confined to between December and April but exceptions do occur. The most active year to date from official records was 1977 when Cairns was influenced by four tropical cyclones.

The Far North is a truly tropical climate. Rather than having a distinct four seasons there are basically only two - the wet and the dry. The wet season runs from November to May and the dry season from June to October. Temperatures generally range between 10^0 – 25^0 in the winter months and 25^0 – 35^0 in the summer months.

1.3 Inland Region

Inland from the coastal strip is the Atherton Tablelands which is a region incorporating the townships of Yungaburra, Malanda, Millaa Millaa, Ravenshoe, Herberton, Atherton and Mareeba. The Atherton Tablelands begins 60 kilometres west of Cairns, and ranges in altitude from 600 to 1100 metres. It is a very fertile part of North Queensland with rich volcanic soils, which supports both dairy farming and agricultural farming. It also has numerous waterfalls and large volcanic lakes surrounded by tropical rainforest.

Figure 1.1 Far North Region

There is also a strong colonial history dating back to the mid 19th Century. The towns mentioned above were originally established for a number of reasons being gold mining centres, some were for loggers and timber cutters and others were railway towns. The weather on the Atherton Tablelands is generally a few degrees cooler than on the coast and also provides a break from the sometimes stifling humidity of the coast.

The Atherton Tableland is considered to have a temperate climate. While this descriptive term is accurate, it is only relevant for visitors from hot climates such as the coastal town of Cairns. For interstate or international visitors, the climate at the Atherton Tablelands could be described as warm in the winter and stifling hot in the summer. The area is free of coastal humidity and high temperatures, making it very comfortable. In summer, temperatures rarely exceed 30^0 C during the day, and drop to 19^0C-20^0C at night. During winter, the daytime temperature is 22^0C in most areas and the nights have temperatures hovering around 8^0C. The average rainfall in the area is 1400mm, which means the flora on the Atherton Tablelands is a tropical green most of the year.

1.4 Climate comparison

Climate data for Cairns, Atherton and Mareeba is included in the tables below. Notice that the temperatures in Mareeba are considerably higher than in Atherton. This is due to the lower altitude and closer proximity to the coast than other towns in the region. The contrast between summer temperatures and winter temperatures in Atherton and Mareeba is much more pronounced than in coastal regions such as Cairns. All temperatures are measured in degrees Celsius, and rainfall levels are measured in millimetres.

Table 1.0 Climate data for Cairns

Average Daily Maximum Temperature - Cairns											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
32	32	30	29	28	26	26	27	29	30	31	32

Average Daily Minimum Temperature - Cairns											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
24	24	23	22	20	18	17	18	19	21	22	23

Average Rainfall per month - Cairns											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
413	435	412	191	94	49	28	27	36	38	90	175

Source: Commonwealth Bureau of Meteorology.

Table 1.1 Climate data for Atherton

Average Daily Maximum Temperature - Atherton											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
29	28.1	27.2	25.6	23.4	22.1	21.8	22.9	24.6	27.7	29.3	29.7

Average Daily Minimum Temperature - Atherton											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
18.3	18.6	17.8	15.5	13.5	11	10.4	9.9	11.6	13.6	16	17.2

Average Rainfall per month - Atherton											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
288.5	304.7	257.5	106.3	60.3	46.3	30	24.3	22.1	27.3	74.2	171.9

Source: Source: Commonwealth Bureau of Meteorology.

Table 1.2 Climate data for Mareeba

Average Daily Maximum Temperature - Mareeba											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
31.2	30.8	29.9	28.5	27	25.6	25.4	26.5	28.3	30.5	32.1	31.5

Average Daily Minimum Temperature - Mareeba											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20.9	20.9	20	17.2	15.1	12.1	11	11.7	13.4	16.1	18.6	20.1

Average Rainfall per month - Mareeba											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
200.5	251.4	192.7	43.9	23.6	14.9	7.2	6.7	4.6	14.7	57.7	106.9

Source: Commonwealth Bureau of Meteorology.

The figure below of Cairns Climatic Conditions indicates that the area receives a large amount of rainfall when compared with most areas in Australia. It is this large amount of rainfall that sets the Far North Queensland road network apart from other road networks in Australia.

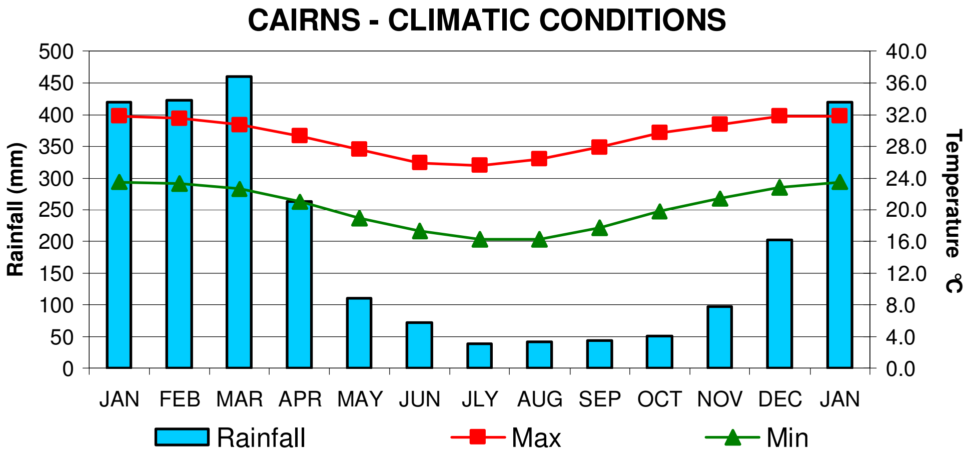


Figure 1.2 Cairns Climatic conditions

Source: Commonwealth Bureau of Meteorology

1.5 Industry

The industries that impact on the Far Northern Road network in decreasing order of importance are:

- Sugar industry
- Exotic fruit industry
- Cattle industry
- Normal public commodities transport
- Fishing industry

1.5.1 Sugar industry

Sugar industry activities impacting on the road network run from approximately June through to December each year, with some years starting early due to the preceding wet season or being extended due to the wet starting early.

The sugar cane is carted to the sugar mills by both tramway locomotives and trucks, and it is the truck component that is of interest in this study. B-Double trucks then cart the raw sugar from the mills to the ship loading facilities at both Cairns and Innisfail harbours. The amount of moisture in the road pavements during the sugar cane season determines how much damage these pavements incur.

1.5.2 Exotic fruit industry

The exotic fruit industry is mainly a seasonal industry like the sugar industry. Mango trees fruit around Christmas time and transport of the crop thus occurs at the same time as the sugar traffic. Bananas are a year round crop and cartage therefore occurs in all seasons. Both of these fruit are carted by truck to the southern markets.

1.5.3 Cattle industry

Cartage in the cattle industry mainly peaks after the wet season as soon as the trucks can get onto the roads, as the cattle are in prime condition and ready for market. There is also some movement of cattle in drought time, as the cattle farmers move their cattle to greener pastures near the coast i.e. agistment.

1.5.4 Normal public commodities transport

The normal carting of goods up and down the coastal strip to support the Far North's Communities occurs throughout the year. During the wet season heavy traffic tends to decrease during the wet season and then increase after the wet season.

1.5.5 Fishing industry

The fishing industry only has a small impact on freight movements with heavy transport carting live fish in their tanks filled with seawater from the minor ports to Cairns International Airport. These live fish are flown to their respective markets either in Southern Australia or overseas.

1.6 Objective

Far North Queensland Main Roads Department uses the software program CIRCLY in its mechanistic pavement design for all rehabilitated pavements. Senior staffs from southern areas of the state, with the absence of specific data from different areas over the state have directed all districts in what parameters that can be used when using the CIRCLY software program. What this has done is to give the Far North Queensland pavement designers a set of input parameters for the software program that are considered conservative.

The main parameter that this study has focused on is the moduli that have been used for the different rehabilitated pavements at the design stage in Far North Queensland. Through the use of Falling Weight Deflectometer (FWD) data gathered from site, using field measurements of existing rut depth and using the initial design parameters, a back analysis using CIRCLY will be done to attempt to qualify the insitu moduli of the existing pavements. This will then be compared with the initial design moduli.

A further part of the study was then to attempt to determine whether the pavements are failing in the expected manner, which has been assumed to be rutting. By entering actual traffic (ESA's) loads into CIRCLY in conjunction with the actual modulus found above, an output 'cumulative damage factor' (CDF) is returned by CIRCLY which, when equal to 1, theoretically results in an actual rut in the field of 20 mm depth, which is theoretical pavement failure.

Using this information, an existing rut depth can be compared with the theoretical 'cumulative damage factor' (CDF) that has been calculated using the actual ESA's. This is in essence a comparison of the initial design against what is actually happening in the field and possibly give an indication of what stage of design life the pavements are at, compared with the designed pavement performance.

By using input parameters that better reflect actual pavement performance. The design of pavements can become more refined, which leads to better value for money, as pavements may become thinner thus using less materials. However pavements that behave stiffer than they are actually designed for, can fail quicker. This can come about due to the different failure mechanisms when one considers an unbound pavement (modified pavement) with a rigid pavement (stabilised pavement). Essentially an unbound pavement is considered flexible and usually fails by either shoving or rutting (Refer to figures 4.2.1 and 4.2.2), where as a rigid pavement is just that, rigid, and usually fails by crocodile cracking (Refer to figure 4.2.5).

Unbound pavements can best be explained by their materials, which consist of gravels or crushed rocks which have a grading that makes them mechanically stable, workable and able to be compacted. They are governed by their stiffness, shear strength and a resistance to breakdown under construction and normal traffic loading. The most common failure for unbound pavements is rutting and shoving through insufficient resistance to deformation by shear and densification and are considered to behave anisotropically (Austroads 2004).

Rigid pavement materials are considered to be isotropic due to being cemented materials. They produce a bound layer with significant tensile strength. The cementitious binder used can consist of portland cement, lime or other hydraulically-binding agent or combinations of the above binders. Further description can be found from the Austroads (2004).

Chapter 2.0

Background

2.1 History of Stabilisation

In Australia the first major specialist contractor to enter the stabilisation market was Stabilisers Limited when they introduced the P&H triple-rotor stabiliser in the 1950's. The first recorded use worldwide was in 1944 by the UK Ministry of Transport (Williams 1986).

The process in Australia was at first cumbersome and mainly performed by specialist contractors using developing techniques and equipment. As time progressed, competition led to inappropriate equipment and unskilled labour being used. This produced some pavements of inadequately mixed materials with inherent localised failures occurring during the service life of the pavement (Vorobieff 1998b). This wrongly resulted in a move away from insitu stabilisation due to the lack of confidence in using the method as a road rehabilitation process.

In 1970, Mobil in Victoria was the only remaining specialist to promote the sale of foamed bitumen stabilisation, a product that was resurrected in 1995. Mobil had sold their NSW operation and from this small company a programme was established for pavement recycling in the Western Suburbs of Sydney. Through particular attention to quality and continued work on the control of reflection cracking, the efficiencies of recycling by cement stabilisation was introduced to Bankstown, Fairfield and Blacktown Councils. At the same time, Mobil sold their Victorian operation, which passed through a number of ownerships before residing with Road Stabilisers and finally Pavement Technology. The 1970s saw a resurgence in the use of stabilisation in Victoria, New South Wales and Victoria, which soon spread to South Australia and later to Western Australia (Wilmot 2001).

In 1976, many articles on completed cement stabilisation projects were seen in technical publications. While the NSW-based operation relied very heavily on the mixing quality of the P&H triple-rotor machine, the industry slowly changed to the single-rotor machines we are familiar with today.

Until recently, two of the major restrictions on pavement stabilisation have been the depth the road pulveriser and compaction equipment could operate effectively. This was usually about 250 mm compacted depths.

The procedure used to construct deeper pavements was therefore by the construction of sequential pavement layers. This procedure resulted in significantly reduced economical benefits and adhesion problems between layers (Andrews and Burgess 1994). There have been a lot less problems with single layer insitu stabilising (White and Carthigesu 2002).

Figure 2.0 Stabilisation Machine

Recent years have seen the first major change in stabilisation equipment in 30 years with the introduction of the CMI RS500, now followed by a number of machines of a similar style from other manufacturers. These new machines are heavier, can have hot bitumen sprayed directly into the mixing chamber for foamed bitumen, are computer controlled for more accurate administrating of additive, are more powerful with better mixing capabilities and can also mix to greater depths. Together with the development of accurate cement spreading equipment, it has led to the extension of stabilisation from the local government low-traffic roads through to major roads and highway construction with the introduction of deep-lift (i.e. depths to 400 mm of stabilisation in a single layer). These greater depths have called for new products to delay the set time, enabling full compaction and finish to be achieved.

Until recently, the binder used was general-purpose cement powder; however since the 1990's a host of other binders have been developed. A general blend (GB) cement powder is now preferred as it has a slower set time then general-purpose cement powder and consequently giving the constructor more time to compact and finish to the design levels. Quick lime has been found to work very effectively on the black soil plains of outback Queensland. Different blends of fly ash, blast furnace slag and non-cementitious binders such as foamed bitumen, bitumen emulsion and dry powder polymers are also available. As the binders behave differently on each different host material, matching of the binder to the material is very important. Published guidelines (Auststab 2000) to assist in matching the binder to the host material have been released by road authorities, such that it is common practice to now use binders consisting of blends of cement and what were previously waste products, namely slag and fly ash. Cement companies are responding to this challenge by providing excellent service and investment in new technology to properly service the market, a far cry from the early 70s when only one product was available.

2.2 Pavement Design

When using a mechanistic pavement design on cementitiously stabilised pavements, the fatigue of the cemented layers is paramount to how the pavement will perform. The current Austroads (1992) method uses the following fatigue model for design:

- $N = (K/ue)^{12}$
- N = fatigue life (Equivalent standard axle ESA).
- K = Material constant. (This depends on the materials modulus, Austroads (1992) provides typical values).

- ue = Horizontal tensile strain induced at the bottom of the layer by one ESA load (equivalent standard axle).

The K factor is often a presumptive modulus value and sometimes an estimate using the relationship between modulus and the unconfined compression strain (UCS). This often leads to a single modulus being used for differing pavement materials and binder combinations. This has lead some researchers to question the Austroads fatigue model ($N = (K/ue)^{12}$), often stating that the fatigue model is too conservative when compared with field observations as was found during the Cooma Accelerated Loading Facility (ALF) trial (Vorobieff 1998b) and the Lake Macquarie field trials (Vorobieff 1998a).

The goal of this project is to identify different moduli for the different binder-material combinations found in Far North Queensland so as to develop a more economical pavement when rehabilitating roads in the region.

Today, Australia is recognised as a world leader in stabilisation theory and application. Australian technology is being used in Europe and Asia to develop the use of stabilisation in those areas; in particular, Australian cement spreaders are the most accurate and advanced in the world. Australian experience has also assisted in the development of new equipment produced in America.

The demand for cement stabilisation and the outstanding success of the process in Australia has been very much due to the concept of the specialist contractor. This has produced and retained in the industry, experience, expertise and development which would not otherwise have been achieved.

Australia needs a national road strategy to maintain and strengthen its economy and export of materials and manufactured goods. This strategy must consider all aspects and be consistent with national objectives of ecologically sustainable development, including a minimal disruption to our natural environment. Stabilisation of natural materials and recycling of roadways by stabilisation will play a major role in such a strategy (Wilmot 2001).

Figure 2.1 Stabilisation Machine

Chapter 3.0

Construction

3.1 Cement: Stabilisation, Modification description

Cementitious stabilisation refers to stabilisation using either cement or supplementary cementitious materials at a rate of approximately 3% or greater by volume. The design intent is to turn a gravel pavement layer which is considered an anisotropic layer (flexible), into an isotropic layer which is considered rigid. A normal unbound gravel pavement layer is considered flexible, whereas a bound gravel layer (i.e. cement stabilised pavement layer with enough cementitious material added to be considered an isotropic (rigid) layer can be likened to a concrete slab once cured. This is the main difference between a cementitious stabilised modified pavement layer which is considered an unbound or flexible layer using up to 2% by volume of cementitious material, and cementitious stabilisation with 3% or greater by volume of cementitious material which is considered a bound or rigid layer.

