University of Southern Queensland

Faculty of Health, Engineering and Sciences

Design of High Modulus Asphalt Overlay for Concrete Pavements

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James Lister

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Abstract

The majority of the main road networks in Australia where completed some time ago, and with over two-thirds of our goods transported by road freight, it is putting increasing pressure on the road system (Sharp and Johnson-Clarke, 1997). A cost-effective alternative to increasing the longevity of the roads is needed. Asphalt overlay is the most common type of pavement restoration; and the two widely used methods are a thin asphalt concrete mix or just thin asphalt (Cülfik, 2014).

This project focuses on the single layer of asphalt only, with an elevated modulus applied on top of a previously cracked rigid pavement. The standard for road design in Australia is predominantly guided by Austroads and although there are specifications in regards to asphalt, a method is yet to be adapted for high modulus overlay on top of cracked concrete pavement. The finite element program EverFE was used to model the pavement designs using different configurations and material properties gathered from Australian pavement literature, including subgrade strength, joint condition, the size of cracked concrete base and modulus of all layers. EverFE although user friendly it is only designed to model multiple slabs on the top layer, therefore multiple designs were modeled using two different types of slab configurations.

The tensile stress in the concrete slab is significantly reduced when an asphalt overlay is applied, on average a 58% reduction amongst all the pavements modeled. The results from the project indicate that a 50mm asphalt layer does not act as a structural layer for the pavement and a large percentage of the stress is directly transferred to the lower layers beneath the asphalt. Further to this, the results highlight that for all the simulations conducted an overlay of 70mm would be suitable.

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James Thomas Lister

Student Number: 006 108 1252

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1.0 Project Idea

1.1 Introduction

Australia has over 800 000 Km of roads and every day more vehicles are using them as their primary method of transport (Australian Beauru of Statistics, 2012). Other countries have adopted rail as one of the main forms of transport, while Australia has followed the American highway model, however this is starting to change in our cities. The majority of the main road networks in Australia where completed some time ago, and with over two-thirds of our goods transported by road freight, it is putting increasing pressure on the road system (Sharp and Johnson-Clarke, 1997).

A cost-effective alternative to increasing the longevity of the roads is needed, with the serviceability of road pavements, depending on the type, ranging from 20-40 years (Zaniewski et al, 2015). This number has increased with the more research that has been undertaken in this area but regardless of the type or designs continuous loading from vehicles and outside conditions cause pavements to inevitably fail (Cülfik, 2014). Asphalt overlay is the most common type of pavement restoration; and the two widely used methods are a thin asphalt concrete mix or just thin asphalt (Cülfik, 2014). This project will be focusing on the single layer of asphalt only, which in most cases can increase the pavement life by 6-10 years (Cülfik, 2014). Using an overlay there is a minimum amount of remedial work to be done, the new layer of asphalt can be placed over the existing pavement and in most cases it is the most economical option (Cülfik, 2014).

1.2 Idea

There needs to be an economical pavement restoration design and methods to assist government bodies and improve rider comfort for the public. The project will attempt to establish a technical guide on the use of asphalt overlays on fatigued concrete pavements, which will result in extending the serviceability of the pavement and reduce the remedial work that needs to be carried out to a minimum. The project will build upon the knowledge gained in the Rehabilitation design of Victoria Road for a Barrier Transfer

Vehicle (BTV) study by Tao et al (2011), who found that by using a BTV reduced the serviceability of a pavement substantially. In the case of Victoria Road, the investigation concluded that the pavement would fail prematurely due to the excessive load, thus remediation options that avoided replacing the reinforced concrete pavement were explored (Tao et al, 2011). The method chosen for the restoration was to use a high modulus asphalt overlay which has been successful in rehabilitating the road surface. The project will build upon this work to work towards suggestions for an economical pavement design.

2.0 Literature Review

2.1 Overview

A literature review was carried out to gain a better understanding and up to date information on the following:

- concrete pavement
- current methods for concrete pavement maintenance
- asphalt overlay
- current practices for asphalt overlay pavement restoration
- current design techniques and applications for asphalt overlay.

Increased traffic volumes and aging road infrastructure has pushed pavement designs to their limits generally failing before its design life, this failure causes significant maintenance costs and as a result extra congestion and dissatisfaction from users (Vennapusa and White, 2014). A substantial amount of research and money is being spent around the world to identify different methods of a cost effective, sustainable alternative for pavement rehabilitation (Vennapusa and White, 2014). There are currently various methods adapted for pavement rehabilitation throughout the world dependent on many factors including but not limited to budget; geographical location; climate; traffic volume; and the existing pavement.

2.2 Concrete Pavement

Concrete pavement, also known as rigid pavement like other designs, has a base and subbase layer but the point of difference is the top layer is rigid and made from Stiff Portland Cement (SPC). The concrete pavement layer disperses the load applied by the vehicle to a wider area of the layers beneath which in turn creates a moderate stress and strain throughout the layers (Sargand et al., 2014).

Cement pavement is typically constructed in the following four main categories:

- joint plain concrete pavement (JPCP)
- joint reinforced concrete pavement (JRCP)
- continuously reinforced concrete pavement (CRCP)
- and prestressed concrete pavement (PCP) (Huang, 2004).

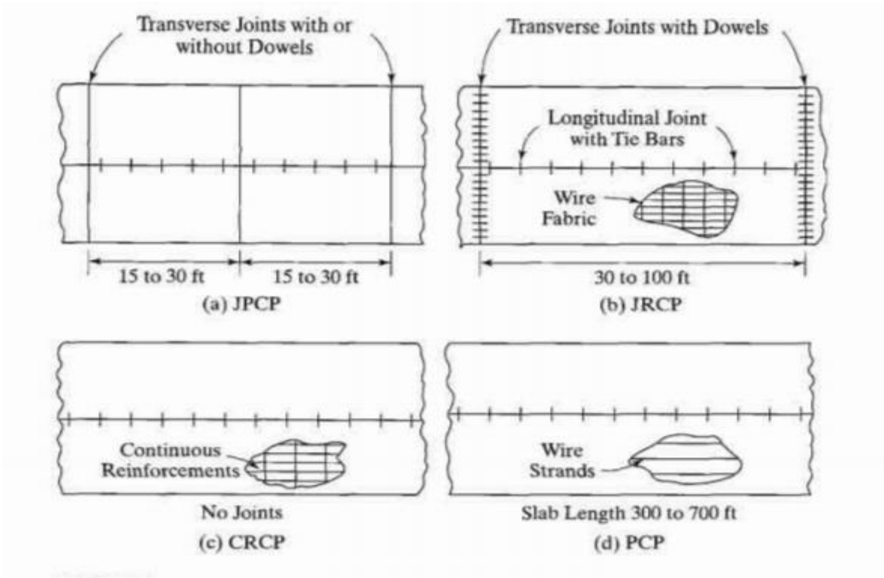


Figure 1: Typical rigid pavement construction. Huang, 2004

The aim for the rigid pavement with the use of dowel bars and interlocking aggregate is to allow the pavement sections to move in a horizontal direction whilst transferring the vehicle load and limiting the vertical movement (Sargand et al., 2014).The most common types of failure in cement pavements are faulting, traverse cracking, and rutting from material failure and inadequate support from the sub-base (Vennapusa and White, 2014). Figure 2 below is an example where cracking in both directions has caused a punch out where a section of the pavement has broken away.

