University of Southern Queensland

Faculty of Engineering and Surveying

Evaluation of EverFE Software for Designing Australian Concrete Pavements

A dissertation submitted by

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Abstract

The Austroads Design Guide for rigid pavements outlines the procedure for designing Australia's concrete pavements. This procedure is based upon the analytical methods developed by the Portland Cement Association in the 1960's. Although this is the accepted method for pavement design, the method has rarely been subjected to benchmarking with more advanced analytical methods. This project seeks to identify limitations to the current Austroads Design Guide for rigid pavements and determine suitability of using EverFE, a Finite Element analysis program, in conjunction with Austroads to analyse concrete pavements.

Literature has been examined and limitations of the design guide were identified as an incapability of modelling predicted future loading conditions, incapability in modelling a shift in traffic load location and inability of modelling temperature gradients. Input parameters were developed for these conditions to be used by EverFE to evaluate pavement stress. A model base pavement was developed in accordance with the Austroads design guide as a point of reference for pavement stress analysed using EverFE.

In conclusion it was found that EverFE offers capability in modelling of both current conditions, and conditions outside the scope of the Austroads method; hence potential exists for the incorporation of EverFE software in the design of Australia's concrete pavements, in conjunction with the existing Austroads design guide.

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Certification of Dissertation

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

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

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Signature

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Date

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Also, thank you to the Roads and Maritime Services Pavement Technology branch from Parramatta, NSW for their help in providing information required within the project.

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1. Introduction

Concrete pavements (also termed rigid pavements) are a type of road pavement in which concrete is used as a base material in place of granular materials. The current design standard for Australia's concrete pavements is outlined in the 2012 edition of the Austroads Design Guide Part 2. The basis of the methods outlined by Austroads is using the methods developed by the Portland Cement Association (PCA) that is based on a semi-empirical design procedure. Austroads have adopted this method with some modifications to suit Australian conditions; however there exist some limitations to its use.

The 2012 version of the design guide is the third revision to the guide with its earlier version being the 2004 guide. Pavement thickness is determined using a mechanistic design procedure that calculates the required depth of concrete base for different types of concrete pavements. These pavement types include: Jointed plain (Unreinforced) concrete pavement (JPCP), Jointed Reinforced Concrete Pavement (JRCP), Continually Reinforced Concrete Pavement (CRCP) and Steel Fibre Reinforced Concrete Pavement (SFCP).

Design input parameters required from the design method include the following for calculation of the base thickness: Design traffic, subgrade CBR, sub-base thickness and type, project design reliability (PDR), flexural strength of concrete, loading configuration of vehicles and dowelling (Darestani et al. 2006).

The program EverFE has been developed by Professor Bill Davids from the University of Maine as a freely downloadable software package. EverFE utilises analytical methods and Finite Element (FE) analysis to model the responses of rigid pavements (JPCP specifically), to loading conditions from vehicles and temperature variations (University of Maine, n.d.).

1.1 Project Objective

The current Austroads design guide for rigid pavements appears to provide adequate design for present traffic conditions and loading configurations. Although the Austroads method is the accepted method for design of rigid pavements it does have some limitations. The aim of this project is to examine these limitations of the current design guide and compare the methods from Austroads with results developed from use of EverFE, with the objective of potentially using EverFE in conjunction with current design methods to develop rigid pavements to Australian conditions. The objectives of the project are defined as follows:

- Identify the current limitations of the Austroads design guide for rigid pavements.
- Compare Austroads design method and EverFE predictions on the result of increased future traffic loading at the critical stress location.
- Identify the predicted differential in stress resulting from changing load location from 600mm (limited in Austroads) to edge condition determined from review of relevant literature using EverFE software.

- Perform a sensitivity analysis to determine if temperature gradient of the pavement slab needs greater consideration in the future.

2. Literature Review

2.1 Introduction

A significant component of project research is to perform a literature review to determine the current position of a topic for further development. This involves identifying and critiquing literature on the project topic and presenting a summary of findings to further develop the project aims.

The literature review provides background into the current Austroads design guide for rigid pavements along with its limitations and introduces the finite element program, EverFE. Literature will be reviewed for design parameters including; future heavy vehicle loading, lateral vehicle positioning, and temperature gradients for sensitivity analysis. Review of literature will provide overview for development of design parameters for comparison between Austroads and EverFE to determine potential incorporation of EverFE as an additional design tool.

2.2 Austroads Design Guide for Rigid Pavements (2012)

The Austroads Guide to Pavement Technology, Part 2: Pavement Structural Design details the design procedure for rigid concrete pavements in Section 9 and has been developed to assist in the planning and design of new road pavements (Austroads, 2012). In 2008 a report was developed titled Technical Basis of Austroads Guide to Pavement Technology Part 2. This report details the revision of rigid pavement design from the 1992 version of Austroads to the 2004 version.

It is stated in Chapter 4 of the Technical Basis of Austroads Guide to Pavement Technology Part 2 (2008a) that there has been no significant technical changes to the rigid pavement design from the design procedures set out in the 2004 guide. A statement in a report prepared by Jameson, G (2013) for the ARRB on the Technical basis of Austroads Guide to Pavement Technology Part 2, states the only change to the 2012 design guide clarified the process of adjusting design base thickness for construction tolerances as well as other factors including new text on joint types and design. This statement provides justification the 2012 revision to the design guide has not been majorly adjusted since 2004.

The Austroads design guide for rigid pavement base thickness calculations is based on the methods developed in the USA by the Portland Cement Association (PCA). Purposes of the methods developed by the PCA were to develop a method of determining slab thickness for rigid pavements to optimise costs between initial costing and ongoing maintenance cost (Packard and Tayabji 1984). Design of pavement thickness using the PCA method is based on semi-empirical charts and models developed based on analytical methods and experimental testing of pavements in the field using typical joint spacing. Revisions have been made to the guide to reflect Australian conditions and it is assumed in Austroads that the base and subbase layers are unbonded. Inputs required for design include predicted traffic volume, traffic composition (heavy vehicle percentage), axle load grouping and load distribution, subgrade California Bearing Ratio (CBR), project design reliability and concrete flexural strength (Clause 9.1 Austroads, 2012).

The PCA method only includes the following axle groups, Single Axle Dual Tyre (SADT), Tandem Axle Dual Tyre (TADT) and Triple Axle Dual Tyre (TRDT). The Austroads method has been extended to include Single Axle Single Tyre (SAST), Tandem Axle Single Tyre (TAST) and Quad Axle Dual Tyre (QADT) in addition to the Heavy Vehicle Axle Groups (HVAG) of the PCA method.

The guide may be used for base thickness design of different concrete base types which include Jointed Plain Concrete Pavement (JPCP – unreinforced), Jointed Reinforced Concrete Pavement (JRCP), Continuously Reinforced Concrete Pavement (CRPCP) and Steel Fibre Concrete Pavements (SFCP) (Austroads, 2012). Typical joint spacing is provided for the two main categories of PCP suited to Australian conditions. These include slabs 4.2m long with undowelled skewed joints, and slabs 4.5m long with dowelled square joints. These dimensions are stated to be upper limits and are influential on the fatigue life of pavement; however these factors are not featured as a design input for thickness design.

Subbase material is provided beneath the concrete pavement to provide uniform support for the base layer as well as erosion resistance under traffic and environmental conditions (Austroads 2012). Austroads specifies that subbase material is to be either lean concrete mix or a bound material for traffic levels analysed in the guide. Lean concrete subbase (LCS) of characteristic strength of 5MPa minimum and a depth of 150mm is the only acceptable subbase for design traffic greater than $1x10^7$ HVAGs as specified in Table 9.1 of the design guide. The strength of the concrete base material is specified as being minimum of 4.5MPa at 28 day characteristic strength for traffic volumes $1x10^6$ HVAG or greater.

The Technical Basis of Austroads Guide to Pavement Technology Part 2 (2008a) states that experience from the NSW state road authority Roads and Maritime Services, herein referred to as RMS, experience with the use of LCS has been very successful in the prevention of erosion distress at subbase level to the extent no distress has been detected in concrete pavements with this type of subbase.

Provision of concrete shoulders is introduced in section 9.3.5 of the design guide. It is stated that concrete shoulders enhance pavement performance and enable pavements to be developed with a lesser base thickness (see Figure 2-1). Two types of shoulders are introduced, either integral or structural shoulders. Integral shoulders are cast to the same thickness as the base material and cast with the pavement material to a minimum width of 600mm. Structural shoulders are connected to the concrete pavement via joints and have a minimum width of 1.5m. Provision of dowels and shoulders are considered in base thickness design through use of coefficients for different HVAGs for erosion and fatigue analysis. Shoulder widths should take into consideration the need for motorists to be able to safely stop and park clear of fast-moving traffic. In accordance with RMS standard drawing MD.R83.CJ for JRCP (RMS, 2015) concrete shoulders in design will be adopted at 2.5m.

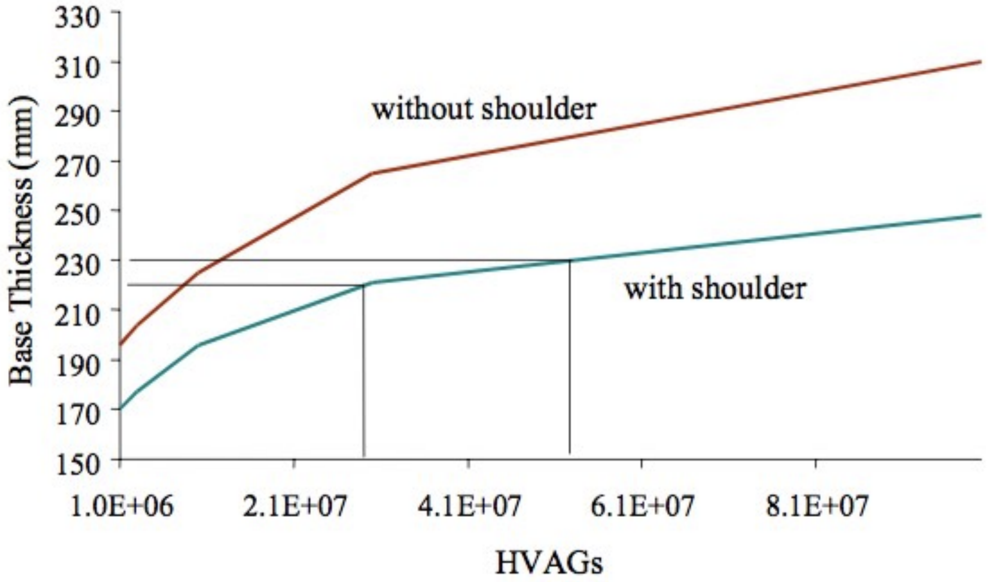


Figure 2-1: Concrete base thickness versus HVAGs with and without shoulder

(Sourced from Technical Basis of Austroads Guide to Pavement Technology 2008a)

It is stated in the design guide (clause 7.2) that the impact of light vehicles on rigid pavements (in terms of structural degradation) is negligible and hence only heavy vehicles are considered in design. Clause 9.3.4 of the design guide states that rigid pavements are very sensitive to axle load magnitudes (overloading) although relatively insensitive to axle load repetitions (traffic volume). Along with axle loading, number of vehicle axles and their grouping must also be considered (Austroads 2012). Project reliability is described in Section 9.3.6 in which it is stated that axle group loads are multiplied by a load safety factor provided in Table 9.2 of the design guide.

Influences of temperature are introduced in Section 4.3 of the design guide (Austroads 2012) in which it is stated that temperature environments play a significant role in the performance of pavements. Temperature changes within a 24-hour period, day and night conditions, can result in significant stress in the pavement and within joints with curling movements induced from the temperature gradient.

The design guide does not explore the effects of temperature impact on pavements in detail, however Section 9.4.3 states that the minimum values for base thickness with traffic exceeding 1×10^7 HVAGs are developed to account for such factors of curling and warping of the concrete.

The PCA method determines pavement thickness by two distress modes, flexural fatigue cracking and subgrade/subbase erosion from the repeated pavement deflection at joints and cracks. The presence or absence of doweled joints and concrete shoulders is taken into consideration in the method (Packard 1984 as cited in Austroads 2012). Design procedures are outlined in Section 9.4.2 of the guide for base thickness calculation. Table 9.7 provides minimum thickness requirements for different pavement types and traffic volumes. Calculations for thickness are rounded up to the nearest 5mm and the design thickness is taken to be the greater of calculated thickness, or minimum value provided in Table 9.7 (Austroads 2012).

Section 9.4.2 of the design guide examines the pavement design procedure. A trial base thickness is selected and calculations are performed on the total fatigue and erosion damage for the entire traffic volume and composition during the design period. If either of these damage modes exceeds 100% the base thickness is increased and the design procedure is repeated. The thickness to be selected is to have total fatigue less than or equal to 100% and erosion fatigue less than of equal to 100% also. Table 9.3 of the design guide provides a step-by-step procedural table for the design process, which is shown in Figure 2-2.

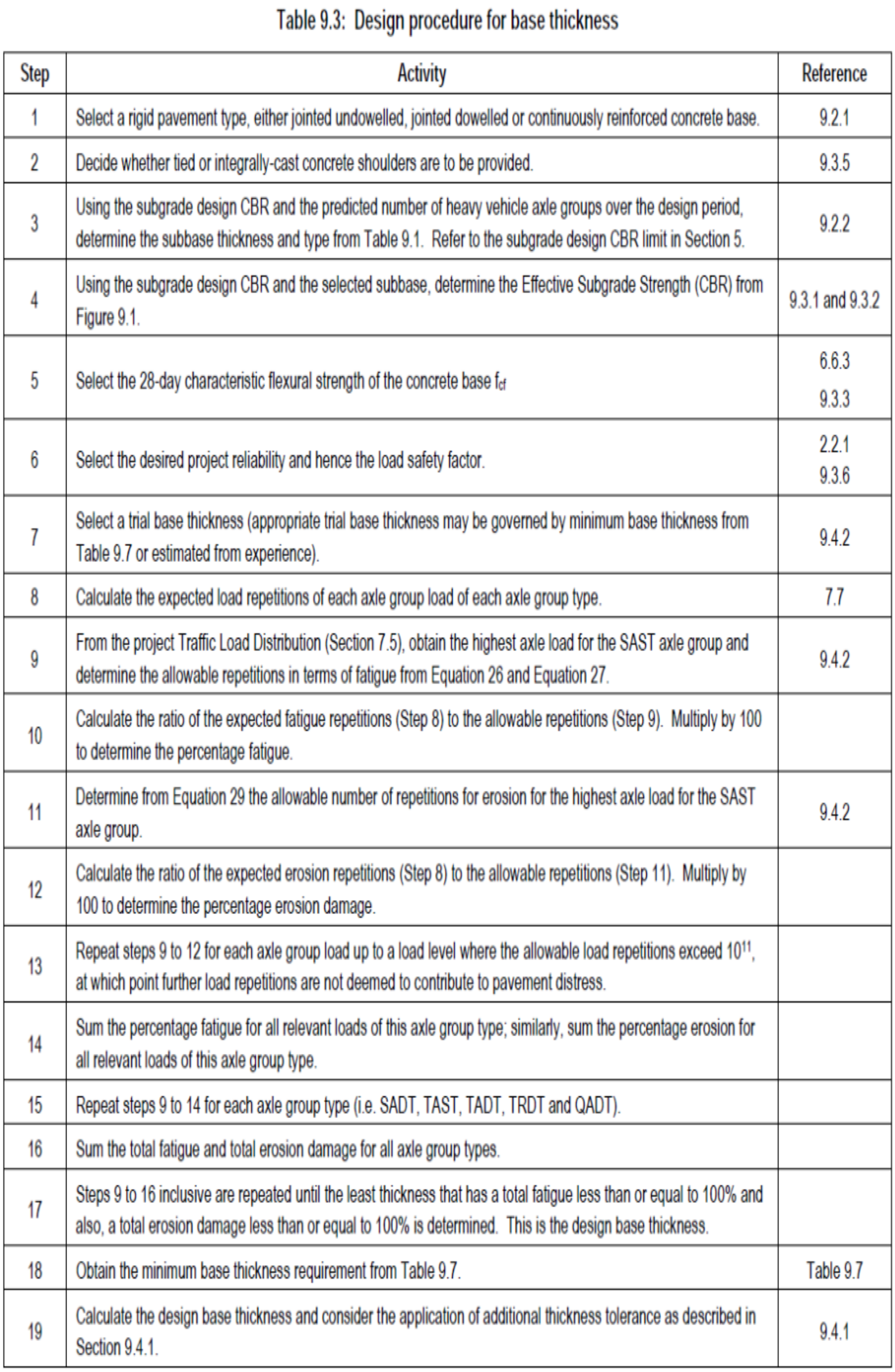


Table 9.3: Design procedure for base thickness

Step	Activity	Reference
1	Select a rigid pavement type, either jointed undowelled, jointed dowelled or continuously reinforced concrete base.	9.2.1
2	Decide whether tied or integrally-cast concrete shoulders are to be provided.	9.3.5
3	Using the subgrade design CBR and the predicted number of heavy vehicle axle groups over the design period, determine the subbase thickness and type from Table 9.1. Refer to the subgrade design CBR limit in Section 5.	9.2.2
4	Using the subgrade design CBR and the selected subbase, determine the Effective Subgrade Strength (CBR) from Figure 9.1.	9.3.1 and 9.3.2
5	Select the 28-day characteristic flexural strength of the concrete base f_{cf}	6.6.3 9.3.3
6	Select the desired project reliability and hence the load safety factor.	2.2.1 9.3.6
7	Select a trial base thickness (appropriate trial base thickness may be governed by minimum base thickness from Table 9.7 or estimated from experience).	9.4.2
8	Calculate the expected load repetitions of each axle group load of each axle group type.	7.7
9	From the project Traffic Load Distribution (Section 7.5), obtain the highest axle load for the SAST axle group and determine the allowable repetitions in terms of fatigue from Equation 26 and Equation 27.	9.4.2
10	Calculate the ratio of the expected fatigue repetitions (Step 8) to the allowable repetitions (Step 9). Multiply by 100 to determine the percentage fatigue.	
11	Determine from Equation 29 the allowable number of repetitions for erosion for the highest axle load for the SAST axle group.	9.4.2
12	Calculate the ratio of the expected erosion repetitions (Step 8) to the allowable repetitions (Step 11). Multiply by 100 to determine the percentage erosion damage.	
13	Repeat steps 9 to 12 for each axle group load up to a load level where the allowable load repetitions exceed 10^{11}, at which point further load repetitions are not deemed to contribute to pavement distress.	
14	Sum the percentage fatigue for all relevant loads of this axle group type; similarly, sum the percentage erosion for all relevant loads of this axle group type.	
15	Repeat steps 9 to 14 for each axle group type (i.e. SADT, TAST, TADT, TRDT and QADT).	
16	Sum the total fatigue and total erosion damage for all axle group types.	
17	Steps 9 to 16 inclusive are repeated until the least thickness that has a total fatigue less than or equal to 100% and also, a total erosion damage less than or equal to 100% is determined. This is the design base thickness.	
18	Obtain the minimum base thickness requirement from Table 9.7.	Table 9.7
19	Calculate the design base thickness and consider the application of additional thickness tolerance as described in Section 9.4.1.	9.4.1

Figure 2-2 - Design procedure for base thickness

(Sourced from Austroads 2012)

Austroads design guide for rigid pavements (2012) has been introduced with background to the development of the guide presented. Input parameters required for base thickness design have been outlined including provision of shoulders and the design procedure is provided.

The sensitivity of pavements to overloading is introduced with further study required to analyse trends in heavy vehicle loading. The influence of temperature environments has also been introduced with temperature gradients not explored in depth in Austroads and hence a sensitivity analysis should be performed on results to identify influence.

2.2.1 Review of the Austroads design guide (2004 version)

In 2006, Darestani et al. performed a review of the 2004 version of the Austroads Design Guide. As stated earlier there have been no major technical changes to the Austroads design guide (2012) from the 2004 version of the guide. The Austroads design guide as described previously is based on the workings of Packard and Tayabji (1984) in the PCA method. It is identified that this method is widely used for the mechanistic design of rigid pavements although it does have limitations. The objective of this review was to identify the limitations of the rigid pavement design guide and introduce design software to analyse the guide. In this study EverFE software version 2.23 was used to determine critical configurations of axle loadings from vehicles. It was determined that configurations are not as simple as those identified in the Austroads guide and involve analysis of the relationship between concrete and subbase boundary conditions as well as variations in temperature and the moisture gradients of the concrete.

Complex relationships exist between the design parameters of the design guide. Despite these relationships Darestani et al. (2006) identified there were some limitations to the Austroads design guide (2004 edition).

In their study they found the following restrictions:

- The Austroads guide provides a maximum spacing of joints in rigid pavements, and hence does not allow for analysis of longer joint spacing.
- Load transfers across the join of shoulder and travel lane are not considered in the PCA method and hence neglected in Austroads.
- It is assumed only six per cent of traffic passed along the edge line (600mm from the longitudinal joints or edges) of the traffic lane. Traffic data obtained from a traffic study by Bunker and Parajuli in 2006 has shown the volume of traffic travelling along the edge line was much higher than the allowed assumption.
- Effects of varying tyre pressure and HVAG configurations and axle spacing on pavement response are not taken into consideration.

Critical axle group positioning on the slab in both the PCA method and Austroads method is provided based on two modes of damage, erosion damage and fatigue damage. For erosion damage the critical positioning of the axle load is at the corner of the slab, and for fatigue damage the critical location is taken to be the midway point of longitudinal joints between the transverse joints Darestani et al. (2006). Research has shown that the jointed concrete pavements suffer from corner and longitudinal cracking Heath et al. 2003 (cited in Darestani et al. 2006, p. 4). Results of the study performed by Darestani et al. (2006) concluded that if temperature gradients are to be considered then the critical position is shifted towards the corner of the slab.

Darestani et al. (2006) states that the Austroads method uses an assumption of the concrete base able to freely curl during temperature gradients, indicating a fully unbonded boundary condition. A study by Tarr et al. (1999) (as cited in Darestani et al. 2006) shows that some bonding typically occurs between base and subbase layers and unbonded conditions may only be achieved through use of double-layered polyethylene sheets. A contrasting study by Yu et al. (cited in Darestani et al. 2006) concluded that the friction between concrete base and subbase layers was sufficient in producing bonded behaviour even with use of polyethylene sheets. It is noted that consideration of unbonded boundary condition results in higher vehicular induced stresses and deflections, although decreases required analysis time.

The study by Darestani et al. (2006) reached the following conclusions:

- Calculations performed using the 2004 design guide suggest an increase in concrete compressive strength decreases potential for fatigue damage however erosion analysis results in a greater pavement thickness.
- Increases of subgrade CBR above 5 per cent have no influence on pavement thickness where the design traffic is greater than $1x10^7$ HVAGs.
- Variation of base thickness with design traffic is complex for fatigue and erosion analysis and is dependent upon provision of dowels and shoulders as well as flexural strength of concrete and subgrade CBR values.
- Consideration of temperature gradients shifts the critical position of axle groups to the corner of the pavement slab.
- Benefits offered by unbonded boundary conditions cease at certain value of differential temperature gradients.

The study by Darestani et al. (2006) has reviewed the 2004 edition of the Austroads design guide and limitations were identified. These limitations have been presented along with conclusions of the study. Conclusions of the paper will be taken into consideration for input parameters required in this study, and some of the identified limitations of the design guide will be focused on within the study.

2.3 EverFE

The computer program, EverFE (current version 2.24), has primarily been developed by Professor Bill Davids from the University of Maine in the USA (University of Maine, n.d). Professor Davids developed this program to analyse and model linear and nonlinear 3D finite elements of JPCP utilising an interactive graphical user interface combined with object orientated C++ finite element code (University of Maine, n.d.).

Features of EverFE are identified below:

- Pavements can be modelled as 1, 2 or 3 slab/shoulder units longitudinally or transversely (maximum of 9 units).
- Tie bars and dowels can be specifically specified between units.
- A maximum of three elastic base layers may be specified with either a bonded or un-bonded base.
- Varied axle configurations/loadings can be defined and applied to the model.
- Linear, bilinear and tri-linear thermal gradients throughout the slab can be applied.
- Visualisations of stresses, displacements and internal dowel forces and moments. Critical values can easily be retrieved.

A paper by Davids et al. (1998) introduces and describes the EverFE software package (original version 1.02). EverFE has been developed to analyse rigid pavements in an attempt to provide ease of access to 3D finite element analysis in a broad range of settings.

It is stated that the program makes it simple and practical to explore effects of various factors such as temperature effects and dowelling on the behaviour of rigid pavements. This allows designers to perform parametric studies and evaluate different design and retrofit strategies. The EverFE design package incorporates graphical pre and post processing capabilities allowing for transparent generation of design models. Pavement configurations can be generated for complex pavement geometries with various factors controlled within minutes and solutions can be produced within a reasonable time from desktop computers.

The paper by Davids et al. (1998) illustrates the computational and interactive features of EverFE with the development and solution of a model rigid pavement. Focus of this paper is stated not to be on the verification and interpretation of results, however to demonstrate the features of the software package. The paper is then broken down into sections on the input parameters and model construction for the concrete pavement including geometries, dowel joints, aggregate interlock, load specifications, meshing and solution of the model. With the model generated and a solution available, results visualisation is examined briefly with an outline of the graphical user interface (GUI). In a concluding statement Davids et al. (1998) states that EverFE makes routine FE analysis of rigid pavements feasible in design and research settings due to a combination of intuitive user interface, rational joint and contact modelling features, and high performance solution strategies.

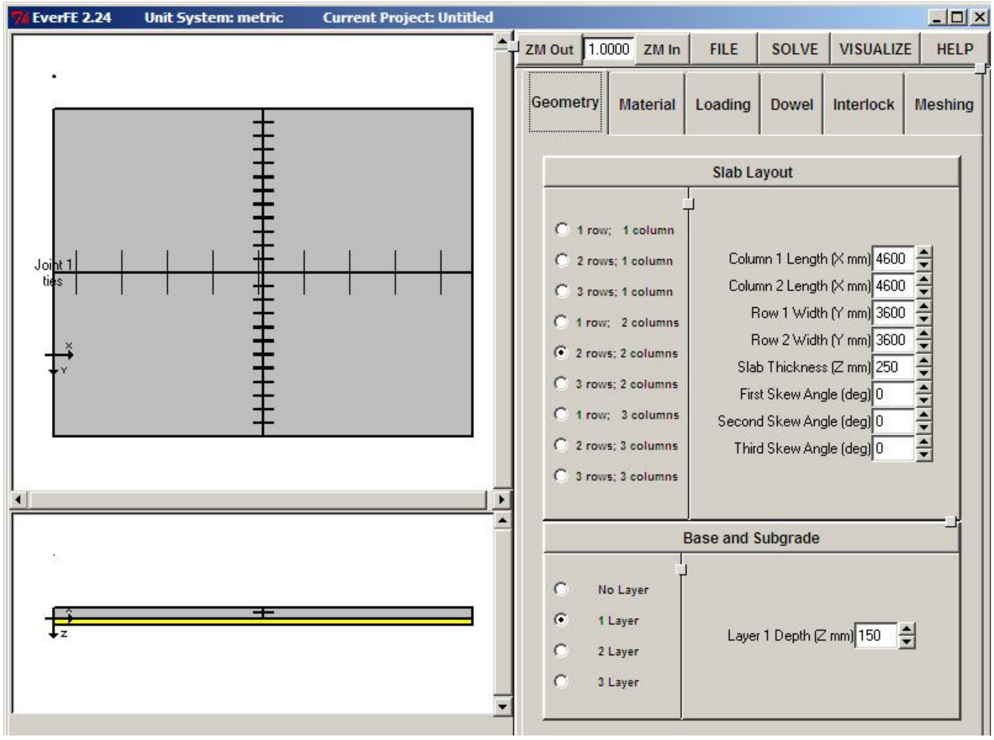
Whilst the previous study examined the original release of EverFE version 1.02 in 1998 a new paper was developed in 2003 for the updated version 2.2. Davids et al. (2003) developed a paper to examine the updated software version. The original capabilities of the software as identified in Davids et al. (1998) are retained, with new capabilities introduced which are as follows:

- Ability to add and tie in adjacent slabs and shoulders. With this a multi-slab system can be modelled with transverse tie bars incorporated.
- Dowel modelling capabilities extended to capture dowel-slab interactions.
- Capability to model nonlinear thermal gradients (bilinear and trilinear) throughout the pavement thickness.
- Simulation of slab-base interaction is provided via inequality constraints.
- Post-processing capabilities have been expanded with users now able to view shear and moments in individual dowels.
- Addition of visualisation for slab stresses and displacement along with retrieval of precise stress and displacement values at specific coordinates.
- Library of axle loads has been expanded to include loads ranging from single wheels to dual wheel, and tandem axles. These can quickly be added, positioned and deleted as required.

A paper by Davids et al. (2003) highlights features of EverFE 2.2. These features include being able to develop concrete pavement systems of one to nine concrete slab panels including the modelling of ties between adjacent slabs. Up to three elastic base layers can be modelled and the subgrade can be either a tensionless or tension supporting dense liquid foundation. An important aspect is that load transfer across longitudinal tie bars can also be modelled along with influence of aggregate interlock in load transfer. The user-friendly interface of EverFE has been retained in the update to version 2.2 continuing to allow ease of model generation and interpretation. The user interface of EverFE is shown in Figure 2-3.

Ability to model nonlinear thermal gradients is also highlighted by Davids et al. (2003) as being a significant improvement to this version of the software. It is noted that prior studies have found that thermal gradients through concrete pavements are not linear and the updated version of EverFE addresses this with ability to consider bilinear or trilinear approximations for nonlinear gradients. EverFE converts temperature changes to equivalent element pre-strains via the concrete coefficient of thermal expansion. These strains are numerically integrated over the elements to generate equivalent nodal forces.

EverFE software has been introduced with the background of software development and previous versions outlined. Features and capabilities of the software have been identified in reports by the developer. From this information it is evident that EverFE software provides adequate capability to rapidly model rigid pavements with a variety of input parameters including the impacts of environmental factors such as thermal gradients.



Slab Layout

○ 1 row; 1 column
○ 2 rows; 1 column
○ 3 rows; 1 column
○ 1 row; 2 columns
● 2 rows; 2 columns
○ 3 rows; 2 columns
○ 1 row; 3 columns
○ 2 rows; 3 columns
○ 3 rows; 3 columns

Column 1 Length (X mm) 4600
Column 2 Length (X mm) 4600
Row 1 Width (Y mm) 3600
Row 2 Width (Y mm) 3600
Slab Thickness (Z mm) 250
First Skew Angle (deg) 0
Second Skew Angle (deg) 0
Third Skew Angle (deg) 0

Base and Subgrade

○ No Layer
● 1 Layer
○ 2 Layer
○ 3 Layer

Layer 1 Depth (Z mm) 150

Figure 2-3 - EverFE user interface

2.4 Is the Austroads design guide adequate for predicting future vehicle loading?

An area of research required by this project is the determination of the adequacy of the Austroads design method in predicting traffic loading in the future. Austroads (2012) states that the guide may be used for design of rigid pavements under conventional road traffic conditions. The guide states in Table 7.2 that the typical design period for a rigid pavement is 30-40 years. It is not known if the current Austroads design guide can continue to be extrapolated for future heavy vehicle loading over this period if these traffic conditions change such as increased heavy vehicle mass and dimension limits.

In the Technical Basis of Austroads Guide to Pavement Technology (2008a) it is stated that pavement thickness is very sensitive to traffic loading. It is stated that a reduction in pavement thickness of 10mm can result in a reduction of pavement traffic life by 24 million HVAGs.