3.2 Cement Stabilisation

Through the mixing of calcium carbonate, alumina, iron oxide and silica, and the calcining and sintering of this mixture, Portland cement is formed.

The primary reaction of cementitious stabilising agents is the hydration in the presence of water to form hydrated silicates and aluminates and calcium hydroxide, which lead to the formation of cementitious material. Secondary cementation occurs as the free-lime is diffused. With soils containing some clay the calcium hydroxide produced will react to modify or cement the clay particles through the soil matrix.

These reactions occur almost independently of the nature of the soil and it is for this reason that cementitious stabilising agents can be used to stabilise a wide range of materials from cohesionless sands and gravels to silts and low plasticity cohesive materials (Auststab 1998).

Contractors mainly use either General Blend (GB) or General Purpose (GP) cement, with the trend towards the use of general blend (GB) cement because of their increased setting times. It is this increase in setting times that allows the contractor longer working times to allow for compaction and achieving better ridability of the finished product for traffic. This is particularly important when pavement depths exceed 250 mm.

However road pavements treated solely with cement, and stabilised with high percentages of cement, 2.5%by volume or greater were identified as having some limitations:

- The higher strength resulted in extensive shrinkage cracking thus reducing the durability of the pavement.
- Producing a bound layer within a flexible pavement that is more susceptible to fatigue (flexural) cracking.
- Reduced working times slowed down production times, compaction and ridability of the finished product.

3.3 Cement Modified Stabilisation

Pavements are considered modified pavements when the percentage of cement is 2% by volume or lower, and is considered to have some advantages over pavements that are treated with high percentages of cement. The following are some advantages:-

- It places less reliance on the binder for long term performance by improving grading and Plasticity Index.
- Optimise the blend of cementitious binders to suit material type and available working time.
- Minimise likelihood of shrinkage cracking. Modified pavements usually exhibit a close spaced network of finely spaced cracks and do not develop a network of widely spaced open cracks like some bound materials.
- Modified pavements are treated as an unbound pavement when using a mechanistic pavement design approach.
- Pavement modification allows construction of multiple layers with minimal reliance on bonding between layers when constructing deep lifts. Where as bonding is critical between layers of stabilised pavements that have high percentages of cement.

Pavement modification by stabilisation using cement is a low cost rehabilitation method that is practically useful for expansive, weak and/or wet subgrades and marginal insitu materials (Vorobieff, G. 2004). It has also been used in Far North Queensland for its ability to help waterproof pavements, which is of concern due to the high rainfall encounted in the tropics.

3.3.1Construction Methodology

Construction methods used in Far North Queensland for rehabilitation of existing pavements involves the following plant:

1. An additive spreader.

2. Stabilising mixer or reclaimer.

3. A watercart with a reasonable capacity.

4. Vibrating steel drum roller, padfoot vibrating roller and a multityred roller.

5. Grader for trimming off widenings etc.

After stabilisation the pavement is then primed and two coat bitumen seal applied with 16 mm and 10 mm screenings used respectively.

Figure 3.0 Grader trimming stabilised material

3.4 Lime Modified Stabilisation

Lime is most commonly used as a modifier of clay soils and in some cases it has been used successfully for the stabilisation of low-clay content granular soils. It has been used successfully on the black soils of inland Queensland with good success. Lime comes in a number of forms;

- Calcium oxide (quicklime).

- Calcium hydroxide (hydrated lime).

- Calcium/Magnesium Oxide (dolomite lime).

- Calcium Carbonate (agricultural lime).

Road stabilisation mainly uses quicklime or hydrated lime, as agricultural lime and dolomite lime are not as effective. In Far North Queensland quicklime is most commonly used being more granular than the hydrated products and is available only as a dry product. This form of lime reacts rapidly with available water producing hydrated lime and releasing considerable amounts of heat.

3.4.1 Determining Lime content and spread rate

In North Queensland the common tests carried out for lime stabilisation are;

- Lime Demand test.

- California Bearing Ratio (CBR).

- Unconfined compressive strength (UCS).

- Determination of the available lime index, i.e. quicklime or hydrated lime content of the lime.

The most used test in Far North Queensland is the Lime Demand test. This test is used to identify the amount of lime required to satisfy cation exchange by reaching a specific pH level of 12.4 to produce long-term reactions. Some soils may not gain in strength due to a dominant ion exchange process. A USC test is also carried out to consider the 28-day material strength of the stabilised pavement. The soaked CBR of the stabilised material is carried out in accordance with AS 1289.6.1.1.

The designer can determine the percentage of quicklime at 100% based on the % calcium hydroxide in the hydrated lime used for testing as follows;

$Rate_{FQ} = 0.0076\ (Rate_{LH} + Rate_{TOL})\ AL_x$

- $Rate_{FQ}$ = Quicklime field application rate (%).
- $Rate_{LH}$ = Hydrated lime rate % determined in the laboratory test program using hydrated lime from the supplier (%).
- $Rate_{TOL}$ = Construction tolerance allowance (%).
- AL_x = Available Lime Index for hydrated lime using hydrated lime in the laboratory test program from the supplier determined from AS4489.6.1 (%).

From the above the contractor can determine the quicklime spread rates using the following equation;

$Rate_{spread} = Rate_{FQ}\ YT/AL_Y.$

- $Rate_{spread}$ = The quicklime field spread rate (kg/m^2).
- $Rate_{FQ}$ = The quicklime field application rate (%).
- AL_Y = Available Lime Index of quicklime expressed as available quicklime from supplier determined from AS4489.6.1 (%).
- Y = Dry density of pavement material (kg/m^3).
- T = Stabilised layer thickness (m).

3.4.2 Methodology

Lime insitu stabilisation requires three specialist pieces of equipment.

1. An additive spreader.
2. Stabilising mixer or reclaimer.
3. A watercart with a reasonable capacity.

The purpose of the spreader is to hold and distribute the lime, prior to the mixing process. The purpose of the stabilising mixer is to thoroughly mix this additive into the host material. In the case of a stabiliser/reclaimer, the machine is also designed to reclaim and pulverise the existing pavement materials in order to break the materials down to a suitable size to use as a new aggregate.

The spreader has to be capable of holding the lime in a weatherproof condition and is loaded by bulk trucks discharging by pneumatics. The lime is spread at the design rate and the lime is then ‘slaked’ with the addition of water from the watercart. The slaking process is an exothermic reaction, which generates a considerable amount of heat releasing large steam clouds into the atmosphere. This slaking process is required to be carried out until all the lime has been hydrated. The material is then mixed with the stabiliser, compacted and trimmed.

3.4.3 Material properties

For lime to be effective the parent material must contain clay particles that are reactive with lime. It is usual that the higher the clay content the more lime is required to produce a specific strength. Lime effects on clay when using what is considered modified amounts, say 2% or lower, are simular to the effects of cement on clay, being strength gains, stability and flexural pavement behaviour. The difference being that materials stabilised with lime will continue to gain strength at a slower rate than cement as long as curing is sustained. High lime content will not necessarily produce higher early strengths.

Lime stabilisation is a two-stage process consisting of:

1. Immediate modification of the soil via agglomeration of the fine clay particles into coarse, friable particles through an ion exchange.

2. Secondary cementing action over time as the remaining free lime (through dispersion via pore water) reacts with either silica or alumina in the soil (or with other added pozzolanic products) to form calcium aluminates or silicates.

These two reactions result in a treated clay soil with decreased plasticity, lower affinity for water (greater volumetric stability and lower permeability), increased cohesion and strength (shear, compressive and tensile) and subsequently greater durability. While its effectiveness is vastly reduced with low to non-cohesive soils, lime is often used as a constituent in blends to react with clay fines in the soil and to act as a catalyst for the reactions of other additives in the blend, such as fly ash or slag (Auststab 2004). Figure 3.1 will illustrate the variations in strength with time and lime content for stabilised materials.

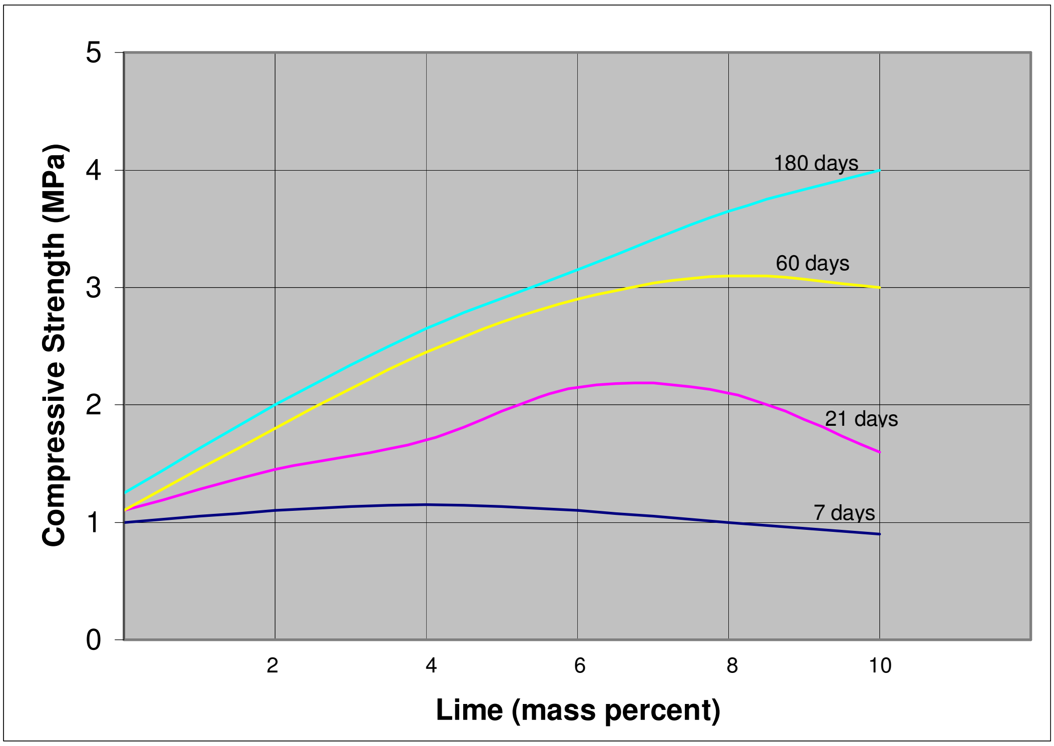


Figure 3.1 Typical Compressive Strength per % Lime

Source Auststab 2004

It should also be noted that lime's ability to dry out wet materials and reduce plasticity in unsuitable materials could be the primary objective in some instances and strength gain a secondary effect. An increase in lime content will increase the optimum moisture content of the material being stabilised.

The initial lime demand of the soil to be stabilised is required to be assessed. This is to ensure that adequate lime is added to achieve excess after initial reactions with the soil are completed so that the stabilised design properties are achieved in the long term (Sherwood 1995).

For Plasticity Index (PI) reduction and workability improvement using lime modification, sufficient lime should be added so that additional quantities do not result in further changes in PI. The use of a pH test to determine whether a soil is reactive to lime and a 28 day UCS test is required to establish the optimum lime content for the material involved. The optimum lime design content occurs when the plot of UCS v. lime content peaks. An additional 1% is usually used to allow for losses and mixing variations.

Sugars and reactive organic materials can retard the development of cementitious bonds with both cementitious binders and lime (Auststab 1998).

3.5 Foamed Bitumen Modified Stabilisation

Foamed bitumen stabilisation is a road construction technique whereby hot bitumen is used to bind the existing or imported granular material to produce a flexible bound pavement material for use in base and subbase pavement layers, and in particular for road rehabilitation.

Foamed bitumen (also known as foamed asphalt, foamed bitumen or expanded asphalt) is a mixture of air, water and bitumen. When injected with a small quantity of cold water, the hot bitumen expands explosively to about fifteen times its original volume and forms a fine mist or foamed. In this foamed state, the bitumen has a very large surface area and an extremely low viscosity (Kendall, Baker, Evans & Ramananujam 1999).

This expanded bitumen mist is incorporated into the mixing drum where the bitumen droplets are attracted to and coat the finer particles of pavement material, thus forming a mastic that effectively binds the mixture together. The stabilisation procedure can either be done insitu with specialised road rehabilitators or the pavements can be produced by a pug mill and paver construction procedure. The insitu stabilisation procedure is the only method used to date for foamed bitumen stabilisation in Far North Queensland and will be the only method considered in this report.

Figure 3.2 Foamed Bitumen Stabilisation

3.5.1 Limitations, advantages and disadvantages.

Foamed bitumen stabilisation has limitations to its use and requires a suitable grading of fines in the pavement material and specific purpose built machinery with experienced operators. Situations where foamed bitumen stabilisation can be considered but not limited to are;

1. A pavement that has been repeatedly repaired to the extent that pavement repairs are no longer cost effective.

2. A weak granular base overlies a reasonably strong subgrade.

3. A granular base too thin to consider using cementitious binders.

4. Conventional reseals or thin asphalt overlays can no longer correct flushing problems.

5. An alternative to full-depth asphalt in moderate to high trafficked roads.

6. Unfavourable wet cyclic conditions unsuitable for granular construction.

7. Situations where an overlay is not possible due to site constraints e.g. entries to adjacent properties & flood prone areas.

8. A requirement to complete the rehabilitation quickly to prevent disruption to business or residents.

Advantages

1. Shear strength of granular pavements is increased.

2. Lower costs than reconstruction.

3. Strength characteristics approach that of cement treated materials while remaining flexible and hence relatively fatigue resistant.

4. The bitumen content provides a water resistance and durability to the pavement material.

5. Lower moisture contents are required in comparison to bitumen emulsion stabilisation and hence wet spots are minimised during construction.

6. May be trafficked immediately.

7. Is carried out insitu and hence is quicker than other methods of rehabilitation such as an overlay.

8. Can be reworked a number of days after final trimming, which is not possible with cement stabilisation.

Disadvantages

1. Purpose built machinery is required.

2. The use of hot bitumen increases the risk of injury to all.

3. Not all pavement material are suitable as a complete grading of all particles from fines through to the coarser materials 20 mm, is required.

4. A more expensive procedure than lime/fly ash stabilisation.

5. Being only a relatively new process there is ongoing development of the design methodologies.

3.5.2 Materials

The bitumen used for foamed bitumen is typically Class 170 (AS 2008). The amount of bitumen required for stabilisation is determined by laboratory testing of the pavement that is to be stabilised. Typical application rates for foamed bitumen stabilisation are 2 to 4%. The addition of supplementary binders, such as lime or cement, is appropriate in some situations.

Potable water is required for both the process of foaming the bitumen and also to increase the moisture content of the pavement material during mixing. One of the key elements of a pavement to be modified with foamed bitumen is to have a suitable grading curve as shown in Figure 3.3. Modification of the material with another material so as to achieve a suitable grading curve can be an appropriate process.
Good results are obtained when the pavement material grading falls into Zone A, and successful stabilisation has occurred when part of the grading is in Zones B or C. The pavement materials should only be considered based on resilient modulus testing (Auststab 2002).