Figure 2: Example of pavement punch out and an attempt to patch.

Source: Texas Department of Transport, 2011

Numerous methods have been adopted to counteract this type of failure without replacing the pavement which includes:

- injected Polyurethane Expandable Foam that is injected underneath the pavement to add extra support to the sub-base in areas of concern
- crack sealing where the opening in the pavement is filled in and sealed with a type of polymer or cement agent
- slab under sealing which consists of drilling a hole through the pavement and pumping a grout mixture into the areas that have dipped or are cracking
- cracking and seating which involves breaking the failing section of concrete pavement into approximately 0.5 to 1m^2 sections which are then rebuilt and rolled, before a layer of new asphalt is seated in the section
- bull pavement replacement where the entire slab is demolished and a new pavement is relayed (Queensland Department of Transport and Main Roads, 2012).

Although these methods have shown to be effective at times, there are mixed views in regards to long term performance, cost, and ride quality once completed (Vennapusa and White, 2014). For complete rehabilitation without complete replacement, an alternative that has shown success internationally is asphalt overlay.

2.3 Asphalt Overlay

An asphalt overlay is a form of pavement rehabilitation which involves laying a thin layer of asphalt over an existing concrete pavement, typically ranging from 30-110mm thick. When completed asphalt overlay can increase driver comfort, safety, and the design life of the road (Newcomb, 2009). Figure 3 below is an example of a highway in Kentucky, USA being rehabilitated with an asphalt overlay on top of a Portland Cement Concrete (PCC) pavement.

Figure 3: Asphalt overlay, Kentucky USA

Source: Sharpe and Walker

Asphalt overlays are not suitable for all types of pavement conditions and special consideration needs to be taken before the method is decided upon. The National Asphalt Association (NAA, 2009) outline overlay should not be used when the structural integrity of the pavement throughout the layers is compromised (NAA, 2009). A pavement with structural distress and showing longitudinal cracking, particularly in areas of the wheel path requires a more substantial reconstruction of each layer (NAA, 2009). If the pavement distress is limited to a small area then the individual section can be excavated and repaired accordingly before the final asphalt layer is placed. With this being said, the performance of the overlay if done correctly can produce surprising results in extending the life of the pavement and increasing ride quality. Table 1 is a summary of case studies throughout the world under different conditions.

An Australian study is not included in the Table, as Australia has adopted this method at a much later stage than other countries, so there is a paucity of data available, and this highlights the need for a technical guide on this type of pavement application.

Table 1: Summary of Asphalt overlay performance

Climate or Location	***Traffic***	***Existing Pavement***	***Expected Performance, yrs.***	***Reference***
Ohio	High and Low	Asphalt	16	Chou et al., 2008
	Low	Composite	11	Chou et al., 2008
	High	Composite	7	Chou et al., 2008
North Carolina	—	Concrete	6 to 10	Corley-Lay and Mastin, 2007
Ontario, Canada	High	Asphalt	8	Uzarowski, et al., 2005
Illinois	Low	Asphalt	7 to 10	Reed, 1994
New York	—	Asphalt	5 to 8	New York Construction Materials Association, undated
Indiana	Low	Asphalt	9 to 11	Labi and Sinha, 2003
Austria	Low or High	Asphalt	≥ 10 years	Litzka, et al., 1994
	High	Concrete	≥ 8 years	Litzka, et al., 1994
Georgia	Low	Asphalt	10 years	Hines, 2009

Source: National Pavement Association, 2009.

2.4 Current Asphalt Overlay Design Specifications

The Austroads Guide 2004 has developed a procedure for asphalt overlays by means of design charts, although this method is not suitable for all types of pavement overlays. Hence the following limitations have been stated by Austroads, APT-T34 (2004.pg.70), the chart based overlay design procedures have the following limitations:

- it is applicable to flexible without cemented materials
- maximum asphalt overlay thickness of 150 mm
- maximum design traffic loading of 10^7 ESA.

Although a simplified method for rigid concrete overlay has not been developed, the current configurations have been adopted for asphalt overlay on cement pavement shown in Figure 4 below.

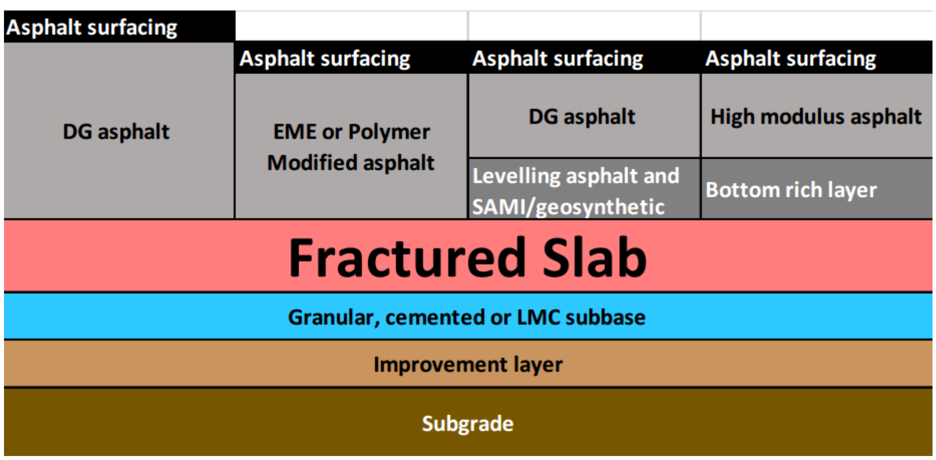


Figure 4: Adopted asphalt overlay configurations

Source: AAPA Asphalt Overlay Design Guide for Rigid Pavement Rehabilitation, 2015

There are various guides on how to undertake pavement rehabilitation by use of an asphalt overlay and the technical guides available are predominantly from the US, first the pavement is assessed to see if it is suitable for an overlay, then the existing slab defects have to be rectified by means of techniques discussed in section 2.2. The American Concrete Pavement Association (ACPA) has provided a recommended order of maintenance repairs before overlay is placed provided in Figure 5 below.