Experience from years of research on rigid pavements has shown that these pavements are subject to numerous overloaded trucks with axle loads in excess of the legal limit. Pavement designers will find it increasingly difficult to estimate traffic loading and volume over the coming ten to forty years with governments under increased pressure to increase the legal axle loading limits of heavy vehicles (Technical Basis of Austroads, 2008a).

A report by Mitchell (2010) identifies the trend in heavy vehicle transportation and road freight regulation. In this report it is forecast that freight volume carried by B-doubles would grow to over 50% of the total road freight moved by the year 2030 with the increased use of B-doubles resulting in a decline in use of other heavy vehicles in freight transportation (assuming no changes to heavy vehicle regulations).

A report from the Australian department of Infrastructure and Transport (2011) projects a similar trend as the B-double offers improved freight movement efficiency over other forms of heavy vehicle movements. It is stated however that growth in B-double freight movements will not be as strong as they were 15 years ago. This report also takes the assumption that there is no regulatory change to heavy vehicle regulations.

Mitchell (2010) notes in his report that recently new areas of the road network have been opened up to the use of larger freight movement vehicles such as B-triples (Road trains). The report from the Australian department of Infrastructure and Transport (2011) proposes that if the road network if opened up to B-triples outside of built up areas their use for freight transportation may increase from negligible levels, to approximately 20% by the year 2030.

With upgrades to major transportation routes continuing the presence of B-triples on road networks may be possible with dual carriageway standards implemented utilising rigid pavements.

Mitchell (2010) examines vehicle mass and dimension limits and their influence on trends in heavy vehicle traffic. Increases to heavy vehicle mass and dimension limits have been contributing factors to the growth in road freight. These limits have been implemented to limit the damage of road assets from heavy vehicles. Regulations governing the legal vehicle mass have progressively been relaxed facilitating the use of larger and heavier road transport vehicles. Mass limits for both rigid and articulated trucks have increased by 12 to 24 per cent since 1971.

A report by the ARRB Transport Research produced by RA Pearson and GD Foley (2001) examined emerging issues in the Australian transportation industry for the years 2000 – 2015. This report summarises the following trends to emerge between the years 2000 to 2015, also making predictions through to the year 2020:

- Average number of axles per vehicle will be greater (particularly an increased number of B-doubles and Road trains).
- Gross loading allowances will be increasing for vehicles (shown in Table 2-1) comparing predicted allowable mass to current allowable vehicle masses).
- Regulation changes will influence the use of wide single tyres (if no differentiation is made between them and dual tyres on Triaxle vehicles) and see an increase in their use.

- Axle group masses for articulated trucks to increase by approximately 1% per annum with gross vehicle masses increasing by 2% (approximately 0.4 tonne per annum).
- Axle group masses for B-doubles increased by approximately 3% per annum with gross vehicle masses increasing by 3% per annum also (equating to approximately one tonne per annum). This trend is greater than the historical trend (0.45 tonne per annum).
- Engine power will increase faster than the increase in axle loads leading to greater tractive efforts being applied to road pavements.
- Potential move to quad axles for general freight vehicles if an allowable mass of approximately three tonne is granted above the current limit on Triaxle.

Table 2-1: Predicted vehicle loads and current allowable limits

Axle Configuration	Predicted Load (t) 2015 - 2020	Allowable Limit (t) 2015
Single axle, single tyre	7	6
Single axle, dual tyre	10-13	9
Tandem axle, dual tyre	19-20	16.5
Triaxle, dual tyres	26-27	20
Gross mass, 6 tyre articulated trucks	50-53	42.5

A study by the ARRB in 2001 titled ‘Relative Effect of Wide Base Radial Tyres on Pavement Performance’ presents information trending towards an increase in the legal mass limit of heavy vehicles. In this report the recognition of suspension technology is taken into consideration and it is stated that the development of airbag suspension technologies produce a softer ride to conventional suspension and in turn result in a reduction to pavement degradation. A scenario is proposed in which mass limits of heavy vehicles fitted with airbag suspension systems would be increased, as they cause no more damage to road pavements than conventional truck suspension systems carrying the current legal axle loads. This information tends to provide justification to predictions that heavy vehicle regulatory bodies will continue to increase legal mass limits as technologies continue to improve in the future. Hence the increased axle loadings of future predictions must be accounted for in design of rigid pavements.

Section 7.2 of the Austroads Design Guide (2012) identifies the role of traffic in pavement design. Damage caused to pavements by heavy vehicles is not only dependent upon the mass of the vehicle but also dependent upon the number of axles on the vehicle, the axle grouping and the axle group load. Design traffic for rigid pavements is described as the cumulative number of HVAGs over the design period that is classified according to the type of axle group and the load on the axle group. There is a clause in this section that states if axle loadings are anticipated to increase, guides provided in Appendix E of the design guide can be used to make adjusments. Appendix E of the design guide provides two scenarios for estimating future increases to the magnitude of axle group loads. One scenario accounts for all axle group loadings being increased by a certain percentage and the other scenario only accounting for specific axle groups increasing in load magnitude.

Information presented identifies the trend towards an increase in the legal mass limits of heavy vehicles in order to improve efficiency and productivity of freight transport. Studies are also trending towards an increased utilisation of larger articulated vehicles such as B-doubles and growth in the use of road trains. The impacts to pavements of mass limit increases and axle groupings will need to be examined in the design of rigid pavements to ensure pavements are adequately designed for the loading conditions predicted.

2.5 Traffic load distribution in travel lane

Assumptions from the PCA method for distribution of vehicles in the travel lane are taken to be six per cent of traffic passing on the edge line of the travel lane (Packard as cited in Darestani et al. 2006). It should also be noted that there is limitation to the PCA method (as used in Austroads) with vehicle loading at a distance of 600mm from the edge line. In a study by Lee and Garner (1996) the lateral positioning of vehicles is examined as it provides guidance on the edge loading for pavement slabs. A statement is made that if all vehicles were to travel in the centre of the travel lane, heavy vehicles would travel closer to the edge line than passenger cars due to the wider dimensions of heavy vehicles. The study also found that as the number of axles on a vehicle increased, the vehicles travelled closer to the edge line and shoulder of the pavement.

In a study performed by Bunker and Parajuli (2006), traffic data in Queensland was collected to determine the lateral positioning of vehicles. The results of this study showed that a higher percentage of vehicle traffic travelled towards the outer edge line than assumed in the PCA method.

Bunker and Parajuli (2006) performed a study to examine lateral positioning of light vehicles and heavy vehicles on a roadway examining both unopposed vehicle travel in which there was no oncoming traffic and opposed vehicle travel with traffic in the opposite direction. The results summarised that vehicle positioning for passenger cars was located straddling the edge line of the travel lane whilst heavy vehicle positioning was located closer to the edge line (unopposed) and into the shoulder area (opposed). The results are shown in Table 2-2 and Table 2-3.

Table 2-2 - Unopposed vehicle lateral positioning

(Sourced from Bunker and Parajuli 2006)

Vehicle Type	Distance from edge line (m)	Distance from centreline (m)
Car	0.68	1.05
Semi-trailer	0.15	0.85
B-double	0.11	0.89

Table 2-3 - Opposed vehicle lateral position

(Sourced from Bunker and Parajuli 2006)

Vehicle Type	Distance from edge line (m)	Distance from centreline (m)
Car	-0.07	1.80
Semi-trailer	-0.45	1.45
B-double	-0.35	1.35

Results of the study found that the 95th percentile passenger car, semi-trailer and B-double straddled the edge line of the road. The study also showed that both semi-trailers and B-doubles occupied part of the shoulder, with semi-trailers wandering further onto the road shoulder than B-doubles. The findings of this study reflect the findings of the previous study by Lee and Garner in 1996 showing larger volume of traffic travelling on the edge line than has been allowed for in the PCA method and Austroads deign guide.

With Austroads (2012) limited by the assumption only six per cent of traffic travels on the edge line of pavement and the study by Bunker and Parajuli (2006) finding the 95th percentile of traffic (cars and heavy vehicles included) travels straddling the edge line, pavement stress will behave differently to predictions from Austroads. Pavement stress will be modelled using EverFE software to determine stress differential from vehicle loading 600mm from the edge line of travel lane, as per Austroads, and at a distance reflective of the results presented to model findings of the traffic conditions found by Bunker and Parajuli.

2.6 Temperature and Environmental Effects

In the study by Darestani et al. (2006) it was intended to find if certain boundary conditions could minimise the damage to pavements with environmental factors taken into consideration. The authors of the paper suggest that whilst Austroads only considers design traffic for concrete flexural strength, flexural strength determinations should also consider the effect of worst possible temperature gradient along with design traffic loading.

The study then concluded that the flexural strength of concrete should be selected based on the combination of effects of the worst possible temperature gradient (environmental effect) and the vehicle-loading configuration. With temperature gradients considered the critical positioning of axle groups is shifted towards the corner of the slab. The study also found that the benefits offered by an unbonded boundary condition also cease at a certain value for differential temperature gradients. This finding dictates that the type of boundary condition (bonded, unbonded or partially bonded) should be selected based on the critical differential temperature of the construction site throughout the service life of the pavement.

A study by Kim et al. (2014) set out to model environmental effects on rigid pavement deformation using FE modelling with two different FE software packages, including EverFE version 2.24. Kim et al. (2014) identifies EverFE as a 3D FE analysis tool useful for simulating the response of JPCP to the combined actions of both traffic loads and temperature effects. It is identified that EverFE 2.24 has limitation in that it cannot directly calculate slab deflections due to moisture change and permanent curling and warping effects, only capable of modelling the effects of temperature change.

Belshe et al. (2011) best describes temperature differentials and resultant on concrete pavements. As temperature changes between day and night time, temperature at the top and bottom of a slab also change. During night-time temperature at the top of the slab is lower than the temperature at the bottom and with the weight of the slab restraining contraction and expansion, tension develops in the top of slab and compression in the bottom of the slab, resulting in upward curling stress of the corners.

The opposite occurs during daytime temperatures in which warmer temperature at the top and cooler temperature underneath results in downward curling of the slab. Figure 2-4 visualises the forces and deflections of the slab during day and night time conditions.

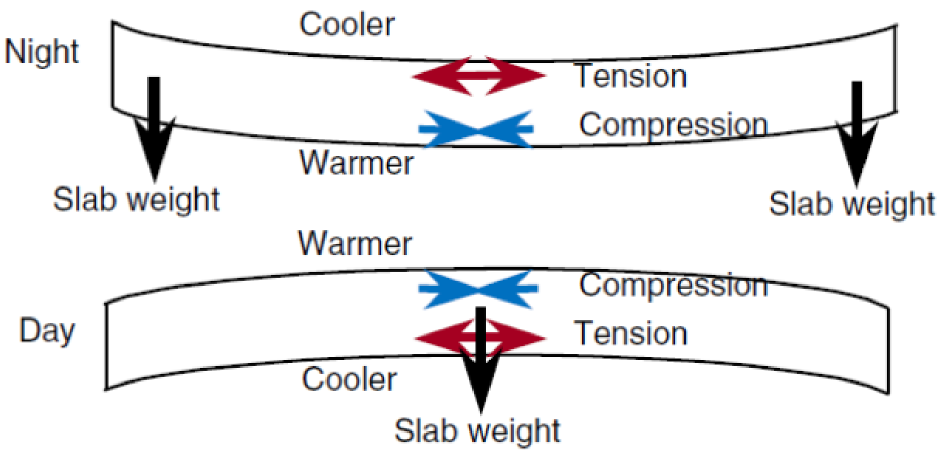


Figure 2-4 - Curling resulting from temperature differentials

(Sourced from Belshe et al. 2011)

This study set out to compare the accuracy of the two programs at modelling the actual slab deformations by comparing the FE analysis with field measurement data of actual slab deformation. A sensitivity analysis was performed to identify input parameters that have the most significant impact on pavement slab deflection from environmental effects. A total of eight key parameters relating to material properties were selected for analysis. Whilst any one input parameter was varied throughout its range, other input values were held constant for sensitivity analysis. The material properties obtained after performing sensitivity analysis are shown below in Figure 2-5.

Results from the study determined that with the input parameters controlled as per the study, the FE programs presented similar results for slab deformations as those recorded from the field measurements (using the same tensionless supporting foundation).

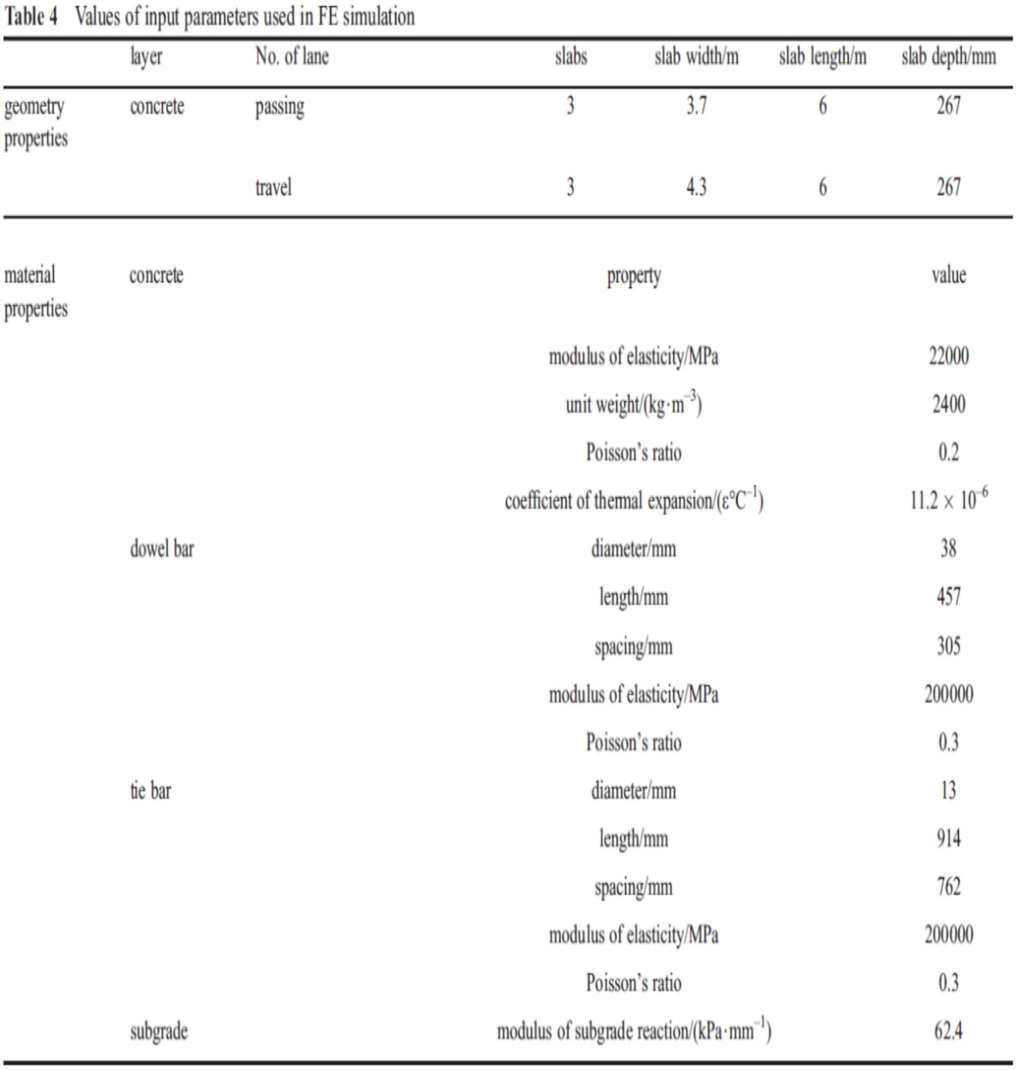


Table 4 Values of input parameters used in FE simulation

	layer	No. of lane	slabs	slab width/m	slab length/m	slab depth/mm
geometry properties	concrete	passing	3	3.7	6	267
		travel	3	4.3	6	267

		property	value
material properties	concrete		
		modulus of elasticity/MPa	22000
		unit weight/(kg·m^{-3})	2400
		Poisson's ratio	0.2
		coefficient of thermal expansion/(ε°C^{-1})	11.2×10^{-6}
	dowel bar	diameter/mm	38
		length/mm	457
		spacing/mm	305
		modulus of elasticity/MPa	200000
		Poisson's ratio	0.3
	tie bar	diameter/mm	13
		length/mm	914
		spacing/mm	762
		modulus of elasticity/MPa	200000
		Poisson's ratio	0.3
	subgrade	modulus of subgrade reaction/(kPa·mm^{-1})	62.4

Figure 2-5 - EverFE input parameters

(Sourced from Kim et al. 2014)

A paper by Siddique et al. (2005) also studied the effects of temperature gradient on the curling of concrete pavements. In this study field data was compared with data developed from FE software (not EverFE) and found the field measurements to be in close agreement with deflections predicted from FE analysis. This conclusion is reflective of the conclusion drawn from the study performed by Kim et al. (2014) in that FE software analysis provides deformation results representative of experimental results from the field. Siddique et al. (2005) also makes an important point that fatigue damage caused by heavy vehicle traffic is ten times higher for a 1°F/in (0.022°C/mm) temperature differential than for a zero temperature gradient. This statement implies the significance for consideration of temperature gradients in rigid pavement design.

Belshe et al. (2011) performed a study examining temperature gradient and curling stresses in concrete pavements with and without wearing courses. EverFE was used in this study to analyse curling stresses in the pavement. This study found that the provision of a wearing course on rigid pavements reduces temperature differentials within the slab. The input parameters used in this study were within the range for input parameters used by Kim et al. (2014), however geometric properties of the rigid pavements varied between the two studies with different slab lengths and widths used. Neither of the slab geometries used in these two studies are reflective of the geometries identified in Austroads (2012) of slab length 4.2m and 4.5m (undowelled and doweled respectively). Vehicle travel lane widths between the two studies varied from 3.7m through to 4.57m. To reflect Australian conditions travel lane widths will be taken as 3.5m in accordance with RMS standard drawing MD.R83.CJ for JRCP (RMS, 2015).

In a study by Byrum and Hansen (1994) as cited in Darestani et al. (2006) the differential temperature gradients throughout the concrete base are stated to range between 0.087°C/mm to 0.109°C/mm during day time and 0.044°C/mm to 0.065°C/mm in the night time. Darestani et al. (2006) states that high temperature gradients of more than 25°C would result in severe damage to unreinforced pavements, therefore a linear gradient of -25°C (for night temperature) to 25°C (day time temperature) was used for analysis for temperature gradient between top and bottom surface layers of concrete base. In this study a temperature gradient of -10°C to 10°C is also used for comparison of results on temperature gradients.

A sensitivity analysis will be performed on results obtained to determine the impact of temperature gradients on rigid pavements, as they are not considered in detail in the Austroads design guide (2012). The most severe temperature gradient of -25°C to 25°C will be used along with gradients of -10°C and 10°C for comparison of results in reflection of temperature gradients used by Darestani et al. in 2006.

3. Research Design and Methodology

The aim of this chapter is to define the methods used within this report to achieve the objectives of the dissertation as determined in the introduction (Section 1.1) providing a detailed description of the project objectives. Details are provided on the methodology used to determine parameters for analysis from the literature review conducted.

3.1 Overview

In order to achieve the objectives of the dissertation to determine the suitability of EverFE software for use in conjunction with the Austroads Design Guide to address limitations, the following methodology is proposed and implemented:

- Describe the use of EverFE software in concrete pavement design.
- Review the minimum pavement thickness requirements of the Austroads method.
- Identify parameters required for design including heavy vehicle loading and load location from the literature review conducted.
- Develop a pavement thickness design using the Austroads Design Guide (2012) in conjunction with RMS rigid pavement design spreadsheet and Traffic Load Data (TLD).

- Perform analysis on the pavement design using EverFE software with input parameters defined for current loading conditions and predicted future loading conditions to determine critical stress values for each.
- Shift traffic load to location reflective of current conditions using EverFE and compare with stress results obtained previously.
- Conduct a sensitivity analysis on results with the inclusion of temperature gradients to determine if temperature gradients require further consideration in the future.
- Present opportunity for use of EverFE in conjunction with Austroads Design Guide in the development of Australia’s rigid pavements.

4. EverFE software in concrete pavement design

Background to EverFE software has been provided in the literature review with features and capabilities of the software outlined. EverFE software provides a simple, easy to use platform for the analysis of rigid pavement stresses of varying configurations and under different loading conditions inclusive of thermal loadings induced from temperature gradients. Although EverFE provides a powerful processing tool for rigid pavement analysis, it is a relatively new program and utilisation of the software isn't widespread in Australia. The capabilities and ease of use of the software do however provide an opportunity for utilisation of the software in the design and development of rigid pavements in Australia.

A study by Rodden et al. (2014) has examined the impact of longitudinal joint locations on rigid pavement stresses using the EverFE software package. Typical road design incorporates longitudinal joints between pavement slabs inline with the edge line (fog line) of the travel lane as well as the dividing line between travel lanes for multilane carriageways. This study uses features of EverFE to adjust longitudinal joint locations and loading conditions to predict pavement stresses developed in the slab. A stress comparison is then conducted on results for longitudinal joints running in the middle of the traffic lanes with longitudinal jointing running along the fog line. Further work in this study is required; however it was concluded from FE analysis that relocation of longitudinal joints to the middle of traffic lanes reduces the stresses developed in pavement. The finding of this study provides justification of successful implementation of joint relocation in the field. Joint relocation has been undertaken in areas of the USA and also in Australia with photographs in the paper of a section of the Hume Highway in NSW that has been in service for over 20 years provided as evidence of its success.

A study by Maske et al. (2013) set out to analyse a rigid pavement design by both empirical methods (Westergaard's Method) and FE methods (EverFE) to compare results of pavement stresses. Conclusions drawn from the study are as follows:

- FE methods used for analysis of rigid pavements can provide an optimum and economical design in practice due to the procedure used to discretise each element being considered and calculates nodal stresses.
- FE methods provide a more accurate estimation for the behaviour of rigid pavement critical points under applied loads.
- Design of pavements and manipulation using trial and error techniques can be completed easier using FE methods.
- Pavement lifetime can be considerably increased through application of FE analysis and fatigue distress can accurately be ascertained.

Conclusions of the study by Maske et al. (2013) provide justification that incorporation of FE analysis, using EverFE, can improve accuracy and optimise rigid pavement design potentially leading to an increase in pavement service life.

Meshram et al. (2013) also studied the comparison of different methods for stress analysis in rigid pavement design. In this study results were compared between two empirical design methods, Westergaard's method, and the Picket and Ray method, and the results of FE methods using EverFE.

Results from this study show there is negligible variation between the results from EverFE and the Westergaard's method. Analysis also indicated that EverFE produces results almost the same as those obtained from the Picket and Ray method. Conclusions drawn from this study again show that there is little variation for stress analysis between empirical design and FE methods using EverFE software.

EverFE is commonly used for its capability in modelling the environmental effects of temperature gradients on pavements. The study by Darestani et al. (2006) reviews the 2004 Austroads Design Guide that is predominantly based on empirical formulations. EverFE is used to in this study for its ability to model environmental effects on pavements, which has been identified as a limitation of the design guide with environmental conditions not taken into consideration in any detail in the guide. It was found that the guide was limited in the capacity that it does not consider effects of temperature gradients in the selection of concrete flexural strength. The authors suggest through utilisation of EverFE and the results that were obtained, minimum flexural strength of concrete for rigid pavements should be selected based on a combination of the worst possible temperature gradient for the construction site, and the vehicular loading.

A study by Kim et al. (2014) also examined the use of EverFE in design for modelling the environmental effects of temperature gradients on rigid pavement response. In this study model pavements were developed to replicate a real world highway in Iowa, USA. Geometric proportions and material properties were collected based on the actual pavement. The models developed were subject to temperature gradients measured in the field from temperature gauges installed during the construction of the pavement. Deflection models were then produced using EverFE corresponding to the temperature gradients of the pavement.

To determine the accuracy of the models, field measurements of deflection were taken from the highway under examination for comparison to the computed deflection output from EverFE. From this comparison it was concluded that values produced from EverFE were reflective, within an acceptable level of accuracy, for pavement deflections measured in the field. Although EverFE produces accurate results for pavement deformation under temperature gradients the authors identified limitation. It was identified that the program cannot directly calculate deflections resulting from moisture change and for the effects resulting from permanent curling and warping of the pavement.

Belshe et al. (2011) studied temperature gradients within rigid pavement profiles with and without wearing courses. Through this study EverFE was used to calculate pavement stresses due to its capability in modelling loading from temperature gradients. In the study, field data was collected to determine if the inclusion of a wearing course overlay on rigid pavements would be beneficial to minimise damaging temperature swings. The authors noted that for temperature inputs, EverFE requires temperature changes relative to the zero-strain condition. The zero-strain condition is identified as the temperature at the time of construction of pavement. In reality during the design process the true condition is difficult to determine and hence must be assumed. The assumption of this condition is a potential limitation for accurate estimation of temperature gradient profiles, however results from this study and previous studies by other authors show that impacts from temperature gradients determined from EverFE present reasonably accurate results to field data collected.

Analysis of temperature gradients through use of EverFE is a powerful design tool that is not only limited to rigid pavements for road design. A study by Kim et al. (2013) looked at the effects of temperature induced loading on airport concrete pavements. It was identified that the pavement design method and software used to design airport pavements, FAARFIELD, is limited in design capacity in that temperature loading is not considered. This limitation is reflective of an identified limitation of the Austroads design guide in that temperature-induced loading is not considered. In this study EverFE was used to model airport pavements subjected to positive and negative temperature gradients with and without aircraft traffic loading. Observations from the study showed that pavement distress types and locations were in accordance with actual distress types and locations found in the field. Results from the study concluded the significance of temperature gradient consideration in the design of airport concrete pavements to minimise the deterioration of pavements and improve their performance.

5. Review of the Austroads minimum thickness requirements

Section 9 of the Austroads Guide details the design procedure for rigid pavements. This section of the design guide is aimed at the determination of pavement configuration and base thickness for the pavement, however guidance is also provided on structural issues such as dowels and joints. The main input variables required for the thickness design are:

- Predicted traffic volumes and traffic composition for the design period (discussed in section 7 of the design guide).
- Subgrade strength in terms of CBR (Section 5).
- Base concrete flexural strength (Section 6).

The Austroads method states it is based on the assumption that there is no bonding between the base and subbase layers. In the study by Darestani et al. (2006) it was found that the determination of boundary condition between concrete base and subbase, whether it be bonded or unbonded, should in fact be selected based on the critical temperature differential of the pavement construction site and not assumed to be unbonded for all cases.

Pavement thickness calculations are dependent on the strength of subgrade beneath the pavement, assessed in terms of CBR. The determination of effective subgrade strength is taken from Figure 9.1 of the design guide that presents values for different subbase materials and design subgrade strength (shown in Figure 5-1). The methods for determining the design subgrade strength are analysed in Section 5 of the Austroads Design Guide (2012).

Subgrade CBR values can be measured in two ways, in field-testing and through laboratory testing. In practice these values are determined from samples taken at on-site locations where a road pavement is to be constructed. For the purposes of this study, as an in field study is not examined and these results are not available, a common value for subgrade CBR will be adopted (CBR of 3.5) as used in the study by Darestani et al. (2006). With a design subgrade CBR selected the effective subgrade strength can then be determined from Figure 5-1 for various subbase treatments. In the case of design traffic greater than 1x10^7 the only subbase option is 150mm LCS (Austroads, 2012).

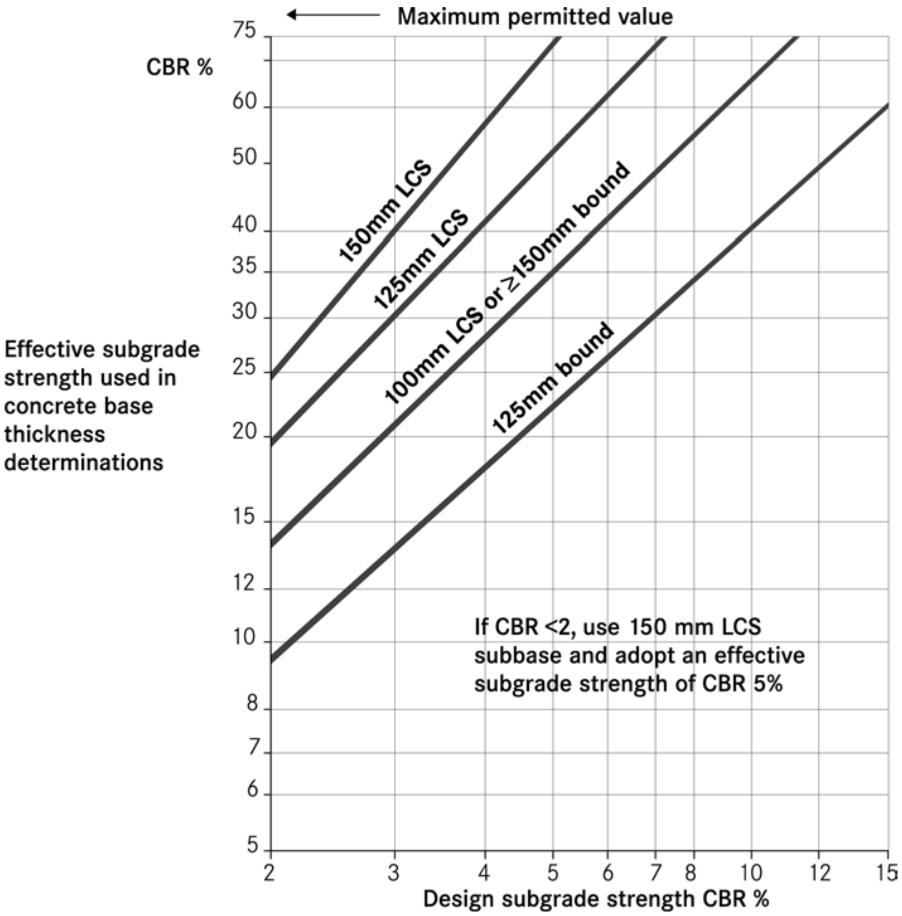
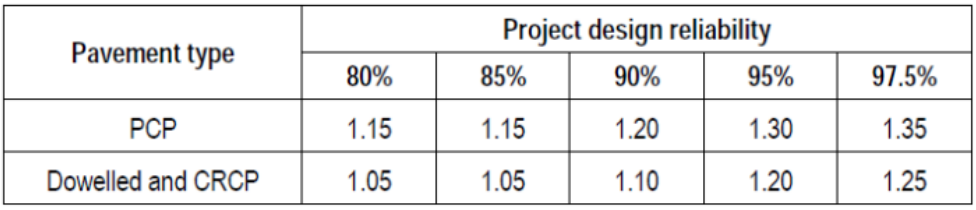


Figure 5-1 - Design subgrade CBR vs. Effective CBR (Austroads Figure 9.1)

Section 9.3.3 discusses the selection of base concrete strength. It is stated that base concrete strength is typically selected based on the 28-day characteristic flexural strength of concrete. For traffic conditions greater than $1x10^6$ HVAGs the minimum allowable concrete flexural strength is 4.5MPa at 28-day strength. The study by Darestani et al. (2006) found that an increase in concrete compressive strength decreases the possibility or damage caused by erosion however increases the fatigue damage. It was concluded that flexural strength should be selected based on the consideration of worse case temperature gradients and vehicular loading.

Design traffic is identified in section 9.3.4 of the design guide that refers to section 7 for the determination of design traffic. The procedure for selecting design traffic is determinant on a sequential process involving collection of heavy vehicle traffic data, estimating number of axle groups per heavy vehicle and estimating proportions of axle group types and distribution of axle group loads. The design guide provides tables of coefficients for the determination of equivalent stresses for each axle group in different pavement configurations (with/without shoulders, dowelled, undowelled). With axle group loadings determined the design procedure requires these be multiplied by a load safety factor (L_{sf}). These factors are determined by the desired project reliability for the pavement, shown in Figure 5-2.