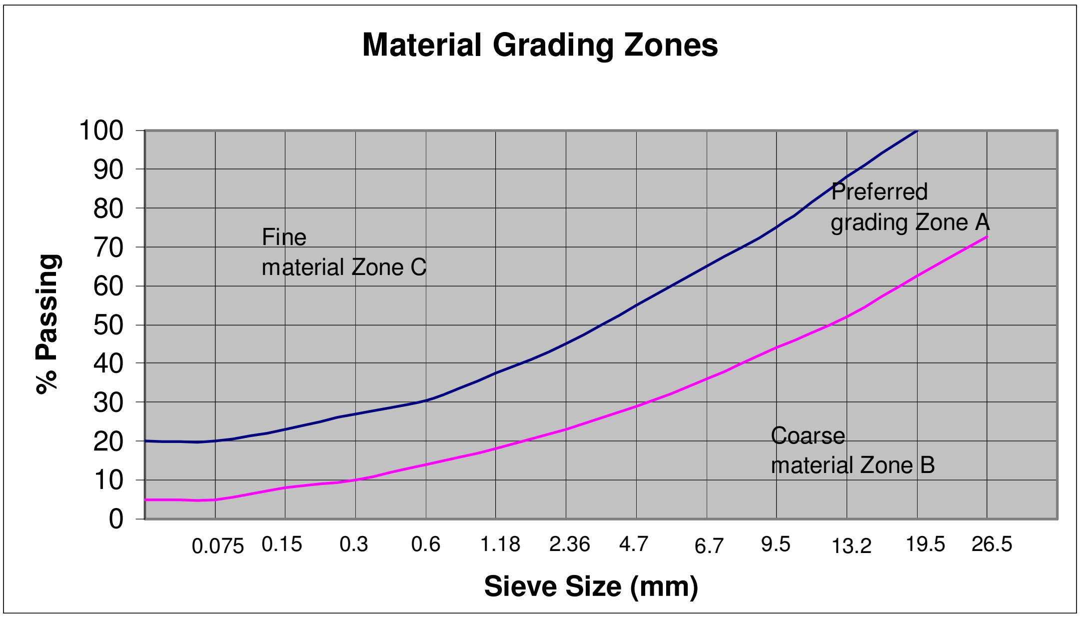


Figure 3.3 Material Grading Zones

Good particle size distribution is required to achieve strength and durability

Source: (Austroads, 1992).

3.5.3 Pavement design

In Far North Queensland the Main Roads Department uses CIRCLY extensively in designing pavements for rehabilitation with foamed bitumen. Foamed bitumen stabilisation of the base course results in an anisotropic pavement or in simpler terms a unbound flexible pavement.

Chapter 4.0

Mechanistic Pavement Designs

4.0 CIRCLY description

CIRCLY is a computer software mechanistic pavement design program that is used to calculate elastic strains at subgrade level and at the underside of stabilised pavement layers. The pavement life is then calculated using empirical equations that relate these stains to load repetitions that cause unacceptable rutting of the surface, or cracking of the stabilised pavement layers (Wardle, Youdale and Rodway, 2002).

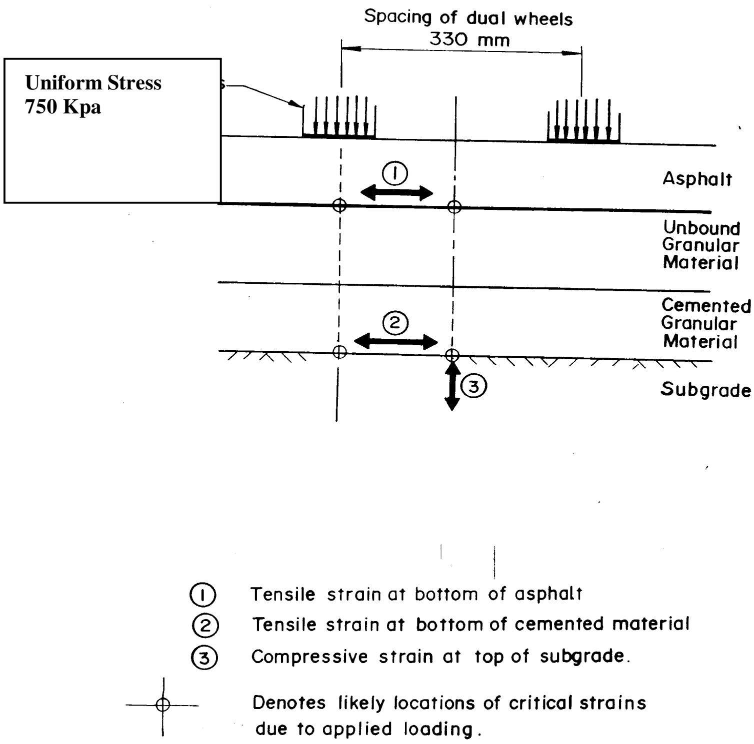
The program requires input parameters with the main parameters being but not limited to:

- Moduli for the type of modification to be used in Mpa.
- Design traffic ESA.
- Subgrade strength in Mpa.
- Pavement thickness.

4.1 Mechanistic pavement Design

Mechanistic pavement design can be described as a method that uses a layered elastic analysis to calculate traffic induced elastic strains in pavements. Critical strains are then empirically related to the rate at which pavements deteriorate by calibration against observed performance of test pavements or in service pavements. The vertical compressive strain at subgrade level is related to the traffic repetitions to cause surface rutting, and the tensile strain at the underside of stabilised pavement layers is related to traffic repetitions to cause cracking of those pavement layers (Wardle, Youdale and Rodway, 2002).

This chapter will briefly deal with how the Main Roads Department in Far North Queensland go about their modified pavement design for rehabilitation of existing pavements with the design software package CIRCLY. Below is a diagrammatic view of the pavement analysis model used in mechanistic pavement design.



Typical Pavement Analysis Model

Figure 4.0 Typical Pavement Analysis Model
Source Pavement Design Manual Queensland Transport 1990

Far Northern Main Roads pavement design engineers are given the following input parameters to use by senior management in the Main Roads Department.

Tyre pressure = 750 Kpa

Poisson's Ratio

Granular Material	0.35
Cement Treated Material	0.20
Cement Modified Material	0.35
Subgrade	0.45
Asphalt	0.40

Modulus of various layers of pavement.

Cement Modified Material	500 Mpa
Cement Treated Material	5000 Mpa Cat 1
	2000 Mpa Cat2
Post cracked CTB/CTSB	500 Mpa
(Cement Treated Base/ Cement Treated Sub-base)	
Foamed Bitumen	1600 Mpa

Granular base and Subgrade

Table 4.0 CBR/MODULUS

CBR	**MODULUS** Mpa
2	30
3	40
4	48
5	57
6	64
7	71
8	78
9	85
10	91

12	103
15	120
20	144
25	166
30	187
35	206
40	225
45	242
50	259
55	276
60	291
65	307
70	322
75	336
80	350

The above input parameters were used in this study whilst using the CIRCLY software program.

To design the pavement the designer collects the following information.

- Existing pavement configuration and the different depths of the layers from pot holing onsite. This helps in determining what rehabilitation process is going to be used i.e. cement, lime or foamed bitumen.

- The onsite CBR value for the different layers in the pavement including the subgrade. These are input parameters for the CIRCLY programme.

- Existing Annual Average Daily Traffic (AADT) which is the total yearly two- way traffic volume divided by 365, expressed as vehicles per day (Austroads 2004) so as to calculate the '20 year design traffic load' for the new rehabilitated pavement as per the Queensland Transport Pavement Design Manual.

Once the above parameters are entered, the software program is used to determine the most appropriate depth to be rehabilitated.

4.2 Pavement Failure Mechanisms

There are five broad types of pavement distress:-

- Deformation.
- Cracks.
- Surface texture deficiencies.
- Edge defects.
- Potholes and patches.

4.2.1 Deformation

Deformation is a change in the road surface as when compared with the intended constructed profile of the pavement. It can be caused by traffic conditions, environmental conditions, inadequate construction controls during construction or a combination of all or some of the above. It is an important element of a pavement's condition and may reflect structural inadequacies both in the pavement and below the pavement. The main attribute is always vertical displacement and has been standardised as the maximum depth obtainable under a 1.2 metre straight edge as depicted in figure 4.2.0. (Austroads 1987).

There are four main types of deformation which occur:-

- Depressions
- Rutting
- Shoving
- Corrugations

Depressions

A localised area in the pavement that is lower then the surrounding area which may extend across several wheel paths though not confined to wheel paths.

Figure 4.2.0 Road Pavement Depression

SOURCE hotmix.ce.washington.edu

Rutting

A longitudinal deformation usually contained in the wheel paths of a pavement.

Figure 4.2.1 Road Pavement Rutting

SOURCE hotmix.ce.washington.edu

Shoving

Is a bulging of the road surface generally parallel to the direction of the traffic flow though transverse shoving can occur due to turning movements of the traffic. Braking and accelerating movements are the main causes of pavement shoving.

Figure 4.2.2. Road Pavement Shoving

SOURCE hotmix.ce.washington.edu

Corrugations

Are transverse undulations closely and regularly spaced usually with wave lengths less than 2 metres (Austroads 1987).

Figure 4.2.3. Road Pavement Corrugations

SOURCE hotmix.ce.washington.edu

4.2.2 Cracks

Cracks are fissures from partial or complete fractures of the pavement surface (Austroads 1987). They appear in a wide variety of patterns ranging from single cracks to vast interconnected cracks extending over the entire pavement surface. Cracks can contribute to the accelerated deterioration of pavements by the loss of traffic load –spreading ability and allowing the ingress of water to the underlaying layers. Some of the factors that can lead to cracking but not limited too are:-

- Reflection cracking from underlaying layers.
- Shrinkage.
- Deformation.
- Poorly constructed construction joints.
- Age embrittlement of the surface.
- Surfacing fatigue life exceeded.

Due to cracks permitting water entry into the under laying layers, they can be a major cause of a range of secondary failure mechanisms, i.e. potholing, shoving and deformations. The main crack types are:-

- Block.
- Crocodile.
- Crescent shaped.
- Diagonal.
- Longitudinal.
- Transverse.
- Meandering.

Block Cracking

Consists of interconnecting cracks that form in a series of blocks. The blocks are usually greater that 200 mm in size and in some instances exceed 3000 mm in size. The cracks may reflect pavement layer joints underlaying the surface layer. This is the reason why concrete pavements overlaid with asphalt predominately have this problem.

Figure 4.2.4. Block Cracking

SOURCE hotmix.ce.washington.edu

Crocodile Cracking

Are small interconnecting cracks that resemble the hide of a crocodile. Usually found in wheelpaths and may have a noticeable longitudinal grain.

Figure 4.2.5 Road Pavement Crocodile Cracking

SOURCE hotmix.ce.washington.edu

Crescent Shaped Cracks.

Crescent or half moon shaped cracks commonly associated with shoving and are mainly associated with asphalt.

Figure 4.2.6 Crescent Shaped Cracks

SOURCE hotmix.ce.washington.edu

Diagonal Crack.

A diagonal crack across the pavement surface can be caused by reflection from underlaying layers, tree roots, differential settlement or poor construction methodology. The crack is simular to a transverse crack except in crosses the pavement on the diagonal, hence the name.

Longitudinal Cracking.

A single crack or a series of parrel cracks running longitudinally along the pavement. Longitudinal cracking can be caused by poorly constructed construction joints, differential settlement, and reflection cracking from underlaying layers or a volume change from expansive clays used in the embankment construction.

Figure 4.2.7. Longitudinal Cracking

SOURCE hotmix.ce.washington.edu

Transverse Cracking.

Is a crack running transversely across the pavement. This cracking can be caused by reflection cracking from underlaying layers, shrinkage cracking or structural failure of a portland cement concrete base.

4.2.8 Transverse Cracking.

SOURCE hotmix.ce.washington.edu

Meandering Cracks.

Are unconnected irregular cracks, varying in direction, usually singly (Austroads 1987). Some possible causes are reflection of shrinkage cracking in underlaying layers, tree roots and differential settlement.

4.2.9 Meandering Cracks.

SOURCE hotmix.ce.washington.edu

4.2.3 Surface texture deficiencies.

This covers loss of surfacing materials, loss of surface macrotexture and microtexture. Surface texture deficiencies do not usually indicate structural failure of the pavement layers but will significantly impact on the serviceability of pavement in regards to skid resistance and quality of ride. This deficiency if recognized early can be rectified by resurfacing the affected areas before damage of the underlaying layers occurs. It is not a major trigger for modified pavement rehabilitation methods and will not be explained further in any detail. Readers are directed to 'A guide to the Visual Assessment of Pavement Conditions', Austroads 1987 for further explanation of surface texture deficiencies.

4.2.4 Edge defects.

Edge defects as the name implies occurs along the interface of the bituminous surfacing and the unsealed shoulder of the pavements. These defects can occur continuously along the length of the pavement being caused mainly by tyre wear and attrition along the edge of the pavement. Edge defects are considered a bituminous surfacing problem and consequently will not be dealt with any further. However readers are directed to ‘A guide to the Visual Assessment of Pavement Conditions’, Austroads 1987 for further explanation of Edge defects

4.2.4 Potholes and Patches.

Pot Holes are a bowl shaped depression in the pavement surfacing created by traffic abrading small surface imperfections (cracks etc) which then allows the ingress of water. The water helps to accelerate the development of the pot hole in conjunction with the traffic.

Patches take the following two forms:-

- Expedient patches.
- Reconstruction patches.

An expedient patch is a surface repair without a dig out, an example being the filling of a pot hole with bituminous materials. A reconstruction patch is where material is excavated and then replaced and brought back to the existing profile of the surrounding material. The repair could be either just the surface layers or all pavement layers or combinations of these.

4.2.10. Potholes

SOURCE hotmix.ce.washington.edu

4.2.11 Patches

SOURCE hotmix.ce.washington.edu

Chapter 5.0

Existing pavement assessment

5.1 Site details

Three sites where assessed for this report and their details are as follows:-

Cowley beach turnoff Bruce Highway Job No 66/10N/M10

Approximately 126 Km's south of Cairns. Chainages 125.534 – 127.008 km's

Construction date:- October 2000, Cement modified insitu stabilised pavement.

Design ESA = 1.1 X 10^6

Design subgrade CBR = 8

250 mm cement modified layer with 2% by volume of cement General Blend (GB) powder used with an underlaying layer of 50 mm of CBR 80 insitu gravel.

A two coat bitumen chip seal used.

> 1st coat primer seal, bitumen type C170 sprayed at 1.4 litres/m^2, 16 mm precoated screenings spread at $80m^2/m^3$, 2nd coat C170 sprayed at 1.0 litres/m^2, 10 mm precoated screenings spread at $120m^2/m^3$

Palmerston Highway Job No 66/21A/805

Approximately 100 Km's south of Cairns and 25 km's west of Innisfail. Chainages 18.620 – 28.720 km's

Construction date:- June 2002, Foamed bitumen modified insitu pavement.

Design ESA = 2.17 X 10^6

Design subgrade CBR = 8

250 mm foamed bitumen modified layer with 2% by volume of un-hydrated lime powder and 2% by volume of bitumen used, with an underlaying layer of 50 mm of CBR 80 insitu gravel.

A single coat bitumen chip seal used.

> 1st coat primer seal, bitumen type C170 sprayed at 1.4 litres/m^2, 16 mm precoated screenings spread at $80m^2/m^3$.

Deeral Bruce Highway Job No 158/10P/710

Approximately 44 Km's south of Cairns. Chainages 43.880 – 44.830 km's

Construction date:- July 1992, Lime modified insitu pavement.

Design ESA = 1.1 X 10^6

Design subgrade CBR = 8

250 mm cement modified layer with 2% by volume of un-hydrated lime powder used with an underlaying layer of 50 mm of CBR 80 insitu gravel.

A two coat bitumen chip seal used.

> 1st coat primer seal, bitumen type C170 sprayed at 1.4 litres/m^2, 16 mm precoated screenings spread at $80m^2/m^3$, 2nd coat C170 sprayed at 1.0 litres/m^2, 10 mm precoated screenings spread at $120m^2/m^3$.

The following dot points lists out the procedure that was used in investigating the existing pavements. A more detailed explanation of each point will follow in subsequent sections.

- Site inspection to determine any modes of failure and existing pavement conditions and/or extenuating conditions that may have exacerbated the condition. This helps to give the designer a 'feel' for the section in consideration.

- Assessment of the existing pavement by the use of a 'Falling Weight Deflectometer' (FWD).

- The traffic load the road has sustained during its life and at what times of the year the pavement received any heavy loading, i.e. was the commercial traffic cyclic in nature.

- Comparison of the existing pavement materials, with the materials used in the design.

- Determination of the strength of the subgrade in both wet and dry states. This is commonly done by determining its California Bearing Ratio, known more commonly as its CBR value.

- Environmental considerations were assessed as pavement performance is significantly affected by water and temperature.