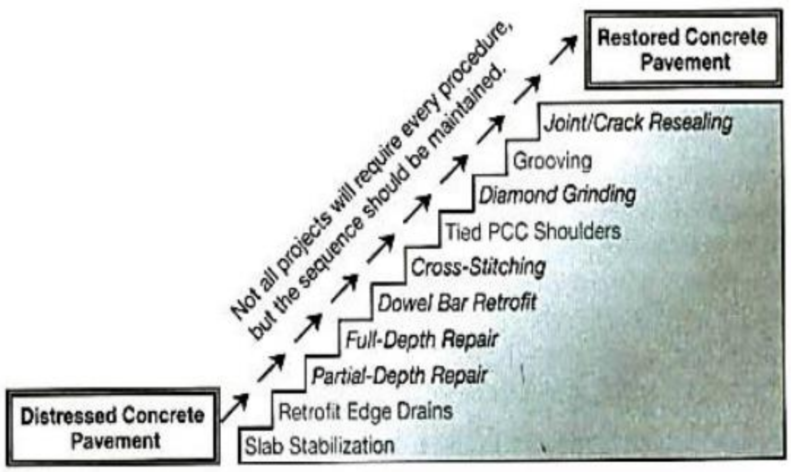


Figure 5: Recommended order of repairs before pavement overlay.

Source: Khazanovich et al, 2013.

Once the existing pavement is sound it acts as a base for the asphalt to be laid on top of, special care has to be taken during implantation of preparing the two layers as PCC pavement and asphalt have different properties (Khazanovich, 2008). The design and material used are crucial to the overall performance and is a balance between limiting the reflective cracking but also aiming to minimize rutting which will govern the type of asphalt used for application (Khazanovich et al, 2013). Dependent upon the design four different types of asphalt can be selected to use for the overlay, for a more structural design a dense graded or gap graded/ stone mastic asphalt is used and alternatively open graded mixes reduce tyre spray and/or noise. Figure 6 below depicts the different configurations for the adopted asphalt blends in Australia.

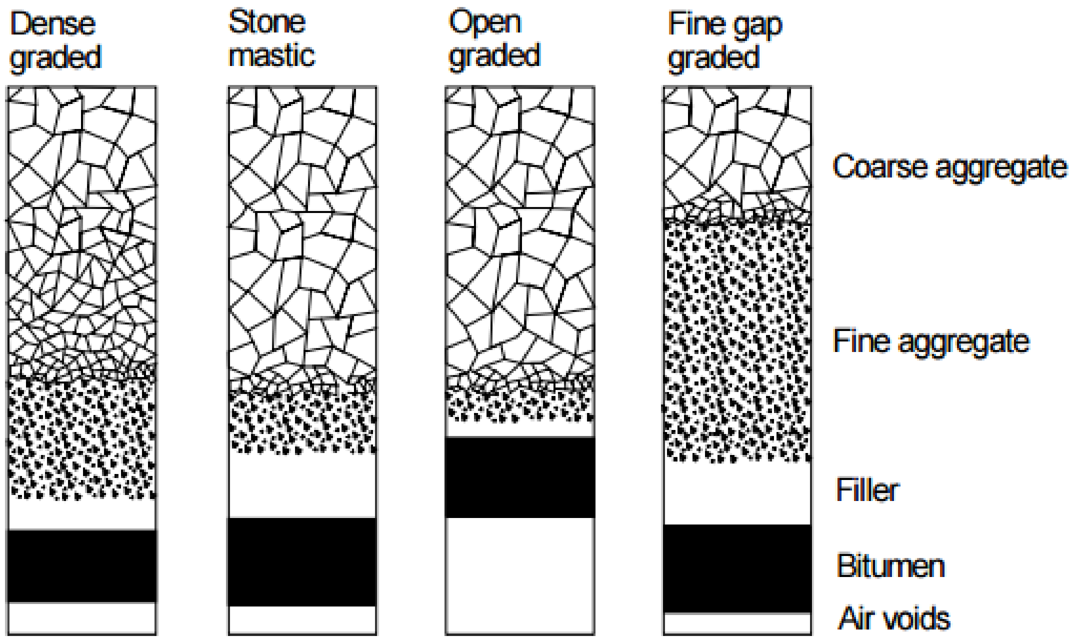


Figure 6: Types of asphalt

Source: Austroads, 2014

Austroads do not provide a guide for concrete pavement overlay but the following definitions and specifications for each asphalt design is stated in Austroads (2014) which can be used as a guide:

- Dense Graded Asphalt (DGA) – A dense graded asphalt mix has a continuous distribution of aggregate particle size and filler (i.e. evenly distributed from coarse to fine) and a low design air voids content, generally in the range of 3 to 7%. Dense graded mixes represent the most widely used form of asphalt. This type of mix provides the greatest load carrying capacity for structural layers as well as a range of other properties appropriate to a wide variety of wearing course applications.
- Stone Mastic Asphalt (SMA) – SMA is a gap graded mix with a high proportion of coarse aggregate providing an interlocking stone-on-stone skeleton that resists permanent deformation.

The coarse aggregate skeleton is filled with a mastic of binder, filler and fine aggregate. Generally, fibres are used to prevent drainage of the relatively high binder content during transport and placing.

- Open Graded Asphalt (OGA) – The particle size distribution of an OGA mix is characterized by a large proportion of coarse aggregate and only small amounts of fine aggregate and filler. OGA has relatively high air voids, generally in the range 18 to 25%, and relies largely on mechanical interlock of aggregate particles for stability. High air voids lead to reduced durability although the impact of reduced durability can be lessened with the use of high binder contents to increase the binder film thickness around the individual aggregate particles and the use of modified binders. Coarse textured aggregates with angular shape are desirable for surface texture and stability.
- Fine Gap Graded Asphalt (FGGA) – FGGA is a dense (low air voids) mix but with intermediate sized fractions replaced by finer fractions. It may also contain more filler. Fine gap graded mixes rely on the stiffness of the fine aggregate/filler/binder mixture for stability. When used in residential streets and other lightly trafficked applications, they provide a fine textured surface and a workable mix that is readily compacted to low in situ air voids. The combination of low air voids and relatively high binder content provides an extremely durable surface as well as good fatigue resistance.