Pavement type	Project design reliability				
	80%	85%	90%	95%	97.5%
PCP	1.15	1.15	1.20	1.30	1.35
Dowelled and CRCP	1.05	1.05	1.10	1.20	1.25

Figure 5-2 - Load Safety Factors for Rigid Pavements

(Sourced from Austroads 2012)

For the purposes of this project, RMS has provided TLD to be used in the study from data collection throughout a variety of roads across NSW. TLD data is provided in spreadsheet format identifying axle group types and their percentage of total heavy vehicle traffic, separated into axle group loadings from 10kN through to 400kN. TLD data used in pavement design is shown in Appendix B.

Rigid pavement design base thickness is dependent on two dominating distress modes, flexural fatigue cracking of the pavement base, and subgrade/subbase erosion arising from the repeated deflections of joints and cracks in the pavement. Pavement thickness calculations take into consideration the provision of concrete shoulders and inclusion or exclusion of dowelled joints. Traffic load is taken into consideration in the form of axle group types and the distribution of each axle group type and the predicted number of repetitions of each axle load throughout the pavement design life.

Section 9.4.2 details the base thickness design procedure for rigid pavements. At first a trial base thickness is selected, usually based on experience in pavement design, and calculations are performed to develop total fatigue and erosion damage for the entire traffic volume and composition over the pavement design period. The calculated fatigue and erosion damage are represented as percentages and it is a requirement that both of these figures are below 100%. If either of the values come in over 100% then the pavement thickness is increased and the design procedure is repeated until a pavement thickness is determined that satisfies fatigue and erosion damage less than or equal to 100%. Figure 2-2 shown previously in the literature review provides a detailed step-by-step procedural process for determining pavement thickness.

With Section 9.4.2 of the Design Guide providing formulations for the calculation of a base thickness design, Table 9.7 of the Design Guide provides minimum base thickness requirements for different traffic volumes and different pavement types, shown in Figure 5-3. The thickness calculated from Section 9.4.2 must be greater than the values presented in this table. It is stated that the minimum values presented in this table are to account for environmental factors of curling and warping of slabs due to temperature differentials.

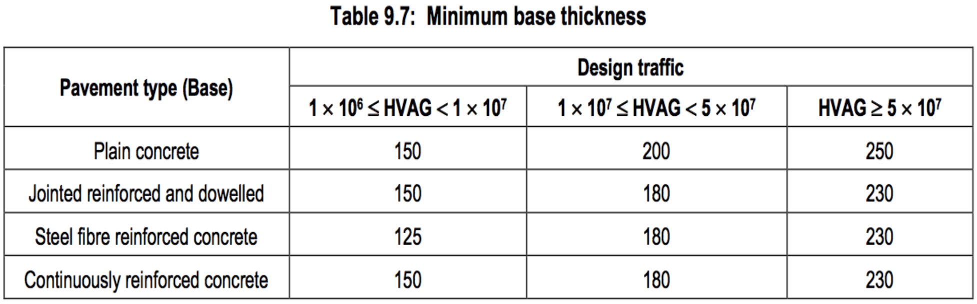


Table 9.7: Minimum base thickness

Pavement type (Base)	Design traffic		
	$1 \times 10^6 \leq \text{HVAG} < 1 \times 10^7$	$1 \times 10^7 \leq \text{HVAG} < 5 \times 10^7$	$\text{HVAG} \geq 5 \times 10^7$
Plain concrete	150	200	250
Jointed reinforced and dowelled	150	180	230
Steel fibre reinforced concrete	125	180	230
Continuously reinforced concrete	150	180	230

Figure 5-3 - Austroads Minimum Base Thickness Requirements

(Sourced from Austroads 2012)

The design guide also provides examples on pavement thickness procedure presenting charts that allow designers to compare design base thicknesses for two pavement configurations, PCP and dowelled jointed pavements or CRCP. The charts provide different traffic volumes, effective subgrade strengths and different load safety factors. The two example charts provided in the Austroads design guide are shown in Figure 5-4 and Figure 5-5.

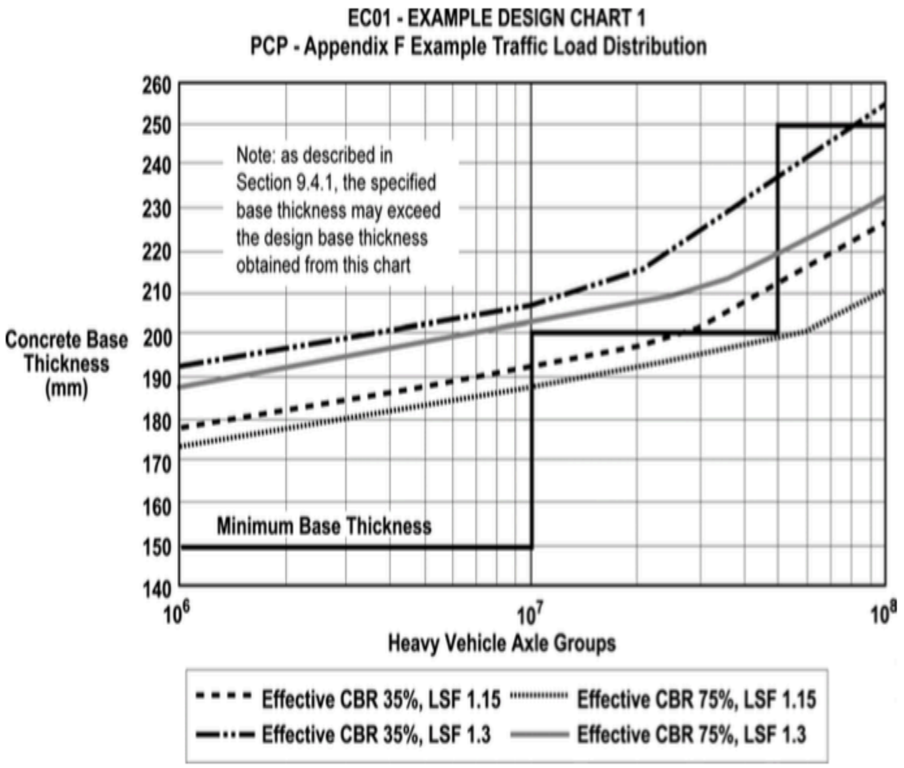


Figure 5-4 - Austroads Design Chart Example 1

(Sourced from Austroads 2012)

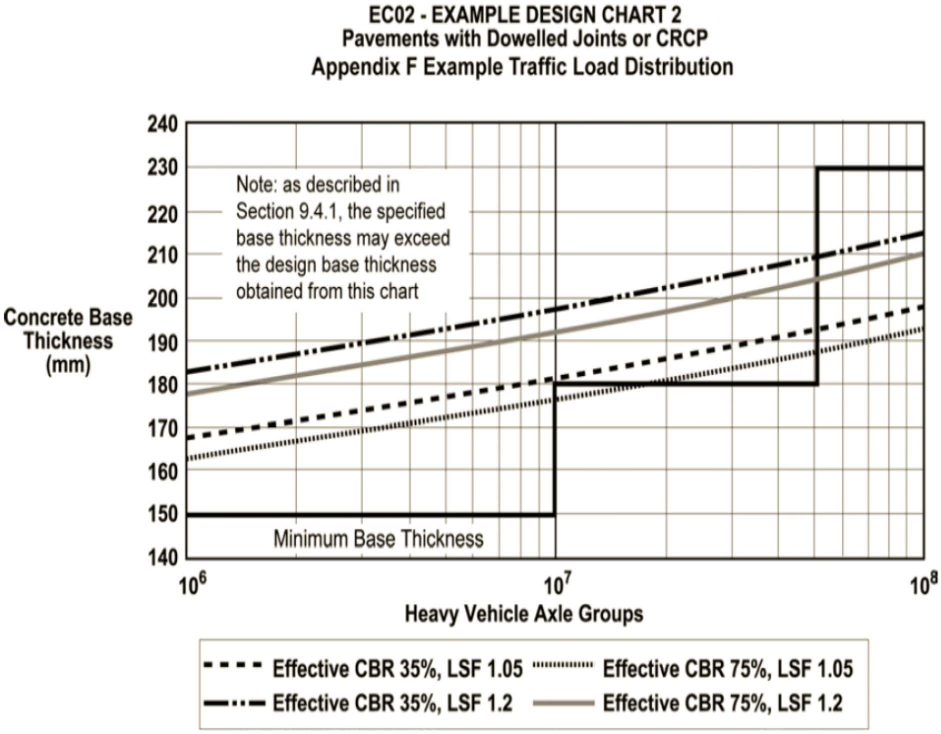


Figure 5-5- Austroads Design Chart Example 2

(Sourced from Austroads 2012)

The report on the technical basis to the Austroads design guide in 2013 by the ARRB group reviews the changes to the design guide in the 2012 revision and provides justification to the technical basis for changes. It is stated that the recommended minimum base thickness for rigid pavements has been increased from previous revisions. It is also stated that additional thickness to pavement base be allowed for to account for limitations in paving and measuring systems in the field and also for possible losses from future surface treatments such as milling of asphalt, diamond grinding and grooving. The base thickness specified for construction should be the sum of the base thickness calculated in design and the additional thickness allowances mentioned.

As stated previously the design guide does not cover environmental factors in the selection of a minimum pavement thickness in any detail and they state it would be inappropriate to increase the load safety factor to determine a minimum base thickness. Therefore the authors based the design guide recommendation on minimum pavement thickness (shown in Figure 5-3) on their own experience within the industry. As there is no analytical or technical determination of environmental factors in the design guide, the recommended values of minimum pavement thickness may not be completely accurate and hence could be a limiting factor in pavement design.

6. Design input parameters

6.1 Traffic Load Distribution

It was identified from the literature review conducted that the current Austroads design methodology does not accurately reflect the traffic load distribution observed on our roads. The Austroads Design Guide is based on an assumption of only six per cent traffic travelling along the edge line, however traffic studies show this percentage to be higher and therefore impact of this change on pavement performance should be identified.

Influence on pavement response from relocation of traffic loading will be examined in this study. The study aims to reflect results from the study by Bunker and Parajuli in 2006. These results will form the basis for design parameter adjustments as this traffic study examined traffic conditions in Queensland. Table 2-2 and Table 2-3 presented data obtained from the study for unopposed vehicle travel and opposed vehicle travel respectively. As the impact of light vehicles on pavement design is negligible, data presented in the tables for light vehicles (cars) will be neglected and distance from edge line will only be examined for semi-trailers and B-doubles.

Lateral positioning of unopposed vehicles from the edge line is 0.15m for semi-trailers and 0.11m for B-doubles as shown in Table 2-2. Lateral positioning of opposed vehicles from the edge line is -0.45m for semi-trailers and -0.35m for B-doubles. From the literature review on heavy vehicles it was identified that the number of B-doubles used for transportation of freight is predicted to increase. Therefore the figure adopted for comparison of designs will be vehicular loading of B-doubles located at 0.100m from the edge line.

The condition of opposed vehicle travel with vehicle travel beyond the edge line and into the shoulder, as indicated by results of opposed traffic conditions, will not be examined. This condition will not be examined as it is becoming increasingly common for new rigid pavements to be designed with separation of carriage ways with divided carriageways, widened and raised medians. The separation between opposing lanes of traffic minimises impact between opposing vehicles and hence traffic conditions will be assumed as unopposed vehicle travel.

Traffic load distribution will therefore be analysed under two conditions, traffic load located in the centre of travel lane (a distance of 600mm from the edge line) and traffic load located with the outermost wheel 100mm from the edge line. Pavements will be analysed in EverFE under these two conditions and stress results will be compared between the two load locations.

6.2 Future Traffic Conditions (Heavy Vehicle Loading)

As stated previously in the literature review, pavement designers will find it increasingly difficult to estimate the vehicle loading conditions for rigid pavements over the design life of thirty to forty years. This difficulty arises from pressure on governments to increase vehicle axle load limits on heavy vehicles and the potential for changes to heavy vehicle laws and regulations. Trends indicate an increased utilisation of larger articulated vehicles such as B-doubles and road trains to be used for road freight transport due to improved efficiency per vehicle kilometre travelled. Forecasts from the report by Mitchell (2010) predict that B-double freight volumes will increase to over 50% of the total road freight task by the year 2030, assuming there are no significant changes in regulation.

The report by the ARRB in 2001 identified trends in heavy vehicle transportation. Identified trends indicate a projection for axle mass increases for articulated trucks by approximately 1% and gross vehicle mass increasing by 2% per annum, which equates to an increased loading capacity of 0.4 tonne per annum. Trends for B-doubles predict increases to axle loading and gross vehicle mass by up to 3% (approximately 1.0 tonne) per annum. Current axle mass limits and gross mass limits (GML) for B-doubles are provided in Table 6-1 sourced from the National Heavy Vehicle Regulator mass and dimension limits publication (2014). It should be noted that all heavy vehicle GML are inclusive of a 6.0t single steer axle.

Table 6-1 - B-double mass limits

(Sourced from National Heavy Vehicle Regulator – Mass and Dimension Limits 2014)

Vehicle Type	GML	Tandem Axle Mass Limit	Triaxle Mass Limit	Axle Groupings
7 Axle B-double	50.0 t	16.5 t	N/A	3 x Tandem axles
8 Axle B-double	59.0 t	16.5 t	20.0 t	2 x Tandem axles 1 x Triaxle
9 Axle B-double	62.5 t	16.5 t	20.0 t	1 x Tandem Axle 2x Triaxle

Studies undertaken by Mitchell (2010) and the Australian Department of Infrastructure and Transport (2011) focused on heavy vehicle productivity trends and forecasts up to the year 2030. In these studies the forecast trends that were observed were based on the condition that there would be no changes to heavy vehicle rules and regulations. Therefore in reflection of assumptions made by these studies for determination of future heavy vehicle loading parameters, it is assumed there will be no significant changes to current laws and regulations on heavy vehicles for the purpose of this project.

If historical trends in axle mass increases for heavy vehicles are sustained into the future, the following loading conditions should be expected for axle configurations of current and future loading conditions, shown in Table 6-2 in tonnage and Table 6-3 in Kilo-Newtons (kN). In order to import axle loading into EverFE for analysis axle loading must be provided in kN.

Conversion from Tonnes (Kg x 10^3) to kN (N x 10^3) = Tonnes x 9.81m/s^2 (gravitational constant).

Table 6-2 – Current and Future Loading Conditions (Tonnes)

Axle Configuration	Current Limit (2015) in Tonnes	Future Limit (2015) in Tonnes
SAST	6.0	16.88
SADT	9.0	25.32
TAST	11.0	30.95
TADT	16.5	46.43
TRDT	20.0	56.27
QADT	24.0	67.53

Table 6-3 – Current and Future Loading Conditions (kN)

Axle Configuration	Current Limit (2015) in kN	Future Limit (2015) in kN
SAST	58.86	165.62
SADT	88.29	248.44
TAST	107.91	303.64
TADT	161.86	455.47
TRDT	196.2	552.08
QADT	235.44	662.50

EverFE provides input for vehicle loading of single wheel axles, dual wheel axles, single wheel tandem axles and dual wheel tandem axles. It will be possible to model the singular axles and the tandem axles using the current software inputs with axle load input varied, however EverFE does not provide input for TRDT and QADT axle configurations.

For the modelling of TRDT input a superposition will be required between the dual wheel single axle and the dual wheel tandem axle to replicate a TRDT load. The spacing between axles varies with typical Triaxle configurations shown in Figure 6-1with spacing varying from 1250mm to 1500mm. Figure 6-2 shows that from a spacing of 1300mm to 1600mm the variance in maximum tensile forces developed in the pavement is minimal to within 0.25MPa for TAST and TADT. Stress values were lowest for the Triaxle Dual Tyre (TRDT) from 1500mm to 1600mm. Therefore for input into EverFE axle spacing for multi-axle groupings (Tandem and Triaxle) will be taken as 1500mm corresponding to the typical axle spacing provided for Triaxle Dual Tyres (TRDT) and representing lower tensile stress values as shown in the results by Darestani et al. in 2006.

In accordance with heavy vehicle regulations and load limits, load will be distributed equally between all axles in a given axle group. Personal communication from Tao, S on the 19th August 2015 stated that heavy vehicle mass distribution systems incorporate suspension systems built to divide the load between tyres and axle groups so that there is a variance of less than 10% in mass between the axle groups and tyres.

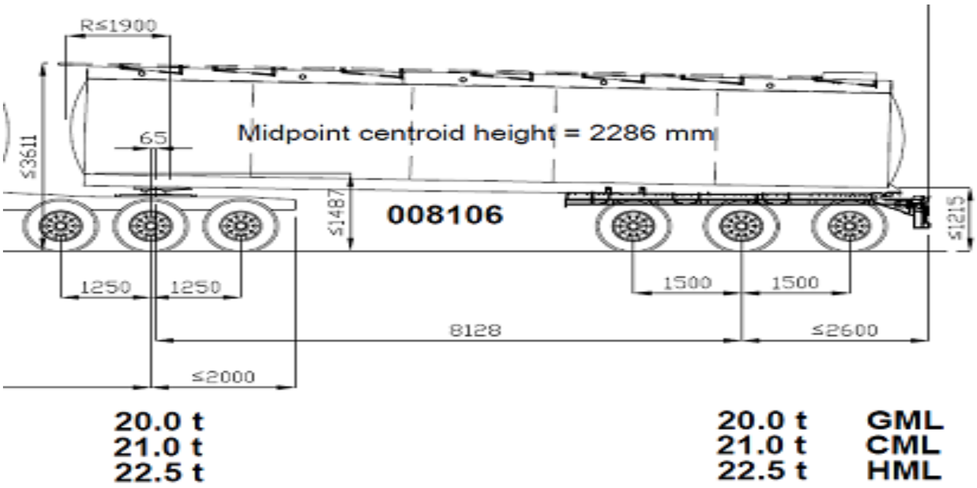


Figure 6-1 - Typical Triaxle Configuration

(Sourced from Tao, S 2015, pers. Comm., 19 August)

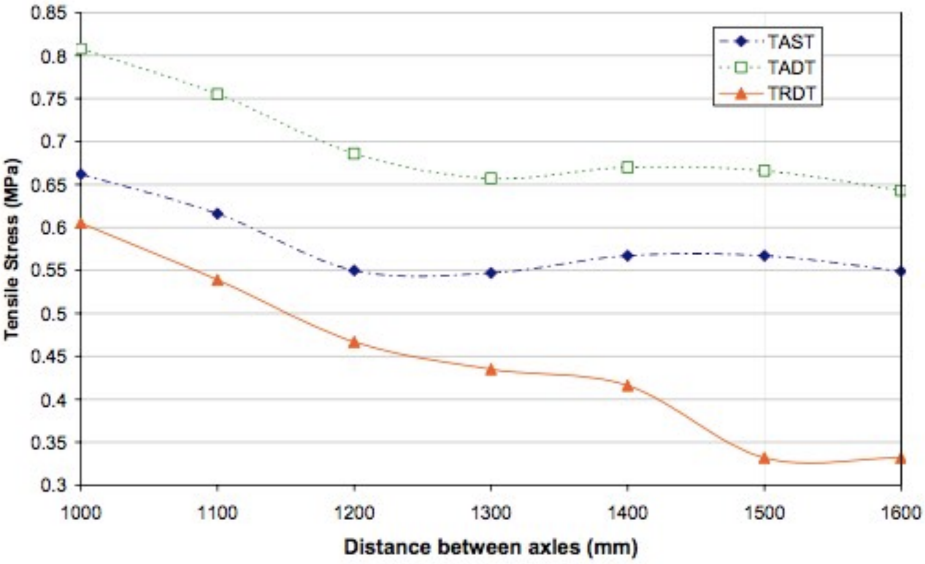


Figure 6-2 - Effect of Axle Spacing on Tensile Stress

(Sourced from Darestani et al. (2006) p. 12)

In summary, for analysis of vehicular axle configurations and loadings on rigid pavement configurations, loads will be imported into EverFE in accordance with the values presented in Table 6-3. Analysis of TRDT and QADT configurations requires a superposition of single axles and tandem axels to produce the desired configuration, with axle spacing specified as 1500mm.

7. Austroads Pavement Thickness Design

The following pavement thickness design has been developed in accordance with the Austroads Design Guide (2012) for rigid pavements. This design procedure follows the step-by-step sequence detailed in Table 9.3 of the design guide (shown previously in Figure 2-2). Pavement thickness design will then be determined using the RMS rigid pavement design spreadsheet that uses parameters that have been calculated in steps 1 to 7, combined with provided TLD data, to develop a pavement thickness that will be adopted in this project for calculations of equivalent stresses using Austroads equations and EverFE software that will then be compared.

Austroads Design Procedure:

1). Select a rigid pavement type, either jointed dowelled or continuously reinforced concrete base (Clause 9.2.1)

Austroads stipulates that there are two main categories for PCP to be used in Australian conditions, which are:

- 4.2m long slabs with undowelled skewed joints
- 4.5m long slabs with dowelled square joints

Although slab lengths and widths are not considered as an input parameter in the Austroads thickness design model it is stated that designers should be aware of this as the dimensions influence fatigue life and the figures stated should be taken as upper limits. In this project dowelled pavements will be analysed and hence slab lengths of 4.5m will be used for pavement modelling.

2). Decide whether tied or integrally-cast shoulders are to be provided (Clause 9.3.5)

Design will incorporate the provision of integrally cast shoulders. With reference to RMS standard drawing MD.R83.CJ for JRCP (RMS, 2015) concrete shoulders are tied in with the pavement and integrally cast with the base pavement. From the RMS standard drawings shoulder design widths will be adopted at 2.5m.

3). Using the subgrade design CBR and the predicted number of heavy vehicle axle groups over the design period, determine the subbase thickness and type from Table 9.1. Refer to subgrade design CBR limit in Section 5. (Clause 9.2.2)

Design CBR is taken to be the in field CBR in which the pavement is to be constructed. This value is typically determined by geotechnical investigations for the proposed construction site; however for the purpose of this study a common value will be selected. For design the CBR value will be taken as 3.5 in accordance with values used by Darestani et al. (2006). The design traffic and number of HVAGs over the design period is assumed to be greater than $1x10^7$ HVAGs. From Table 9.1 in the Austroads Design Guide, minimum subbase requirements are given to be 150mm LCS.

4). Using the subgrade design CBR and selected subbase, determine the Effective Subgrade Strength (CBR) from Figure 9.1. (Clause 9.3.1 and 9.3.2)

With design subgrade strength of 3.5 CBR and subbase of 150mm LCS, Figure 9.1 from the Design Guide provides an Effective Subgrade Strength CBR value of just below 50 (approximately 49 CBR).

5). Select the 28-day characteristic flexural strength of the concrete base f_{cf} (Clause 6.6.3 and 9.3.3)

Clause 6.6.3 specifies 28-day characteristic flexural strength between 4.0 to 5.0MPa. Clause 9.3.3 states that for design traffic greater than $1x10^6$ the minimum strength is 4.5MPa. For pavement thickness design flexural strength will be adopted at 4.5MPa.

6). Select the desired project reliability and hence the load safety factor. (Clause 2.2.1 and 9.3.6)

Project reliability for a Freeway road class is specified to be between 95-97.5% (Austroads Table 2.1). Table 9.2 of the design guide specifies values of load safety factors for dowelled and CRCP between 1.20 and 1.25 for 95% and 97.5% project reliability respectively. In 2013 The Department of Transport and Main Roads in Queensland released a supplement to the Austroads Design Guide (2012). Table Q2.12 of this report provides typical project reliability values used for different roads categories. For freeways and motorways the reliability factor provided is 95%.

The project reliability factor to be adopted in this design is 95%, representing a load safety factor of 1.20.

7). Select a trial base thickness (appropriate trial base thickness may be governed by minimum base thickness from Table 9.7 or estimated from experience). (Clause 9.4.2)

Table 9.7 provides minimum base thickness for pavements with 180mm for HVAGs between $1x10^7$ and $5x10^7$ and a thickness of 230mm for HVAGs greater than $5x10^7$. For the purpose of design, traffic volume will be selected in the highest volume condition with HVAGs greater than $5x10^7$ (taken as $5.1 x10^7$ for pavement design).

8). Calculate the expected load repetitions of each axle group load of each axle group type

The expected load repetitions for each axle group load and each axle group type have been provided by the RMS pavement technology branch based out of Parramatta in NSW. This data was collected in 2011 using Weigh-In-Motion (WIM) data collection stations on various roads across the state to obtain traffic data in a format that could be used directly in the Austroads pavement design procedure. For the purposes of this study traffic data will be examined for two roads in Sydney, NSW. The first is for Pennant Hills Road in North Parramatta and the second is for the eastbound lanes of the M2 Motorway in North Epping, Sydney. The TLD data that has been used can be found in Appendix B.

The following steps of the procedure, steps 9 through to 18 will be completed using the RMS Rigid Pavement Thickness Spreadsheet. The RMS pavement technology branch based out of Parramatta, NSW has provided the pavement thickness design spreadsheet (based on the Austroads Design Guide) to be used with provided TLD data. This data provides a breakdown of axle group loads, axle group types and the group proportions across a selection of roads throughout Sydney and surrounding areas as well as various locations throughout regional NSW. The data provided through this spreadsheet can be used by the Rigid Pavement design spreadsheet to develop a pavement thickness using input parameters identified in steps 1 through to 7. From the selected pavement thickness, erosion and fatigue damage percentages are provided and the thickness can then be altered to satisfy the required damage criteria of erosion and fatigue damage both less than 100%. The procedure for determining erosion and fatigue damage is explained in Steps 9 to 18 of Table 9.3 of the design guide. These steps of the guide are identified below.

9). From the project TLD obtain the highest axle load for the SAST axle group and determine the allowable repetitions in terms of fatigue from Equation 26 and Equation 27.

To determine the allowable axle load repetitions equations 26 and 27 from the Austroads Design Guide are used, shown below. These equations form the basis of the RMS rigid pavement design spreadsheet.

Equation 26: $\log(N_f) = \left[0.9719 - {S_r}/{0.0828}\right]$ when $S_r > 0.55$

Equation 27: $N_f = \left[{4.258}/{S_r - 0.4325}\right]^{3.268}$ when $0.45 \leq S_r \geq 0.55$

Where: $S_r = {S_e}/{0.944\, f_{cf}} \times \left[{PL_{SF}}/{4.45\, F_1}\right]^{0.94}$

S_e = equivalent concrete stress (MPa)

f_{cf} = design characteristic flexural strength at 28 days (MPa)

P = axle group load (kN)

L_{SF} = load safety factor

F_1 = load adjustment factor for fatigue due to axle group (9 for SAST, 18 for SADT and TAST, 36 for TADT, 54 for TRDT, 72 for QADT)

S_e is calculated using Equation 28 of the design guide

Equation 28: $S_e = a + \frac{b}{D} + c.\ln(E_f) + \frac{d}{D^2} + e.[\ln(E_f)]^2 + f.\ln\frac{E_f}{D} + \frac{g}{D^3} + h.[\ln(E_f)]^3 + i.\frac{[\ln(E_f)]^2}{D} + j.\ln(E_f)/D^2$

(Note a, b, c, d, e, f, g, h, j are coefficients that can be found in Tables 9.4 to 9.6 of the Austroads Design Guide)

D = thickness of concrete base (mm)

E_f = effective subgrade design CBR (%)

10). Calculate the ratio of the expected fatigue repetitions (step 8) to the allowable repetitions (step 9). Multiply by 100 to determine a percentage for fatigue.

11). Determine from Equation 29 the allowable number of repetitions for erosion for the highest axle load for the SAST axle group.

To determine the allowable repetitions for erosion distress equation 29 from the Austroads Guide is used.

Equation 29: $\log(F_2N_e) = 14.524 - 6.777\left[\max\left(0,\ \left({}^{PL_{SF}}/_{4.45F_4}\right)^2 \times {}^{10^{F_3}}/_{41.35} - 9.0\right)\right]^{0.103}$

F_2 = adjustments for slab edge effects (0.06 for no shoulder, 0.94 with concrete shoulder)

F_3 = erosion factor (same formula as equation 28)

F_4 = load adjustment factor for fatigue due to axle group (9 for SAST, 18 for SADT and TAST, 36 for TADT, 54 for TRDT and QADT)

12). Calculate the ratio of expected erosion repetitions (step 8) to the allowable repetitions in step 11. Multiply by 100 to determine the percentage erosion damage.

13). Repeat steps 9 through to 12 for each axle group load up to a level where the allowable load repetitions exceed 10^{11}, at which point any further loads are not deemed to contribute to pavement stress.

14). Sum the percentage fatigue for all relevant loads of this axle group type; similarly sum the percentage for erosion for all relevant loads of this axle group.

15). Repeat steps 9 through 14 for all axle group types.

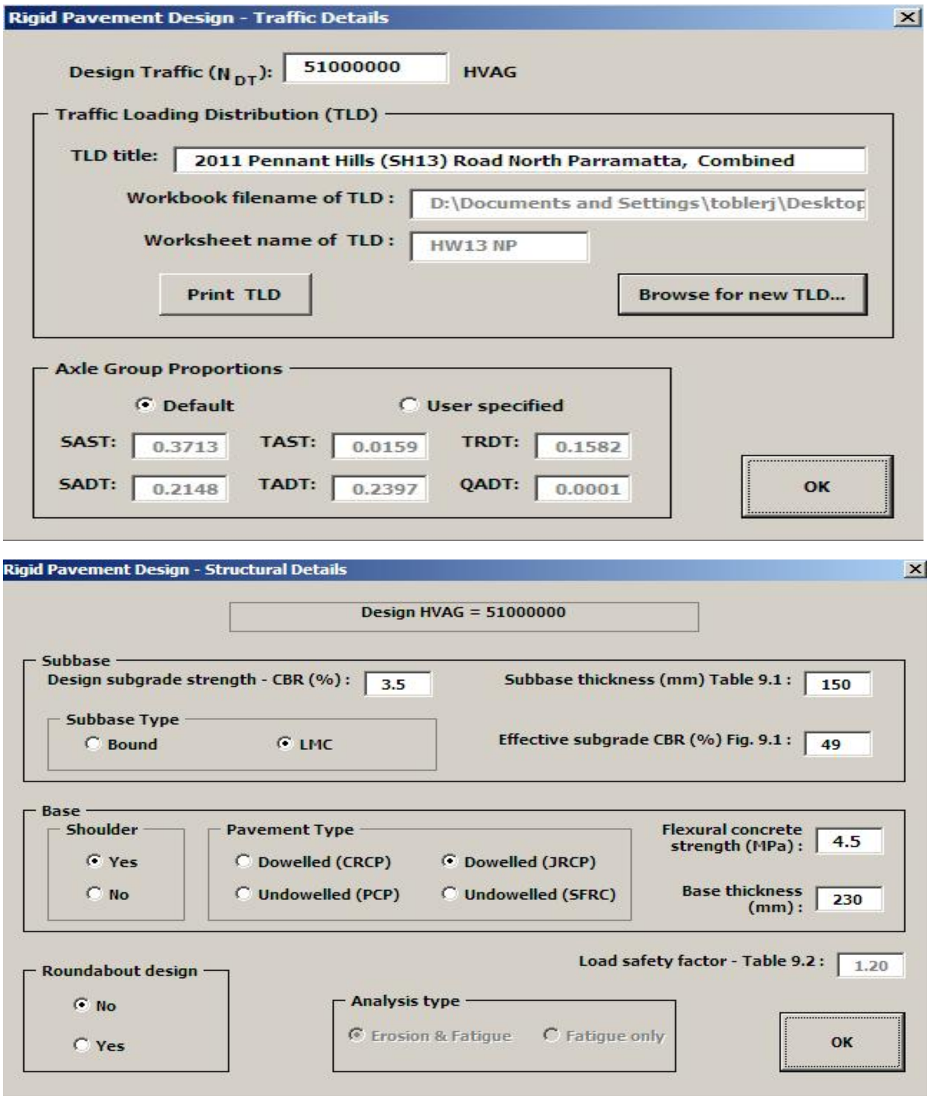
16). Sum the total fatigue and total erosion damage for all axle group types.