5.2 Site inspection

Prior to going onsite, a work place health and safety risk analysis was carried out to ensure safety whilst visually inspecting each site. This involved placement of warning signs for the travelling public, the wearing of safety boots and the consideration of UV exposure. The work place health and safety risk analysis sheets can be found in Appendix B.

On each section in question a visual inspection was done whilst measuring rut deformation to help in determining the failure mechanism types of the pavement i.e. rutting or crocodile cracking. It is generally accepted in the Far North that rutting of the pavement is most likely to be caused by subgrade failure, whilst crocodile cracking is regarded as a rigid or bound pavement failure.

Figure 5.0 Rut measurement

Rut measurement was carried out by using a 1.2 metre straight edge placed across the outside wheel path and the rut depth measured with a tape measure approximately every 25 metres longitudinally along the road between the chainages stated for each location as noted in section 5.1 above.

During the design of the initial pavement, designers use certain parameters that are entered into the software program CIRCLY prior to running the program, which will determine the most appropriate gravel depth with the given parameters. Two of these parameters are equivalent standard axle's (ESA) and the design subgrade strength in CBR. It is these two parameters that will now be discussed.

5.2.1. Subgrade CBR

The subgrade CBR is stated in the initial drawings and specifications for the road sections in question. Before rehabilitation can commence an analysis of the section in question is required so as to verify that the subgrade CBR that was used in the initial construction was that which was used in the design. This is done by excavating down beside the pavement and taking soil samples back to the soil laboratory for material testing.

5.2.2. ESA (Equivalent Standard Axle)

A standard axle consists of a dual –wheeled single axle, applying a load of 80 KN. The contact stress is assumed to be uniform over the loaded area and is assumed to be 750 kPa, which represents the tyre pressure of highway traffic (Austroads 2004).

The design ESA's for the initial pavement design was based on existing traffic counts with a forecasted ESA for the life of the pavement. In Far North Queensland the design life of pavements is 20 years, with a rut of 20 mm developing over this time. This 20-year expected life is based on the amount of ESA's the pavement receives. Whilst the intent is for the life of the pavement to be 20 years this is not strictly correct, as it is the amount of traffic the pavement receives that determines the pavement's life. For an example, if a pavement was designed for 2 X 10^6 ESA (20 years) and this was reached after 10 years then theoretically this pavement has reached the end of its life and would also exhibit a 20 mm rut.

Using the above rationale, sample sections have been measured in the study areas. By measuring the ruts at each section every 25 metres, determining the design ESA's for each section and then comparing with the actual ESA's, it was anticipated that there would be a correlation between rut depth and used portion of design life. As a 10 mm rut would theoretically equal half of the pavement's expected life. The measurements can be found in Appendix C.

This process aided in providing a broad 'feel' for the sections but was in no way conclusive. This was due to a number of factors;

- Vertical construction tolerances on the finished pavement surface allowed under Main Roads Department specifications was $\pm$ 5 mm at time of construction. This has the potential to 'pollute' the gathered data.

- Traffic usually travels along the same wheel path thus wearing the stone down under the tyres of the vehicles and not uniformly across the whole pavement. This can give the appearance of ruts starting to form and also has the potential to 'pollute' the gathered data.

- Due to the vehicles tracking in the same wheel path, the stones in the bitumen tend to be 'worked ' by the continual traffic load and will orientate themselves down onto their flattest side quicker than the stones in the lesser trafficked sections of the road.

Due to the above, unless there is a large deformation the information is too ambiguous to accurately determine the exact actual state of the pavement though it can give a broad indication of its condition.

5.2 Falling Weight Deflectometer (FWD)

The Falling Weight Deflectometer (FWD) is a machine that uses dynamics to assess the modulus of a pavement. The FWD is roughly the size of a small box trailer and can be easily towed behind a car and operated while attached to the vehicle.

Figure 5.2 Falling Weight Deflectometer

The FWD works by dropping a 300 mm diameter disc weight that impacts the road at approximately 750 Kpa. The intent is to replicate the pressures of a single axle truck with dual tyres impacting on the road. Upon impact the pavement will deflect and the FWD has sensors spaced at every 150 mm out to 1500 mm to measure these deflections. Below is a diagram showing the weight on the ground with the 150 mm spaced sensors.

Figure 5.2.1 FWD sensors

The FWD can be used to assess pavements taking readings at whatever the desired spacing is required. In North Queensland the spacing used is normally 1 every 100 metres. This testing frequency was used in this study.

The data from all the 'hits' is then collected for each site; Appendix D has all the raw data for each site in question. Below is an example of the graphical representation of the data. The shape of the line is given the term 'bowl'.

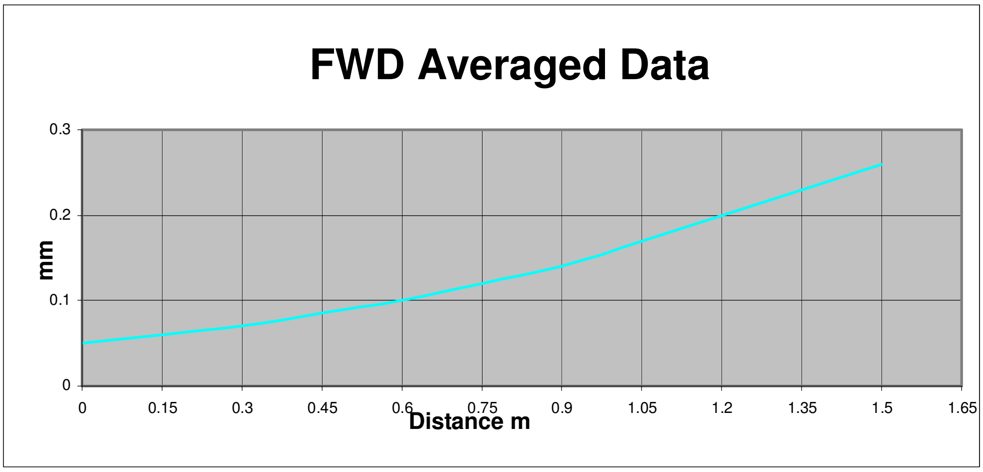


Figure 5.2.2 FWD Data

In determining the moduli for each section, the above graph is critical to the results that are given. Further information on the above will be discussed in Chapter 6-CIRCLY Back Analysis.

5.3 Existing Pavement Materials

It is necessary to compare the materials that were specified in the initial construction design with the materials that were actually used onsite. The gathering of soil samples is done by pot holing onsite and soil samples taken and then compared with the actual design. This is a verification process as construction methodology is sometimes changed but these changes are not recorded.

Figure 5.3 Pot Holing for soil sampling

5.4 Traffic Assessment

This section deals with the procedures used in assessing the traffic loadings of each section under study. The Main Roads Department's traffic counting unit in Cairns has collected the traffic load count over the study sections for a number of years. This study is based on these recorded traffic counts.

The procedure used in this study to assess loading is documented as , Method 3 in Appendix E of Austroads pavement design manual(Austroads 1990) and also using a combination of Method 2 Appendix E of Austroads pavement design manual(Austroads 1990) with the Queensland Transport Pavement design manual 1988/1990. The methods are explained in more detail under section 5.4.1 and section 5.4.2.

The main features of traffic that will determine pavement performance are the number of axles that pass, the axle configuration and loading over the axles. It must be noted that pavement design using traffic data is only interested in the heavy traffic i.e. trucks. Cars and light commercial traffic is not considered for loading, though they do affect the road carrying capacity.

Assessment of axle type in this study has been done on four main groups (bins) using Method 3;

- Single axle with single wheel.
- Single axle with dual wheels.
- Tandem axles both with dual wheels.
- Tri-axles all with dual wheels.

For Method 2, commercial traffic has been allocated into one 'bin'.
Damage done to pavements is dependant on axle spacing, the number of tyres per axle and the load on the group and the suspension (Austroads 1992).
The standard axle is defined 'as a single axle with dual wheels that carries a load of 8.2 tonne' (Austroads 1992).

Presently, fine-tuning of traffic counts has lead to the Main Roads Department in North Queensland using up to 13 groups or bins. A greater number of data categories provides a better understanding of the impact different types of vehicles have on the road network and thus better designing of roads with the available materials. Having a better understanding will help engineers to design more economical, socialably and environmentally acceptable roads than are being presently constructed.

5.4.1 Method 3

Method 3 has the following steps:

(i) From Main Roads data enter the Annual Average Daily Traffic (AADT) and the percent of commercial traffic for each year.

(ii) Estimate the number of equivalent standard axles (ESA) per commercial vehicle. The percent commercial figure is produced from the traffic census data supplied by The Main Roads Department North Queensland.

(iii) Calculate the commercial ESA's per day = AADT x commercial% x f.

(iv) The year is then broken up into three parts, Wet 122 days, Medium 122 days and Dry 121 days. Due to industry seasons a '% of AADT in this seasons' is introduced to account for industry seasons, 0.894 for wet times, 1.012 for medium times and 1.092 for dry times.

(v) The ESA's per year per season is then calculated:
(Days) x (comm. ESA per day) x (% of AADT in this seasons) = ESA's/year/season.

When using the above method there are some conservative assumptions that have been used. The following items will set out these assumptions, with possible methods to fine-tune the data at a later date.

(i) With more accurate counting techniques, the actual commercial traffic percentage would be known thus giving a more accurate count of commercial vehicles year by year, season by season.

(ii) When calculating the ESA's, an 'f' factor is used. The appropriate 'f' factor is given in table E5 Appendix E Austroads pavement design manual (Austroads 1992). These 'f' factors where devised from historic traffic data and it must be remembered that axle configuration and loading is constantly changing. Prior to 1987 legal load limits of 5.4t, 8.5t, 15t and 18t for single axle single tyres, single axle dual tyres, tandem axle dual tyres and tri-axle dual tyres applied. After 1987 these changed to 6t, 9t, 15t, and 20t (Angell 1988). It is to be expected that there will be an overall increase in vehicle loadings over the design life of pavements.

(iii) Breaking the year up into wet and dry times allows for periods when the road network is at its most vulnerable to damage. A more accurate assessment of the average duration of the wet seasons would provide the appropriate proportion of time to be applied.

The number of days for each season each year varies. Tis then casts doubt over the assumption that the seasons last approximately 122 days and replacing this with the actual season length would lead to more accurate historical data. As can be appreciated, seasons change duration and in North Queensland the wet season has been known to last from just one month to nearly six months in one year.

'% of AADT in this season' is another ambiguous figure that requires careful analysis. In North Queensland the sugar industry is seasonal by nature, which starts usually in the dry time of the year. If the wet season starts early, the cane season can finish in the wet season. Heavy vehicles cart sugar cane to the sugar mills for processing and other heavy vehicles cart the raw sugar to warehouses, in preparation for loading onto ships for export. The amount of rain received prior to the cane season commencing will often determine the amount of damage the road network sustains, since a large amount of rain prior to the cane season, leads to more damage to the road network.

Another industry that is also seasonal in relation to heavy vehicles is the beef industry, although the impact is not as great as the sugar industry, especially on the coastal area. Cattle are taken to market after the wet season when in prime condition. Cattle are also moved about in times of drought as they are moved on agistment to greener pastures to sit out the drought, usually on the coastal area.

This shows a relationship between wet weather conditions, and how seasonal industry can affect the road network in North Queensland. Thus a more careful analysis of seasonal heavy traffic and the growth of heavy traffic in relationship with wet weather conditions would lead to a more accurate determination of design traffic when designing pavements for rehabilitation.

5.4.2 Method 2

Method 2 is simular to Method 3, with the added parameter of breaking up the commercial traffic into groups (bins) of simular nature and then multiplying by an 'f' factor that relates to that group. Classes of vehicles are set out below as per Austroads pavement design manual (Austroads 1992).

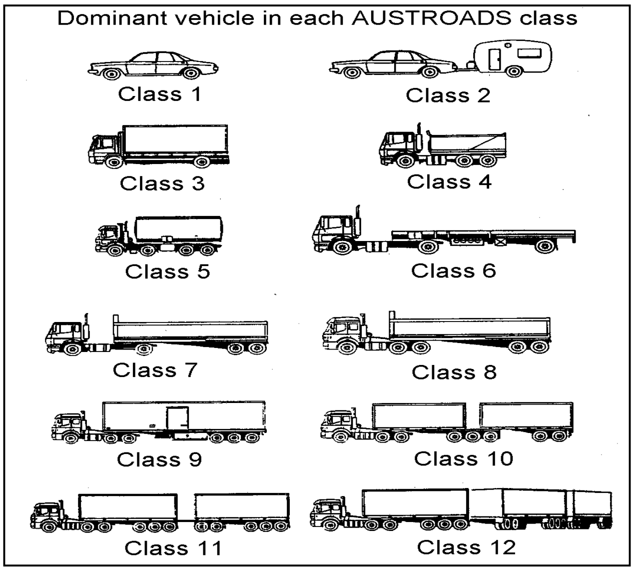


Figure 5.4.2 Vehicle Classes

The classes are broken up in North Queensland by the Main Roads department as per below:

Table 5.4.2 Vehicle 'F' factors

Vehicle Type	**Factor**
2,3,4 axle rigid truck	1.5
3,4,5,6 axle articulated vehicle	2.5
Medium length combination	3.1

These ‘f’ factors are then used in the calculation of ESA’s per year per season. The consensus amongst North Queensland traffic design engineers is that Method 2 is more representative of actual commercial traffic than Method 3, due to the commercial traffic being grouped into bins as per table 5.4. Whilst there is more explicit data being used, the ‘f’ factors are based on old studies around the 1960’s and as such needs to be treated with suspicion, as they appear to be over conservative. This, in time, will be overcome as more detailed analysis is done with the gathering of better data.

5.4.3 Design Traffic verses Actual Traffic

All information for Columns 1 and 3 was supplied by Department of Main Roads Northern Region. Column 1 was derived from Table 5.4.4 by dividing initial design ESA by 20, and then multiplying by years of service to arrive at Column 1, Table 5.4.3. Column 2 will be dealt with in section 5.4.4.

As can be seen, the traffic growth has far exceeded Department of Main Roads Northern Regions expectation for all sections.

Table 5.4.3 Design traffic to date / Actual traffic to date

	1	**2**	**3**	
Section	**Design to date ESA**	**Actual to date ESA**	**Years of service from new**	**Actual traffic compared with design. % over**
Cowley turnoff Bruce Hwy 66/10N/M10	247,500	729,350	4.5	294
Palmerston Hwy 66/21A/805	162,750	269,800	1.5	166
Deeral Bruce Hwy 158/10P/710	275,000	833,100	5	303

Table 5.4.4 Initial ESA design parameter

Description	Initial design ESA based on 20 mm rut over 20 years
Cowley turnoff Bruce Hwy 66/10N/M10	1,100,000
Palmerston Hwy 66/21A/805	2,170,000
Deeral Bruce Hwy 158/10P/710	1,100,000

5.4.4 Calculated ESA's to date

Method 3 as per Section 5.4.1 was used in the calculation of existing ESA's used for each road section. Spreadsheets containing the calculations used for the three sections can be found in Appendix E.

Chapter 6.0

CIRCLY Back Analysis

6.1 CIRCLY back analysis procedure

The procedure used for the analysis of each road section can be outlined as follows, and should be read in conjunction with the summary spreadsheets shown as Table 6.1, 6.2 and 6.3.

- A spread of rut depths measured in the field that correlate with FWD data chainages are inserted into the Tables 6.1, 6.2 and 6.3.

- The design parameters are placed into the software program CIRCLY. i.e. base gravel depth and modulus, sub-base gravel depth and modulus, FWD load used.

- Working through one chainage at a time using CIRCLY, the subgrade CBR is manipulated until the deflection on the graph at the X point, 900 mm, is the same or close as possible to the deflection given on the field FWD data trials for the same 900mm, X point.

- The CIRCLY output graphs can be found for each road section in Appendix F.

- The base gravel modulus is then manipulated in CIRCLY until it represents the deflection achieved during the field FWD data trials at the point 0 mm. This procedure is simular to that used on the subgrade above.

- The graph print out is checked for further minor alterations and adjusted if necessary, by manipulating the gravel modulus and/or subgrade CBR.