Table 2: Typical Mix sizes for Various Applications

Application	Typical mix size
Dense graded wearing course ▪ lightly trafficked pavements ▪ medium to heavily trafficked pavements ▪ highway pavements ▪ heavy duty industrial pavements	 7 or 10 mm 10 or 14 mm Generally 14 mm (also 10 mm) 14 or 20 mm
Dense graded intermediate course	In general it is better to use the largest size practicable where the wearing course is dense graded asphalt. Where the asphalt surface is open graded asphalt, the largest size mix used in this application is typically 14 mm
Dense graded basecourse	Normally 20 mm. 28 mm may also be used depending on layer thickness and availability. 40 mm has been used in the past but now largely discontinued through difficulties associated with increased segregation in larger sized mixes and general unavailability
Dense graded corrective course	5, 7, 10, 14 or 20 mm
Stone mastic asphalt wearing course	7, 10 or 14 mm

Source: Adapted from Austroads, 2014

Table 3: Typical Asphalt Thickness

Nominal mix size (mm)	Compacted layer thickness (mm)
10	25 to 40
14	35 to 55
20	50 to 80
28	70 to 110

Source: Adapted from Austroads, 2014

This study will build upon current standards provided by Austroads and other Australian pavement authorities and give a clear guideline on the application of asphalt when placed over an existing fatigued concrete pavement.

2.5 Overlay Case Studies

The following information is a summary of some of the current studies on asphalt overlay that have been assessed for performance and other key indicators. Gaspard et al (2014) reported on the performance of the rehabilitation of approximately 10km of the Louisiana Interstate Highway 20. After assessment of the concrete pavement section, it was suffering multiple fatiguing issues including; surface cracks, joint spalling and pop outs, core samples were taken during assessment and also found that there were alkali-carbonate reactions (ACR). After the assessment was completed it was decided that after the remedial work was complete a 102mm asphalt overlay would be used (Gaspard et al, 2014).

The added performance and serviceability of the pavement was significantly improved by adding an extra structural layer to improve the effects of loading and distribute the stress and strain throughout the layers (Gaspard et al, 2014). The overlay created an extra barrier between the concrete slab preventing any moisture penetration into the layers, the pavement was tested almost 15 years after placement and it showed minimal cracking that had been patched and a smooth ride still apparent when driving on the pavement (Gaspard et al, 2014).

In 1998 Cho et al conducted a field study and analysis of 14 different overlays on a widely used road in Texas, USA. Cho et al (1998) found that using thicker overlays did not necessarily improve the susceptibility to reflective cracking although using an interlayer did but found with using this interlayer there was more rutting apparent. The study found although it is a recommended method of maintenance to crack and seat concrete pavements, by doing this the pavement had more fatigue and cracking in these areas suggesting it decreased the overall stiffness of the pavement Cho et al (1998). Furthermore, Cho et al (1998) developed finite element models of the sections of road including recommendations for consideration in design as follows:

- rutting of the subgrade is not a likely failure mode for asphalt overlays of concrete pavements
- stiffer interlayers may reduce rutting and fatigue in the asphalt overlay

- thickness of the interlayer only affects deflections close to an applied load
- tensile stresses in the concrete layer are not reduced by thin, flexible interlayers
- flexible base layers do not improve performance and may actually have a negative effect on fatigue resistance
- thicker asphalt layers can increase the fatigue life of both the asphalt overlay and the underlying concrete pavement while reducing the potential for rutting in the asphalt layer
- dynamic loads should be used in analysis rather than static loads, as they are more representative of actual traffic loading conditions, and dynamic loads result in higher peak stresses
- stress distribution in both the asphalt and concrete layers is greatly affected by temperature differentials Cho et al (1998, pg.125-128).

2.6 Fatigue

2.6.1 Concrete Pavement

Studies have shown that one of the most critical parts of a rigid pavement performance is the amount of deflection at the joints. For the pavement to resist excessive cracking and deterioration the average deflection has to be less than 0.36mm and the differential deflection indicated in Figure 7 part (a) less than 0.05mm (Huang, 2004). Part (b) is for a CRCP and this allowable amount of deflection is 15 micro mm before fatiguing and more extensive structural repair would be needed (Huang, 2004).

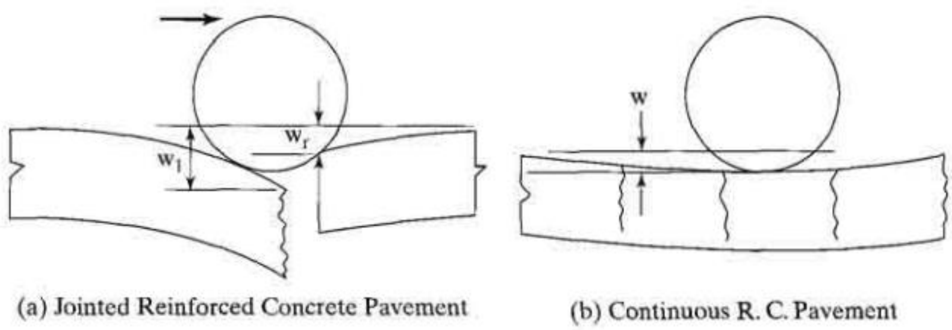


Figure 7: Deflection considerations

The tensile stress ratio (tensile stress/tensile strength) in the concrete slab is another indicator of fatigue. The stress ratio in the concrete slab can be kept below 0.5 the concrete pavement can withstand unlimited repetitions under the type of assessed loading (CCAA, 2009).

2.6.2 Asphalt

Similar to the concrete layer comprehensive studies have been performed in the past to provide guidance on the limits and key indicators of inevitable fatigue of asphalt. Shen and Carpenter (2005) conducted a study to establish a relationship between the amount of tensile strain in the asphalt and its fatigue life as this tensile strain is the major cause of cracking and as a result pavement failure. The study indicated that the threshold for unlimited repetitions hence an unlimited fatigue life is 70 microstrains.

2.7 Victoria Road Rehabilitation

The following is a review of the research conducted by Tao et al (2011) regarding the rehabilitation of a section of Victoria Road in Sydney in which this project is to build upon. It was decided for a section of Victoria Road that a quick change removable barrier system would be implemented to help the flow of traffic in peak times, pictured below (Tao et al, 2011).