17). Steps 9 through 16 inclusive are repeated until a base thickness is achieved that has a total fatigue less than 100% and a total erosion damage less than 100%. This value is taken as the design base thickness.

18). From Table 9.7 of the Austroads design guide, determine the minimum required base thickness.

19). Select a base thickness that satisfies the required thickness, minimum thickness and additional thickness tolerances (asphalt milling, diamond grinding).

The following design has been developed using the RMS pavement design spreadsheet to develop a pavement thickness using TLD data from Pennant Hills Road in North Parramatta. Figure 7-1 provides screenshots of the user interface of the design spreadsheet with input variables inserted for pavement thickness calculation.



Rigid Pavement Design - Traffic Details

Design Traffic (N_{DT}): 51000000 HVAG

Traffic Loading Distribution (TLD)

TLD title: 2011 Pennant Hills (SH13) Road North Parramatta, Combined

Workbook filename of TLD : D:\Documents and Settings\toblerj\Desktop

Worksheet name of TLD : HW13 NP

Axle Group Proportions

● Default ○ User specified

SAST: 0.3713 TAST: 0.0159 TRDT: 0.1582

SADT: 0.2148 TADT: 0.2397 QADT: 0.0001

Rigid Pavement Design - Structural Details

Design HVAG = 51000000

Subbase

Design subgrade strength - CBR (%) : 3.5

Subbase thickness (mm) Table 9.1 : 150

Subbase Type: ○ Bound ● LMC

Effective subgrade CBR (%) Fig. 9.1 : 49

Base

Shoulder: ● Yes ○ No

Pavement Type: ○ Dowelled (CRCP) ● Dowelled (JRCP) ○ Undowelled (PCP) ○ Undowelled (SFRC)

Flexural concrete strength (MPa) : 4.5

Base thickness (mm) : 230

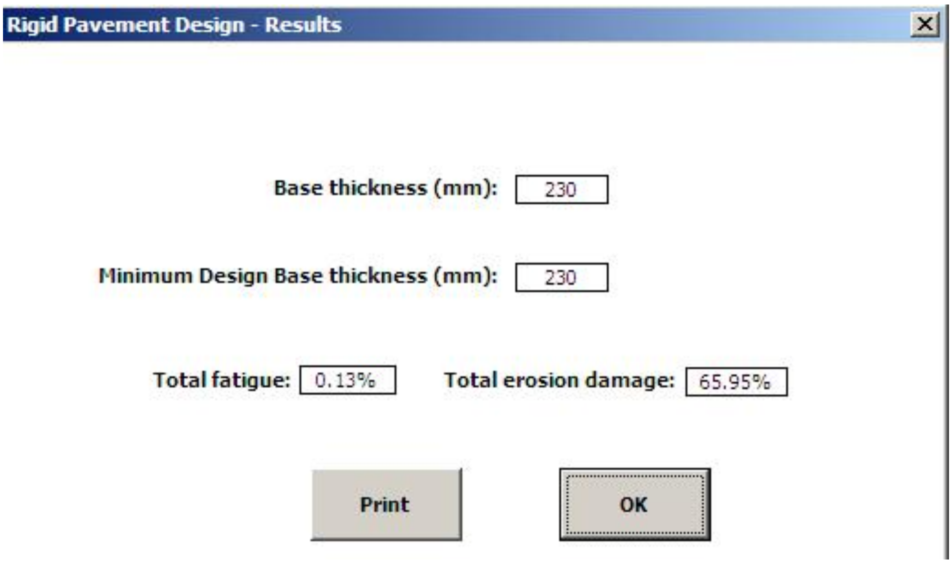
Load safety factor - Table 9.2 : 1.20

Roundabout design: ● No ○ Yes

Analysis type: ● Erosion & Fatigue ○ Fatigue only

Figure 7-1- RMS Pavement Design Spreadsheet User Interface

With the input variables defined as per the Austroads design procedure, the following results were calculated, shown below in Figure 7-2. Due to the traffic volume the minimum pavement thickness available for use is 230mm that provides erosion and fatigue damages both below 100%.



Base thickness (mm): 230

Minimum Design Base thickness (mm): 230

Total fatigue: 0.13%

Total erosion damage: 65.95%

Figure 7-2 - Pavement Thickness Results (Pennant Hills Road)

The procedure has been repeated using TLD data for the eastbound lanes of the M2 motorway in North Epping, Sydney for a comparison of different pavement loading conditions. With a minimum pavement thickness of 230mm, erosion damage was not satisfied as being below 100% (erosion of 163.39%). Further iterations resulted in a pavement thickness being selected at 240mm with an erosion damage of 99.59%. For analysis of pavements with the Austroads method and EverFE, base thickness will be adopted as 240mm (default value of 250mm). This factor will remain constant throughout analysis for comparison of equivalent stress values.

Calculations for the determination of equivalent stress values of EverFE have been performed using Microsoft Excel. With input parameters as specified through the design procedure described previously, equation 28 from the Austroads Design Guide was used to determine equivalent stress values. The formulation of these stress values takes into consideration specified constants (from Austroads Tables 9.4 to 9.6), subgrade effective strength (CBR of 49) and the pavement thickness that was determined previously (240mm as per the RMS rigid pavement design spreadsheet). The following values for equivalent stress were calculated, as shown in Table 7-1, with coefficients used for each axle group type and the corresponding equivalent stress.

Table 7-1 - Equivalent Stress (Se) Values from Austroads Design

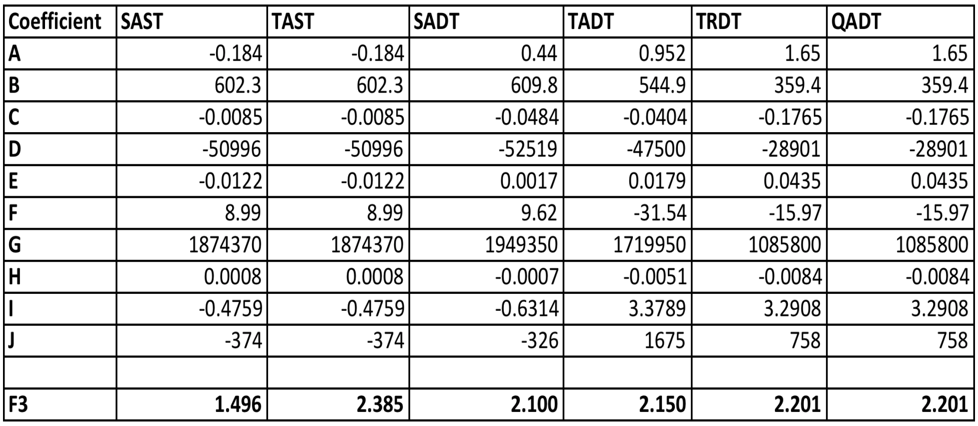
	Axle Group Type					
Coefficient	**SAST**	**TAST**	**SADT**	**TADT**	**TRDT**	**QADT**
A	-0.051	-0.051	0.33	0.088	-0.145	-0.145
B	26	26	206.5	301.5	258.6	258.6
C	0.0899	0.0899	-0.4684	-0.1846	0.008	0.008
D	35774	35774	28661	4418	1408	1408
E	-0.0376	-0.0376	0.165	0.0939	0.0312	0.0312
F	14.57	14.57	2.82	-59.93	-61.25	-61.25
G	-861548	-861548	-686510	280297	488079	488079
H	0.0031	0.0031	-0.0186	-0.0128	-0.0058	-0.0058
I	1.3098	1.3098	-1.9606	4.1791	4.7428	4.7428
J	-4009	-4009	-2717	1768	2564	2564
Se	**0.627**	**0.627**	**0.957**	**0.802**	**0.633**	**0.633**

From these coefficients and the resulting equivalent stress the Austroads design procedure identified previously will be followed to determine allowable axle load repetitions for each axle group category for analysis in fatigue. This is required to determine the accuracy of the coefficients used and will be compared with results obtained from the RMS rigid pavement design spreadsheet to verify validity of results. Table 7-2 shows the allowable repetitions calculated for current loading conditions for each axle type using fatigue analysis. The stress ratio factor is also calculated for each axle group using equation 27 from the Austroads design guide.

Table 7-2 - Allowable repetitions for current axle loads (Fatigue Analysis - Austroads Method)

		SAST	**TAST**	**SADT**	**TADT**	**TRDT**	**QADT**
Current Load	**Sr**	0.252	0.232	0.293	0.226	0.146	0.132
Allowable Repetitions (N_f)		Infinite	Infinite	Infinite	Infinite	Infinite	Infinite

Table 7-3 - Erosion Factor (F3) using Austroads Guide



Coefficient	SAST	TAST	SADT	TADT	TRDT	QADT
A	-0.184	-0.184	0.44	0.952	1.65	1.65
B	602.3	602.3	609.8	544.9	359.4	359.4
C	-0.0085	-0.0085	-0.0484	-0.0404	-0.1765	-0.1765
D	-50996	-50996	-52519	-47500	-28901	-28901
E	-0.0122	-0.0122	0.0017	0.0179	0.0435	0.0435
F	8.99	8.99	9.62	-31.54	-15.97	-15.97
G	1874370	1874370	1949350	1719950	1085800	1085800
H	0.0008	0.0008	-0.0007	-0.0051	-0.0084	-0.0084
I	-0.4759	-0.4759	-0.6314	3.3789	3.2908	3.2908
J	-374	-374	-326	1675	758	758
F3	**1.496**	**2.385**	**2.100**	**2.150**	**2.201**	**2.201**

Values for erosion factor were calculated, as shown in Table 7-3, with coefficients used for each axle group type and the corresponding erosion factor. Table 7-4 shows the allowable repetitions calculated for current loading conditions of each axle type using erosion analysis.

Table 7-4 - Allowable repetitions for current axle loads (Erosion Analysis - Austroads method)

		SAST	TAST	SADT	TADT	TRDT	QADT
Current Load	**Sr**	0.252	0.232	0.293	0.226	0.146	0.132
Allowable Repetitions (Nf)		Infinite	2.31E+06	Infinite	Infinite	Infinite	Infinite

With these values determined a comparison has been made to the values determined from RMS rigid pavement design guide. The values in Table 7-5 show allowable axle repetitions for each axle group class for both methods of pavement failure.

Table 7-5 - Comparison of RMS Design Spreadsheet to Austroads Spreadsheet

Current Load Conditions

Axle Group Type	**RMS Design Spreadsheet**		**Austroads Spreadsheet**	
	Fatigue	**Erosion**	**Fatigue**	**Erosion**
SAST	Unlimited	Unlimited	Unlimited	Unlimited
SADT	Unlimited	Unlimited	Unlimited	Unlimited
TAST	Unlimited	2.37E+06	Unlimited	2.31E+06
TADT	Unlimited	Unlimited	Unlimited	Unlimited
TRDT	Unlimited	Unlimited	Unlimited	Unlimited
QADT	Unlimited	Unlimited	Unlimited	Unlimited

From Table 7-5 it can be seen that allowable repetitions for each axle group were identical for both methods in fatigue analysis with allowable axle repetitions unlimited. Erosion analysis using the RMS design spreadsheet and the Austroads method were similar except for the TAST loading condition. The RMS design spreadsheet determined this value to be larger at 2.37 million allowable axle repetitions, and the result returned by the Austroads spreadsheet lower at 2.31 million allowable axle repetitions. The difference between the two methods is 60,000 allowable repetitions. This is deemed to be an appropriate variance between the two methods with a difference of approximately 2.5%.

8. Analysis using EverFE software

The current Austroads Design Guide for rigid pavements appears adequate for pavement design to current conditions, however continued extrapolation may not be possible for traffic conditions into the future. This study will consider the potential for incorporation of advanced analytical methods in the form of FE software, EverFE, to be used in conjunction with the Austroads Design Guide to aid pavement design. Analysis has been undertaken to determine if EverFE provides adequate capability in modelling pavement stress for pavements subjected to conditions that cannot be modelled using the Austroads Design Guide. The following conditions have been analysed:

- Current vehicle loading conditions for each axle group
- Predicted future loading conditions for each axle group
- Relocation of traffic load to location 100mm from the edge line

In addition to these analyses, a sensitivity analysis has been performed to determine the impact of inclusion of temperature gradients on rigid pavement response and induced stress.

EverFE software requires input parameters for analysis that are included in the following input tabs:

- Pavement geometry: This includes slab layout consisting of number of columns and rows to be used in design (minimum of a single slab up to a maximum of three-by-three slabs), slab widths and lengths, pavement thickness, and skew angle for joints.

- Input is also provided for base and subgrade layers with a maximum of three layers capable of being imported and their thickness specified.
- Material properties: These properties include modulus of elasticity and Poisson's ratio for base slab, dowels, ties and subbase. Density of the concrete slab is included and is especially significant when analysing slab curling as this provides a loading factor for self-weight of the slab. Interface between slab and base can also be changed to either bonded or unbonded condition that is significant whilst temperature gradients are being considered. Input for coefficient of thermal expansion is also included. Option is also available in this tab to specify a dense liquid subgrade providing tensionless support.
- Loading: Axle loadings can be imported as single wheels, SAST, SADT, TAST, TADT and a multi-wheel axle that can be configured to include as many tyres as necessary. Axle properties can also be altered with input for axle loading, axle length, axle spacing, tyre width and distance between wheels. Axle loads can then be shifted throughout the pavement geometry to desired locations. It is important to note that if axle loads are not completely on a slab the accuracy of results are diminished.

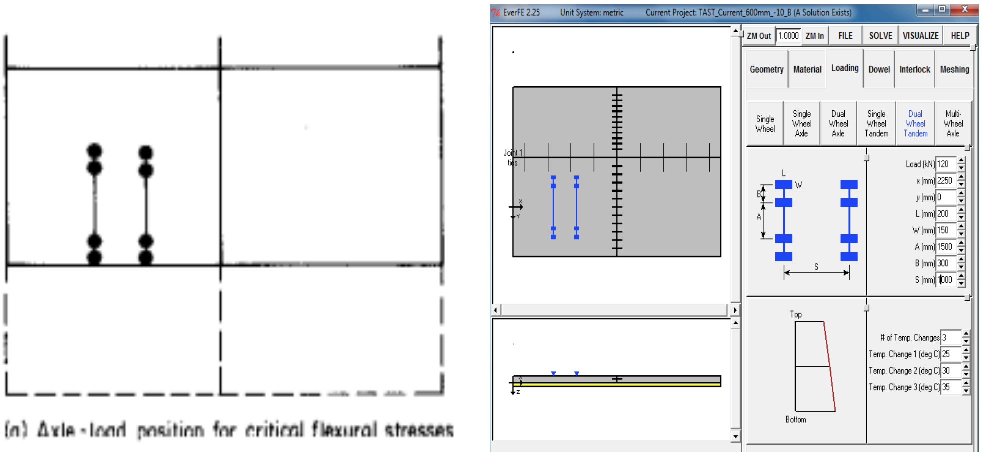
- Temperature differentials are also included in the loading tab with up to three changes allowed across the pavement depth allowing for linear, bilinear and trilinear temperature gradients to be considered. It should be noted that for bilinear temperature gradients FE meshing must be increasing by intervals of two (2, 4, 6, etc.) and for trilinear gradients meshing must be increasing by intervals of three (3, 6, 9, etc.).
- Dowel: The dowel tab allows for dowel and tie inputs to be modified. This includes embedment length, dowel diameter, number of dowels and ties and spacing between them.
- Interlock: Aggregate interlock tab allows for interlock behaviour between transverse joints to be specified. This input can be either linear or non-linear.
- Meshing: This tab allows for finite element meshing to be altered depending on computation capabilities. The number of elements can be increased for columns and rows and increased throughout the depth of the slab also. Increasing the number of finite elements increases the accuracy of results, although increases processing time. This input should be selected on the accuracy of results required and the processing power of the machine performing analysis.

Pavement analysis using EverFE utilised the following input parameters that are reflective of previous studies by Darestani et al. (2006) and Darestani et al. (2008). These input parameters are also reflective of values used in the Austroads spreadsheet and the RMS rigid pavement design spreadsheet:

- Pavement geometry: 2x2 pavement slab (one travel lane and shoulder)
    - Slab length (length between transverse joints) – 4500mm (Austroads 2012)
    - Slab width (distance between longitudinal joints) – 3500mm (RMS standard drawing MD.R83.CJ for JRCP) for two travel lanes and 2500mm for shoulder
    - Slab thickness – 240mm (As per value adopted from RMS rigid pavement design spreadsheet)
    - Base/subgrade – One layer of 150mm thickness
    - Skew angles – Zero degrees
- Material Properties:
    - Modulus of elasticity (slab) – 28000 MPa
    - Poisson's ratio (slab) – 0.2
    - Subbase depth – 150mm
    - Coefficient of Thermal Expansion – $1x10^{-5}$ mm/mm/°C
    - Concrete density – 2400 kg/m3
    - Modulus of elasticity (subbase) – 5000 MPa

  - Poisson’s ration (subbase) – 0.2
  - Subgrade modulus of reaction – 0.03 MPa/mm (CBR approximately 3.5)
- Dowels and ties:
  - Dowels – Eleven evenly spaced cylindrical dowels of 32mm diameter, 450mm length, embedment length 225mm and 1000 MPa dowel-slab modulus support
  - Ties – Tie bars of 13mm diameter, 1000mm length and 1000mm spacing centre to centre have been considered.

The condition of bonded or unbonded boundary condition between base and subbase is not specifically stated in the literature and is to be selected based on worst case temperature differential of the site in which the pavement is to be constructed. The study by Darestani et al. in 2006 found that benefits offered by unbonded boundary conditions cease at a certain value of temperature differential. Therefore both bonded and unbonded conditions were examined in this study to determine impact on rigid pavement response and induced stresses. For the unbonded condition it has been assumed that a frictionless interface exists with no shear transfer between base and subbase. This corresponds to the default values of zero for both initial stiffness and slip displacement. A tensionless subgrade condition was also assumed as per the studies by Darestani et al. 2006. Figure 8-1 below shows the comparison between slab layouts with a tandem axle loading for the PCA method and replication in EverFE.


(a) Axle-load position for critical flexural stresses

EverFE 2.25 Unit System: metric Current Project: TAST_Current_600mm_-10_B (A Solution Exists)

Load (kN) 120
x (mm) 2250
y (mm) 0
L (mm) 200
W (mm) 150
A (mm) 1500
B (mm) 300
S (mm) 1000

# of Temp. Changes 3
Temp. Change 1 (deg C) 25
Temp. Change 2 (deg C) 30
Temp. Change 3 (deg C) 35

Figure 8-1 - Slab layout and axle load (PCA and EverFE)

8.1 Current Loading Conditions

EverFE has been used to model the response of a rigid pavement configuration to the current allowable loading conditions for the axle configurations specified. The axles were imported into EverFE using the load parameters as specified in Section 6 (Table 6-3). Axle loading was positioned in the centre of the loaded slab, 600mm from the edge line. The following results, shown in Table 8-1 were obtained for equivalent stresses in the pavement. A typical stress visualisation exported from EverFE is shown in Figure 8-2 for the results of TADT. A colour map is used by EverFE to indicate stress variations across the entire pavement.

Table 8-1 – Equivalent Stresses from Austroads vs. EverFE results for Current Load

	Equivalent Stress (Se) in MPa		
	Austroads	EverFE (Bonded)	EverFE (Unbonded)
SAST	0.627	0.521	0.904
TAST	0.627	0.448	0.759
SADT	0.957	0.705	1.230
TADT	0.802	0.603	1.036
TRDT	0.633	0.363	0.644
QADT	0.633	0.437	0.765

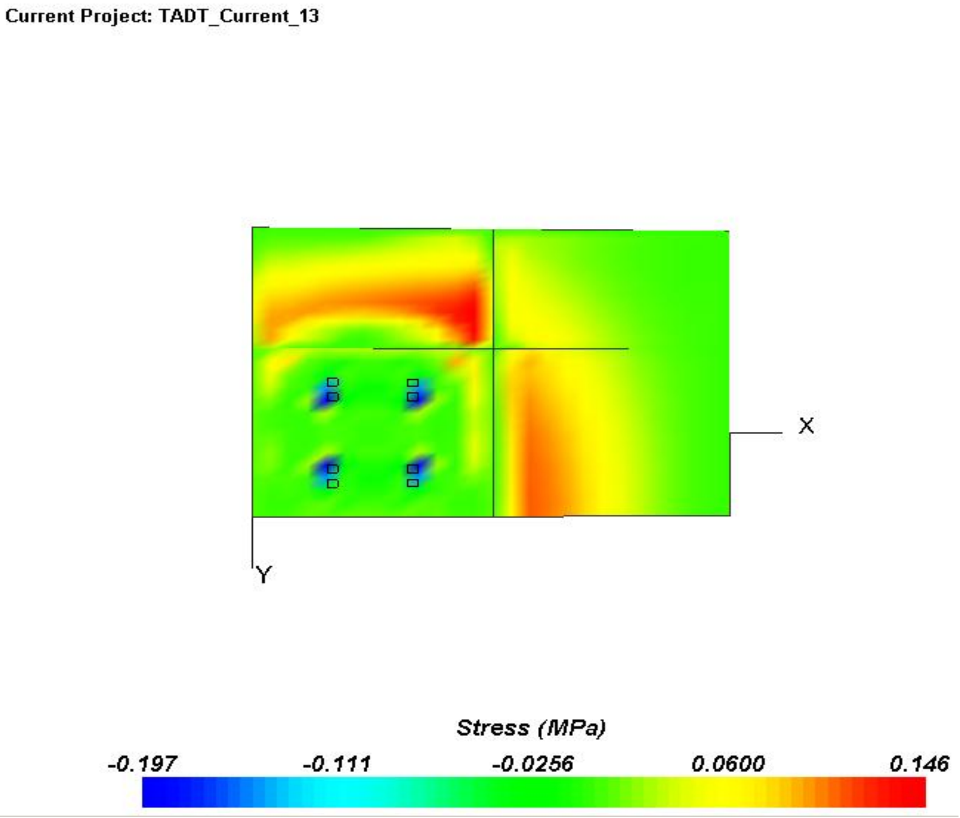


Figure 8-2 - EverFE stress visualisation (Current Load)

Figure 8-3 provides a graphical representation of the difference in equivalent stress values from Austroads versus those values obtained in EverFE, for both bonded and unbonded boundary conditions. Significance of bonded versus unbonded boundary conditions is of significant importance particularly during modelling with temperature gradients. From observation of Figure 8-3 it can be seen that the general trend of results is similar in all cases, however values from EverFE are different to the Austroads method.

This variance is to be expected due to the differences in stress formulations and methods incorporated within the analytical methods of EverFE. It can be seen that an unbonded boundary condition results in higher equivalent stress in the pavement and bonded condition produces stresses lower than the Austroads equivalent stress. As Austroads makes the assumption of an unbonded boundary condition between base and subbase, focus has been directed towards the EverFE results for an unbonded boundary condition as this removes one of the variables between the two methods. Unbonded boundary condition stress differentials vary from as little as 1.72% for TRDT to a maximum of 30.68% for SAST results as shown in Table 8-2.

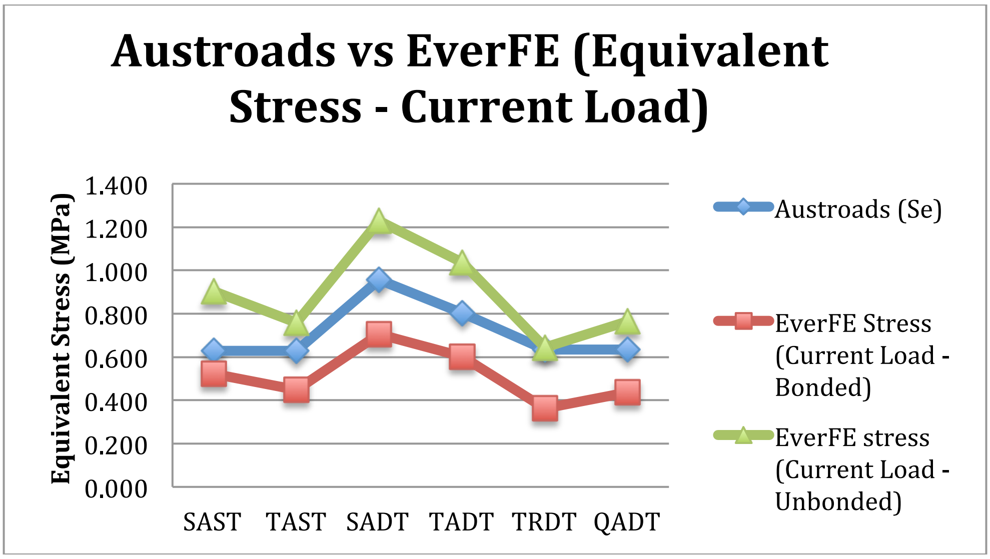


Figure 8-3 - Austroads vs. EverFE (Equivalent Stress for Current Load)

Results shown previously are using a finite element mesh structure of 12 elements. These presented a mean stress value of 0.890 with a standard deviation of 0.215. This value was deemed to be too large with the standard deviation of the Austroads equivalent stress at 0.138. To determine the significance of meshing on results and to refine the results from EverFE to achieve a lower standard deviation, finite element meshing was increased. It was found that meshing of 13 elements presented results closer to the stress results of Austroads. Using 13 mesh elements a mean stress from EverFE was determined to be 0.803 with a resulting standard deviation of 0.143. This value of standard deviation is deemed to be appropriate for results as shown in Table 8-2 with Figure 8-4 providing a graphical overview of these results.

Table 8-2 - Comparison of results for 13 mesh elements (Austroads vs. EverFE)

Axle Group	Austroads (MPa)	EverFE (UB) (MPa)	% Difference	Mesh (13) (MPa)	% Difference
SAST	0.627	0.904	30.68	0.744	15.73
TAST	0.627	0.759	17.40	0.695	9.78
SADT	0.957	1.230	22.18	1.021	6.27
TADT	0.802	1.036	22.60	0.941	14.77
TRDT	0.633	0.644	1.72	0.671	5.66
QADT	0.633	0.765	17.21	0.745	15.03
SD	***0.138***	***0.215***		***0.143***	

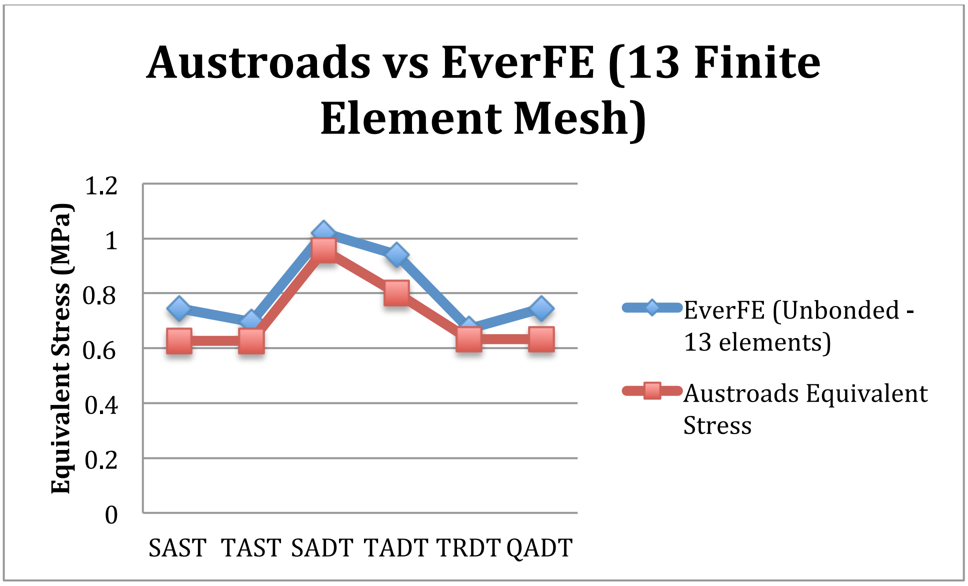


Figure 8-4 - Austroads vs. EverFE (13 element mesh)

The difference in standard deviation between Austroads and EverFE equivalent stresses is 0.005. This is deemed to be an appropriate level of variance between the two methods. To further ensure results, equivalent stress values exported from EverFE for current load will be imported into the Austroads design spreadsheet to determine influence on allowable axle repetitions.

Importing equivalent stress values from EverFE into Austroads deign spreadsheet results in allowable axle load repetitions for fatigue analysis remaining unchanged at infinite repetitions for the current base thickness. Under erosion analysis, allowable repetitions also remain unchanged as those values shown in Table 7-4. This indicates that the slight difference in stress values exported from EverFE do not influence allowable axle repetitions and the resulting pavement thickness.

From these results it has been concluded that EverFE provides adequate capability in modelling of Austroads equivalent stresses for current axle loading conditions. With EverFE capable of determining pavement stresses subjected to current axle loads, future-loading conditions can now be modelled with confidence the results will present an accurate output for equivalent stress values. This is of significance as the stress values exported from EverFE for equivalent stress may then be used by the existing formulations in Austroads to determine stress ratios. From the stress ratios existing Austroads formulas would then be able to determine allowable axle repetitions to determine pavement fatigue and erosion damage, and ultimately determine an optimum base thickness for the given loading conditions.

8.2 Future Loading Conditions

The Austroads formulation for equivalent stress (equation 28) has been shown in Section 7. In this formulation it can be seen that the equivalent stress formula takes into consideration base pavement thickness, effective strength of subgrade CBR and the coefficients provided from the Austroads design guide (shown in Table 7-1). The formulas used for determination of equivalent stress in the base do not take into consideration the design axle load of axle configurations, with axle loading only considered in the stress ratio equation (S_r).

Section 6.3 of the Technical Basis to the Austroads Design Guide (2008a) describes the theory behind maximum wheel loads. An upper limit of 65kN is used in the nomographs of the design guide. It is stated that there are no sighted references to justify the use of this limit and that the limit is sufficient for coverage of current Australian legal axle limits. The authors then go on to state that there is no literature, in Australia or international material covering the use of the thickness design for wheel loads in excess of 65kN. The wheel loads that have been predicted in Table 6-3 forecast loads in excess of this upper maximum load limit.

With this limit to the design guide identified, Austroads would be incapable of accurately modelling the pavement response of the forecast future loading condition due to limitations in the empirical charts the formulations are based upon. This is noted and hence results will be presented for future loading conditions modelled through EverFE, and the exported equivalent stress value will be used in the Austroads spreadsheet to determine allowable axle repetitions for fatigue and erosion analysis.

With confidence EverFE is capable of modelling pavements subject to current loading conditions, it is expected that with conditions and variables maintained as previous, EverFE will be capable of presenting a reasonable representation of the predicted equivalent stresses under future increased axle loading conditions.

EverFE has been used to model the response of a rigid pavement configuration to predicted future loading conditions for the axle configurations specified. The axles were imported into EverFE using the future load parameters as specified in Section 6 (Table 6-3). Axle loading was positioned in the centre of the loaded slab, 600mm from the edge line as per the previous modelling conditions. 13 elements were used for meshing in this investigation as used in the current loading study previously. The following results shown in Table 8-3 were obtained for equivalent stresses in the pavement. A graphical representation of results, along with equivalent stress results for current load limits of Austroads and EverFE are presented in Figure 8-5 for comparison of stress results between current and future conditions.