- The base gravel modulus and subgrade CBR used to achieve the graph are then entered on to the spreadsheet at their respective chainages.

- The actual traffic load to date is then placed onto the software program and the output ticked for a cumulative damage factor (CDF).

- The design load is replaced with ESA's and the program run to give an output for the CDF and is entered onto the spreadsheet.

- If the CDF equals 1, then there should be a 20 mm rut on the existing road, which is then checked against the actual rut to see if there is any correlation. Otherwise the CDF is multiplied by 20 to achieve a calculated rut.

- The CIRCLY print out used by the software program in calculating the graphs for each road section can be found in Appendix G, Deeral chainage 44800, Cowley chainage 126900 and Crawford's lookout chainage 18927. Printouts were done for all chainages but have not been added to Appendix G, as results have been placed on table 6.1, 6.2 and 6.3.

- The CIRCLY print out for the corresponding CDF number can be found in Appendix H. All other chainages returned a CDF number that in practical terms equals zero.

6.2 Summary Bruce Hwy Cowley T/off 66/10N/M10 Cement Modified.

No correlation between actual rut depth and cumulative damage factor could be found in the chainages studied. An example correlation is for chainage's 126050 and 126100 to have CDF's of 0.65 and 0.7 respectively. This represents the 13 and 14 mm ruts found in the field. As can be seen from the summary spreadsheet in Table 6.1, Chainage 126900, with only 1 mm actual rut gave an unexpected low result for the modified base course and subgrade. During the onsite inspection there was no visible cracking of the pavement, though what appeared to be rutting could be seen and was documented as per the rut depths measured in Appendix C.

It is difficult to average the actual moduli used in Table 6.1 in the back analysis as the subgrade CBR varied over each location. It can be seen however that the design moduli should be higher than the 500 Mpa allowed for at present. The study on this section does point out a trend that the actual moduli of the existing pavement is higher than the design moduli, however this study is inconclusive to pin point a new design moduli for pavement design. A moduli of 750 Mpa is recommended to be used in future pavement design.

Reflecting on the results it could be determined that the FWD data should be collected just after the wet season when the road network is at its most vulnerable.
The existing FWD data was collected during September, which traditionally is the driest time of the year in Far North Queensland. The red clays are used as road embankment in Far North Queensland, traditionally giving higher unsoaked CBR's when in a dry state which may be the reason why high subgrade CBR's were encounted during the CIRCLY runs. This factor would need to be verified when doing future studies. Overall, wet weather can have substantial negative effects on the Far Northern road networks.

Another parameter that may bias the collected data is that the rut depths taken in the field must be taken at the exact same chainage and time that the FWD data was taken to ensure an accurate correlation between the two. It can be noticed that the FWD data used in this study was taken a considerable period of time before the rut measurement was taken. Allowances and assumption are then made, which in turn compromises the accuracy of the data.

6.3 Summary Bruce Hwy Deeral Job No 158/10P/710 Lime Modified.

A weak correlation can be seen to exist between the actual rut depth and the modulus, subgrade CBR and the calculated subgrade rut. Chainage 44800 has the lowest back analysis readings with the calculated subgrade rut being only 14% of the actual rut on the surface. The subgrade strength can be seen to be stronger than the design strength and this may be so, however the FWD data was compiled in early January and could have been prior to the wet season starting that year thus giving the higher than expected CBR's (i.e. unsoaked). Actual CBR testing would need to be carried out to determine the insitu subgrade strengths for both soaked and unsoaked CBR's to help in better understanding of the material's behaviour.

During the onsite inspection there was no visible cracking of the pavement, though evidence of rutting could be seen and was documented as per rut depths measured in Appendix C.

This section of road returned the best correlation when a comparison was done between the actual rut depth and the cumulative damage factor (CDF), though only a weak correlation at best. Closer timeframes for the gathering of FWD data and measurement of rut depth would make for more accurate results that are representative of the performance of the pavement.

It is difficult to average the actual moduli used on Table 6.2 as the subgrade CBR's varied over each location. From the data collected on this section and represented in Table 6.2, no trend can be seen with respect to higher actual moduli than the design moduli of 1000 Mpa. In the absence of more compelling information the design moduli for lime modified pavements should stay at 1000 Mpa.

6.4 Summary Palmerston Hwy Job No 66/21A/805 Foamed Bitumen.

No correlation between actual rut depth and cumulative damage factor could be found in the chainages studied. Actual rut depth and subgrade strength was also reviewed, however no pattern could be established. During the onsite inspection, there was no visible cracking of the pavement, though rutting could be seen and was documented as per rut depths measured in Appendix C.

The rutting could be attributed to a number of factors as set out below, though unsubstantiated and would require further investigation.

- Bitumen's viscosity is affected by temperature, thus the time of the year it was constructed and the time of the year when it receives heavy traffic. i.e. traffic content during the hot summers could be creating a rut due to the bitumen flowing out of the traffic wheel path when hot.

- The bitumen type used can have different effects. (i.e.-Type 170 or 320 bitumen) Type 320 is stiffer bitumen than 170.

- The stone in the pavement may orientate itself to its average least dimension under service life, giving the impression of a rut.

- The subgrade could be deforming during the wet season by traffic load.

- The past seasons should be checked as to whether or not there have been a number of wet years or a number of dry years, thus influencing the subgrade materials.

It can be seen from Table 6.3 that all moduli used in the back analysis for foamed bitumen modified pavements is higher than the design moduli. The average for the pavement moduli is 5,330 Mpa with all chainages having a higher subgrade reading then the design CBR of 8. This points out a strong case for increasing the design moduli for foamed bitumen modified pavements from 1600 Mpa up to 3000 Mpa.

Table 6.1 Bruce Hwy Cowley Beach T/off 66/10N/M10 cement modified

Bruce Hwy Cowley Beach T/off 66/10N/M10 cement modified

		Modified Base Layer		Sub-base Layer		Subgrade (CBR)	Nov 2000-July 2004			
Lane	Chainage	Gravel depth	Modulus used	Gravel depth	Modulus used		ESA to date	Cumulative damage factor	Calculated subgrade rut mm	Actual Rut depth mm
2	Design	250	500	65	300	8	220,000	0.00E+00	0.0000	0
2	125500	250	6750	65	300	15	729,350	0.00E+00	0.0000	3
2	125550	250	1000	65	300	15	729,350	0.00E+00	0.0000	3
2	125600	250	2400	65	300	15	729,350	0.00E+00	0.0000	1
2	125650	250	1100	65	300	30	729,350	0.00E+00	0.0000	8
2	125850	250	850	65	300	20	729,350	0.00E+00	0.0000	6
2	125950	250	3000	65	300	25	729,350	0.00E+00	0.0000	2
2	126050	250	2500	65	300	20	729,350	0.00E+00	0.0000	13
2	126100	250	2100	65	300	20	729,350	0.00E+00	0.0000	14
2	126150	250	650	65	300	30	729,350	0.00E+00	0.0000	6
2	126550	250	800	65	300	25	729,350	0.00E+00	0.0000	4
2	126900	250	500	65	300	15	729,350	1.74E-03	0.0348	1

Table 6.2 Bruce Hwy Deeral Job No 158/10P/710 Lime stabilisation

Bruce Hwy Deeral Job No 158/10P/710 Lime stabilisation

		Modified Base Layer		Sub-base Layer		Subgrade (CBR)	July 1998-July 2004			
Lane	Chainage	Gravel depth	Modulus used	Gravel depth	Modulus used		ESA to date	Cumulative damage factor	Calculated subgrade rut mm	Actual Rut depth mm
1	Design	180	1000	70	300	8	220,000		0.0	0
1	44400	180	1500	70	300	25	833,100	0.00E+00	0.0	2
1	44500	180	1800	70	300	15	833,100	0.00E+00	0.0	4
1	44600	180	1425	70	300	30	833,100	0.00E+00	0.0	5
1	44700	180	218	70	300	20	833,100	0.00E+00	0.0	9
1	44200	180	950	70	300	20	833,100	0.00E+00	0.0	10
1	44800	180	120	70	300	15	833,100	1.45E-01	2.9	20

Table 6.3 Palmerston Hwy Crawford's Lookout 66/21A/805 Foamed Bitumen

Palmerston Hwy Crawfords Lookout 66/21A/805 Foamed Bitumen

		Modified Base Layer		Sub-base Layer		Subgrade (CBR)	Nov 2002-July 2004			
Lane	Chainage	Gravel depth	Modulus used	Gravel depth	Modulus used		ESA to date	Cumulative damage factor	Calculated subgrade rut mm	Actual Rut depth mm
2	Design	200	1600	50	300	8	325,500	0.00E+00	0.0000	0
2	18627	200	4000	50	300	30	269,800	0.00E+00	0.0000	3
2	18827	200	7250	50	300	30	269,800	0.00E+00	0.0000	6
2	18927	200	2300	50	300	20	269,800	1.81E-05	0.0004	1
2	19027	200	5000	50	300	20	269,800	0.00E+00	0.0000	2
2	19127	200	5000	50	300	20	269,800	0.00E+00	0.0000	2
2	19327	200	4250	50	300	30	269,800	0.00E+00	0.0000	4
2	19427	200	5850	50	300	20	269,800	0.00E+00	0.0000	5
2	20730	200	4700	50	300	30	269,800	0.00E+00	0.0000	3
2	20830	200	4100	50	300	15	269,800	0.00E+00	0.0000	6
2	21030	200	6800	50	300	20	269,800	0.00E+00	0.0000	5

2	21130	200	3900	50	300	20	269,801	0.00E+00	0.0000	4
2	21330	200	3900	50	300	20	269,802	0.00E+00	0.0000	2
2	21530	200	5000	50	300	15	269,803	0.00E+00	0.0000	5
2	21630	200	4200	50	300	20	269,804	0.00E+00	0.0000	2
2	26130	200	3700	50	300	20	269,800	0.00E+00	0.0000	7
2	26330	200	7000	50	300	30	269,800	0.00E+00	0.0000	6
2	26430	200	12000	50	300	30	269,800	0.00E+00	0.0000	5
2	26530	200	3500	50	300	30	269,800	0.00E+00	0.0000	1
2	26630	200	2800	50	300	25	269,800	0.00E+00	0.0000	4
2	26730	200	8000	50	300	30	269,800	0.00E+00	0.0000	6
2	26830	200	4500	50	300	30	269,801	0.00E+00	0.0000	6
2	26930	200	9500	50	300	30	269,800	0.00E+00	0.0000	4

Chapter 7.0
Conclusion

The gathering of accurate well-documented data is paramount as pavement performance is assessed over the long term. This is acknowledged in 'Pavement Design – A Guide to the Structural Design of Road Pavements' second revision 2004 Austroads chapter 11 (Austroads 2004).
Only one of the sections studied Deeral lime stabilisation and, showed any correlation with existing fatigue failure and site rut measurements, which was only a very weak correlation and requires further study to verify this. This site was also the oldest since construction, which may have helped in registering the weak correlation.

In relation with the stated aim of the project 'to determine flexible moduli for different pavements materials for use in future mechanistic pavement design in North Queensland', the foamed bitumen modified pavement (Table 6.3) demonstrated higher moduli in the field when compared with the initial design moduli of 1600 Mpa. As a result it is recommended moduli of 3000 Mpa be used when designing simular pavements for rehabilitation. The cement modified pavement (Table 6.1) also demonstrated higher moduli in the field when compared with the initial design moduli of 500 Mpa. As a result it is recommended moduli of 750 Mpa be used when designing simular pavements for rehabilitation.

In conclusion, the moduli produced by the back analysis for foamed bitumen and cement modified pavements should only be used as indicative of the pavements within the parameters used, and as such be used with caution.

In hindsite the following points should be followed to study all sites appropriately:

- FWD data gathering and field rut measurements should be done at the same time, preferably immediately after the wet season to represent worst case scenario.

- Assessment of number of ‘wet years’ or ‘dry years’ leading up to the study would allow an accurate historical perspective of the pavement performance.

- Insitu testing of all materials should be done to establish their respective depths, CBR’s and gravel type.

- Gathering of accurate initial construction records to determine construction tolerances used. If possible straight edge measurements taken during construction.

- Types of stabilisation products used i.e. quick lime or hydrated lime, general-purpose cement or general blend cement, bitumen grade used, as these properties can affect the data.

- Accurate chainage markers used, Latitude and longitude may be more accurate than running chainages, as running chainages tend to be changed over long periods of time due to new road construction altering routes.

Whilst this study is incomplete it has addressed the Project Specification for two of the pavements, being foamed bitumen and cement modified pavements.

Lime stabilisation will need to be investigated further to better determine appropriate design moduli. The Far Northern Main Roads Department at this point in time, has indicated they will use these sections as ongoing test cases and future student projects.

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Appendix A

Project Specification

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/ENG4112 RESEARCH PROJECT

PROJECT SPECIFICATION

FEBUARY 2004

Student: Craig Gordon Student No: 0039070025

Project Topic: **Determination of Insitu Flexible Moduli of Modified Pavement Materials.**

Supervisors: Associate Professor Ron Ayers, USQ
Dave Hamilton, Peninsula District, Main Roads, QLD

Aim:

To determine the flexible moduli for different modified pavement materials for use in future mechanistic pavement design in North Queensland.

Background:

There are 6 sections of road in North Queensland that have been nominated as trial sections and have been monitored by Main Roads, QLD, for up to 7 years. They have been designed using a mechanistic pavement design for modified pavements (i.e. stabilised granular pavements with 1% to 4% binders of cement, lime and bitumen). These pavements have been designed with conservative assumptions on the flexural moduli for these pavement materials.

Programme:

1. Review existing literature, particularly in regard to the following:
   Performance of modified pavement materials;
   Insitu determination of the moduli of modified granular materials; and assessment of fatigue life of modified granular materials.

2. Select 6 experimental sites.

3. Assess traffic load in E.S.A.'s for experimental sites. This will require extrapolation of traffic composition from adjacent or nearby permanent traffic counting sites.

4. Assess pavement performance at existing sites, including rut assessment and Falling Weight Deflectometer (FWD) measurement.