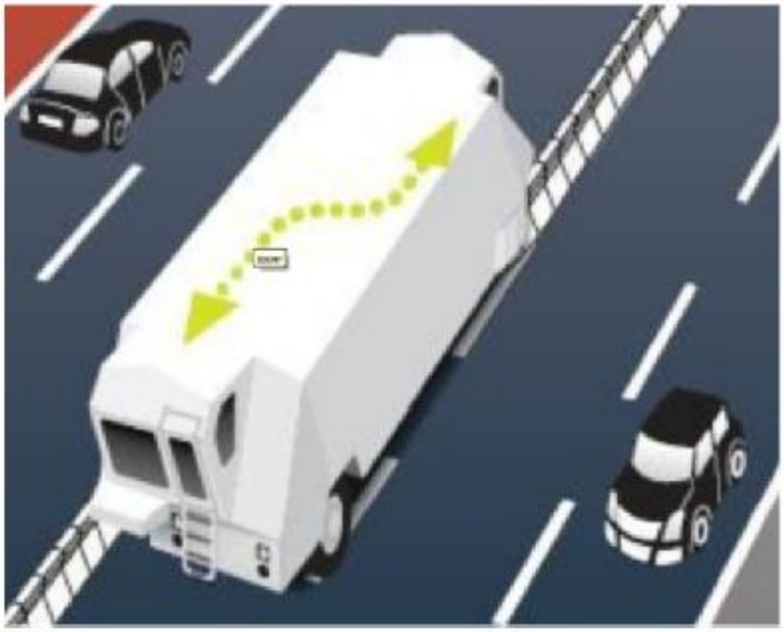


Figure 8: Removable barrier system.

Source: Tao et al, 2011 from Bain, 2011

A great system although as the removable barrier truck has to run twice a day to swap directions of the extra lane, it was found that the existing concrete pavement would fail prematurely with this loading. With this in mind, it was decided that a cost effective method was to be decided upon to increase the serviceability of the pavement and make it robust enough to handle the extra load exerted by the barrier transfer truck (estimated at 100kN per wheel) (Tao et al, 2011). After extensive research and tests there were two viable options to which to decide upon:

1. Pavement Reconstruction: Demolish existing asphalt and concrete pavement of the proposed BTV lane and replace with jointed reinforced concrete pavement as per Austroads standard design.

2. Rehabilitation: Mill to remove temporary and older asphalt, prime concrete surface and provide high modulus asphalt overlay over the existing concrete pavement (3.7m wide joint to joint) at a maximum thickness of 130 mm, then overlay adjacent lanes to match kerbs and adjust cross falls Tao et al (pg.8, 2011).

It was decided that the most effective approach would be the rehabilitation method using a high modulus asphalt and this would also serve as a study for future pavements rehabilitations (Tao et al, 2011). The EverFE program that was used for the project was also used to model the tensile stresses when the pavement is loaded, and find the most appropriate design for the rehabilitation (Tao et al, 2011). It was concluded that,

> …regular inspections have been carried out along the pavement section, which included the use of GIPSICAM and crack monitoring. While it is still too early to conclude that the rehabilitated pavement will perform according to the expectation, so far the pavement has not shown any significant sign of distress Tao et al (pg. 15, 2011).

2.8 Rehabilitation Type (High Modulus Asphalt Overlay)

Not widely adopted at this stage in Australia but the rehabilitation design is based on a high modulus asphalt overlay similar to the one used above by Tao at el (2011). High modulus asphalt was developed by the France and recently has been used in other countries around the world including South Africa and the United Kingdom (Transport and Main Roads, 2015).It provides a cost-effective and timely alternative with the added bonus of resisting rutting due to the robust mix (Sun and Li, 2014). It has also shown in the Victoria Road Rehabilitation project it can help towards resisting early fatigue when there are extreme cases of loading (removable barrier truck). Using high modulus asphalt reduces the thickness of the overlay as to still maintain specific grade and reduce cost, the mix is typically densely graded with limited air voids and a hard bitumen binder (Transport and Main Roads, 2015).

2.9 Project Feasibility

Providing a technical guide for the application of asphalt overlay on top of fatigued cracked concrete pavement will make available a cost-effective, efficient alternative to pavement rehabilitation. Although there is more research to be done, this project will build upon current practices and provide a clear and specific guide for this type of asphalt application in Australia. At present, there is information regarding this type of application for American standards but due to the nature of different climate, available materials etc. it is necessary to customise best practice for Australian conditions.

The analysis will be done through the computer program 3D finite-element program EVERFE and different designs will be assessed based on the following key areas that make up a pavement design (Huang, 2004).

Pavement configurations - the configurations are heavily dependent on the conditions of the existing subgrade, the type and amount of vehicles that are expected to travel on the pavement.

Loading conditions - this can vary depending on the type of road the design is for, local road may be for small to medium sized vehicles or a main highway route for heavy vehicles. The standard for determining this is the by using the Equivalent Single Axel Load (ESAL) which estimates a number of times this axle load is expected to apply to the pavement throughout its life. The loading conditions have a detrimental effect on the life of the pavement and amount of maintenance needed.

Material characteristics - make up the structural forms of the pavement and are tested for the compression strength, resilient modulus and Californian Bearing Ratio (penetration test). The quality of the material used and the existing conditions will determine the thickness and type of layers needed in the design.

Subgrade support - the purpose of the bottom layer is to resist the vertical stresses that are applied by the loading of the vehicles, if it is not adequate failure will continue to the layers above. The reaction and resistance to the stresses are dependent on the material characteristics mentioned above.

Pavement deflection – mentioned earlier in section 2.6 is to be limited to resist fatiguing and cracking of the concrete and other layers.

3.0 Project Development

3.1 Aim, Objectives, Scope

The standard for road design in Australia is predominantly guided by Austroads and although there are specifications in regards to asphalt, a method is yet to be adapted for overlay on top of cracked concrete pavement. The aim of the project is to build upon available information in this area and propose a technical guide in the application of asphalt overlay on top of the concrete pavement. The objectives through literature investigation and computer modeling are to:

- identify further case studies in Australia regarding asphalt overlay on concrete pavement and source the application details of the Rehabilitation design of Victoria Road for Barrier Transfer Vehicle (BTV) study by Tao et al (2011)
- determine an effective robust configuration of pavement design for an asphalt overlay assessed on the basis of the 5 categories stated in section 2.9
- establish a guide on the application of asphalt overlay on top of cracked concrete pavement.