Table 8-3 - EverFE Equivalent Stress for Future Load

Axle Group Type	**EverFE (Future - UB) (MPa)**	**EverFE (Future - UB) 13 elements (MPa)**
SAST	2.497	2.059
TAST	2.139	1.952
SADT	3.509	2.891
TADT	2.958	2.654
TRDT	1.813	2.560
QADT	2.090	2.044
Mean	2.501	2.360
SD	0.632	0.391
Variance	0.400	0.153

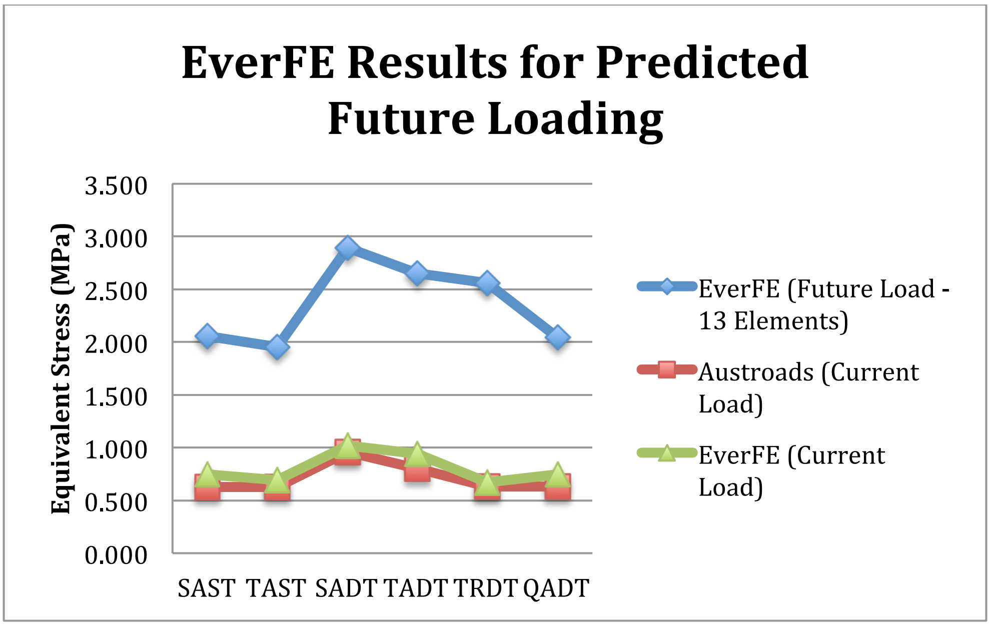


Figure 8-5 - EverFE equivalent stress for future load

As expected the equivalent stress for the future loading is much larger than the stresses induced for the current loading condition. Percentage increases in stress are shown in Table 8-4 for representation of the stress increase from current equivalent stress values of both the Austroads and EverFE methods.

Table 8-4 - Percentage increase in stress from current to future loading

% Increase from current loading conditions to Future loading	% Increase (Austroads stress)	% Increase (EverFE stress)
SAST	228.35	176.72
TAST	211.29	180.83
SADT	202.09	183.16
TADT	230.92	182.04
TRDT	304.48	281.58
QADT	222.86	174.32

With values for equivalent stress produced from EverFE, these values were imported into the Austroads design spreadsheet to observe what allowable axle load repetitions would be presented. The following results in Table 8-5 show the allowable axle repetitions for future loading using fatigue and erosion analysis.

Table 8-5 - Allowable axle repetitions for future load (Fatigue and Erosion)

Fatigue Analysis (Future Load from EverFE)							
Axle Group Type		**SAST**	**TAST**	**SADT**	**TADT**	**TRDT**	**QADT**
Current Load	**Se**	**2.059**	**1.952**	**2.891**	**2.654**	**2.560**	**2.044**
	Sr	2.185	1.909	2.341	1.980	1.248	1.131
Allowable Repetitions (Nf)		0.000	0.000	0.000	0.000	0.000	0.012

Erosion Analysis (Future Load from EverFE)							
Axle Group Type		**SAST**	**TAST**	**SADT**	**TADT**	**TRDT**	**QADT**
Current Load	**F3**	**1.496**	**1.496**	**2.100**	**2.150**	**2.201**	**2.201**
Allowable Repetitions (Nf)		1.00 E+06	2.09 E+06	6.91 E+04	8.21 E+04	2.11 E+05	6.99 E+04

From the results presented in Table 8-5 it can be seen that the pavement has failed in fatigue analysis with zero allowable axle repetitions for all axle group types with a pavement thickness of 240mm in EverFE. Erosion analysis of the pavement does not take into consideration the equivalent stress; however it does consider the increased axle group load. As there is not a formulation in the Austroads method to determine equivalent stress for future changes to vehicle axle loads, further iterations could not be performed quickly.

To determine a pavement thickness that could satisfy the future loading and present higher allowable repetitions in fatigue analysis, further iterations would be required with EverFE using different base thicknesses; exporting the equivalent stress back into the Austroads spreadsheet and determining allowable repetitions.

Results from this study have concluded that as expected, predicted increases to allowable axle loading will result in substantial increase to pavement equivalent stress; with Future loading conditions resulting in increases to pavement stress of 175 to 280 per cent. The Austroads design guide would be incapable of predicting these stresses in its current form, with limitations to the underlying formulations it is based on. A limitation of EverFE is that it only provides a stress analysis of the pavement and does not provide allowable repetitions of different axle loadings. There is potential to use the Austroads guide with the exported values from EverFE to determine the allowable repetitions and perform fatigue and erosion analysis.

8.3 Traffic Load Location

EverFE has been used to model the response of a rigid pavement configuration to both current allowable loading and predicted future loading conditions for the axle configurations specified. These loading conditions were modelled at two differing loading locations. The axles were imported into EverFE using the load parameters as specified in Section 6 (Table 6-3). The purpose of this test was to analyse the stress differential resulting from changes to vehicle positioning in the travel lane.

The two conditions tested were axle loading positioned in the centre of the loaded slab, a location 600mm from the edge line (Austroads condition), and axle loading positioned 100mm from the edge line of the pavement as per studies found from the literature. For each case pavements were modelled in the unbonded boundary condition due to the Austroads modelling constraint. The following results, shown in Table 8-6 were obtained for equivalent stresses in the pavement for each of the conditions tested using EverFE.

Figure 8-6 provides a visual presentation of the equivalent stress resulting from changed loading location, compared with Austroads and EverFE values for current loading.

Table 8-6 – Stress differential (Changed load location – Current load)

	Current Load – MPa (600mm from edge line)	**Current Load – MPa (100mm from edge line)**	**Stress Differential (MPa)**
SAST	0.744	0.860	0.116
SADT	0.695	1.121	0.426
TAST	1.021	0.776	-0.245
TADT	0.941	1.004	0.063
TRDT	0.671	0.707	0.036
QADT	0.745	0.730	-0.015

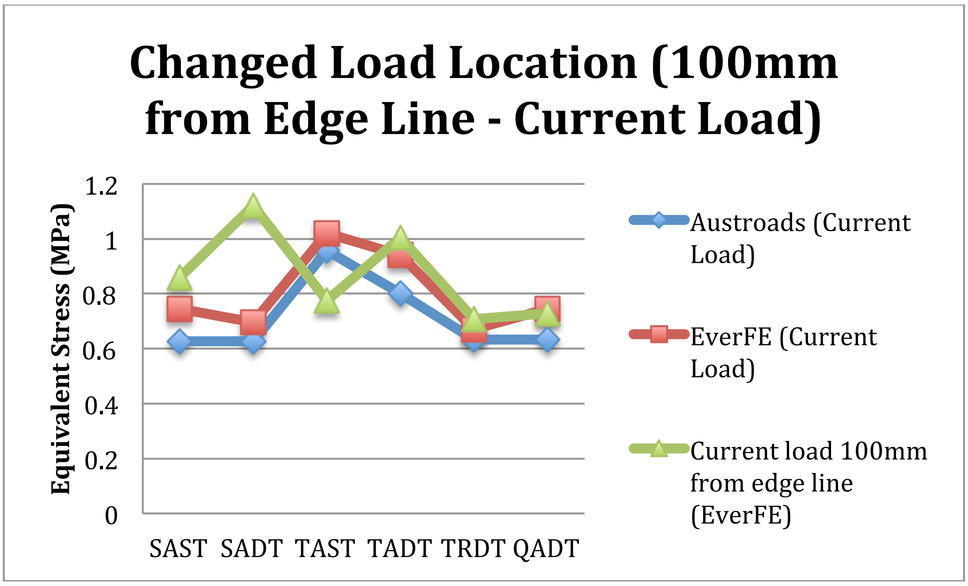


Figure 8-6 – Changed load location (100mm from edge line - Current Load)

It is stated in Packard (1985) that vehicle axle loads placed at the outside edge of the pavement result in more severe conditions than any other loading position; and as axle loads move inward these effects are decreased substantially. As loading is shifted away from the edge line the frequency of load repetitions is stated to increase and magnitudes of stress are to decrease. It is stated that data on load placement at or near the pavement edge is difficult to use in the design procedure of the PCA method and as a result loads were analysed at more easily modelled locations to ease the design procedure. From Figure 8-6 it can be seen that equivalent stress increases for a shift in load location to the edge line for all axle configurations except for TAST configuration with stress in this case decreasing by approximately 0.25MPa. A maximum stress increase of 0.42MPa was obtained for the SADT axle configuration.

To quantify the impact of a changed load location under current loading conditions; equivalent stress results exported from EverFE were imported into the Austroads spreadsheet to determine influence upon the allowable axle repetitions. Importing the equivalent stress results from EverFE into the spreadsheet presented allowable axle load repetitions unchanged at infinite repetitions for fatigue analysis. Erosion fatigue also remained unchanged as per the results in Table 7-5 as erosion formulations are not influenced by the equivalent stress of the pavement. This is an interesting conclusion drawn from the stress analysis with results for allowable repetitions remaining unchanged. This result indicates that changed load location to the edge line of pavement for current loading conditions does not influence the overall fatigue of the pavement.

The impact of shifting the load location for predicted future vehicle axle loading has also been studied. In this study axle loads were imported as per section 8.2, however axle loading was shifted to 100mm from the edge line as per literature. The impact on pavement stress from the shift in load location is shown in Table 8-7 and graphically presented in Figure 8-7.

Table 8-7 - Stress differential (Changed Load Location - Future Load)

	Future Load - MPa (600mm from edge line)	**Future Load - MPa (100mm from edge line)**	**Stress Differential**
SAST	2.059	2.556	0.497
TAST	1.952	2.283	-0.608
SADT	2.891	3.295	1.343
TADT	2.654	2.900	0.246
TRDT	2.560	2.042	-0.518
QADT	2.044	2.002	-0.042

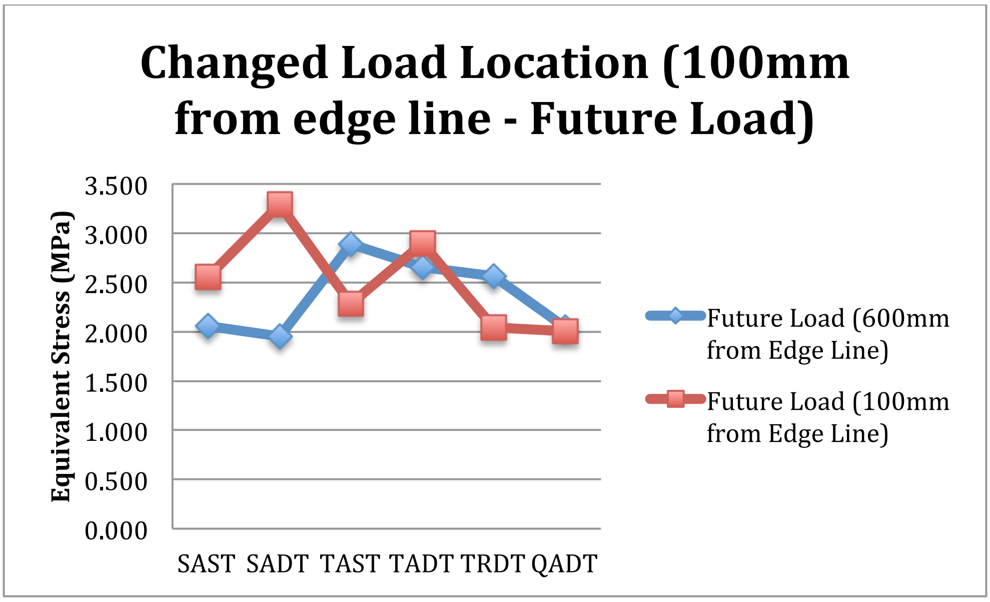


Figure 8-7 - Changed Load Location (100mm from edge line - future load)

From Figure 8-7 it can be seen that equivalent stress increases for a shift in load location to the edge line for axle configurations of SAST, SADT and TADT. A maximum stress increase of 1.343MPa was found for axle configuration of SADT. A maximum stress decrease of 0.608MPA was obtained for the TAST axle configuration. The general trends of the stress results were similar to those results obtained for stress differentials of changed load location of current load limits.

To quantify the impact of a changed load location under the predicted future loading conditions; equivalent stress results exported from EverFE were imported into the Austroads spreadsheet to determine influence upon the allowable axle repetitions. Importing the equivalent stress results from EverFE into the spreadsheet presented allowable axle load repetitions for fatigue and erosion failure modes. Fatigue analysis presented zero allowable repetitions for SAST, TAST, SADT and TADT. These results are equal to the results presented in Table 8-5.

Allowable repetitions for TRDT and QADT were slightly different with values calculated at 0.001 and 0.023 respectively, although still rounding to a value of zero allowable repetitions. Erosion damage presented values unchanged from results for future loading at 600mm from edge line that are shown in Table 8-5. Due to limitations in the formulas for determining allowable repetitions for increased future stress results it is difficult to determine the impact of allowable axle repetitions for the current pavement thickness (with the pavement failing at 240mm depth). With continued iterations of pavement base thickness in EverFE, additional stress results could be obtained for increased pavement thickness that could be then imported into the Austroads spreadsheet to determine influence on allowable axle repetitions.

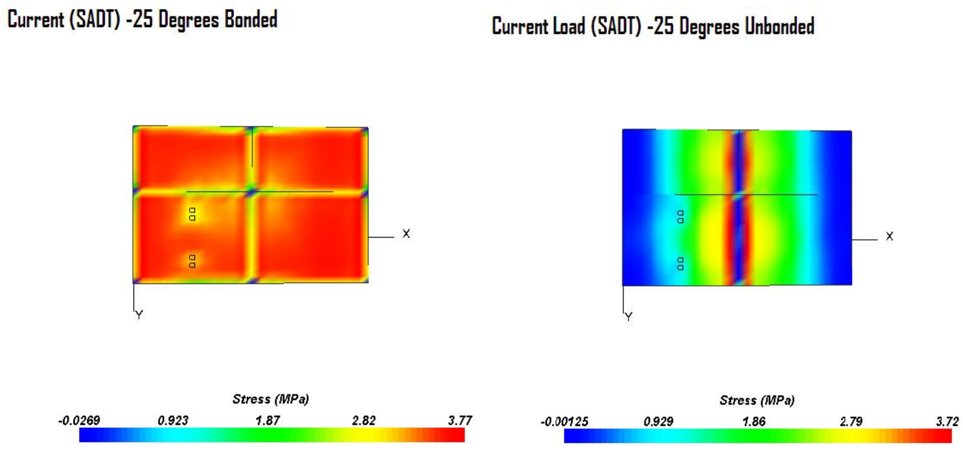
The results for future loading at a location 100mm from the edge line presented failure mode in fatigue, with zero allowable repetitions of each axle group. It should be noted that allowable repetitions increased slightly for TRDT and QADT configurations at location 100mm from edge line although not enough to impact results. This would indicate that as loading is shifted towards the edge line of the pavement, allowable repetitions of multi-axle vehicle configurations results in decreased pavement stress (for future load conditions).

8.4 Sensitivity Analysis – Temperature Gradients

A sensitivity analysis has been performed on the results presented previously for both current and future loading conditions, including both loading locations (600mm from edge line and 100mm from edge line). As Austroads does not consider the impact of temperature effects in detail, this section aims at identifying the impact temperature gradients have on pavement equivalent stress. EverFE offers capability in modelling pavements subjected to axle loading and loading from temperature gradients and will therefore be used to determine the change in pavement stress from inclusion of temperature differentials.

As presented in the literature review, four temperature differentials have been analysed. These were positive and negative temperature differential of ten degrees Celsius, and positive and negative temperature differential of twenty-five degrees. These values represent average (ten degrees) and extreme (twenty-five degrees) values of temperature differentials obtained from field studies by researchers. Boundary condition between base and subbase plays a significant role in pavement performance and is of importance during modelling of pavements subject to temperature differentials as this influences ability of the pavement to curl freely. As stated previously Austroads assumes an unbonded boundary condition, although temperature gradients are not considered in any detail as part of the design procedure. For the purpose of sensitivity analysis in this section pavements were modelled using both unbonded and bonded boundary conditions. Due to the size of graphics and tables that have been developed for sensitivity analysis of temperature gradients, to avoid downscaling results have been attached as Appendix D.

Figure 8-8 provides a representation of results exported from EverFE for a visual stress comparison of bonded versus unbonded. The results shown in the figure are for current loading conditions of a SADT subject to a negative twenty-five degree temperature differential.


Current (SADT) -25 Degrees Bonded

Current Load (SADT) -25 Degrees Unbonded

Figure 8-8 - EverFE stress visualisation (Temperature Gradient)

Sensitivity analysis for the impact of temperature gradients was conducted on current allowable axle loads under both loading conditions, 600mm from the edge line (Austroads limitation) and 100mm from the edge line. From observation of results presented in Appendix D it can be seen that with consideration of temperature gradients, pavement stress is predominantly dictated by the temperature differential and not by the axle loading. This is evident in the graphs for both current-loading cases as they present almost linear results for all axle group types under each condition tested. Stress resultants are varied depending on each temperature differential and boundary condition, however in each case pavement stress does not vary to a large degree across all axle types.

It should also be noted that all temperature differential results returned stress values greater than the stress results obtained from modelling in the absence of temperature gradients for all conditions. This provides evidence that the dominating stress contribution is temperature differential with pavement stress not significantly influenced by a change in axle group type and axle loading.

Stress results for temperature gradient of ten degrees (positive and negative differentials) presented lower stress values for unbonded boundary conditions with stress values for both conditions below the flexural strength of the concrete pavement. For temperature differential of twenty-five degrees these results were different with unbonded boundary condition increasing pavement stress compared to stresses for bonded condition. The increase in this condition resulted in stress levels above the flexural strength of the concrete pavement with stress results of approximately 5MPa (maximum stress value of 5.59MPa). In this extreme condition concrete strength adopted in design would have to be increased to allow for a large temperature induced stress in the pavement, as the concrete used in design is 4.5MPa.

The results of the analysis in this study are reflective of the conclusions drawn from the study by Darestani et al. (2006). In the study by Darestani the authors concluded that the minimum flexural strength of concrete should be selected based on the combination of effects from the worse possible temperature gradient and from vehicle axle loading. This conclusion has been shown through the results obtained from temperature sensitivity analysis performed in this study. Modelling of temperature differentials at extreme conditions (twenty-five degrees) presented stress values in excess of the flexural strength of concrete initially adopted in design.

This indicates that the temperature gradient is of significant influence to the flexural strength of concrete and it is found that the concrete flexural strength should be adopted in design based on the temperature differential of the site.

Sensitivity analysis has also been performed for the predicted future loading conditions subjected to temperature gradients and vehicular axle loading. Future axle loads were used as per those studied in Section 8.2 for both load locations, 600mm from the edge line and 100mm from the edge line. From observation of the results presented in Appendix D it can be seen that inclusion of temperature gradients in pavement modelling influences pavement stress to a large degree with equivalent stress results above those determined from modelling in the absence of temperature gradients. It was found that out of the eight conditions that were modelled for temperature analysis, three conditions (positive and negative gradients of ten degrees bonded and negative twenty-five degrees bonded) stress results presented a linear progression of results with no significant change in stress for each axle group load. The remaining five conditions (all unbonded conditions and positive twenty-five degrees bonded) presented results of pavement stress of similar trend to the results obtained for future loading conditions modelled without temperature gradients at the changed load location 100mm from edge line.

In contrast to the results presented previously for current loading conditions, stress results for temperature gradients of positive ten degrees resulted in bonded boundary conditions presenting lower stress values than unbonded condition. Negative gradient of ten degrees returned stress values similar to those presented for current loading conditions with unbonded stress lower than the bonded condition. Results for gradient of twenty-five degrees were also reflective of the trends observed with current loading conditions.

For future loading conditions, stress results exceeded the allowable concrete flexural strength of 4.5MPa adopted in design in all unbonded boundary conditions apart from negative ten degrees. The maximum stress value determined in the pavement resulted from a positive gradient of twenty-five degrees (unbonded) with future loading at 100mm from the edge line. The stress value presented was 6.899MPa from a SADT axle configuration. For pavement analysis of future loading conditions subject to extreme temperature gradients, concrete flexural strength would require revision to prevent failure and temperature should be considered in pavement design as identified previously.

In conclusion it has been found that the impact of temperature gradients on rigid pavement performance is a significant factor in pavement design. With the findings from this study, along with conclusions drawn from previous studies, further consideration in the pavement design process is required for inclusion of temperature gradients. Results indicate that the flexural strength of concrete should be selected based on the combination of worst possible temperature gradient of the construction site and from vehicle axle loading.

9. Conclusion

9.1 Current Work

This project has investigated the potential for integration of a finite element software package, EverFE, into the design procedure for rigid pavements in Australia.

From the studies performed in this report it has been found that there exist limitations to the design procedure currently used for design of Australia's rigid pavements through use of the Austroads Design Guide. These limitations include an incapability of modelling future loading conditions, incapability of presenting results for changed traffic locations and incapability in modelling pavements subjected to temperature gradients.

The utilisation of EverFE software has presented results that were deemed to accurately represent current stresses developed in the Austroads design guide and this provided justification that EverFE is capable at modelling rigid pavement stress resultants for current loading conditions. With this finding results were then modelled for future loading conditions and it was found that pavement stress results increased by 175 to 280 per cent under future loading conditions. Through limitation of the Austroads methods equivalent stress values could not be determined for future loading to compare against EverFE results. There exists potential for stress results exported from EverFE to be imported into Austroads design spreadsheet as the equivalent stress to determine allowable axle repetitions, however this process would require continued iteration between EverFE and the spreadsheet with varied pavement base thickness.

Modelling a shift in traffic load location presented results typically unchanged from the results that were found for current loading conditions with allowable axle repetitions from resultant stress values unchanged. This concluded that for a shift in load location for current loading conditions, pavement damage has not been influenced. Conclusions drawn from a shift in position of predicted future axle loadings using EverFE found that as loading was shifted towards the edge line, pavement stress from multi-axle vehicle configurations actually decreases pavement stress values compared to a centrally loaded pavement.

Analysis of temperature gradients in pavement design using EverFE was found to be a significant factor contributing to pavement stress that requires further consideration in pavement design. Extreme temperature differentials of twenty-five degrees resulted in concrete pavements failing under loading. Flexural strength of concrete adopted in design should therefore be selected based on a combination of the worst possible temperature gradient and vehicle axle loadings. It was found that EverFE offers capability in modelling pavements subjected to temperature loadings under the conditions tested.

In summary it has been demonstrated through the experiments undertaken that EverFE provides capability in modelling rigid pavement stress for Australian conditions. EverFE provides a user-friendly interface capable of analysing pavements subjected to various conditions not covered by the Austroads design guide. This presents opportunity for the incorporation of EverFE, in conjunction with the Austroads design guide, to be used for the design of Australia’s future concrete pavements.

9.2 Further Work

Through the works completed in this study it has been found that the EverFE software package offers capability in determination of stress values of the Austroads method. It has also found that EverFE is capable at modelling pavements under different conditions to those allowed in Austroads, those being future loading, changed load location and the inclusion of temperature gradients.

Despite capabilities in modelling these conditions, EverFE is limited in that it only provides an equivalent stress value for the pavement subject to a single axle group load. This does not provide stress analysis for continued repetition of axle group loads and as a result does not present erosion and fatigue damage. Further work in this area could seek to find an efficient way of extracting stress output from EverFE and importing this value into formulations that can be used by the Austroads design procedure to determine a base thickness.

In regards to future traffic loading conditions, potential further work may involve the use of EverFE software in modelling of rigid pavements subject to large, super-heavy vehicle loads such as for roads leading into ports and military facilities. Currently the Austroads guide does not provide a method for designing these pavements, however with incorporation of EverFE software there could be potential to provide pavement thickness design for these conditions, and other conditions outside of the scope of the Austroads method.

As determined from the results of temperature analysis, extreme temperature gradients result in very large pavement stress. It has been stated that the flexural strength of concrete should be selected based on the worst temperature gradient. Potential further work could be conducted to find a way of minimising the stress resultant from temperature differentials by way of changed modelling conditions (geometry, joint spacing and configuration, material properties).

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Appendix A – Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 – Engineering Research Project 2015

PROJECT SPECIFICATION

FOR: **Chris Snook**

TOPIC: Evaluation of EverFE software for designing Australian Concrete Pavements

SUPERVISOR: Dr Andreas Nataatmadja
University of Southern Queensland, Faculty of Engineering and Surveying

ENROLMENT: ENG4111 – S1, 2015;
ENG4112 – S2, 2015

PROJECT AIM: This project seeks to identify limitations of the current Austroads design guide for Australian rigid pavements and determine the suitability of using a Finite Element analysis program, EverFE, in conjunction with Austroads design guide to address these identified limitations.

PROGRAMME: **Issue 2, 10th March 2015**

1. Introduce Austroads and EverFE software and identify limitations of the Austroads design guide for rigid pavements
2. Research the trends in heavy vehicle loading and traffic load distribution in the vehicle travel lane to determine parameters for future traffic loading and load location.
3. Compare results obtained from Austroads and EverFE predictions on the result of increased future traffic loading at the critical stress location.
4. Identify the predicted stress differential resulting from changing load location (a factor limited in Austroads) to location identified from research trends using EverFE software.
5. Perform sensitivity analysis on the impact of temperature on pavement design to determine if temperature gradients of concrete pavements need further consideration in design for the future.

AGREED:

(Student) (Supervisor)

10/3/2015 10/3/2015

Appendix B – Traffic Load Data (TLD)

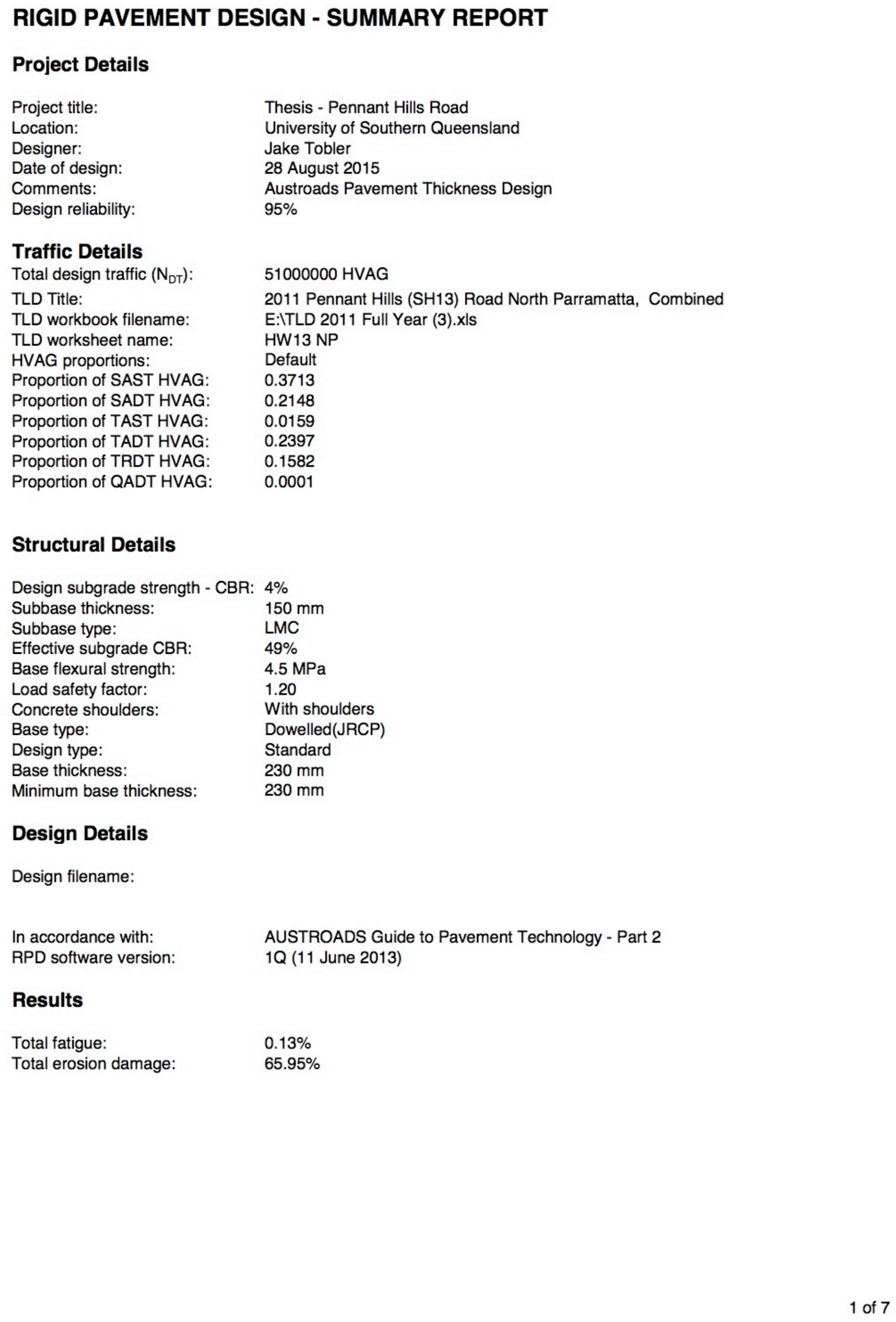
2011 Pennant Hills (SH13) Road North Parramatta, Combined

	Axle group type					
Axle group load (kN)	**SAST %**	**SADT %**	**TAST %**	**TADT %**	**TRDT %**	**QADT %**
10	0.72	7.49	0.94	0.06	0.00	0.00
20	12.81	14.19	9.14	0.72	0.06	1.72
30	13.39	16.32	3.03	2.15	0.37	3.02
40	11.54	13.79	3.73	3.65	1.12	3.49
50	20.21	10.15	4.91	5.76	3.20	1.80
60	30.67	8.30	9.27	8.90	6.38	1.63
70	9.84	5.92	12.57	8.03	6.97	3.46
80	0.76	9.77	14.58	7.74	6.74	3.72
90	0.05	8.96	13.46	7.04	6.03	4.36
100	0.01	3.49	10.65	6.49	5.51	2.47
110	0.00	1.22	8.53	6.87	5.57	3.00
120	0.00	0.28	4.86	6.07	4.67	2.77
130	0.00	0.08	2.41	6.34	4.63	2.22
140	0.00	0.03	1.23	7.30	4.59	1.93
150	0.00	0.00	0.57	7.75	4.69	3.06
160	0.00	0.00	0.13	7.16	5.86	2.77
170	0.00	0.00	0.00	4.01	6.43	2.94
180	0.00	0.00	0.00	2.04	7.11	2.99
190	0.00	0.00	0.00	1.01	7.14	10.13
200	0.00	0.00	0.00	0.50	5.73	5.57
210	0.00	0.00	0.00	0.25	3.97	4.94
220	0.00	0.00	0.00	0.09	1.72	5.68
230	0.00	0.00	0.00	0.05	0.80	0.60
240	0.00	0.00	0.00	0.02	0.36	3.43
250	0.00	0.00	0.00	0.00	0.17	2.00
260	0.00	0.00	0.00	0.00	0.10	3.37
270	0.00	0.00	0.00	0.00	0.05	0.00
280	0.00	0.00	0.00	0.00	0.02	2.54
290	0.00	0.00	0.00	0.00	0.01	4.14
300	0.00	0.00	0.00	0.00	0.00	1.57
310	0.00	0.00	0.00	0.00	0.00	0.94
320	0.00	0.00	0.00	0.00	0.00	2.17
330	0.00	0.00	0.00	0.00	0.00	2.81
340	0.00	0.00	0.00	0.00	0.00	1.21
350	0.00	0.00	0.00	0.00	0.00	1.57
360	0.00	0.00	0.00	0.00	0.00	0.00
370	0.00	0.00	0.00	0.00	0.00	0.00
380	0.00	0.00	0.00	0.00	0.00	0.00
390	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00
Group proportions	0.371	0.215	0.016	0.240	0.158	0.000