5. Examine pavement material properties from historical and gathered data.

6. Determine moduli of modified pavement materials from back analysis using CIRCLY.

7. Use material properties and pavement performance data to determine pavement material fatigue relationships.

8. Compare experimental and computed results with published work.

9. Report findings to peer group via oral presentations and in required written format.

AGREED: ____________ (student) ________________ , (Supervisors) ______________

__/__/__ , __/__/__ , __/__/__ .

Appendix B

Workplace Health and Safety Risk Analysis

Risk Management Chart for site location rut assessment

Description of Hazards	People At risk	Number At risk	Parts of body	Risk Level
Working in the sun	1	1	Exposed body parts Eyes	Moderate Low

Categories	Short term controls	Long term controls	Completion Details
P.P.E.	Sun block cream. Wide bream hat. Long sleeve shirts and trousers. Sun Glasses	Limit exposure as much as practical	Employer : M.R.D. Main Roads Department Prepared by : C. Gordon Date : 30/04/04 Assented to by : D. Hamilton Position : Assets Manager Signature: Date:

Risk Management Chart for site location rut assessment

Description of Hazards	People At risk	Number At risk	Parts of body	Risk Level
Being struck on feet when installing/de-installing signs as per M.U.T.C.D.	1	1	feet	Moderate

Categories	Short term controls	Long term controls	Completion Details
P.P.E.	Steel cap safety boots	Steel cap safety boots	Employer : M.R.D. Main Roads Department Prepared by : C. Gordon Date : 30/04/04 Assented to by : D. Hamilton Position : Assets Manager Signature: Date:

Risk Management Chart for site location rut assessment

Description of Hazards	People At risk	Number At risk	Parts of body	Risk Level
Working next to and within traffic lanes	All in area	All	All	High

Categories	Short term controls	Long term controls	Completion Details
Separation P.P.E.	Work area to be separated from traffic as per Manual of Uniform Traffic Control Devices' High visibility shirt/jackets to be worn.		Employer : M.R.D. Main Roads Department Prepared by : C. Gordon Date : 30/04/04 Assented to by : D. Hamilton Position : Assets Manager Signature: Date:

Appendix C

Field Rut Assessment

Field rut depths August 2004 Hand measured

Bruce Highway Cowley Beach Turnoff 66/10N/M10

Depth of Ruts in mm outer wheel path **Right hand side**.Cement modified

Chainage Km's	mm			Chainage Km's	mm
126.983	1			126.033	3
126.958	0			126.008	2
126.933	1			125.983	3
126.908	1			125.958	2
126.883	2			125.933	1
126.858	3			125.908	6
126.833	3			125.883	3
126.808	0			125.858	6
126.783	4			125.833	13
126.758	4			125.808	3
126.733	7			125.783	2
126.708	4			125.758	3
126.683	9			125.733	6
126.658	7			125.708	3
126.633	4			125.683	4
126.608	7			125.658	8
126.583	7			125.633	6
126.558	4			125.608	1
126.533	5			125.583	10
126.508	4			125.558	3
126.483	6			125.533	2
126.458	6			125.508	3
126.433	4			125.483	2
126.408	6			125.458	1
126.383	3			125.433	2
126.358	6				
126.333	6				
126.308	6				
126.283	3				
126.258	4				
126.233	6				
126.208	4				
126.183	6				
126.158	6				
126.133	12				
126.108	14				
126.083	10				
126.058	13				
				Average	**4.70**

Field rut depths August 2004 Hand measured

Palmerston Highway Crawfords lookout 66/21A/805

Depth of Ruts in mm outer wheel path **Right hand side only**.Foam bitumen

Chainage Km's	mm	Chainage Km's	mm	Chainage Km's	mm
25.980	4	20.680	4	18.477	5
26.005	7	20.705	4	18.502	2
26.030	6	20.730	3	18.527	2
26.055	6	20.755	4	18.552	2
26.080	7	20.780	6	18.577	5
26.105	5	20.805	2	18.602	5
26.130	7	20.830	6	18.627	3
26.155	6	20.855	4	18.652	6
26.180	5	20.880	6	18.677	2
26.205	5	20.905	4	18.702	5
26.230	7	20.930	4	18.727	3
26.255	5	20.955	2	18.752	6
26.280	6	20.980	2	18.777	8
26.305	6	21.005	3	18.802	2
26.330	6	21.030	5	18.827	6
26.355	5	21.055	7	18.852	2
26.380	3	21.080	5	18.877	6
26.405	2	21.105	6	18.902	3
26.430	5	21.130	4	18.927	1
26.455	3	21.155	3	18.952	6
26.480	2	21.180	6	18.977	5
26.505	1	21.205	2	19.002	3
26.530	1	21.230	5	19.027	2
26.555	2	21.255	5	19.052	3
26.580	7	21.280	5	19.077	4
26.605	4	21.305	2	19.102	2
26.630	4	21.330	2	19.127	2
26.655	4	21.355	4	19.152	2
26.680	5	21.380	2	19.177	4
26.705	4	21.405	3	19.202	3
26.730	6	21.430	2	19.227	2
26.755	6	21.455	6	19.252	2
26.780	5	21.480	2	19.277	4
26.805	4	21.505	5	19.302	2
26.830	6	21.530	5	19.327	4
26.855	5	21.555	2	19.352	7
26.880	5	21.580	6	19.377	4
26.905	3	21.605	6	19.402	3
26.930	4	21.630	2	19.427	5
26.955	7	21.655	6	19.452	3
26.980	6				
Average	**4.80**	Average	**4.05**	Average	**3.65**

Field rut depths August 2004 Hand measured

Bruce Highway Deeral 158/10P/710

Depth of Ruts in mm outer wheel path **Right and left hand side**.Lime stabilisa

LHS			RHS	
Chainage Km's	**mm**		**Chainage Km's**	**mm**
43.880	1			8
43.905	2			8
43.930	1			8
43.955	3			6
43.980	2			8
44.005	3			6
44.030	2			6
44.055	2			8
44.080	3			4
44.105	3			10
44.130	2			6
44.155	11			4
44.180	8			3
44.205	10			3
44.230	7			2
44.255	10			6
44.280	2			4
44.305	4			2
44.330	4			3
44.355	1			2
44.380	2			4
44.405	2			3
44.430	1			4
44.455	1			4
44.480	5			2
44.505	4			9
44.530	2			18
44.555	2			6
44.580	4			6
44.605	5			4
44.630	4			1
44.655	4			2
44.680	8			3
44.705	9			1
44.730	6			6
44.755	4			5
44.780	4			4
44.805	20			3
44.830	10			3
Average	**4.56**		**Average**	**5.00**

Appendix D

Falling Weight Deflectometer Data

FWD Data Job No 158/10P/710 Bruce Hwy Deeral

Chainage	Lane	Load (Kpa)	Deflections									Survey
(Gazettal)			0mm	200mm	300mm	450mm	600mm	750mm	900mm	1200mm	1500mm	Date
43802	1	707	870	646	478	300	201	143	112	80	63	1/09/2000
43903	1	707	129	109	92	73	60	52	44	37	32	1/09/2000
44002	1	707	357	268	223	161	120	90	65	49	40	1/09/2000
44101	1	707	348	296	223	183	138	111	94	66	48	1/09/2000
44203	1	707	518	399	315	222	155	111	81	51	36	1/09/2000
44303	1	707	251	222	163	124	97	72	58	38	28	1/09/2000
44401	1	707	385	315	261	179	129	92	71	45	36	1/09/2000
44506	1	707	500	418	348	276	210	160	121	71	42	1/09/2000
44600	1	707	354	264	202	148	107	77	59	40	29	1/09/2000
44700	1	707	996	753	528	311	184	118	84	55	42	1/09/2000
44799	1	707	1590	1195	866	483	283	177	112	66	50	1/09/2000
44900	1	707	1452	1071	777	414	229	141	96	65	47	1/09/2000
45008	1	707	712	565	448	328	233	157	109	61	46	1/09/2000
45101	1	707	663	528	426	287	174	104	62	38	32	1/09/2000
45201	1	707	850	664	531	381	250	166	108	61	47	1/09/2000
45300	1	707	1109	852	640	353	203	128	89	57	40	1/09/2000
45401	1	707	147	135	125	112	99	87	74	56	42	1/09/2000
45507	1	707	463	388	339	284	237	192	158	107	72	1/09/2000
45601	1	707	617	499	421	321	245	185	140	84	56	1/09/2000
45700	1	707	1019	750	598	418	284	199	138	81	55	1/09/2000
45791	1	707	885	633	499	345	232	163	117	73	56	1/09/2000
Average			**677**	**522**	**405**	**272**	**184**	**130**	**95**	**61**	**45**	

FWD Data Job No 66/21A/805 Palmerston Hwy Crawfords Lookout												
Chainage	Lane	Load (Kpa)	Deflections									Survey
(Gazettal)			0mm	200mm	300mm	450mm	600mm	750mm	900mm	1200mm	1500mm	Date
18620	2L	745	210	163	143	115	92	74	60	41	30	Nov-03
18719	2L	707	277	233	207	178	146	123	100	69	48	Nov-03
18820	2L	735	178	150	132	106	85	69	57	38	28	Nov-03
18919	2L	691	339	294	257	208	165	133	105	67	46	Nov-03
19020	2L	750	260	222	196	165	138	111	93	61	41	Nov-03
19119	2L	787	224	197	176	147	124	101	84	56	39	Nov-03
19220	2L	766	261	218	189	154	127	103	85	60	44	Nov-03
19319	2L	752	210	178	154	124	101	80	65	43	31	Nov-03
19424	2L	737	245	219	199	172	146	121	100	67	44	Nov-03
19521	2L	715	320	263	222	169	129	95	77	50	38	Nov-03
19621	2L	744	315	257	226	183	147	117	93	61	44	Nov-03
19718	2L	758	226	177	148	116	91	71	57	39	29	Nov-03
19819	2L	752	293	259	234	196	162	134	111	75	53	Nov-03
19919	2L	740	296	262	234	197	162	134	110	72	49	Nov-03
20018	2L	749	213	181	160	132	109	90	73	49	35	Nov-03
20119	2L	751	264	230	206	175	145	119	98	64	44	Nov-03
20219	2L	755	270	230	198	159	126	101	80	54	40	Nov-03
20319	2L	737	285	257	234	201	171	141	116	75	51	Nov-03
20420	2L	747	281	245	221	184	150	122	98	62	43	Nov-03
20520	2L	771	208	181	163	141	118	101	86	62	45	Nov-03
20621	2L	750	309	264	232	192	156	126	102	64	42	Nov-03
20720	2L	775	205	170	150	122	96	74	59	37	27	Nov-03
20819	2L	728	335	295	260	218	179	143	115	72	47	Nov-03
20919	2L	766	173	149	131	108	89	75	64	47	35	Nov-03
21020	2L	772	237	210	190	162	135	113	94	65	47	Nov-03
21112	2L	770	204	185	166	146	126	107	94	65	47	Nov-03
21222	2L	739	280	238	208	171	140	113	95	64	44	Nov-03
21320	2L	744	279	246	222	180	150	121	99	62	42	Nov-03

21419	2L	758	250	220	197	167	141	115	97	64	45	Nov-03
21519	2L	716	309	270	241	198	162	130	105	68	46	Nov-03
21620	2L	733	279	234	204	163	129	101	82	54	42	Nov-03
21720	2L	780	246	201	168	129	95	73	57	38	29	Nov-03
21820	2L	753	232	190	160	124	98	78	65	46	34	Nov-03
21915	2L	743	359	302	266	217	175	142	117	77	56	Nov-03
22019	2L	708	349	305	272	223	185	145	118	74	47	Nov-03
22117	2L	728	283	241	212	171	137	109	87	58	42	Nov-03
22218	2L	688	446	373	326	256	197	149	114	67	46	Nov-03
22319	2L	718	338	303	275	231	189	152	121	73	44	Nov-03
22420	2L	727	323	249	208	160	119	91	70	46	34	Nov-03
22517	2L	756	237	203	179	147	120	96	78	52	38	Nov-03
22621	2L	755	289	237	206	168	134	108	86	55	39	Nov-03
22719	2L	705	446	385	337	271	214	169	129	78	51	Nov-03
22819	2L	735	340	297	262	216	176	138	116	74	51	Nov-03
22920	2L	780	192	163	145	119	97	77	63	44	33	Nov-03
23016	2L	742	275	232	216	186	158	131	111	73	51	Nov-03
23119	2L	699	499	433	380	309	245	189	149	86	59	Nov-03
23221	2L	726	384	326	279	220	171	135	106	70	51	Nov-03
23319	2L	726	376	319	272	216	170	134	108	71	52	Nov-03
23420	2L	710	376	328	284	227	179	140	111	70	50	Nov-03
23520	2L	740	281	210	171	129	99	80	68	49	39	Nov-03
23619	2L	730	342	301	267	223	180	147	118	77	51	Nov-03
23718	2L	737	397	342	294	229	177	137	105	64	47	Nov-03
23821	2L	729	267	235	211	177	144	116	91	56	38	Nov-03
23919	2L	747	300	253	221	178	138	109	82	51	36	Nov-03
24020	2L	732	407	338	296	233	180	137	105	64	43	Nov-03
24120	2L	691	557	465	404	318	249	184	139	80	52	Nov-03
24215	2L	699	573	457	368	272	203	150	115	70	50	Nov-03
24318	2L	723	392	333	287	231	184	146	113	73	51	Nov-03
24418	2L	728	334	275	234	181	140	109	90	64	50	Nov-03
24514	2L	703	465	375	310	225	161	109	80	48	39	Nov-03
24619	2L	712	478	406	349	270	207	159	117	70	48	Nov-03

24719	2L	720	412	359	309	251	202	162	125	77	51	Nov-03
24817	2L	696	522	439	382	304	235	180	140	86	58	Nov-03
24920	2L	754	307	263	228	186	149	118	93	61	40	Nov-03
25019	2L	757	199	175	157	131	109	87	71	46	33	Nov-03
25119	2L	751	198	158	137	113	91	73	60	42	32	Nov-03
25217	2L	732	263	225	201	165	138	111	94	61	44	Nov-03
25317	2L	712	348	297	258	208	166	132	106	71	49	Nov-03
25420	2L	730	271	239	213	179	148	121	99	66	46	Nov-03
25519	2L	731	266	239	216	183	152	124	101	61	41	Nov-03
25621	2L	729	292	220	188	152	118	93	73	45	31	Nov-03
25716	2L	731	257	227	200	166	134	108	87	55	37	Nov-03
25821	2L	731	287	248	217	176	141	113	90	60	41	Nov-03
25918	2L	741	296	180	153	121	96	76	61	39	29	Nov-03
26020	2L	758	210	178	154	126	103	84	69	48	35	Nov-03
26119	2L	736	288	236	204	161	128	103	83	57	42	Nov-03
26215	2L	750	252	209	179	141	113	91	75	52	39	Nov-03
26319	2L	777	181	140	116	90	73	64	52	39	31	Nov-03
26418	2L	755	149	121	102	82	67	57	49	37	29	Nov-03
26519	2L	749	225	185	160	128	103	82	66	44	33	Nov-03
26620	2L	745	273	229	194	153	121	97	79	52	37	Nov-03
26719	2L	753	171	143	125	104	88	74	63	45	35	Nov-03
26820	2L	753	207	171	149	122	101	87	73	53	41	Nov-03
26920	2L	760	162	137	121	101	85	72	64	46	37	Nov-03
27019	2L	761	177	146	126	101	83	68	56	41	32	Nov-03
27120	2L	768	178	152	137	114	97	80	70	51	39	Nov-03
27220	2L	741	242	196	162	124	94	76	62	44	34	Nov-03
27321	2L	748	147	129	115	97	82	71	62	45	35	Nov-03
27419	2L	751	193	165	148	125	106	88	75	52	38	Nov-03
27518	2L	729	256	215	194	167	140	118	97	66	45	Nov-03
27620	2L	734	250	217	193	160	129	103	81	53	38	Nov-03
27719	2L	731	250	212	186	149	119	92	72	42	28	Nov-03
27819	2L	748	235	205	184	155	129	107	89	60	43	Nov-03
27916	2L	740	215	183	160	133	108	89	73	49	35	Nov-03

28019	2L	739	213	187	167	138	118	96	80	54	39	Nov-03
28120	2L	738	265	238	216	185	156	132	111	75	53	Nov-03
28219	2L	724	335	290	257	214	175	142	114	72	49	Nov-03
28319	2L	712	438	358	297	225	169	127	97	62	46	Nov-03
28420	2L	709	339	279	239	191	151	121	99	66	49	Nov-03
28519	2L	699	437	376	327	265	211	165	128	81	56	Nov-03
28618	2L	730	353	273	236	188	148	116	93	62	45	Nov-03
28720	2L	706	387	328	285	225	174	134	103	61	44	Nov-03

FWD Data Job No 66/10N/M10 Bruce Hwy Cowlet Beach T/off												
Chainage	Lane	Load (Kpa)	Deflections									Survey
(Gazettal)			0mm	200mm	300mm	450mm	600mm	750mm	900mm	1200mm	1500mm	Date
125500	2	1151	242	213	162	162	147	123	117	81	74	9/02/2002
125550	2	1115	508	405	308	226	180	138	100	71	59	9/02/2002
125600	2	1123	360	237	206	177	153	140	115	88	76	9/02/2002
125650	2	1134	334	250	190	150	117	81	60	91	23	9/02/2002
125700	2	1194	173	140	121	104	87	71	58	41	32	9/02/2002
125750	2	1142	511	407	242	180	164	138	93	61	58	9/02/2002
125800	2	1131	1221	194	168	138	126	152	81	76	43	9/02/2002
125850	2	1161	478	263	220	168	134	101	74	48	35	9/02/2002
125900	2	1144	279	182	162	125	104	84	61	39	15	9/02/2002
125950	2	881	262	147	157	134	115	87	69	42	16	9/02/2002
126000	2	866	483	349	263	210	164	139	106	61	0	9/02/2002
126050	2	877	339	191	170	152	140	101	81	58	0	9/02/2002
126100	2	871	315	249	211	178	140	115	92	60	35	9/02/2002
126150	2	868	446	327	236	165	107	80	48	29	18	9/02/2002
126200	2	853	662	360	370	223	145	127	81	47	0	9/02/2002
126250	2	826	1398	1042	834	587	436	309	221	132	76	9/02/2002
126300	2	824	1013	731	475	315	239	167	122	86	67	9/02/2002
126350	2	838	718	472	311	191	127	98	66	42	36	9/02/2002
126400	2	848	275	145	125	92	76	59	42	23	22	9/02/2002
126450	2	852	565	389	316	214	153	114	84	57	46	9/02/2002
126500	2	837	545	420	319	216	158	119	84	52	49	9/02/2002
126550	2	842	423	300	241	179	134	96	69	44	29	9/02/2002