Due to the wide variation in climatic conditions in Australia, the project provides a general guideline and climatic conditions were not taken into consideration. The project provides a basis that then designs can be tweaked dependent upon local conditions and materials

3.2 Expectations and Benefits

The expectation of the project is to provide an effective alternative to pavement rehabilitation and although asphalt overlay is not a new concept, a clear guide on how to apply this type of pavement over cracked concrete will benefit the wider pavement community. At the moment the current standards for asphalt overlay design set by Austroads is limited to:

- flexible without cemented materials
- maximum asphalt overlay thickness of 150 mm

- maximum design traffic loading of 10^7 ESA
- standard modulus asphalt (Austroads, APT-T34, 2004.pg.70).

This project will offer a guide that will cover rigid pavements with cemented materials under Australian conditions as this is an effective method for pavement rehabilitation. The project built on the information gathered in the successful pavement rehabilitation program where a high modulus asphalt overlay was applied on top of 60 year old concrete pavement on Victoria Road in Sydney (Nataatmadja, 2015).

3.3 Methodology

1. Literature investigation –the purpose of the investigation is to gather evidence on the performance of the project and gain a better understanding of the method which will include the Victoria Road Rehabilitation by Tao et al (2011).
2. Computer Simulation – information from step 1 was a base point for designs to be used for computer simulation using the finite-element program EverFE. The program helped to simulate conditions such as pavement configurations, loading conditions, material characteristics, subgrade support, pavement deflection (Nataatmadja, 2015). Test simulations were run as to make sure any errors are not present in the method of using EverFE.
3. Data analysis – the results from the computer simulations were compared and recommended designs were chosen for further scrutiny and discussion.
4. Identify Design – final economical design that meets all the requirements mentioned earlier was decided and a guide dependent on existing pavement conditions was formulated.

4.0 Design

The purpose of the research was to investigate and analysis the possible configurations when applying high modulus asphalt layer on top of a fatigued and cracked rigid concrete pavement. Using high modulus asphalt will help to reduce the thickness of the overlay and still maintain strength, specific grade and assist to reduce cost (Von et al, 2001).High modulus asphalt is typically a densely graded mix with limited air voids and a hard bitumen binder (Von et al, 2007).

4.1 General Design Considerations

As mentioned earlier Cho et al conducted a field study and analysis of 14 different overlays and recommended the following to take into consideration:

- rutting of the subgrade is not a likely failure mode for asphalt overlays of concrete pavements.
- stiffer interlayers may reduce rutting and fatigue in the asphalt overlay
- thickness of the interlayer only affects deflections close to an applied load
- tensile stresses in the concrete layer are not reduced by thin, flexible interlayers
- flexible base layers do not improve performance and may actually have a negative effect on fatigue resistance
- thicker asphalt layers can increase the fatigue life of both the asphalt overlay and the underlying concrete pavement while reducing the potential for rutting in the asphalt layer Cho et al (1998).

Austroads (2012) key areas for consideration for design are:

- the type and amount of traffic that will be using the section of road
- strength of the subgrade typically the Californian Bearing Ratio (CBR)
- strength of the concrete base.

4.2 Design Requirements and material properties

Material properties and pavement geometry in the designs to be simulated will be gathered from studies on a similar pavement design with a large amount of guidance from the commonly used standard Austroads Guide Technical Papers. To vary the conditions in the pavement layers including subgrade strength, joint condition, the size of cracked concrete base are gathered from various studies throughout Australia and the US as this will play a role in stress distribution.Information gathered during the literature review and other forms of research and consultation, the basic design for the modeling process will be a four layered pavement system. The layers from bottom to top will consist of the following:

- Subgrade - existing soil modified to meet requirements ranging in from a CBR of 3-15% estimated strength between 30-150 MPa (Cray, 2013).
- Subbase - can be a road base mixture or concrete 150-250 mm thick (RMS, 2016). For simulation purposes, it will be a damaged lean mix concrete (LMC) with a reduced strength of between 2000- 8200 MPa (Harold et al, 2007).
- Concrete base - in this situation it will be the existing pavement that is been rehabilitated, therefore multiple small slabs are modeled to represent cracked and seated parts.
- Asphalt - thin high modulus layer added to improve pavement, typically ranging in modulus between 6000- 12000 MPa (SAMI, 2015).

If complete information was not available for modelling Austroads standards was used and if varied values are given the lower values were used to model low strength conditions.

4.3 Modeling

EverFE was used to model the pavement designs using different configurations and material properties gathered from Australian pavement literature. EverFE although user friendly it is only designed to model multiple slabs on the top layer, therefore multiple designs were modeled using two different types of slab configurations with an 8 x 8 mesh. Figure 9 below is the typical configuration for modeling repaired concrete slab sections to analysis the impact the repaired joints had on the deflection of the slab and the stress distribution. The multiple slab in Figure 9 consisted of 6 slabs that were 1.2m wide and 2.4m long to simulate worst case scenario of multiple repairs in one section of a single lane. The multiple slabs had 24mm dowels at 300 centres on the traverse joins and the longitudinal joins were stitched with 13mm tie bars at 1 m centres to Austroads specification.

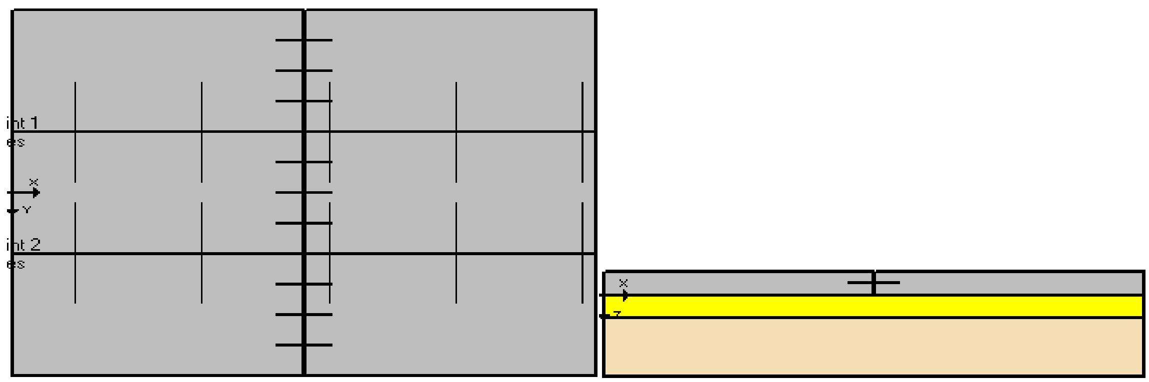


Figure 9: Typical 3 layer pavement configuration for multiple slab modeling without asphalt layer

Below in Figure 10 is the four-layered single slab pavement which includes the addition of the asphalt overlay with varying thicknesses and moduli for all layers outlined in the results analysis.