2011 M2 Motorway North Epping (opp East Tunnel Portal), Eastbound, Combined Lanes

Axle group load (kN)	Axle group type					
	SAST %	SADT %	TAST %	TADT %	TRDT %	QADT %
10	4.08	5.37	3.23	0.32	0.00	0.00
20	11.75	15.13	12.04	1.01	1.01	0.00
30	8.94	13.52	4.20	1.22	0.84	43.58
40	16.13	13.33	1.05	6.63	1.18	6.23
50	27.48	8.64	0.57	4.98	2.79	6.23
60	23.07	7.58	2.93	9.07	5.65	0.00
70	7.45	4.78	5.76	12.46	13.85	6.23
80	0.93	6.81	11.42	9.04	13.24	6.23
90	0.14	11.25	17.17	5.27	10.59	6.23
100	0.03	8.39	16.18	5.35	8.00	0.00
110	0.00	3.55	10.94	11.11	5.58	0.00
120	0.00	1.12	10.37	9.04	4.17	0.00
130	0.00	0.44	2.91	6.16	2.59	18.68
140	0.00	0.07	0.57	3.62	3.63	0.00
150	0.00	0.00	0.65	3.54	2.35	0.00
160	0.00	0.00	0.00	3.79	2.59	0.00
170	0.00	0.00	0.00	3.04	2.49	0.00
180	0.00	0.00	0.00	1.86	4.17	0.00
190	0.00	0.00	0.00	1.02	3.09	6.23
200	0.00	0.00	0.00	0.85	3.97	0.00
210	0.00	0.00	0.00	0.33	3.33	0.39
220	0.00	0.00	0.00	0.13	1.95	0.00
230	0.00	0.00	0.00	0.14	1.34	0.00
240	0.00	0.00	0.00	0.00	0.37	0.00
250	0.00	0.00	0.00	0.00	0.60	0.00
260	0.00	0.00	0.00	0.00	0.57	0.00
270	0.00	0.00	0.00	0.00	0.07	0.00
280	0.00	0.00	0.00	0.00	0.00	0.00
290	0.00	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	0.00
310	0.00	0.00	0.00	0.00	0.00	0.00
320	0.00	0.00	0.00	0.00	0.00	0.00
330	0.00	0.00	0.00	0.00	0.00	0.00
340	0.00	0.00	0.00	0.00	0.00	0.00
350	0.00	0.00	0.00	0.00	0.00	0.00
360	0.00	0.00	0.00	0.00	0.00	0.00
370	0.00	0.00	0.00	0.00	0.00	0.00
380	0.00	0.00	0.00	0.00	0.00	0.00
390	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00
Group proportions	0.406	0.282	0.025	0.241	0.044	0.002

Appendix C – RMS Rigid Pavement Design Spreadsheet Results



RIGID PAVEMENT DESIGN - SUMMARY REPORT

Project Details

Project title:	Thesis - Pennant Hills Road
Location:	University of Southern Queensland
Designer:	Jake Tobler
Date of design:	28 August 2015
Comments:	Austroads Pavement Thickness Design
Design reliability:	95%

Traffic Details

Total design traffic (N_{DT}):	51000000 HVAG
TLD Title:	2011 Pennant Hills (SH13) Road North Parramatta, Combined
TLD workbook filename:	E:\TLD 2011 Full Year (3).xls
TLD worksheet name:	HW13 NP
HVAG proportions:	Default
Proportion of SAST HVAG:	0.3713
Proportion of SADT HVAG:	0.2148
Proportion of TAST HVAG:	0.0159
Proportion of TADT HVAG:	0.2397
Proportion of TRDT HVAG:	0.1582
Proportion of QADT HVAG:	0.0001

Structural Details

Design subgrade strength - CBR:	4%
Subbase thickness:	150 mm
Subbase type:	LMC
Effective subgrade CBR:	49%
Base flexural strength:	4.5 MPa
Load safety factor:	1.20
Concrete shoulders:	With shoulders
Base type:	Dowelled(JRCP)
Design type:	Standard
Base thickness:	230 mm
Minimum base thickness:	230 mm

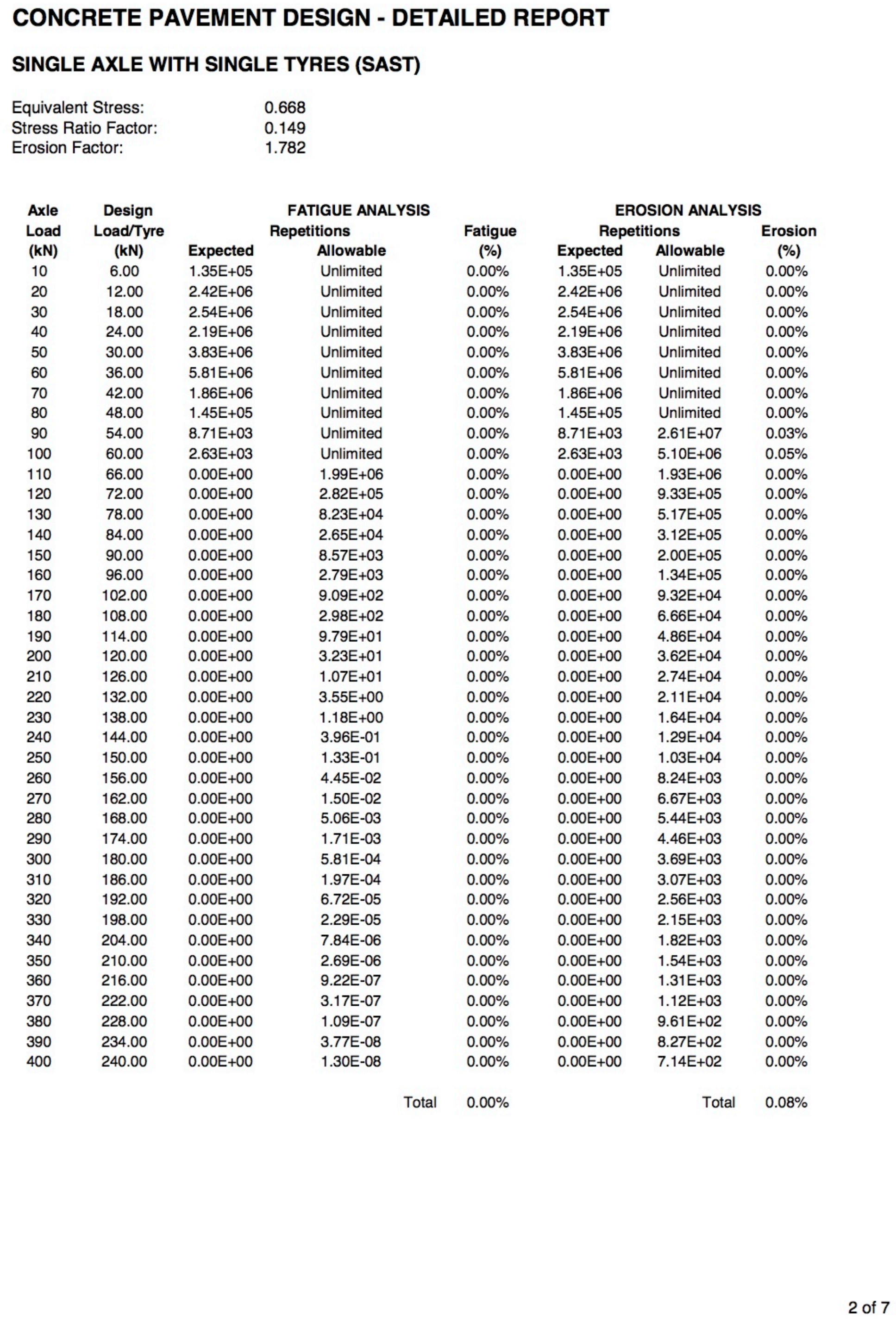
Design Details

Design filename:

In accordance with:	AUSTROADS Guide to Pavement Technology - Part 2
RPD software version:	1Q (11 June 2013)

Results

Total fatigue:	0.13%
Total erosion damage:	65.95%

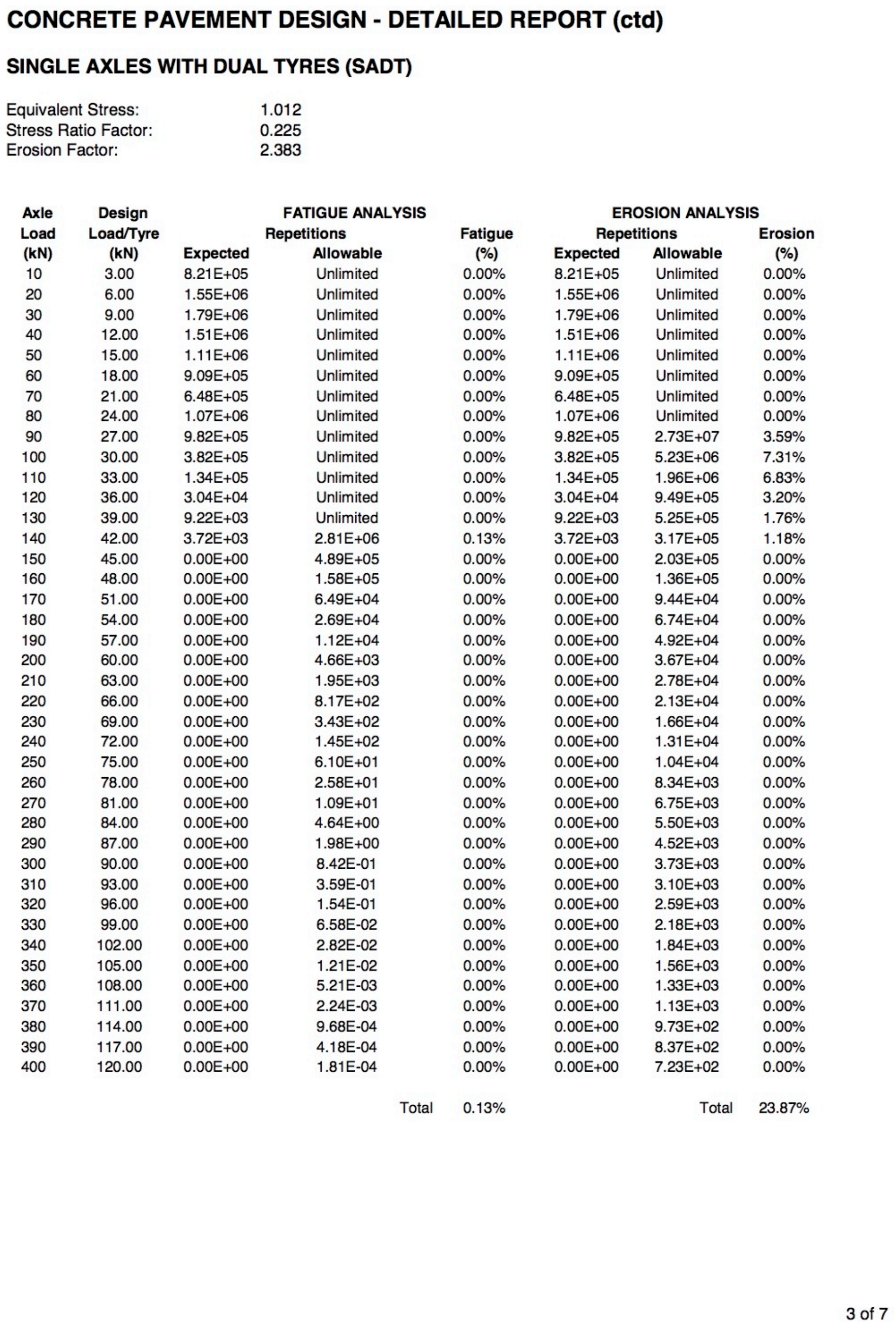


CONCRETE PAVEMENT DESIGN - DETAILED REPORT

SINGLE AXLE WITH SINGLE TYRES (SAST)

Equivalent Stress:	0.668
Stress Ratio Factor:	0.149
Erosion Factor:	1.782

Axle	Design	FATIGUE ANALYSIS			EROSION ANALYSIS		
Load	Load/Tyre	Repetitions		Fatigue	Repetitions		Erosion
(kN)	(kN)	Expected	Allowable	(%)	Expected	Allowable	(%)
10	6.00	1.35E+05	Unlimited	0.00%	1.35E+05	Unlimited	0.00%
20	12.00	2.42E+06	Unlimited	0.00%	2.42E+06	Unlimited	0.00%
30	18.00	2.54E+06	Unlimited	0.00%	2.54E+06	Unlimited	0.00%
40	24.00	2.19E+06	Unlimited	0.00%	2.19E+06	Unlimited	0.00%
50	30.00	3.83E+06	Unlimited	0.00%	3.83E+06	Unlimited	0.00%
60	36.00	5.81E+06	Unlimited	0.00%	5.81E+06	Unlimited	0.00%
70	42.00	1.86E+06	Unlimited	0.00%	1.86E+06	Unlimited	0.00%
80	48.00	1.45E+05	Unlimited	0.00%	1.45E+05	Unlimited	0.00%
90	54.00	8.71E+03	Unlimited	0.00%	8.71E+03	2.61E+07	0.03%
100	60.00	2.63E+03	Unlimited	0.00%	2.63E+03	5.10E+06	0.05%
110	66.00	0.00E+00	1.99E+06	0.00%	0.00E+00	1.93E+06	0.00%
120	72.00	0.00E+00	2.82E+05	0.00%	0.00E+00	9.33E+05	0.00%
130	78.00	0.00E+00	8.23E+04	0.00%	0.00E+00	5.17E+05	0.00%
140	84.00	0.00E+00	2.65E+04	0.00%	0.00E+00	3.12E+05	0.00%
150	90.00	0.00E+00	8.57E+03	0.00%	0.00E+00	2.00E+05	0.00%
160	96.00	0.00E+00	2.79E+03	0.00%	0.00E+00	1.34E+05	0.00%
170	102.00	0.00E+00	9.09E+02	0.00%	0.00E+00	9.32E+04	0.00%
180	108.00	0.00E+00	2.98E+02	0.00%	0.00E+00	6.66E+04	0.00%
190	114.00	0.00E+00	9.79E+01	0.00%	0.00E+00	4.86E+04	0.00%
200	120.00	0.00E+00	3.23E+01	0.00%	0.00E+00	3.62E+04	0.00%
210	126.00	0.00E+00	1.07E+01	0.00%	0.00E+00	2.74E+04	0.00%
220	132.00	0.00E+00	3.55E+00	0.00%	0.00E+00	2.11E+04	0.00%
230	138.00	0.00E+00	1.18E+00	0.00%	0.00E+00	1.64E+04	0.00%
240	144.00	0.00E+00	3.96E-01	0.00%	0.00E+00	1.29E+04	0.00%
250	150.00	0.00E+00	1.33E-01	0.00%	0.00E+00	1.03E+04	0.00%
260	156.00	0.00E+00	4.45E-02	0.00%	0.00E+00	8.24E+03	0.00%
270	162.00	0.00E+00	1.50E-02	0.00%	0.00E+00	6.67E+03	0.00%
280	168.00	0.00E+00	5.06E-03	0.00%	0.00E+00	5.44E+03	0.00%
290	174.00	0.00E+00	1.71E-03	0.00%	0.00E+00	4.46E+03	0.00%
300	180.00	0.00E+00	5.81E-04	0.00%	0.00E+00	3.69E+03	0.00%
310	186.00	0.00E+00	1.97E-04	0.00%	0.00E+00	3.07E+03	0.00%
320	192.00	0.00E+00	6.72E-05	0.00%	0.00E+00	2.56E+03	0.00%
330	198.00	0.00E+00	2.29E-05	0.00%	0.00E+00	2.15E+03	0.00%
340	204.00	0.00E+00	7.84E-06	0.00%	0.00E+00	1.82E+03	0.00%
350	210.00	0.00E+00	2.69E-06	0.00%	0.00E+00	1.54E+03	0.00%
360	216.00	0.00E+00	9.22E-07	0.00%	0.00E+00	1.31E+03	0.00%
370	222.00	0.00E+00	3.17E-07	0.00%	0.00E+00	1.12E+03	0.00%
380	228.00	0.00E+00	1.09E-07	0.00%	0.00E+00	9.61E+02	0.00%
390	234.00	0.00E+00	3.77E-08	0.00%	0.00E+00	8.27E+02	0.00%
400	240.00	0.00E+00	1.30E-08	0.00%	0.00E+00	7.14E+02	0.00%
			Total	0.00%		Total	0.08%



CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

SINGLE AXLES WITH DUAL TYRES (SADT)

Equivalent Stress:	1.012
Stress Ratio Factor:	0.225
Erosion Factor:	2.383

Axle Load (kN)	Design Load/Tyre (kN)	FATIGUE ANALYSIS			EROSION ANALYSIS		
		Repetitions		Fatigue (%)	Repetitions		Erosion (%)
		Expected	Allowable		Expected	Allowable	
10	3.00	8.21E+05	Unlimited	0.00%	8.21E+05	Unlimited	0.00%
20	6.00	1.55E+06	Unlimited	0.00%	1.55E+06	Unlimited	0.00%
30	9.00	1.79E+06	Unlimited	0.00%	1.79E+06	Unlimited	0.00%
40	12.00	1.51E+06	Unlimited	0.00%	1.51E+06	Unlimited	0.00%
50	15.00	1.11E+06	Unlimited	0.00%	1.11E+06	Unlimited	0.00%
60	18.00	9.09E+05	Unlimited	0.00%	9.09E+05	Unlimited	0.00%
70	21.00	6.48E+05	Unlimited	0.00%	6.48E+05	Unlimited	0.00%
80	24.00	1.07E+06	Unlimited	0.00%	1.07E+06	Unlimited	0.00%
90	27.00	9.82E+05	Unlimited	0.00%	9.82E+05	2.73E+07	3.59%
100	30.00	3.82E+05	Unlimited	0.00%	3.82E+05	5.23E+06	7.31%
110	33.00	1.34E+05	Unlimited	0.00%	1.34E+05	1.96E+06	6.83%
120	36.00	3.04E+04	Unlimited	0.00%	3.04E+04	9.49E+05	3.20%
130	39.00	9.22E+03	Unlimited	0.00%	9.22E+03	5.25E+05	1.76%
140	42.00	3.72E+03	2.81E+06	0.13%	3.72E+03	3.17E+05	1.18%
150	45.00	0.00E+00	4.89E+05	0.00%	0.00E+00	2.03E+05	0.00%
160	48.00	0.00E+00	1.58E+05	0.00%	0.00E+00	1.36E+05	0.00%
170	51.00	0.00E+00	6.49E+04	0.00%	0.00E+00	9.44E+04	0.00%
180	54.00	0.00E+00	2.69E+04	0.00%	0.00E+00	6.74E+04	0.00%
190	57.00	0.00E+00	1.12E+04	0.00%	0.00E+00	4.92E+04	0.00%
200	60.00	0.00E+00	4.66E+03	0.00%	0.00E+00	3.67E+04	0.00%
210	63.00	0.00E+00	1.95E+03	0.00%	0.00E+00	2.78E+04	0.00%
220	66.00	0.00E+00	8.17E+02	0.00%	0.00E+00	2.13E+04	0.00%
230	69.00	0.00E+00	3.43E+02	0.00%	0.00E+00	1.66E+04	0.00%
240	72.00	0.00E+00	1.45E+02	0.00%	0.00E+00	1.31E+04	0.00%
250	75.00	0.00E+00	6.10E+01	0.00%	0.00E+00	1.04E+04	0.00%
260	78.00	0.00E+00	2.58E+01	0.00%	0.00E+00	8.34E+03	0.00%
270	81.00	0.00E+00	1.09E+01	0.00%	0.00E+00	6.75E+03	0.00%
280	84.00	0.00E+00	4.64E+00	0.00%	0.00E+00	5.50E+03	0.00%
290	87.00	0.00E+00	1.98E+00	0.00%	0.00E+00	4.52E+03	0.00%
300	90.00	0.00E+00	8.42E-01	0.00%	0.00E+00	3.73E+03	0.00%
310	93.00	0.00E+00	3.59E-01	0.00%	0.00E+00	3.10E+03	0.00%
320	96.00	0.00E+00	1.54E-01	0.00%	0.00E+00	2.59E+03	0.00%
330	99.00	0.00E+00	6.58E-02	0.00%	0.00E+00	2.18E+03	0.00%
340	102.00	0.00E+00	2.82E-02	0.00%	0.00E+00	1.84E+03	0.00%
350	105.00	0.00E+00	1.21E-02	0.00%	0.00E+00	1.56E+03	0.00%
360	108.00	0.00E+00	5.21E-03	0.00%	0.00E+00	1.33E+03	0.00%
370	111.00	0.00E+00	2.24E-03	0.00%	0.00E+00	1.13E+03	0.00%
380	114.00	0.00E+00	9.68E-04	0.00%	0.00E+00	9.73E+02	0.00%
390	117.00	0.00E+00	4.18E-04	0.00%	0.00E+00	8.37E+02	0.00%
400	120.00	0.00E+00	1.81E-04	0.00%	0.00E+00	7.23E+02	0.00%
			Total	0.13%		Total	23.87%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

TANDEM AXLE WITH SINGLE TYRES (TAST)

Equivalent Stress:	0.668
Stress Ratio Factor:	0.149
Erosion Factor:	2.428

Axle	Design	FATIGUE ANALYSIS			EROSION ANALYSIS		
Load	Load/Tyre	Repetitions		Fatigue	Repetitions		Erosion
(kN)	(kN)	Expected	Allowable	(%)	Expected	Allowable	(%)
10	3.00	7.60E+03	Unlimited	0.00%	7.60E+03	Unlimited	0.00%
20	6.00	7.41E+04	Unlimited	0.00%	7.41E+04	Unlimited	0.00%
30	9.00	2.46E+04	Unlimited	0.00%	2.46E+04	Unlimited	0.00%
40	12.00	3.03E+04	Unlimited	0.00%	3.03E+04	Unlimited	0.00%
50	15.00	3.98E+04	Unlimited	0.00%	3.98E+04	Unlimited	0.00%
60	18.00	7.51E+04	Unlimited	0.00%	7.51E+04	Unlimited	0.00%
70	21.00	1.02E+05	Unlimited	0.00%	1.02E+05	Unlimited	0.00%
80	24.00	1.18E+05	Unlimited	0.00%	1.18E+05	3.60E+08	0.03%
90	27.00	1.09E+05	Unlimited	0.00%	1.09E+05	1.06E+07	1.03%
100	30.00	8.63E+04	Unlimited	0.00%	8.63E+04	2.96E+06	2.92%
110	33.00	6.92E+04	Unlimited	0.00%	6.92E+04	1.25E+06	5.52%
120	36.00	3.94E+04	Unlimited	0.00%	3.94E+04	6.41E+05	6.15%
130	39.00	1.96E+04	Unlimited	0.00%	1.96E+04	3.67E+05	5.33%
140	42.00	9.95E+03	Unlimited	0.00%	9.95E+03	2.26E+05	4.40%
150	45.00	4.64E+03	Unlimited	0.00%	4.64E+03	1.47E+05	3.16%
160	48.00	1.02E+03	Unlimited	0.00%	1.02E+03	9.93E+04	1.03%
170	51.00	0.00E+00	Unlimited	0.00%	0.00E+00	6.94E+04	0.00%
180	54.00	0.00E+00	Unlimited	0.00%	0.00E+00	4.98E+04	0.00%
190	57.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.65E+04	0.00%
200	60.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.72E+04	0.00%
210	63.00	0.00E+00	1.12E+07	0.00%	0.00E+00	2.07E+04	0.00%
220	66.00	0.00E+00	1.99E+06	0.00%	0.00E+00	1.59E+04	0.00%
230	69.00	0.00E+00	6.49E+05	0.00%	0.00E+00	1.24E+04	0.00%
240	72.00	0.00E+00	2.82E+05	0.00%	0.00E+00	9.75E+03	0.00%
250	75.00	0.00E+00	1.46E+05	0.00%	0.00E+00	7.76E+03	0.00%
260	78.00	0.00E+00	8.23E+04	0.00%	0.00E+00	6.22E+03	0.00%
270	81.00	0.00E+00	4.67E+04	0.00%	0.00E+00	5.04E+03	0.00%
280	84.00	0.00E+00	2.65E+04	0.00%	0.00E+00	4.10E+03	0.00%
290	87.00	0.00E+00	1.51E+04	0.00%	0.00E+00	3.37E+03	0.00%
300	90.00	0.00E+00	8.57E+03	0.00%	0.00E+00	2.78E+03	0.00%
310	93.00	0.00E+00	4.88E+03	0.00%	0.00E+00	2.31E+03	0.00%
320	96.00	0.00E+00	2.79E+03	0.00%	0.00E+00	1.93E+03	0.00%
330	99.00	0.00E+00	1.59E+03	0.00%	0.00E+00	1.62E+03	0.00%
340	102.00	0.00E+00	9.09E+02	0.00%	0.00E+00	1.36E+03	0.00%
350	105.00	0.00E+00	5.20E+02	0.00%	0.00E+00	1.16E+03	0.00%
360	108.00	0.00E+00	2.98E+02	0.00%	0.00E+00	9.83E+02	0.00%
370	111.00	0.00E+00	1.71E+02	0.00%	0.00E+00	8.40E+02	0.00%
380	114.00	0.00E+00	9.79E+01	0.00%	0.00E+00	7.20E+02	0.00%
390	117.00	0.00E+00	5.62E+01	0.00%	0.00E+00	6.19E+02	0.00%
400	120.00	0.00E+00	3.23E+01	0.00%	0.00E+00	5.34E+02	0.00%
			Total	0.00%		Total	29.57%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

TANDEM AXLE WITH DUAL TYRES (TADT)

Equivalent Stress:	0.846
Stress Ratio Factor:	0.188
Erosion Factor:	2.428

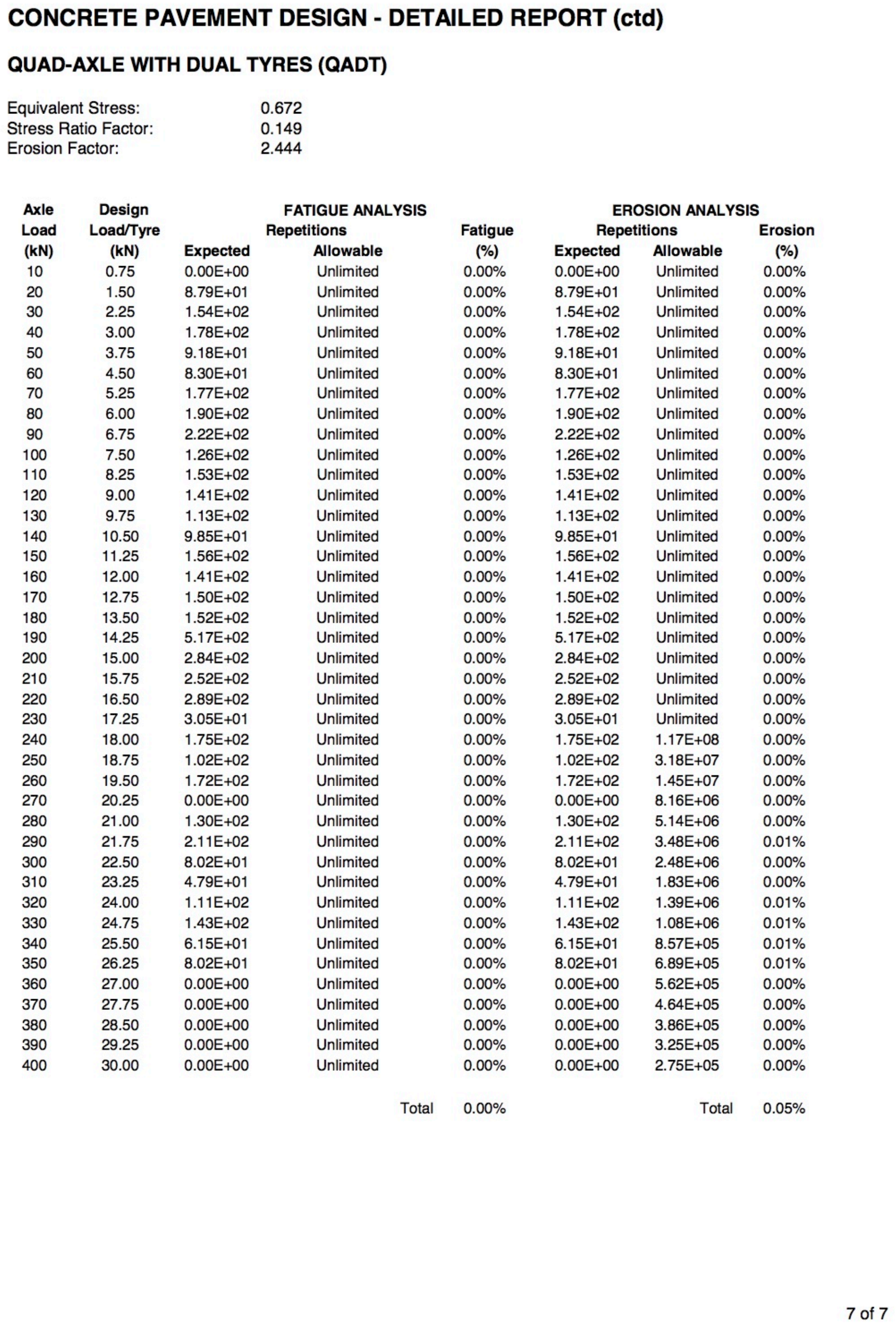
Axle	**Design**		**FATIGUE ANALYSIS**			**EROSION ANALYSIS**	
Load	**Load/Tyre**		**Repetitions**	**Fatigue**		**Repetitions**	**Erosion**
(kN)	**1.5**	**3739.96**	**Unlimited**	**0**	**3739.96**	**Unlimited**	**0**
10	1.50	7.26E+03	Unlimited	0.00%	7.26E+03	Unlimited	0.00%
20	3.00	8.85E+04	Unlimited	0.00%	8.85E+04	Unlimited	0.00%
30	4.50	2.63E+05	Unlimited	0.00%	2.63E+05	Unlimited	0.00%
40	6.00	4.46E+05	Unlimited	0.00%	4.46E+05	Unlimited	0.00%
50	7.50	7.04E+05	Unlimited	0.00%	7.04E+05	Unlimited	0.00%
60	9.00	1.09E+06	Unlimited	0.00%	1.09E+06	Unlimited	0.00%
70	10.50	9.81E+05	Unlimited	0.00%	9.81E+05	Unlimited	0.00%
80	12.00	9.46E+05	Unlimited	0.00%	9.46E+05	Unlimited	0.00%
90	13.50	8.60E+05	Unlimited	0.00%	8.60E+05	Unlimited	0.00%
100	15.00	7.94E+05	Unlimited	0.00%	7.94E+05	Unlimited	0.00%
110	16.50	8.39E+05	Unlimited	0.00%	8.39E+05	Unlimited	0.00%
120	18.00	7.42E+05	Unlimited	0.00%	7.42E+05	Unlimited	0.00%
130	19.50	7.75E+05	Unlimited	0.00%	7.75E+05	Unlimited	0.00%
140	21.00	8.93E+05	Unlimited	0.00%	8.93E+05	Unlimited	0.00%
150	22.50	9.47E+05	Unlimited	0.00%	9.47E+05	Unlimited	0.00%
160	24.00	8.76E+05	Unlimited	0.00%	8.76E+05	3.60E+08	0.24%
170	25.50	4.90E+05	Unlimited	0.00%	4.90E+05	3.06E+07	1.60%
180	27.00	2.50E+05	Unlimited	0.00%	2.50E+05	1.06E+07	2.35%
190	28.50	1.23E+05	Unlimited	0.00%	1.23E+05	5.17E+06	2.38%
200	30.00	6.08E+04	Unlimited	0.00%	6.08E+04	2.96E+06	2.05%
210	31.50	3.11E+04	Unlimited	0.00%	3.11E+04	1.87E+06	1.67%
220	33.00	1.14E+04	Unlimited	0.00%	1.14E+04	1.25E+06	0.91%
230	34.50	5.55E+03	Unlimited	0.00%	5.55E+03	8.81E+05	0.63%
240	36.00	1.86E+03	Unlimited	0.00%	1.86E+03	6.41E+05	0.29%
250	37.50	0.00E+00	Unlimited	0.00%	0.00E+00	4.80E+05	0.00%
260	39.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.67E+05	0.00%
270	40.50	0.00E+00	Unlimited	0.00%	0.00E+00	2.86E+05	0.00%
280	42.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.26E+05	0.00%
290	43.50	0.00E+00	Unlimited	0.00%	0.00E+00	1.81E+05	0.00%
300	45.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.47E+05	0.00%
310	46.50	0.00E+00	Unlimited	0.00%	0.00E+00	1.20E+05	0.00%
320	48.00	0.00E+00	3.79E+07	0.00%	0.00E+00	9.93E+04	0.00%
330	49.50	0.00E+00	7.36E+06	0.00%	0.00E+00	8.27E+04	0.00%
340	51.00	0.00E+00	2.49E+06	0.00%	0.00E+00	6.94E+04	0.00%
350	52.50	0.00E+00	1.11E+06	0.00%	0.00E+00	5.86E+04	0.00%
360	54.00	0.00E+00	5.78E+05	0.00%	0.00E+00	4.98E+04	0.00%
370	55.50	0.00E+00	3.37E+05	0.00%	0.00E+00	4.25E+04	0.00%
380	57.00	0.00E+00	2.12E+05	0.00%	0.00E+00	3.65E+04	0.00%
390	58.50	0.00E+00	1.42E+05	0.00%	0.00E+00	3.15E+04	0.00%
400	60.00	0.00E+00	9.80E+04	0.00%	0.00E+00	2.72E+04	0.00%
			Total	0.00%		Total	12.12%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