126600	2	841	319	221	171	134	102	80	56	35	23	9/02/2002
126650	2	854	502	311	256	205	171	130	102	72	54	9/02/2002
126700	2	832	534	463	273	214	146	84	67	43	33	9/02/2002
126750	2	822	665	526	340	257	174	114	80	43	32	9/02/2002
126800	2	831	758	524	399	257	172	120	86	48	16	9/02/2002
126850	2	843	730	575	437	339	267	214	169	125	99	9/02/2002
126900	2	845	676	465	323	233	191	139	102	68	44	9/02/2002
126950	2	858	584	386	292	232	204	167	131	91	34	9/02/2002
127000	2	832	768	440	318	210	172	135	93	60	37	9/02/2002
127050	2	823	803	446	305	211	154	115	85	58	40	9/02/2002
Average			**559**	**368**	**279**	**206**	**159**	**123**	**90**	**62**	**38**	

Appendix E

Calculated ESA's Method 3

Cowley turnoff Bruce Hwy 66/10N/M10 Method 3

						%age of AADT in this season		
					Comm	89.40%	101.20%	109.20%
			No of		ESA per	Wet days	Medium days	Dry days
Year	AADT	Comm %	Comm	f	Day	122	122	121
29/11/2000	2,100	13.6	286	1.5	428	46,727	52,894	56,608
30/11/2001	2,165	13.6	294	1.5	442	48,172	54,530	58,358
1/12/2002	2,232	13.6	304	1.5	455	49,662	56,217	60,163
2/12/2003	2,299	13.6	313	1.5	469	51,152	57,903	61,968
2/12/2004	2,368	13.6	322	1.5	483	52,686	59,640	63,827
3/12/2005	2,439	13.6	332	1.5	498	54,267	61,429	65,742
4/12/2006	2,512	13.6	342	1.5	512	55,895	63,272	67,714
5/12/2007	2,587	13.6	352	1.5	528	57,572	65,170	69,746
5/12/2008	2,665	13.6	362	1.5	544	59,299	67,126	71,838
6/12/2009	2,745	13.6	373	1.5	560	61,078	69,139	73,993
7/12/2010	2,827	13.6	385	1.5	577	62,910	71,214	76,213
8/12/2011	2,912	13.6	396	1.5	594	64,797	73,350	78,500
8/12/2012	3,000	13.6	408	1.5	612	66,741	75,550	80,855
9/12/2013	3,090	13.6	420	1.5	630	68,743	77,817	83,280
10/12/2014	3,182	13.6	433	1.5	649	70,806	80,151	85,779
11/12/2015	3,278	13.6	446	1.5	669	72,930	82,556	88,352
11/12/2016	3,376	13.6	459	1.5	689	75,118	85,033	91,003
12/12/2017	3,477	13.6	473	1.5	709	77,371	87,584	93,733
13/12/2018	3,582	13.6	487	1.5	731	79,692	90,211	96,545
14/12/2019	3,689	13.6	502	1.5	753	82,083	92,918	99,441
14/12/2020	3,800	13.6	517	1.5	775	84,546	95,705	102,424
Totals from 2000 to 2003 inclusive						**195,712**	**221,544**	**237,098**
add 25,000 for half year for time of study						25000	25000	25000
						220,712	**246,544**	**262,098**
Total Actual ESA's =							**729,354**	

Palmerston Hwy 66/21A/805 Method 3

Year	Lane 1 AADT	Comm %	No of Comm	f	Comm ESA per Day	%age of AADT in this season 89.40% Wet days 122	101.20% Medium days 122	109.20% Dry days 121
1/07/2002	967	16.5	160	1.5	239	26,104	29,549	31,623
1/07/2003	996	16.5	164	1.5	247	26,887	30,435	32,572
1/07/2004	1,026	16.5	169	1.5	254	27,693	31,348	33,549
1/07/2005	1,057	16.5	174	1.5	262	28,524	32,289	34,556
1/07/2006	1,088	16.5	180	1.5	269	29,380	33,258	35,593
1/07/2007	1,121	16.5	185	1.5	277	30,261	34,255	36,660
1/07/2008	1,155	16.5	191	1.5	286	31,169	35,283	37,760
1/07/2009	1,189	16.5	196	1.5	294	32,104	36,341	38,893
1/07/2010	1,225	16.5	202	1.5	303	33,067	37,432	40,060
1/07/2011	1,262	16.5	208	1.5	312	34,059	38,555	41,261
1/07/2012	1,300	16.5	214	1.5	322	35,081	39,711	42,499
1/07/2013	1,339	16.5	221	1.5	331	36,133	40,903	43,774
1/07/2014	1,379	16.5	227	1.5	341	37,217	42,130	45,088
1/07/2015	1,420	16.5	234	1.5	351	38,334	43,394	46,440
1/07/2016	1,463	16.5	241	1.5	362	39,484	44,695	47,833
1/07/2017	1,507	16.5	249	1.5	373	40,668	46,036	49,268
1/07/2018	1,552	16.5	256	1.5	384	41,888	47,417	50,746
1/07/2019	1,598	16.5	264	1.5	396	43,145	48,840	52,269
1/07/2020	1,646	16.5	272	1.5	407	44,439	50,305	53,837
1/07/2021	1,696	16.5	280	1.5	420	45,773	51,814	55,452
1/07/2022	1,747	16.5	288	1.5	432	47,146	53,369	57,116
					1,239,764	80,683	91,333	97,745

Total Actual ESA's = 269,761

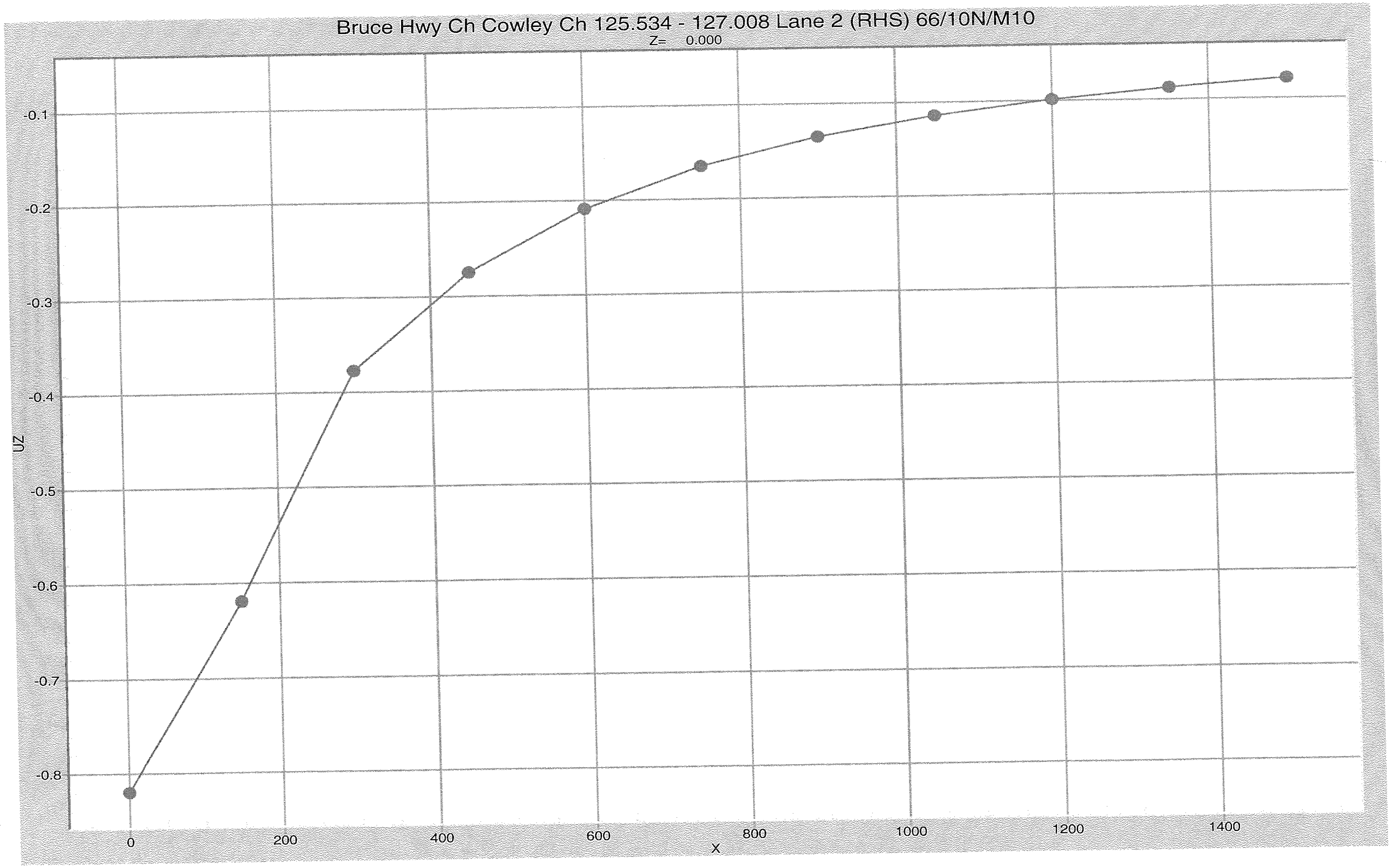
Deeral Bruce Hwy   158/10P/710   Method 3

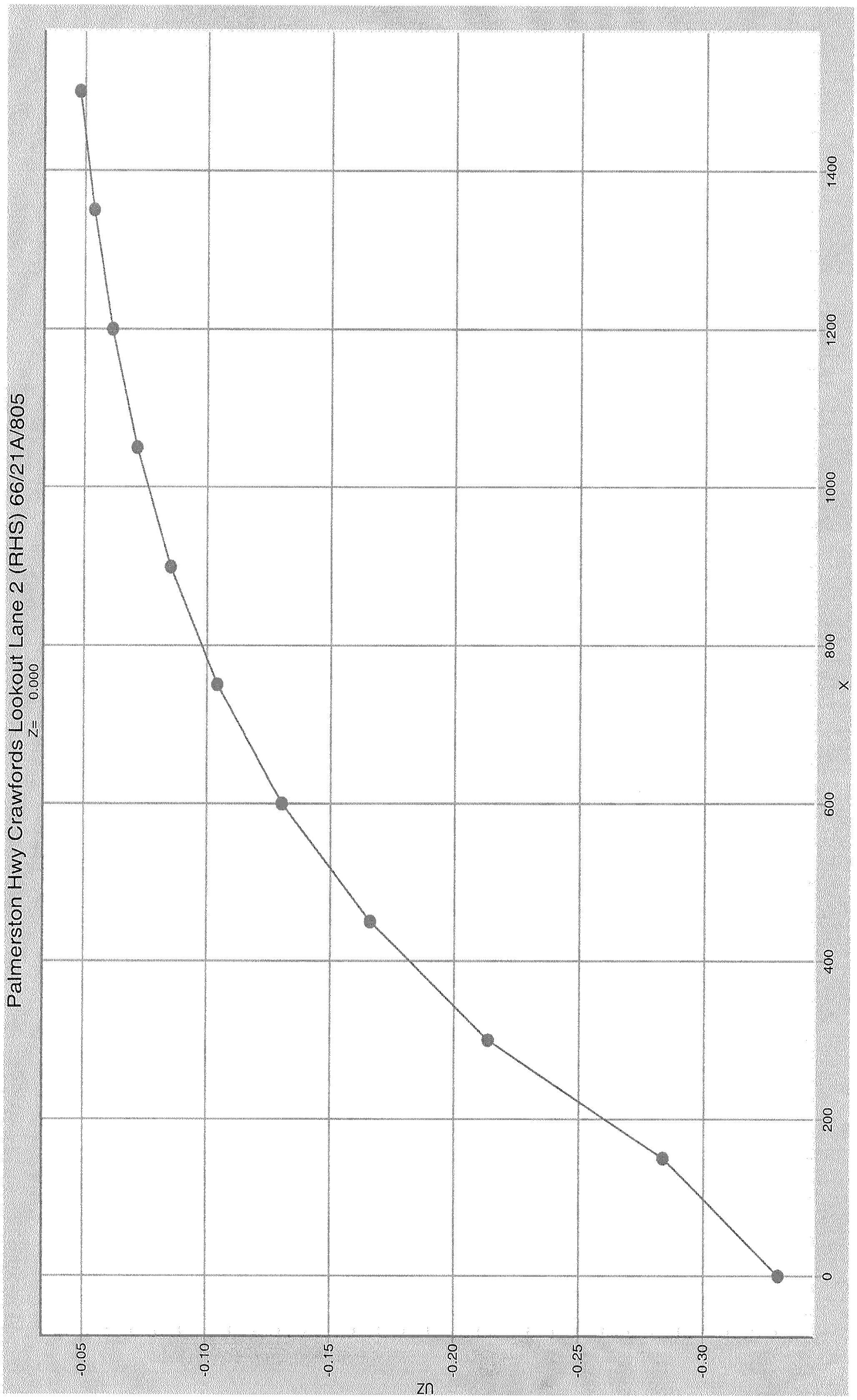
						%age of Comm AADT in this season		
						89.40%	101.20%	109.20%
			No of		Comm	ESA's /year/season		
	Lane 1	Commercial	Comm		ESA per	Wet days	Medium days	Dry days
Year	AADT	%	AADT	f	Day	122	122	121
1992	1,716	12	206	1.5	309	33,689	38,136	40,813
1993	1,804	12	216	1.5	325	35,407	40,080	42,894
1994	1,850	12	222	1.5	333	36,320	41,114	44,000
1995	1,900	12	228	1.5	342	37,301	42,225	45,189
1996	1,988	12	239	1.5	358	39,029	44,180	47,282
1997	2,052	12	246	1.5	369	40,285	45,603	48,804
1998	2,027	12	243	1.5	365	39,795	45,047	48,210
1999	2,068	12	248	1.5	372	40,590	45,947	49,173
2000	2,109	12	253	1.5	380	41,404	46,869	50,160
2001	2,076	12	249	1.5	374	40,757	46,136	49,375
2002	2,167	12	260	1.5	390	42,543	48,158	51,539
2003	2,246	12	269	1.5	404	44,084	49,903	53,406
2004	2,295	12	275	1.5	413	45,054	51,001	54,581
2005	2,345	12	281	1.5	422	46,045	52,123	55,782
2006	2,397	12	288	1.5	431	47,058	53,269	57,009
2007	2,450	12	294	1.5	441	48,094	54,441	58,264
2008	2,504	12	300	1.5	451	49,152	55,639	59,545
2009	2,559	12	307	1.5	461	50,233	56,863	60,855
2010	2,615	12	314	1.5	471	51,338	58,114	62,194
2011	2,673	12	321	1.5	481	52,467	59,393	63,562
2012	2,731	12	328	1.5	492	53,622	60,699	64,961
2013	2,791	12	335	1.5	502	54,801	62,035	66,390
2014	2,853	12	342	1.5	514	56,007	63,399	67,851
2015	2,916	12	350	1.5	525	57,239	64,794	69,343
2016	2,980	12	358	1.5	536	58,498	66,220	70,869
2017	3,045	12	365	1.5	548	59,785	67,677	72,428
2018	3,112	12	373	1.5	560	61,101	69,165	74,021
			Totals from 1998 to 2003			249,172	282,061	301,863