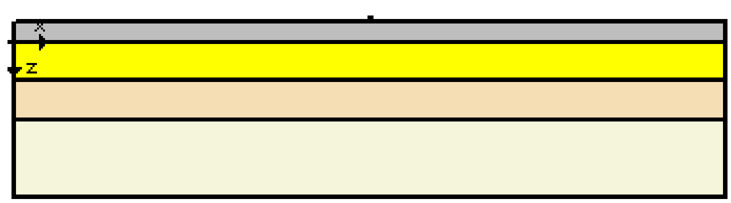


Figure 10: Typical four layer single slab pavement configuration with asphalt layer

Memory and other computer requirements limited the loading to a single axle hence for the analysis using EverFE the mechanistic procedure used in the Austroads Guide was adapted. Although asphalt would be considered flexible it will be forming a structural layer on top of a rigid pavement plate theory will be used, where single complete axel needs consideration appose to a single contact area for flexible pavements (layered theory). The different analysis is due to the different responses in types of pavements (Huang, 2004). Loading of the multiple slabs will be as close as possible to the joints were the slab has been repaired as it has been shown in previous studies to have the maximum differential deflection, explained in section 2.6.

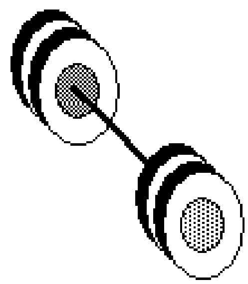


Figure 11: Typical loading axle model

Source: Mahoney, 1984.

The model will simulate a dual wheeled single axle vehicle that applies a load of 80kN similar to a medium size truck with an overall axle width of 1965mm. The stress and strain in the cement base and asphalt were the key areas for analysis in this study. Carrying over from the Victoria Road Rehabilitation by Tao et al (2011) the suitability of the pavement design is assessed on the limited amount of tensile strain within the asphalt layer. Shen and Carpenter (2005) found for unlimited load repetitions the strain has to be a maximum of 70 microstrains with this being calculated by finding the maximum tensile stress and dividing by the modeled modulus ranging which ranged from 3000 MPa – 8000 MPa. Included in this analysis was the stress in the bottom of the concrete slab below the asphalt layer.

Similar to the stress in the asphalt it has been found for unlimited repetitions and a robust design the stress ratio of the concrete slab to be below 0.5 summarised below in Figure 12.

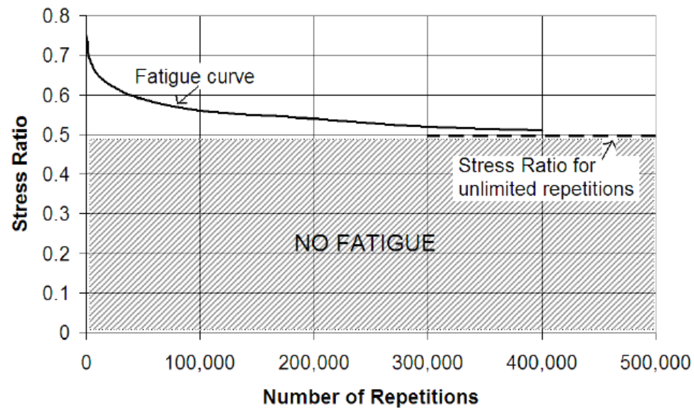


Figure 12: Variation of stress ratio with load repetitions

Source: Tao et al, 2011.

As mentioned multiple slabs can only be modeled in the top most layer using EverFE, therefore, the first part of modeling was to investigate the effect multiple joints have in a repaired slab shown in Figure 9. The second part of the analysis will be using a single slab with the same material properties as the multiple slab base, subbase and subgrade with the addition of the asphalt layer (Figure 10). The base modulus was estimated by multiplying the CBR by 10 and other layers were taken from data gathered in the literature review.

5 Results and Discussion

5.1 Multiple slabs no asphalt layer

The multiple slab configurations were loaded at a critical point as indicated below, to obtain the maximum deflection at the joints where the slab has been repaired.

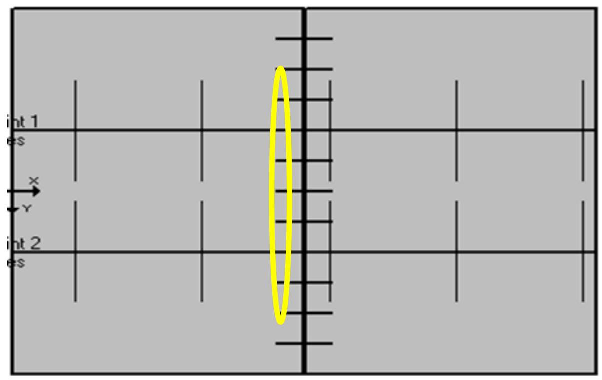


Figure 13: Multiple slab loading area

The modeling showed tensile stress in the bottom of the concrete slab varied between 0.5-1MPa with a maximum stress ratio of 0.3 on Type 1 design for the three by two slab simulations. The maximum deflection differential 0.06mm was also in Type 1 multiple slab design. Table 4 below shows the summary of the results noting the moduli and thickness of each layer with the corresponding maximum tensile stress, stress ratio, deflection, and deflection differential.

Table 4: Multiple slab modeling no asphalt layer

	Layer	Thickness	Modulus	Max tensile stress	Stress ratio	Max deflection	Max deflection differential
	(Bottom,middle, top)	mm	MPa	MPa	Stress/T Strength	mm	mm
Type 1	Subgrade	300	50				
	Subbase	150	2000				
	Cement	150	12000				
			Results	**1.02**	**0.3**	**1.2**	**0.058**
Type 2	**Subgrade**	**500**	**50**				
	Subbase	**150**	**2000**				
	Cement	**150**	**12000**				
			Results	**0.92**	**0.24**	**1.40**	**0.03**
Type 3	**Subgrade**	**500**	**100**				
	Subbase	**200**	**5000**				
	Cement	**200**	**19500**				
			Results	**0.57**	**0.12**	**0.64**	**0.02**
Type 4	**Subgrade**	**500**	**150**				
	Subbase	**250**	**8000**				
	Cement	**250**	**27000**				
			Results	**0.52**	**0.11**	**1.25**	**0.08**

Although all three types may be considered suitable for overlay, Type 2 and 3 would suggest that if repaired correctly the existing pavement would be suitable for standard single axle dual wheel loading even without an overlay. Figure 14 below demonstrates the stress distribution in model Type 2 multiple slab without asphalt layer. It can be seen that the stress distribution in the bottom of the concrete slab is linear along the line of the axle. The point indicated in Figure 14 is where the maximum deflection occurred for all 4 models. Model Type 1 in Table 4 above would indicate that further foundation work would be required as the deflection differential is greater than 0.05, which is the maximum allowable (Huang, 2004).