TRIAXLE WITH DUAL TYRES (TRDT)

Equivalent Stress:	0.672
Stress Ratio Factor:	0.149
Erosion Factor:	2.444

Axle	Design		FATIGUE ANALYSIS			EROSION ANALYSIS	
Load	Load/Tyre	Repetitions		Fatigue	Repetitions		Erosion
(kN)	(kN)	Expected	Allowable	(%)	Expected	Allowable	(%)
10	1.00	4.84E+01	Unlimited	0.00%	4.84E+01	Unlimited	0.00%
20	2.00	5.17E+03	Unlimited	0.00%	5.17E+03	Unlimited	0.00%
30	3.00	2.99E+04	Unlimited	0.00%	2.99E+04	Unlimited	0.00%
40	4.00	9.01E+04	Unlimited	0.00%	9.01E+04	Unlimited	0.00%
50	5.00	2.58E+05	Unlimited	0.00%	2.58E+05	Unlimited	0.00%
60	6.00	5.14E+05	Unlimited	0.00%	5.14E+05	Unlimited	0.00%
70	7.00	5.62E+05	Unlimited	0.00%	5.62E+05	Unlimited	0.00%
80	8.00	5.44E+05	Unlimited	0.00%	5.44E+05	Unlimited	0.00%
90	9.00	4.87E+05	Unlimited	0.00%	4.87E+05	Unlimited	0.00%
100	10.00	4.44E+05	Unlimited	0.00%	4.44E+05	Unlimited	0.00%
110	11.00	4.49E+05	Unlimited	0.00%	4.49E+05	Unlimited	0.00%
120	12.00	3.77E+05	Unlimited	0.00%	3.77E+05	Unlimited	0.00%
130	13.00	3.73E+05	Unlimited	0.00%	3.73E+05	Unlimited	0.00%
140	14.00	3.70E+05	Unlimited	0.00%	3.70E+05	Unlimited	0.00%
150	15.00	3.78E+05	Unlimited	0.00%	3.78E+05	Unlimited	0.00%
160	16.00	4.72E+05	Unlimited	0.00%	4.72E+05	Unlimited	0.00%
170	17.00	5.19E+05	Unlimited	0.00%	5.19E+05	Unlimited	0.00%
180	18.00	5.73E+05	Unlimited	0.00%	5.73E+05	Unlimited	0.00%
190	19.00	5.76E+05	Unlimited	0.00%	5.76E+05	Unlimited	0.00%
200	20.00	4.63E+05	Unlimited	0.00%	4.63E+05	Unlimited	0.00%
210	21.00	3.21E+05	Unlimited	0.00%	3.21E+05	Unlimited	0.00%
220	22.00	1.39E+05	Unlimited	0.00%	1.39E+05	Unlimited	0.00%
230	23.00	6.49E+04	Unlimited	0.00%	6.49E+04	Unlimited	0.00%
240	24.00	2.92E+04	Unlimited	0.00%	2.92E+04	1.17E+08	0.02%
250	25.00	1.40E+04	Unlimited	0.00%	1.40E+04	3.18E+07	0.04%
260	26.00	8.10E+03	Unlimited	0.00%	8.10E+03	1.45E+07	0.06%
270	27.00	3.74E+03	Unlimited	0.00%	3.74E+03	8.16E+06	0.05%
280	28.00	1.78E+03	Unlimited	0.00%	1.78E+03	5.14E+06	0.03%
290	29.00	8.15E+02	Unlimited	0.00%	8.15E+02	3.48E+06	0.02%
300	30.00	3.55E+02	Unlimited	0.00%	3.55E+02	2.48E+06	0.01%
310	31.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.83E+06	0.00%
320	32.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.39E+06	0.00%
330	33.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.08E+06	0.00%
340	34.00	0.00E+00	Unlimited	0.00%	0.00E+00	8.57E+05	0.00%
350	35.00	0.00E+00	Unlimited	0.00%	0.00E+00	6.89E+05	0.00%
360	36.00	0.00E+00	Unlimited	0.00%	0.00E+00	5.62E+05	0.00%
370	37.00	0.00E+00	Unlimited	0.00%	0.00E+00	4.64E+05	0.00%
380	38.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.86E+05	0.00%
390	39.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.25E+05	0.00%
400	40.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.75E+05	0.00%
			Total	0.00%		Total	0.23%



CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

QUAD-AXLE WITH DUAL TYRES (QADT)

Equivalent Stress:	0.672
Stress Ratio Factor:	0.149
Erosion Factor:	2.444

Axle Load (kN)	Design Load/Tyre (kN)	FATIGUE ANALYSIS Repetitions Expected	Allowable	Fatigue (%)	EROSION ANALYSIS Repetitions Expected	Allowable	Erosion (%)
10	0.75	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
20	1.50	8.79E+01	Unlimited	0.00%	8.79E+01	Unlimited	0.00%
30	2.25	1.54E+02	Unlimited	0.00%	1.54E+02	Unlimited	0.00%
40	3.00	1.78E+02	Unlimited	0.00%	1.78E+02	Unlimited	0.00%
50	3.75	9.18E+01	Unlimited	0.00%	9.18E+01	Unlimited	0.00%
60	4.50	8.30E+01	Unlimited	0.00%	8.30E+01	Unlimited	0.00%
70	5.25	1.77E+02	Unlimited	0.00%	1.77E+02	Unlimited	0.00%
80	6.00	1.90E+02	Unlimited	0.00%	1.90E+02	Unlimited	0.00%
90	6.75	2.22E+02	Unlimited	0.00%	2.22E+02	Unlimited	0.00%
100	7.50	1.26E+02	Unlimited	0.00%	1.26E+02	Unlimited	0.00%
110	8.25	1.53E+02	Unlimited	0.00%	1.53E+02	Unlimited	0.00%
120	9.00	1.41E+02	Unlimited	0.00%	1.41E+02	Unlimited	0.00%
130	9.75	1.13E+02	Unlimited	0.00%	1.13E+02	Unlimited	0.00%
140	10.50	9.85E+01	Unlimited	0.00%	9.85E+01	Unlimited	0.00%
150	11.25	1.56E+02	Unlimited	0.00%	1.56E+02	Unlimited	0.00%
160	12.00	1.41E+02	Unlimited	0.00%	1.41E+02	Unlimited	0.00%
170	12.75	1.50E+02	Unlimited	0.00%	1.50E+02	Unlimited	0.00%
180	13.50	1.52E+02	Unlimited	0.00%	1.52E+02	Unlimited	0.00%
190	14.25	5.17E+02	Unlimited	0.00%	5.17E+02	Unlimited	0.00%
200	15.00	2.84E+02	Unlimited	0.00%	2.84E+02	Unlimited	0.00%
210	15.75	2.52E+02	Unlimited	0.00%	2.52E+02	Unlimited	0.00%
220	16.50	2.89E+02	Unlimited	0.00%	2.89E+02	Unlimited	0.00%
230	17.25	3.05E+01	Unlimited	0.00%	3.05E+01	Unlimited	0.00%
240	18.00	1.75E+02	Unlimited	0.00%	1.75E+02	1.17E+08	0.00%
250	18.75	1.02E+02	Unlimited	0.00%	1.02E+02	3.18E+07	0.00%
260	19.50	1.72E+02	Unlimited	0.00%	1.72E+02	1.45E+07	0.00%
270	20.25	0.00E+00	Unlimited	0.00%	0.00E+00	8.16E+06	0.00%
280	21.00	1.30E+02	Unlimited	0.00%	1.30E+02	5.14E+06	0.00%
290	21.75	2.11E+02	Unlimited	0.00%	2.11E+02	3.48E+06	0.01%
300	22.50	8.02E+01	Unlimited	0.00%	8.02E+01	2.48E+06	0.00%
310	23.25	4.79E+01	Unlimited	0.00%	4.79E+01	1.83E+06	0.00%
320	24.00	1.11E+02	Unlimited	0.00%	1.11E+02	1.39E+06	0.01%
330	24.75	1.43E+02	Unlimited	0.00%	1.43E+02	1.08E+06	0.01%
340	25.50	6.15E+01	Unlimited	0.00%	6.15E+01	8.57E+05	0.01%
350	26.25	8.02E+01	Unlimited	0.00%	8.02E+01	6.89E+05	0.01%
360	27.00	0.00E+00	Unlimited	0.00%	0.00E+00	5.62E+05	0.00%
370	27.75	0.00E+00	Unlimited	0.00%	0.00E+00	4.64E+05	0.00%
380	28.50	0.00E+00	Unlimited	0.00%	0.00E+00	3.86E+05	0.00%
390	29.25	0.00E+00	Unlimited	0.00%	0.00E+00	3.25E+05	0.00%
400	30.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.75E+05	0.00%
			Total	0.00%		Total	0.05%

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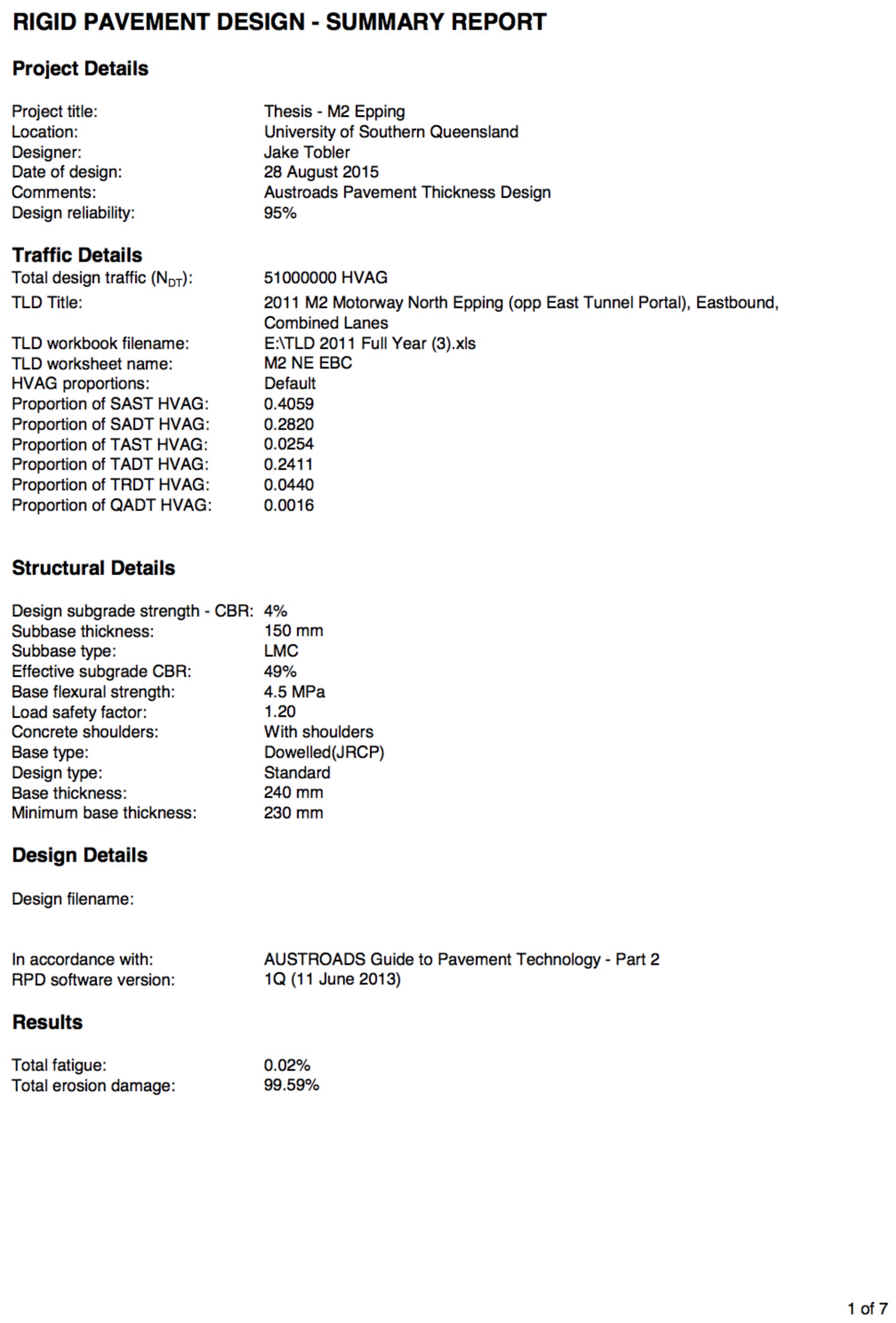


RIGID PAVEMENT DESIGN - SUMMARY REPORT

Project Details

Project title: Thesis - M2 Epping
Location: University of Southern Queensland
Designer: Jake Tobler
Date of design: 28 August 2015
Comments: Austroads Pavement Thickness Design
Design reliability: 95%

Traffic Details

Total design traffic (N_{DT}): 51000000 HVAG
TLD Title: 2011 M2 Motorway North Epping (opp East Tunnel Portal), Eastbound, Combined Lanes
TLD workbook filename: E:\TLD 2011 Full Year (3).xls
TLD worksheet name: M2 NE EBC
HVAG proportions: Default
Proportion of SAST HVAG: 0.4059
Proportion of SADT HVAG: 0.2820
Proportion of TAST HVAG: 0.0254
Proportion of TADT HVAG: 0.2411
Proportion of TRDT HVAG: 0.0440
Proportion of QADT HVAG: 0.0016

Structural Details

Design subgrade strength - CBR: 4%
Subbase thickness: 150 mm
Subbase type: LMC
Effective subgrade CBR: 49%
Base flexural strength: 4.5 MPa
Load safety factor: 1.20
Concrete shoulders: With shoulders
Base type: Dowelled(JRCP)
Design type: Standard
Base thickness: 240 mm
Minimum base thickness: 230 mm

Design Details

Design filename:

In accordance with: AUSTROADS Guide to Pavement Technology - Part 2
RPD software version: 1Q (11 June 2013)

Results

Total fatigue: 0.02%
Total erosion damage: 99.59%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT

SINGLE AXLE WITH SINGLE TYRES (SAST)

Equivalent Stress:	0.627
Stress Ratio Factor:	0.139
Erosion Factor:	1.733

Axle Load (kN)	Design Load/Tyre (kN)	FATIGUE ANALYSIS Repetitions		Fatigue (%)	EROSION ANALYSIS Repetitions		Erosion (%)
		Expected	Allowable		Expected	Allowable	
10	6.00	8.45E+05	Unlimited	0.00%	8.45E+05	Unlimited	0.00%
20	12.00	2.43E+06	Unlimited	0.00%	2.43E+06	Unlimited	0.00%
30	18.00	1.85E+06	Unlimited	0.00%	1.85E+06	Unlimited	0.00%
40	24.00	3.34E+06	Unlimited	0.00%	3.34E+06	Unlimited	0.00%
50	30.00	5.69E+06	Unlimited	0.00%	5.69E+06	Unlimited	0.00%
60	36.00	4.78E+06	Unlimited	0.00%	4.78E+06	Unlimited	0.00%
70	42.00	1.54E+06	Unlimited	0.00%	1.54E+06	Unlimited	0.00%
80	48.00	1.92E+05	Unlimited	0.00%	1.92E+05	Unlimited	0.00%
90	54.00	2.83E+04	Unlimited	0.00%	2.83E+04	1.69E+08	0.02%
100	60.00	6.25E+03	Unlimited	0.00%	6.25E+03	1.08E+07	0.06%
110	66.00	0.00E+00	3.71E+07	0.00%	0.00E+00	3.33E+06	0.00%
120	72.00	0.00E+00	1.17E+06	0.00%	0.00E+00	1.48E+06	0.00%
130	78.00	0.00E+00	2.29E+05	0.00%	0.00E+00	7.81E+05	0.00%
140	84.00	0.00E+00	7.48E+04	0.00%	0.00E+00	4.58E+05	0.00%
150	90.00	0.00E+00	2.60E+04	0.00%	0.00E+00	2.88E+05	0.00%
160	96.00	0.00E+00	9.04E+03	0.00%	0.00E+00	1.91E+05	0.00%
170	102.00	0.00E+00	3.16E+03	0.00%	0.00E+00	1.31E+05	0.00%
180	108.00	0.00E+00	1.11E+03	0.00%	0.00E+00	9.30E+04	0.00%
190	114.00	0.00E+00	3.91E+02	0.00%	0.00E+00	6.76E+04	0.00%
200	120.00	0.00E+00	1.38E+02	0.00%	0.00E+00	5.02E+04	0.00%
210	126.00	0.00E+00	4.89E+01	0.00%	0.00E+00	3.79E+04	0.00%
220	132.00	0.00E+00	1.74E+01	0.00%	0.00E+00	2.91E+04	0.00%
230	138.00	0.00E+00	6.20E+00	0.00%	0.00E+00	2.26E+04	0.00%
240	144.00	0.00E+00	2.22E+00	0.00%	0.00E+00	1.78E+04	0.00%
250	150.00	0.00E+00	7.94E-01	0.00%	0.00E+00	1.41E+04	0.00%
260	156.00	0.00E+00	2.85E-01	0.00%	0.00E+00	1.13E+04	0.00%
270	162.00	0.00E+00	1.03E-01	0.00%	0.00E+00	9.17E+03	0.00%
280	168.00	0.00E+00	3.71E-02	0.00%	0.00E+00	7.48E+03	0.00%
290	174.00	0.00E+00	1.34E-02	0.00%	0.00E+00	6.14E+03	0.00%
300	180.00	0.00E+00	4.86E-03	0.00%	0.00E+00	5.08E+03	0.00%
310	186.00	0.00E+00	1.77E-03	0.00%	0.00E+00	4.22E+03	0.00%
320	192.00	0.00E+00	6.43E-04	0.00%	0.00E+00	3.53E+03	0.00%
330	198.00	0.00E+00	2.34E-04	0.00%	0.00E+00	2.97E+03	0.00%
340	204.00	0.00E+00	8.57E-05	0.00%	0.00E+00	2.51E+03	0.00%
350	210.00	0.00E+00	3.13E-05	0.00%	0.00E+00	2.13E+03	0.00%
360	216.00	0.00E+00	1.15E-05	0.00%	0.00E+00	1.81E+03	0.00%
370	222.00	0.00E+00	4.22E-06	0.00%	0.00E+00	1.55E+03	0.00%
380	228.00	0.00E+00	1.55E-06	0.00%	0.00E+00	1.33E+03	0.00%
390	234.00	0.00E+00	5.72E-07	0.00%	0.00E+00	1.15E+03	0.00%
400	240.00	0.00E+00	2.11E-07	0.00%	0.00E+00	9.91E+02	0.00%
			Total	0.00%		Total	0.08%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

SINGLE AXLES WITH DUAL TYRES (SADT)

Equivalent Stress:	0.957
Stress Ratio Factor:	0.213
Erosion Factor:	2.333

Axle	**Design**	**FATIGUE ANALYSIS**			**EROSION ANALYSIS**		
Load	**Load/Tyre**	**Repetitions**		**Fatigue**	**Repetitions**		**Erosion**
(kN)	**(kN)**	**Expected**	**Allowable**	**(%)**	**Expected**	**Allowable**	**(%)**
10	3.00	7.72E+05	Unlimited	0.00%	7.72E+05	Unlimited	0.00%
20	6.00	2.18E+06	Unlimited	0.00%	2.18E+06	Unlimited	0.00%
30	9.00	1.94E+06	Unlimited	0.00%	1.94E+06	Unlimited	0.00%
40	12.00	1.92E+06	Unlimited	0.00%	1.92E+06	Unlimited	0.00%
50	15.00	1.24E+06	Unlimited	0.00%	1.24E+06	Unlimited	0.00%
60	18.00	1.09E+06	Unlimited	0.00%	1.09E+06	Unlimited	0.00%
70	21.00	6.88E+05	Unlimited	0.00%	6.88E+05	Unlimited	0.00%
80	24.00	9.79E+05	Unlimited	0.00%	9.79E+05	Unlimited	0.00%
90	27.00	1.62E+06	Unlimited	0.00%	1.62E+06	1.90E+08	0.85%
100	30.00	1.21E+06	Unlimited	0.00%	1.21E+06	1.12E+07	10.79%
110	33.00	5.11E+05	Unlimited	0.00%	5.11E+05	3.40E+06	15.03%
120	36.00	1.62E+05	Unlimited	0.00%	1.62E+05	1.50E+06	10.75%
130	39.00	6.27E+04	Unlimited	0.00%	6.27E+04	7.93E+05	7.91%
140	42.00	1.06E+04	4.59E+07	0.02%	1.06E+04	4.65E+05	2.27%
150	45.00	0.00E+00	2.10E+06	0.00%	0.00E+00	2.92E+05	0.00%
160	48.00	0.00E+00	4.43E+05	0.00%	0.00E+00	1.93E+05	0.00%
170	51.00	0.00E+00	1.56E+05	0.00%	0.00E+00	1.33E+05	0.00%
180	54.00	0.00E+00	6.73E+04	0.00%	0.00E+00	9.41E+04	0.00%
190	57.00	0.00E+00	2.94E+04	0.00%	0.00E+00	6.84E+04	0.00%
200	60.00	0.00E+00	1.28E+04	0.00%	0.00E+00	5.08E+04	0.00%
210	63.00	0.00E+00	5.63E+03	0.00%	0.00E+00	3.83E+04	0.00%
220	66.00	0.00E+00	2.48E+03	0.00%	0.00E+00	2.94E+04	0.00%
230	69.00	0.00E+00	1.09E+03	0.00%	0.00E+00	2.29E+04	0.00%
240	72.00	0.00E+00	4.81E+02	0.00%	0.00E+00	1.80E+04	0.00%
250	75.00	0.00E+00	2.13E+02	0.00%	0.00E+00	1.43E+04	0.00%
260	78.00	0.00E+00	9.44E+01	0.00%	0.00E+00	1.15E+04	0.00%
270	81.00	0.00E+00	4.19E+01	0.00%	0.00E+00	9.27E+03	0.00%
280	84.00	0.00E+00	1.86E+01	0.00%	0.00E+00	7.56E+03	0.00%
290	87.00	0.00E+00	8.31E+00	0.00%	0.00E+00	6.21E+03	0.00%
300	90.00	0.00E+00	3.71E+00	0.00%	0.00E+00	5.13E+03	0.00%
310	93.00	0.00E+00	1.66E+00	0.00%	0.00E+00	4.27E+03	0.00%
320	96.00	0.00E+00	7.42E-01	0.00%	0.00E+00	3.57E+03	0.00%
330	99.00	0.00E+00	3.33E-01	0.00%	0.00E+00	3.00E+03	0.00%
340	102.00	0.00E+00	1.49E-01	0.00%	0.00E+00	2.53E+03	0.00%
350	105.00	0.00E+00	6.72E-02	0.00%	0.00E+00	2.15E+03	0.00%
360	108.00	0.00E+00	3.03E-02	0.00%	0.00E+00	1.83E+03	0.00%
370	111.00	0.00E+00	1.37E-02	0.00%	0.00E+00	1.57E+03	0.00%
380	114.00	0.00E+00	6.17E-03	0.00%	0.00E+00	1.35E+03	0.00%
390	117.00	0.00E+00	2.79E-03	0.00%	0.00E+00	1.16E+03	0.00%
400	120.00	0.00E+00	1.26E-03	0.00%	0.00E+00	1.00E+03	0.00%
			Total	0.02%		Total	47.60%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

TANDEM AXLE WITH SINGLE TYRES (TAST)

Equivalent Stress:	0.627
Stress Ratio Factor:	0.139
Erosion Factor:	2.391

Axle Load (kN)	Design Load/Tyre (kN)	FATIGUE ANALYSIS			EROSION ANALYSIS		
		Repetitions		Fatigue	Repetitions		Erosion
		Expected	Allowable	(%)	Expected	Allowable	(%)
10	3.00	4.19E+04	Unlimited	0.00%	4.19E+04	Unlimited	0.00%
20	6.00	1.56E+05	Unlimited	0.00%	1.56E+05	Unlimited	0.00%
30	9.00	5.44E+04	Unlimited	0.00%	5.44E+04	Unlimited	0.00%
40	12.00	1.36E+04	Unlimited	0.00%	1.36E+04	Unlimited	0.00%
50	15.00	7.44E+03	Unlimited	0.00%	7.44E+03	Unlimited	0.00%
60	18.00	3.80E+04	Unlimited	0.00%	3.80E+04	Unlimited	0.00%
70	21.00	7.46E+04	Unlimited	0.00%	7.46E+04	Unlimited	0.00%
80	24.00	1.48E+05	Unlimited	0.00%	1.48E+05	Unlimited	0.00%
90	27.00	2.22E+05	Unlimited	0.00%	2.22E+05	2.23E+07	1.00%
100	30.00	2.10E+05	Unlimited	0.00%	2.10E+05	4.68E+06	4.48%
110	33.00	1.42E+05	Unlimited	0.00%	1.42E+05	1.80E+06	7.86%
120	36.00	1.34E+05	Unlimited	0.00%	1.34E+05	8.82E+05	15.23%
130	39.00	3.77E+04	Unlimited	0.00%	3.77E+04	4.91E+05	7.67%
140	42.00	7.44E+03	Unlimited	0.00%	7.44E+03	2.98E+05	2.50%
150	45.00	8.37E+03	Unlimited	0.00%	8.37E+03	1.91E+05	4.38%
160	48.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.28E+05	0.00%
170	51.00	0.00E+00	Unlimited	0.00%	0.00E+00	8.93E+04	0.00%
180	54.00	0.00E+00	Unlimited	0.00%	0.00E+00	6.38E+04	0.00%
190	57.00	0.00E+00	Unlimited	0.00%	0.00E+00	4.66E+04	0.00%
200	60.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.47E+04	0.00%
210	63.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.63E+04	0.00%
220	66.00	0.00E+00	3.71E+07	0.00%	0.00E+00	2.02E+04	0.00%
230	69.00	0.00E+00	4.25E+06	0.00%	0.00E+00	1.57E+04	0.00%
240	72.00	0.00E+00	1.17E+06	0.00%	0.00E+00	1.24E+04	0.00%
250	75.00	0.00E+00	4.67E+05	0.00%	0.00E+00	9.86E+03	0.00%
260	78.00	0.00E+00	2.29E+05	0.00%	0.00E+00	7.91E+03	0.00%
270	81.00	0.00E+00	1.27E+05	0.00%	0.00E+00	6.40E+03	0.00%
280	84.00	0.00E+00	7.48E+04	0.00%	0.00E+00	5.22E+03	0.00%
290	87.00	0.00E+00	4.40E+04	0.00%	0.00E+00	4.28E+03	0.00%
300	90.00	0.00E+00	2.60E+04	0.00%	0.00E+00	3.54E+03	0.00%
310	93.00	0.00E+00	1.53E+04	0.00%	0.00E+00	2.94E+03	0.00%
320	96.00	0.00E+00	9.04E+03	0.00%	0.00E+00	2.46E+03	0.00%
330	99.00	0.00E+00	5.34E+03	0.00%	0.00E+00	2.06E+03	0.00%
340	102.00	0.00E+00	3.16E+03	0.00%	0.00E+00	1.74E+03	0.00%
350	105.00	0.00E+00	1.87E+03	0.00%	0.00E+00	1.48E+03	0.00%
360	108.00	0.00E+00	1.11E+03	0.00%	0.00E+00	1.26E+03	0.00%
370	111.00	0.00E+00	6.58E+02	0.00%	0.00E+00	1.07E+03	0.00%
380	114.00	0.00E+00	3.91E+02	0.00%	0.00E+00	9.21E+02	0.00%
390	117.00	0.00E+00	2.32E+02	0.00%	0.00E+00	7.93E+02	0.00%
400	120.00	0.00E+00	1.38E+02	0.00%	0.00E+00	6.85E+02	0.00%
			Total	0.00%		Total	43.12%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

TANDEM AXLE WITH DUAL TYRES (TADT)