Total Actual ESA's = 833,097

Appendix F

FWD DEFLECTION GRAPHS


Bruce Hwy Ch Cowley Ch 125.534 - 127.008 Lane 2 (RHS) 66/10N/M10
Z= 0.000
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
UZ
0
200
400
600
800
1000
1200
1400
X


Palmerston Hwy Crawfords Lookout Lane 2 (RHS) 66/21A/805
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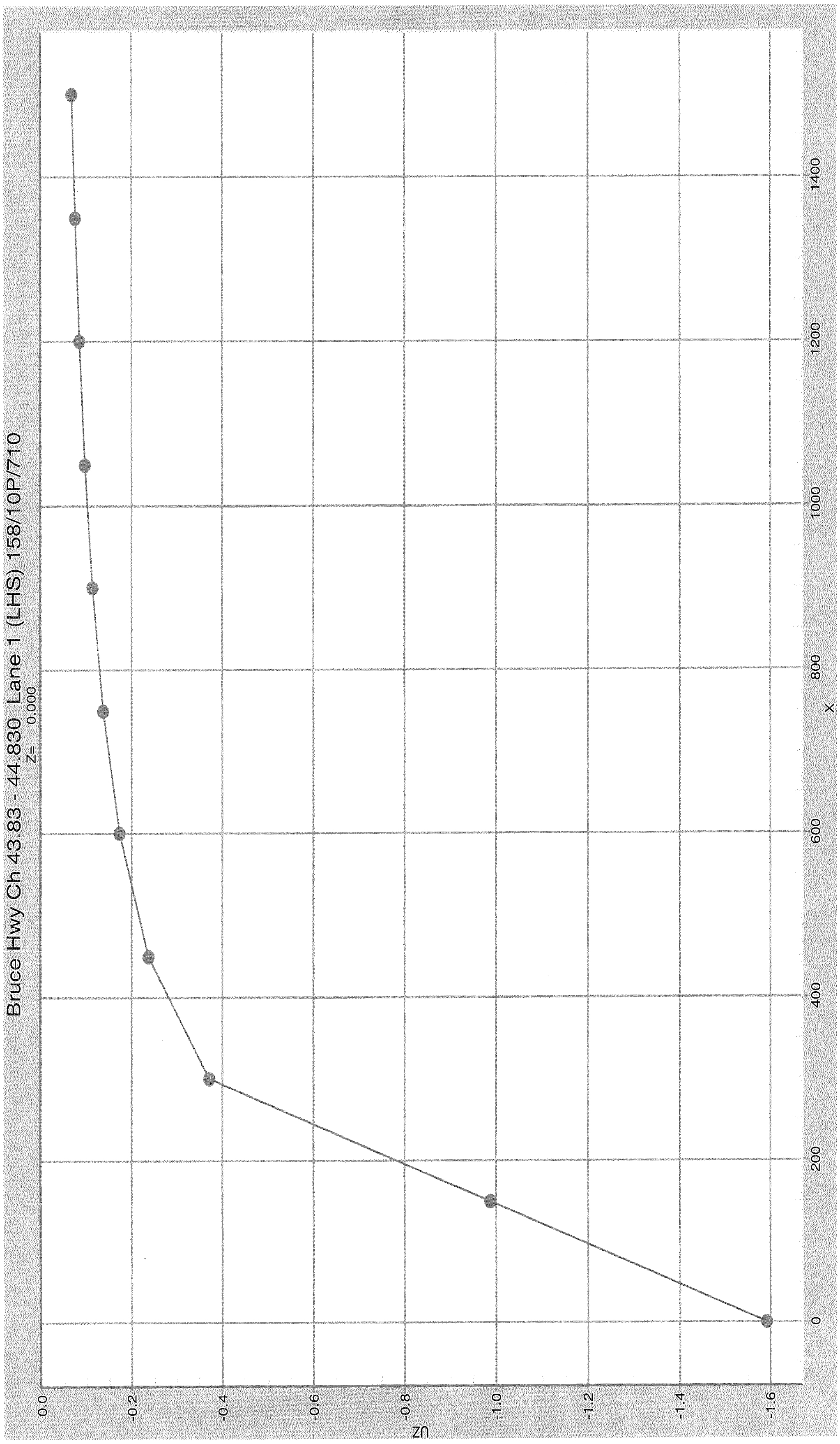
X
UZ
0
200
400
600
800
1000
1200
1400
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30


Bruce Hwy Ch 43.83 - 44.830 Lane 1 (LHS) 158/10P/710
Z= 0.000
UZ
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
X
0
200
400
600
800
1000
1200
1400

Appendix G

FWD CIRCLY PRINTOUTS

CIRCLY Version 5.0b (9 February 2004)

Z-value no. 1: 0
Job Title: Bruce Hwy Ch Cowley Ch 125.534 - 127.008 Lane 2 (RHS) 66/10N/M10

Calculation of Selected Component at Selected z-values

Assumed number of damage pulses per movement:
One pulse per axle (i.e. use NROWS)

Traffic Spectrum Details:

ID: FWD Packer Title: FWD Loading

Load No.	Load ID	Movements
1	FWD	1.00E+00

Details of Load Groups:

Load No.	Load ID	Load Category	Load Type	Radius	Pressure/ Ref. stress	Exponent
1	FWD	FWD1	Vertical Force	150.0	0.83	0.00

Load Locations:

Location No.	Load ID	Gear No.	X	Y	Scaling Factor	Theta
1	FWD	1	0.0	0.0	1.00E+00	0.00

Layout of result points on horizontal plane:
Xmin: 0 Xmax: 1500 Xdel: 150
Y: 0

Details of Layered System:

ID: 15810P710 Title: Deeral lime stab

Layer No.	Lower i/face	Material ID	Isotropy	Modulus (or Ev)	P.Ratio (or vvh)	F	Eh	vh
1	rough	CM500	Iso.	5.00E+02	0.20			
2	rough	Gran_300	Aniso.	3.00E+02	0.35	2.20E+02	1.50E+02	0.35
3	rough	Sub_CBR15	Aniso.	1.50E+02	0.45	1.03E+02	7.50E+01	0.45

Performance Relationships:

Layer No.	Location	Performance ID	Component	Perform. Constant	Perform. Exponent	Traffic Multiplier
3	top	Sub_2004	EZZ	0.009300	7.000	1.000

Details of Layers to be sublayered:
Layer no. 2: Austroads (2004) sublayering

CIRCLY Version 5.0b (9 February 2004)

Z-value no. 1: 0
Job Title: Palmerston Hwy Crawfords Lookout Lane 2 (RHS) 66/21A/805

Calculation of Selected Component at Selected z-values

Assumed number of damage pulses per movement:
One pulse per axle (i.e. use NROWS)

Traffic Spectrum Details:

ID: FWD Packer Title: FWD Loading

Load No.	Load ID	Movements
1	FWD	1.00E+00

Details of Load Groups:

Load No.	Load ID	Load Category	Load Type	Radius	Pressure/ Ref. stress	Exponent
1	FWD	FWD1	Vertical Force	150.0	0.69	0.00

Load Locations:

Location No.	Load ID	Gear No.	X	Y	Scaling Factor	Theta
1	FWD	1	0.0	0.0	1.00E+00	0.00

Layout of result points on horizontal plane:
Xmin: 0 Xmax: 1500 Xdel: 150
Y: 0

Details of Layered System:

ID: 15810P710 Title: Deeral lime stab

Layer No.	Lower i/face	Material ID	Isotropy	Modulus (or Ev)	P.Ratio (or vvh)	F	Eh	vh
1	rough	FBdifmod	Iso.	2.30E+03	0.40			
2	rough	Gran_300	Aniso.	3.00E+02	0.35	2.20E+02	1.50E+02	0.35
3	rough	Sub_CBR20	Aniso.	2.00E+02	0.45	1.38E+02	1.00E+02	0.45

Performance Relationships:

Layer No.	Location	Performance ID	Component	Perform. Constant	Perform. Exponent	Traffic Multiplier
3	top	Sub_2004	EZZ	0.009300	7.000	1.000

Details of Layers to be sublayered:
Layer no. 2: Austroads (2004) sublayering

CIRCLY Version 5.0b (9 February 2004)

Z-value no. 1: 0
Job Title: Bruce Hwy Ch 43.83 - 44.830 Lane 1 (LHS) 158/10P/710

Calculation of Selected Component at Selected z-values

Assumed number of damage pulses per movement:
One pulse per axle (i.e. use NROWS)

Traffic Spectrum Details:

ID: 1-ESA Title: 1 ESA

Load No.	Load ID	Movements
1	FWD	1.00E+00

Details of Load Groups:

Load No.	Load ID	Load Category	Load Type	Radius	Pressure/ Ref. stress	Exponent
1	FWD	FWD1	Vertical Force	150.0	0.71	0.00

Load Locations:

Location No.	Load ID	Gear No.	X	Y	Scaling Factor	Theta
1	FWD	1	0.0	0.0	1.00E+00	0.00

Layout of result points on horizontal plane:
Xmin: 0 Xmax: 1500 Xdel: 150
Y: 0

Details of Layered System:

ID: 15810P710 Title: Deeral lime stab

Layer No.	Lower i/face	Material ID	Isotropy	Modulus (or Ev)	P.Ratio (or vvh)	F	Eh	vh
1	rough	lime01	Iso.	1.20E+02	0.20			
2	rough	Gran_300	Aniso.	3.00E+02	0.35	2.20E+02	1.50E+02	0.35
3	rough	Sub_CBR15	Aniso.	1.50E+02	0.45	1.03E+02	7.50E+01	0.45

Performance Relationships:

Layer No.	Location	Performance ID	Component	Perform. Constant	Perform. Exponent	Traffic Multiplier
3	top	Sub_2004	EZZ	0.009300	7.000	1.600

Details of Layers to be sublayered:
Layer no. 2: Austroads (2004) sublayering

Appendix H

CUMULATIVE DAMAGE FACTOR (CDF)

CIRCLY PRINTOUTS

CIRCLY Version 5.0b (9 February 2004)

Job Title: Bruce Hwy Ch Cowley Ch 125.534 - 127.008 Lane 2 (RHS) 66/10N/M10

Damage Factor Calculation

Assumed number of damage pulses per movement:
One pulse per axle (i.e. use NROWS)

Traffic Spectrum Details:

ID: 1-ESA Title: 1 ESA

Load No.	Load ID	Movements
1	ESA75-Half	7.29E+05

Details of Load Groups:

Load No.	Load ID	Load Category	Load Type	Radius	Pressure/ Ref. stress	Exponent
1	ESA75-Half	SA750-Half	Vertical Force	92.1	0.75	0.00

Load Locations:

Location No.	Load ID	Gear No.	X	Y	Scaling Factor	Theta
1	ESA75-Half	1	-165.0	0.0	1.00E+00	0.00
2	ESA75-Half	1	165.0	0.0	1.00E+00	0.00

Layout of result points on horizontal plane:
Xmin: 0 Xmax: 1500 Xdel: 150
Y: 0

Details of Layered System:

ID: 15810P710 Title: Deeral lime stab

Layer No.	Lower i/face	Material ID	Isotropy	Modulus (or Ev)	P.Ratio (or vvh)	F	Eh	vh
1	rough	CM500	Iso.	5.00E+02	0.20			
2	rough	Gran_300	Aniso.	3.00E+02	0.35	2.20E+02	1.50E+02	0.35
3	rough	Sub_CBR15	Aniso.	1.50E+02	0.45	1.03E+02	7.50E+01	0.45

Performance Relationships:

Layer No.	Location	Performance ID	Component	Perform. Constant	Perform. Exponent	Traffic Multiplier
3	top	Sub_2004	EZZ	0.009300	7.000	1.600

Details of Layers to be sublayered:
Layer no. 2: Austroads (2004) sublayering

Results:

Layer No.	Thickness	Material ID	Load ID	Critical Strain	CDF
1	250.00	CM500		n/a	n/a
2	65.00	Gran_300		n/a	n/a
3	0.00	Sub_CBR15	ESA75-Half	5.10E-04	1.74E-03

CIRCLY Version 5.0b (9 February 2004)

Job Title: Palmerston Hwy Crawfords Lookout Lane 2 (RHS) 66/21A/805

Damage Factor Calculation

Assumed number of damage pulses per movement:
One pulse per axle (i.e. use NROWS)

Traffic Spectrum Details:

ID: FWD Packer Title: FWD Loading

Load No.	Load ID	Movements
1	ESA75-Half	2.70E+05

Details of Load Groups:

Load No.	Load ID	Load Category	Load Type	Radius	Pressure/ Ref. stress	Exponent
1	ESA75-Half	SA750-Half	Vertical Force	92.1	0.75	0.00

Load Locations:

Location No.	Load ID	Gear No.	X	Y	Scaling Factor	Theta
1	ESA75-Half	1	-165.0	0.0	1.00E+00	0.00
2	ESA75-Half	1	165.0	0.0	1.00E+00	0.00

Layout of result points on horizontal plane:
Xmin: 0 Xmax: 1500 Xdel: 150
Y: 0

Details of Layered System:

ID: 15810P710 Title: Deeral lime stab

Layer No.	Lower i/face	Material ID	Isotropy	Modulus (or Ev)	P.Ratio (or vvh)	F	Eh	vh
1	rough	FBdifmod	Iso.	2.30E+03	0.40			
2	rough	Gran_300	Aniso.	3.00E+02	0.35	2.20E+02	1.50E+02	0.35
3	rough	Sub_CBR20	Aniso.	2.00E+02	0.45	1.38E+02	1.00E+02	0.45

Performance Relationships:

Layer No.	Location	Performance ID	Component	Perform. Constant	Perform. Exponent	Traffic Multiplier
3	top	Sub_2004	EZZ	0.009300	7.000	1.600

Details of Layers to be sublayered:
Layer no. 2: Austroads (2004) sublayering

Results:

Layer No.	Thickness	Material ID	Load ID	Critical Strain	CDF
1	200.00	FBdifmod		n/a	n/a
2	50.00	Gran_300		n/a	n/a
3	0.00	Sub_CBR20	ESA75-Half	3.06E-04	1.81E-05

CIRCLY Version 5.0b (9 February 2004)

Job Title: Bruce Hwy Ch 43.83 - 44.830 Lane 1 (LHS) 158/10P/710

Damage Factor Calculation

Assumed number of damage pulses per movement:
One pulse per axle (i.e. use NROWS)

Traffic Spectrum Details:

ID: FWD Packer Title: FWD Loading

Load No.	Load ID	Movements
1	ESA75-Half	8.33E+05

Details of Load Groups:

Load No.	Load ID	Load Category	Load Type	Radius	Pressure/ Ref. stress	Exponent
1	ESA75-Half	SA750-Half	Vertical Force	92.1	0.75	0.00

Load Locations:

Location No.	Load ID	Gear No.	X	Y	Scaling Factor	Theta
1	ESA75-Half	1	-165.0	0.0	1.00E+00	0.00
2	ESA75-Half	1	165.0	0.0	1.00E+00	0.00

Layout of result points on horizontal plane:
Xmin: 0 Xmax: 1500 Xdel: 150
Y: 0

Details of Layered System:

ID: 15810P710 Title: Deeral lime stab

Layer No.	Lower i/face	Material ID	Isotropy	Modulus (or Ev)	P.Ratio (or vvh)	F	Eh	vh
1	rough	lime01	Iso.	1.20E+02	0.20			
2	rough	Gran_300	Aniso.	3.00E+02	0.35	2.20E+02	1.50E+02	0.35
3	rough	Sub_CBR15	Aniso.	1.50E+02	0.45	1.03E+02	7.50E+01	0.45

Performance Relationships:

Layer No.	Location	Performance ID	Component	Perform. Constant	Perform. Exponent	Traffic Multiplier
3	top	Sub_2004	EZZ	0.009300	7.000	1.600

Details of Layers to be sublayered:
Layer no. 2: Austroads (2004) sublayering

Results:

Layer No.	Thickness	Material ID	Load ID	Critical Strain	CDF
1	180.00	lime01		n/a	n/a
2	70.00	Gran_300		n/a	n/a
3	0.00	Sub_CBR15	ESA75-Half	9.41E-04	1.45E-01