Equivalent Stress:	0.802
Stress Ratio Factor:	0.178
Erosion Factor:	2.391

Axle	**Design**		**FATIGUE ANALYSIS**			**EROSION ANALYSIS**	
Load	**Load/Tyre**		**Repetitions**	**Fatigue**		**Repetitions**	**Erosion**
(kN)	**1.5**	**3739.96**	**Unlimited**	**0**	**3739.96**	**Unlimited**	**0**
10	1.50	3.96E+04	Unlimited	0.00%	3.96E+04	Unlimited	0.00%
20	3.00	1.25E+05	Unlimited	0.00%	1.25E+05	Unlimited	0.00%
30	4.50	1.50E+05	Unlimited	0.00%	1.50E+05	Unlimited	0.00%
40	6.00	8.15E+05	Unlimited	0.00%	8.15E+05	Unlimited	0.00%
50	7.50	6.12E+05	Unlimited	0.00%	6.12E+05	Unlimited	0.00%
60	9.00	1.12E+06	Unlimited	0.00%	1.12E+06	Unlimited	0.00%
70	10.50	1.53E+06	Unlimited	0.00%	1.53E+06	Unlimited	0.00%
80	12.00	1.11E+06	Unlimited	0.00%	1.11E+06	Unlimited	0.00%
90	13.50	6.48E+05	Unlimited	0.00%	6.48E+05	Unlimited	0.00%
100	15.00	6.58E+05	Unlimited	0.00%	6.58E+05	Unlimited	0.00%
110	16.50	1.37E+06	Unlimited	0.00%	1.37E+06	Unlimited	0.00%
120	18.00	1.11E+06	Unlimited	0.00%	1.11E+06	Unlimited	0.00%
130	19.50	7.58E+05	Unlimited	0.00%	7.58E+05	Unlimited	0.00%
140	21.00	4.45E+05	Unlimited	0.00%	4.45E+05	Unlimited	0.00%
150	22.50	4.35E+05	Unlimited	0.00%	4.35E+05	Unlimited	0.00%
160	24.00	4.65E+05	Unlimited	0.00%	4.65E+05	Unlimited	0.00%
170	25.50	3.74E+05	Unlimited	0.00%	3.74E+05	1.19E+08	0.31%
180	27.00	2.29E+05	Unlimited	0.00%	2.29E+05	2.23E+07	1.03%
190	28.50	1.26E+05	Unlimited	0.00%	1.26E+05	8.98E+06	1.40%
200	30.00	1.04E+05	Unlimited	0.00%	1.04E+05	4.68E+06	2.23%
210	31.50	4.09E+04	Unlimited	0.00%	4.09E+04	2.79E+06	1.47%
220	33.00	1.64E+04	Unlimited	0.00%	1.64E+04	1.80E+06	0.91%
230	34.50	1.72E+04	Unlimited	0.00%	1.72E+04	1.24E+06	1.40%
240	36.00	0.00E+00	Unlimited	0.00%	0.00E+00	8.82E+05	0.00%
250	37.50	0.00E+00	Unlimited	0.00%	0.00E+00	6.50E+05	0.00%
260	39.00	0.00E+00	Unlimited	0.00%	0.00E+00	4.91E+05	0.00%
270	40.50	0.00E+00	Unlimited	0.00%	0.00E+00	3.79E+05	0.00%
280	42.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.98E+05	0.00%
290	43.50	0.00E+00	Unlimited	0.00%	0.00E+00	2.37E+05	0.00%
300	45.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.91E+05	0.00%
310	46.50	0.00E+00	Unlimited	0.00%	0.00E+00	1.56E+05	0.00%
320	48.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.28E+05	0.00%
330	49.50	0.00E+00	Unlimited	0.00%	0.00E+00	1.07E+05	0.00%
340	51.00	0.00E+00	2.96E+07	0.00%	0.00E+00	8.93E+04	0.00%
350	52.50	0.00E+00	6.77E+06	0.00%	0.00E+00	7.52E+04	0.00%
360	54.00	0.00E+00	2.47E+06	0.00%	0.00E+00	6.38E+04	0.00%
370	55.50	0.00E+00	1.14E+06	0.00%	0.00E+00	5.44E+04	0.00%
380	57.00	0.00E+00	6.14E+05	0.00%	0.00E+00	4.66E+04	0.00%
390	58.50	0.00E+00	3.64E+05	0.00%	0.00E+00	4.01E+04	0.00%
400	60.00	0.00E+00	2.33E+05	0.00%	0.00E+00	3.47E+04	0.00%
			Total	0.00%		Total	8.75%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

TRIAXLE WITH DUAL TYRES (TRDT)

Equivalent Stress:	0.633
Stress Ratio Factor:	0.141
Erosion Factor:	2.410

Axle	Design		FATIGUE ANALYSIS			EROSION ANALYSIS	
Load	Load/Tyre		Repetitions	Fatigue		Repetitions	Erosion
(kN)	(kN)	Expected	Allowable	(%)	Expected	Allowable	(%)
10	1.00	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
20	2.00	2.26E+04	Unlimited	0.00%	2.26E+04	Unlimited	0.00%
30	3.00	1.89E+04	Unlimited	0.00%	1.89E+04	Unlimited	0.00%
40	4.00	2.64E+04	Unlimited	0.00%	2.64E+04	Unlimited	0.00%
50	5.00	6.26E+04	Unlimited	0.00%	6.26E+04	Unlimited	0.00%
60	6.00	1.27E+05	Unlimited	0.00%	1.27E+05	Unlimited	0.00%
70	7.00	3.11E+05	Unlimited	0.00%	3.11E+05	Unlimited	0.00%
80	8.00	2.97E+05	Unlimited	0.00%	2.97E+05	Unlimited	0.00%
90	9.00	2.38E+05	Unlimited	0.00%	2.38E+05	Unlimited	0.00%
100	10.00	1.80E+05	Unlimited	0.00%	1.80E+05	Unlimited	0.00%
110	11.00	1.25E+05	Unlimited	0.00%	1.25E+05	Unlimited	0.00%
120	12.00	9.35E+04	Unlimited	0.00%	9.35E+04	Unlimited	0.00%
130	13.00	5.81E+04	Unlimited	0.00%	5.81E+04	Unlimited	0.00%
140	14.00	8.15E+04	Unlimited	0.00%	8.15E+04	Unlimited	0.00%
150	15.00	5.28E+04	Unlimited	0.00%	5.28E+04	Unlimited	0.00%
160	16.00	5.81E+04	Unlimited	0.00%	5.81E+04	Unlimited	0.00%
170	17.00	5.58E+04	Unlimited	0.00%	5.58E+04	Unlimited	0.00%
180	18.00	9.35E+04	Unlimited	0.00%	9.35E+04	Unlimited	0.00%
190	19.00	6.94E+04	Unlimited	0.00%	6.94E+04	Unlimited	0.00%
200	20.00	8.90E+04	Unlimited	0.00%	8.90E+04	Unlimited	0.00%
210	21.00	7.47E+04	Unlimited	0.00%	7.47E+04	Unlimited	0.00%
220	22.00	4.37E+04	Unlimited	0.00%	4.37E+04	Unlimited	0.00%
230	23.00	3.02E+04	Unlimited	0.00%	3.02E+04	Unlimited	0.00%
240	24.00	8.29E+03	Unlimited	0.00%	8.29E+03	Unlimited	0.00%
250	25.00	1.36E+04	Unlimited	0.00%	1.36E+04	1.05E+08	0.01%
260	26.00	1.28E+04	Unlimited	0.00%	1.28E+04	3.11E+07	0.04%
270	27.00	1.51E+03	Unlimited	0.00%	1.51E+03	1.47E+07	0.01%
280	28.00	0.00E+00	Unlimited	0.00%	0.00E+00	8.39E+06	0.00%
290	29.00	0.00E+00	Unlimited	0.00%	0.00E+00	5.34E+06	0.00%
300	30.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.65E+06	0.00%
310	31.00	0.00E+00	Unlimited	0.00%	0.00E+00	2.61E+06	0.00%
320	32.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.94E+06	0.00%
330	33.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.48E+06	0.00%
340	34.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.16E+06	0.00%
350	35.00	0.00E+00	Unlimited	0.00%	0.00E+00	9.21E+05	0.00%
360	36.00	0.00E+00	Unlimited	0.00%	0.00E+00	7.43E+05	0.00%
370	37.00	0.00E+00	Unlimited	0.00%	0.00E+00	6.08E+05	0.00%
380	38.00	0.00E+00	Unlimited	0.00%	0.00E+00	5.03E+05	0.00%
390	39.00	0.00E+00	Unlimited	0.00%	0.00E+00	4.20E+05	0.00%
400	40.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.54E+05	0.00%
			Total	0.00%		Total	0.06%

CONCRETE PAVEMENT DESIGN - DETAILED REPORT (ctd)

QUAD-AXLE WITH DUAL TYRES (QADT)

Equivalent Stress:	0.633
Stress Ratio Factor:	0.141
Erosion Factor:	2.410

Axle	Design		FATIGUE ANALYSIS			EROSION ANALYSIS	
Load	Load/Tyre	Repetitions		Fatigue	Repetitions		Erosion
(kN)	(kN)	Expected	Allowable	(%)	Expected	Allowable	(%)
10	0.75	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
20	1.50	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
30	2.25	3.56E+04	Unlimited	0.00%	3.56E+04	Unlimited	0.00%
40	3.00	5.08E+03	Unlimited	0.00%	5.08E+03	Unlimited	0.00%
50	3.75	5.08E+03	Unlimited	0.00%	5.08E+03	Unlimited	0.00%
60	4.50	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
70	5.25	5.08E+03	Unlimited	0.00%	5.08E+03	Unlimited	0.00%
80	6.00	5.08E+03	Unlimited	0.00%	5.08E+03	Unlimited	0.00%
90	6.75	5.08E+03	Unlimited	0.00%	5.08E+03	Unlimited	0.00%
100	7.50	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
110	8.25	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
120	9.00	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
130	9.75	1.52E+04	Unlimited	0.00%	1.52E+04	Unlimited	0.00%
140	10.50	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
150	11.25	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
160	12.00	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
170	12.75	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
180	13.50	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
190	14.25	5.08E+03	Unlimited	0.00%	5.08E+03	Unlimited	0.00%
200	15.00	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
210	15.75	3.18E+02	Unlimited	0.00%	3.18E+02	Unlimited	0.00%
220	16.50	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
230	17.25	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
240	18.00	0.00E+00	Unlimited	0.00%	0.00E+00	Unlimited	0.00%
250	18.75	0.00E+00	Unlimited	0.00%	0.00E+00	1.05E+08	0.00%
260	19.50	0.00E+00	Unlimited	0.00%	0.00E+00	3.11E+07	0.00%
270	20.25	0.00E+00	Unlimited	0.00%	0.00E+00	1.47E+07	0.00%
280	21.00	0.00E+00	Unlimited	0.00%	0.00E+00	8.39E+06	0.00%
290	21.75	0.00E+00	Unlimited	0.00%	0.00E+00	5.34E+06	0.00%
300	22.50	0.00E+00	Unlimited	0.00%	0.00E+00	3.65E+06	0.00%
310	23.25	0.00E+00	Unlimited	0.00%	0.00E+00	2.61E+06	0.00%
320	24.00	0.00E+00	Unlimited	0.00%	0.00E+00	1.94E+06	0.00%
330	24.75	0.00E+00	Unlimited	0.00%	0.00E+00	1.48E+06	0.00%
340	25.50	0.00E+00	Unlimited	0.00%	0.00E+00	1.16E+06	0.00%
350	26.25	0.00E+00	Unlimited	0.00%	0.00E+00	9.21E+05	0.00%
360	27.00	0.00E+00	Unlimited	0.00%	0.00E+00	7.43E+05	0.00%
370	27.75	0.00E+00	Unlimited	0.00%	0.00E+00	6.08E+05	0.00%
380	28.50	0.00E+00	Unlimited	0.00%	0.00E+00	5.03E+05	0.00%
390	29.25	0.00E+00	Unlimited	0.00%	0.00E+00	4.20E+05	0.00%
400	30.00	0.00E+00	Unlimited	0.00%	0.00E+00	3.54E+05	0.00%
			Total	0.00%		Total	0.00%

Appendix D – EverFE Results

Current Loading Conditions

	CURRENT LOAD (Austroads Condition 600mm from edgeline)							
	+10 Degrees		-10 Degrees		+25 Degrees		-25 Degrees	
	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded
SAST	3.02036	2.08819	3.3591	2.33965	3.348	5.27924	3.88266	5.25661
SADT	3.05911	2.39288	3.36233	2.3996	3.34732	5.2669	3.88534	5.37423
TAST	3.05029	2.07563	3.35418	2.37472	3.3496	5.28341	3.8679	5.36701
TADT	3.06345	2.31074	3.35542	2.44182	3.34982	5.2466	3.8673	5.48688
TRDT	3.07206	2.13521	3.37173	2.27645	3.35522	5.31396	3.8578	5.30892
QADT	3.05523	2.14607	3.35992	2.24021	3.37826	5.33815	3.85829	5.22779

Current Loading Conditions

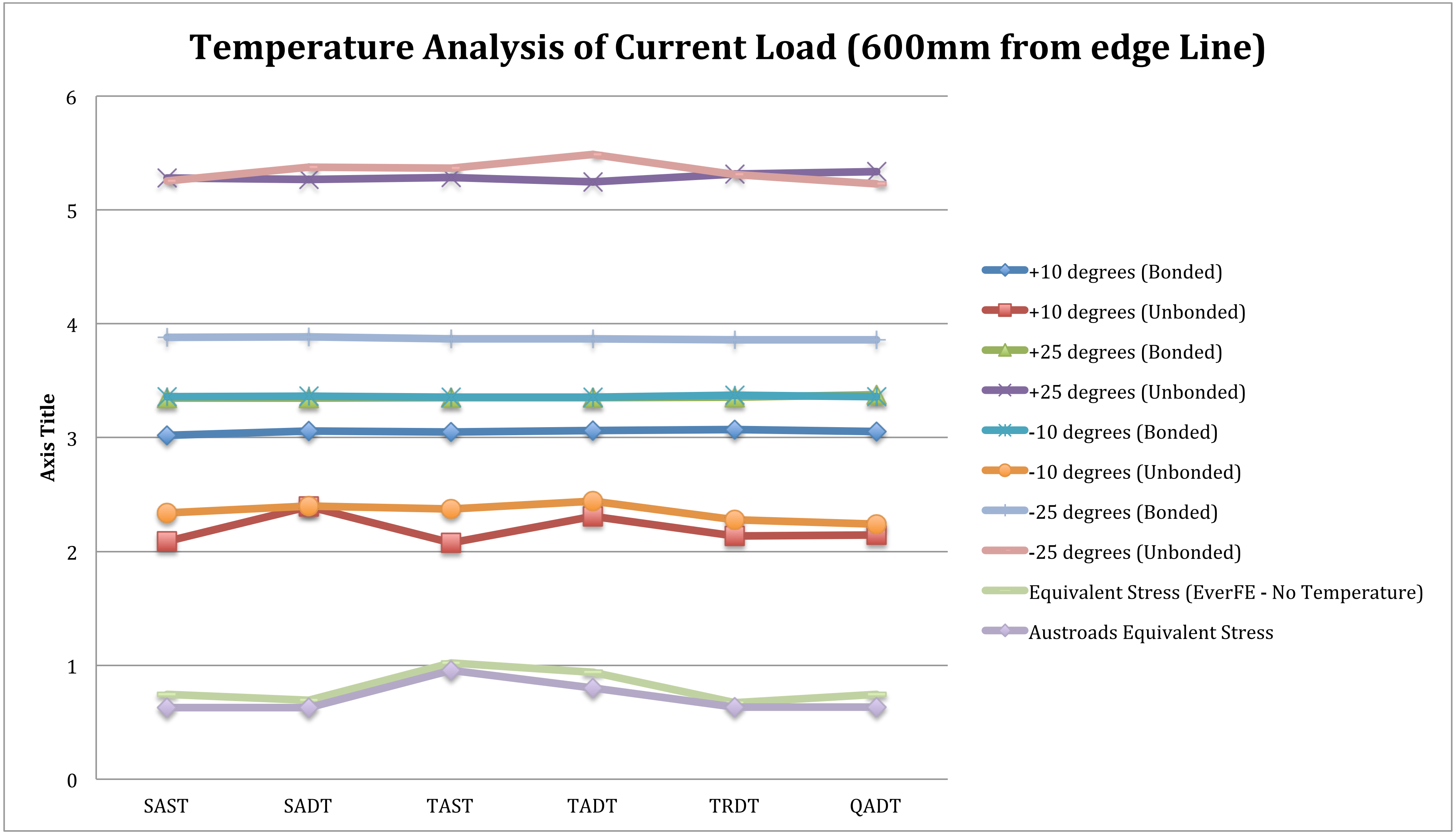
	CURRENT LOAD (100mm from edgeline)							
	+10 Degrees		-10 Degrees		+25 Degrees		-25 Degrees	
	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded
SAST	3.10753	2.193	3.3588	2.32953	3.38729	5.35258	3.8784	5.21342
SADT	3.10374	2.46923	3.35913	2.39971	3.38668	5.29633	3.87814	5.3174
TAST	3.14545	2.06681	3.36252	2.36522	3.4253	5.38907	3.87168	5.3753
TADT	3.14744	2.26917	3.36246	2.45254	3.42585	5.28164	3.8715	5.49825
TRDT	3.12933	2.12091	3.36434	2.26901	3.45135	5.42322	3.86531	5.34669
QADT	3.18991	2.13112	3.35425	2.23614	3.49456	5.59036	3.86242	5.17371

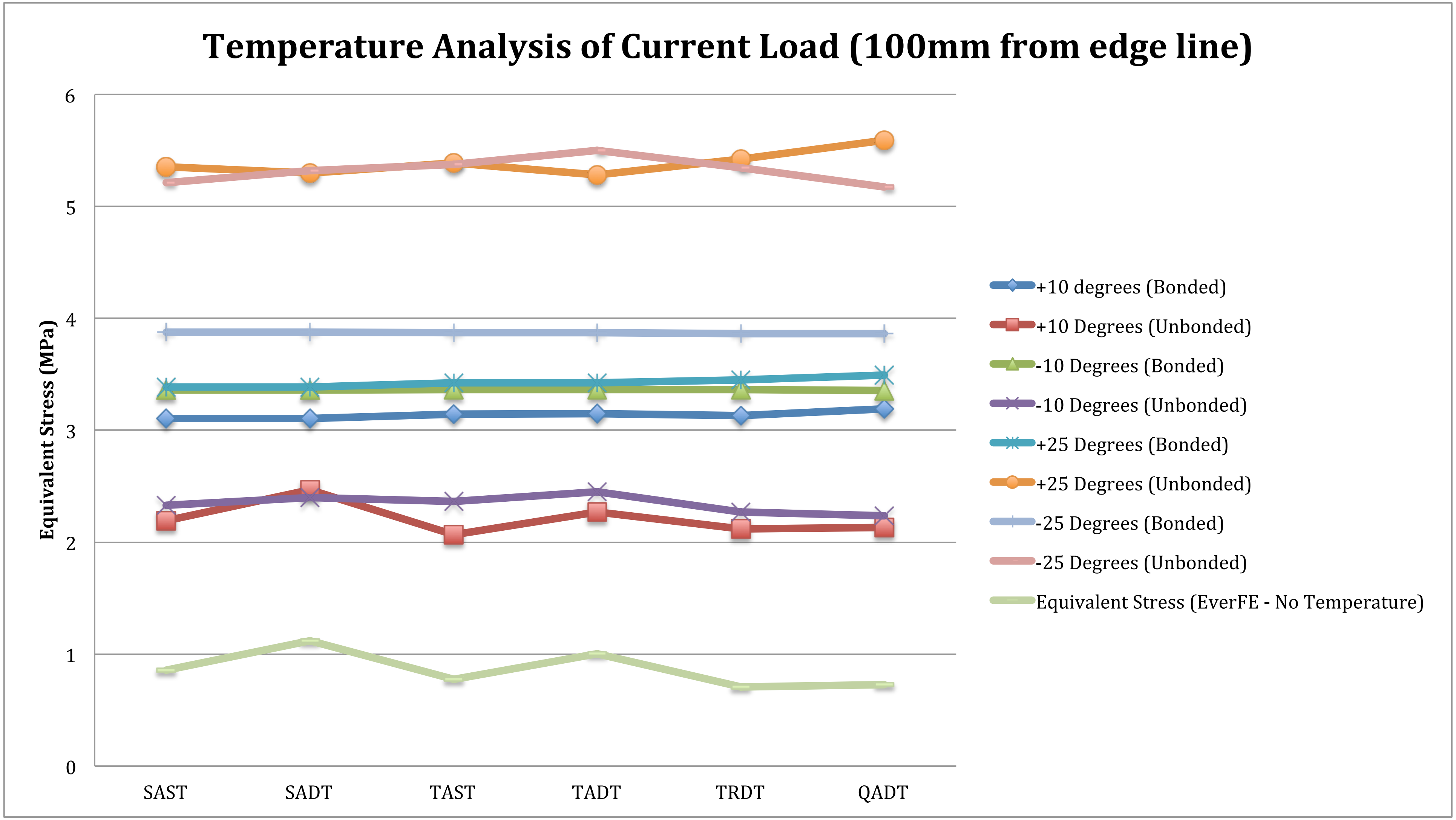
Future Loading Conditions

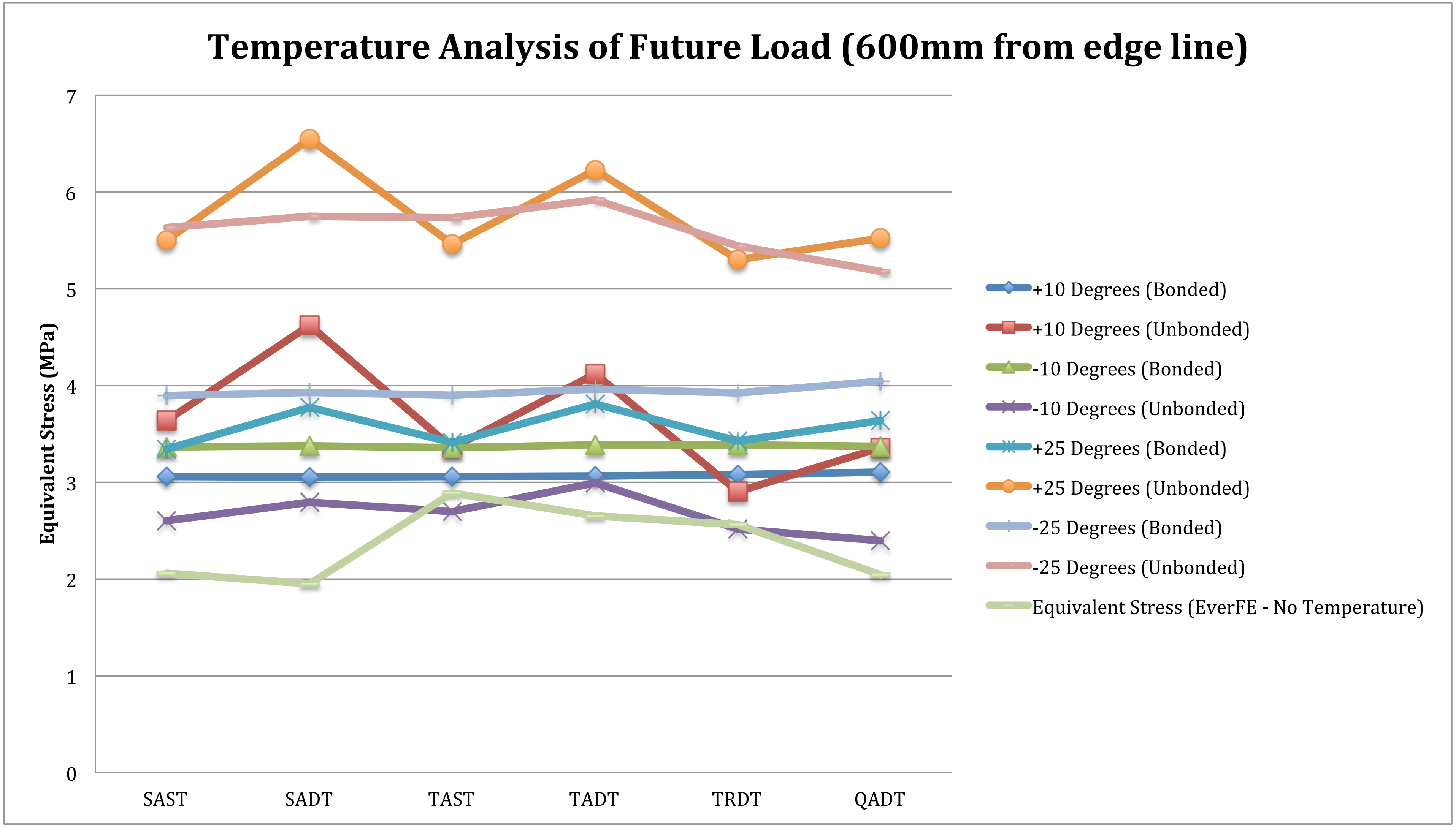
	FUTURE LOAD (Austroads Condition 600mm from edgeline)							
	+10 Degrees		-10 Degrees		+25 Degrees		-25 Degrees	
	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded
SAST	3.05864	3.63691	3.36757	2.60506	3.34317	5.50338	3.89604	5.63093
SADT	3.05555	4.62435	3.37817	2.79341	3.77524	6.54702	3.93192	5.74926
TAST	3.06252	3.35513	3.35852	2.69784	3.41225	5.4609	3.90173	5.73162
TADT	3.06316	4.11912	3.38728	2.99737	3.80998	6.22439	3.9623	5.92167
TRDT	3.08098	2.90357	3.38719	2.51909	3.4247	5.30094	3.92265	5.44361
QADT	3.10647	3.35627	3.37394	2.39516	3.63992	5.52062	4.04697	5.1795

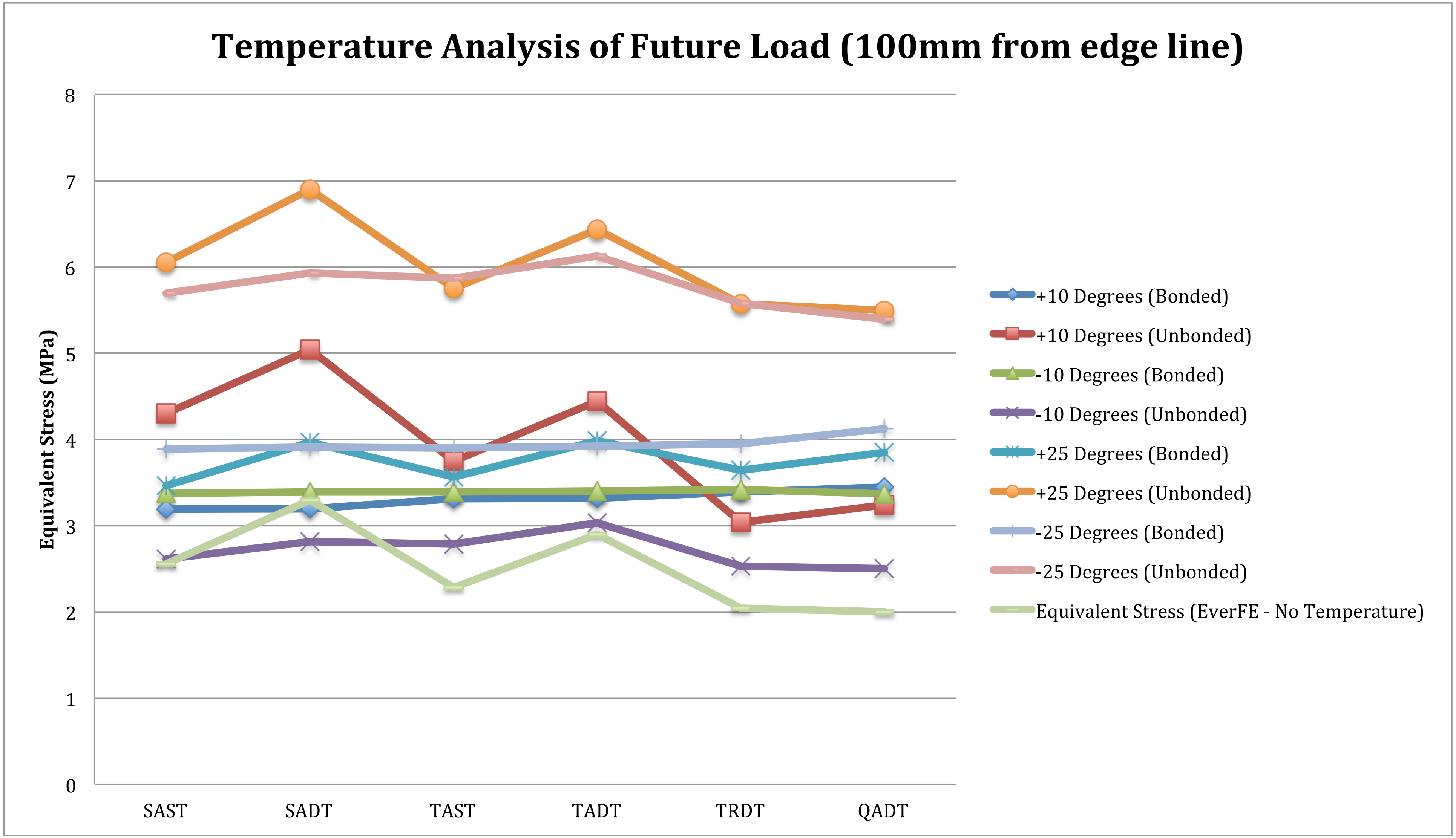
Future Loading Conditions

	FUTURE LOAD (100mm from edgeline)							
	+10 Degrees		-10 Degrees		+25 Degrees		-25 Degrees	
	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded	Bonded	Unbonded
SAST	3.19285	4.30422	3.37497	2.6128	3.46423	6.05384	3.88841	5.69747
SADT	3.19413	5.04016	3.38994	2.81804	3.96629	6.89941	3.90928	5.93011
TAST	3.31211	3.75073	3.39135	2.79058	3.5636	5.7511	3.89876	5.86892
TADT	3.31766	4.44555	3.40252	3.03168	3.9867	6.43613	3.922252	6.12436
TRDT	3.38914	3.03908	3.41761	2.52801	3.64082	5.57166	3.95364	5.57678
QADT	3.4465	3.23902	3.3691	2.50219	3.8492	5.49694	4.1228	5.39425


Temperature Analysis of Current Load (600mm from edge Line)
Axis Title
0
1
2
3
4
5
6
SAST
SADT
TAST
TADT
TRDT
QADT
+10 degrees (Bonded)
+10 degrees (Unbonded)
+25 degrees (Bonded)
+25 degrees (Unbonded)
-10 degrees (Bonded)
-10 degrees (Unbonded)
-25 degrees (Bonded)
-25 degrees (Unbonded)
Equivalent Stress (EverFE - No Temperature)
Austroads Equivalent Stress


Temperature Analysis of Current Load (100mm from edge line)
Equivalent Stress (MPa)
0
1
2
3
4
5
6
SAST
SADT
TAST
TADT
TRDT
QADT
+10 degrees (Bonded)
+10 Degrees (Unbonded)
-10 Degrees (Bonded)
-10 Degrees (Unbonded)
+25 Degrees (Bonded)
+25 Degrees (Unbonded)
-25 Degrees (Bonded)
-25 Degrees (Unbonded)
Equivalent Stress (EverFE - No Temperature)


Temperature Analysis of Future Load (600mm from edge line)
Equivalent Stress (MPa)
0
1
2
3
4
5
6
7
SAST
SADT
TAST
TADT
TRDT
QADT
+10 Degrees (Bonded)
+10 Degrees (Unbonded)
-10 Degrees (Bonded)
-10 Degrees (Unbonded)
+25 Degrees (Bonded)
+25 Degrees (Unbonded)
-25 Degrees (Bonded)
-25 Degrees (Unbonded)
Equivalent Stress (EverFE - No Temperature)


Temperature Analysis of Future Load (100mm from edge line)