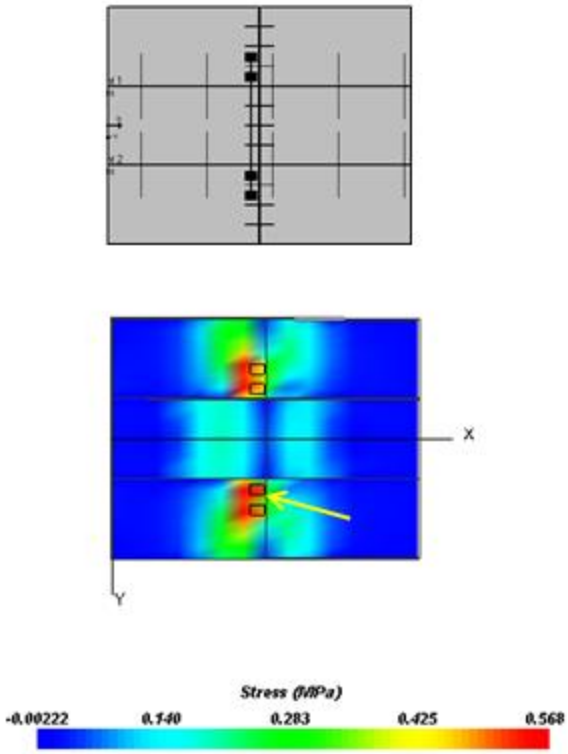


Figure 14: Stress distribution of Type 2 multiple slab model

5.2 Single slab with asphalt overlay

The single slab arrangement had identical material properties and thicknesses as the multiple slab Type 1, 2, 3 and 4; with the addition of an overlay. The asphalt had varying moduli and varying thicknesses 50, 70, 100 and 130mm. Figure 15 below is the typical arrangement used for all 4 of the design types.

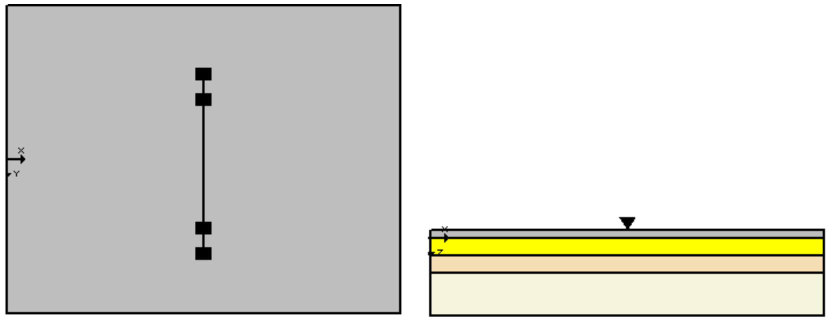


Figure 15: Typical arrangement for single slab models

5.3 Stresses and strains single slab with asphalt layer

As mentioned earlier the analysis on the asphalt layer will focus on the maximum tensile stress which is taken from the output of the simulation using EverFE. Once this is calculated it will be divided by the particular moduli used for the model type to obtain the tensile strain and this value will be multiplied by $10^{\wedge 6}$ to obtain the microstrains. The single slab was the width of a standard lane of 3.6 m and length of 4.6 m, which was the default length. The design with material properties is shown in Figure 16 for Type 1 of the designs that was modeled.

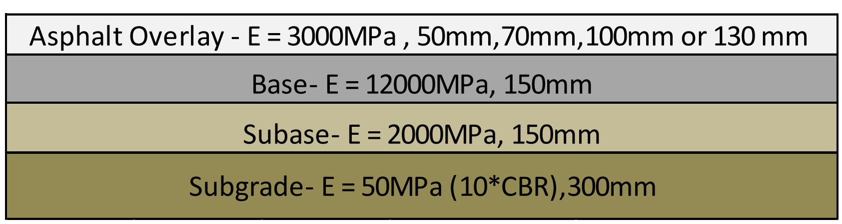


Figure 16: Properties for Type 1 of single slab design for modeling

Type 1 with a modulus of 3000MPa had a maximum tensile strain of 41 microstrains when the asphalt layer is thin at 70mm. The minimum of 20 microstrains was when the asphalt layer was modeled at 130mm, typically showing an increase in strain as the asphalt layer was reduced. Although the 50mm layer has only a minimal tensile strain which may indicate the layer is too thin allowing a large amount of stress and strain to be transferred to the concrete slab. A summary of the results is provided below (Table 5), along with the output of the 70mm asphalt model for Type 1 design indicating the maximum tensile stress in the top of the asphalt (Figure 17).

Table 5: Summary of Type 1 results for asphalt layer

Type 1		
Asphalt thickness	**Microstrain (AC)**	**Max tensile stress (MPa)**
50	13.27	0.04
70	41	0.12
100	27	0.08
130	20	0.06

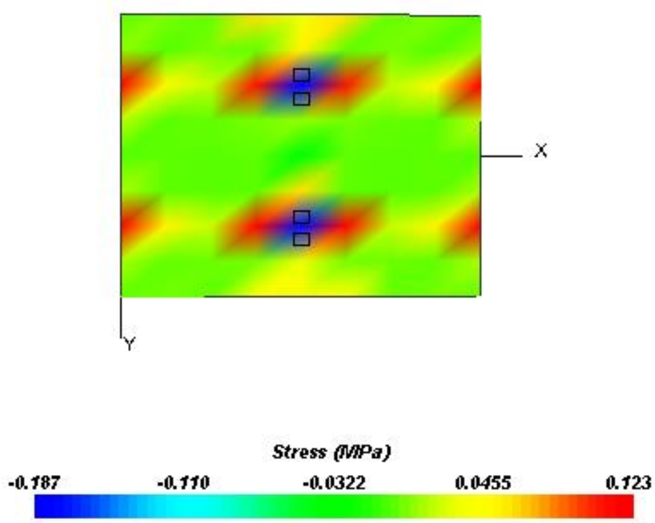


Figure 17: Stress in the top layer of the 70mm asphalt modeled in Type 1 design

The second model had the material properties and characteristics shown in Figure 18 below.

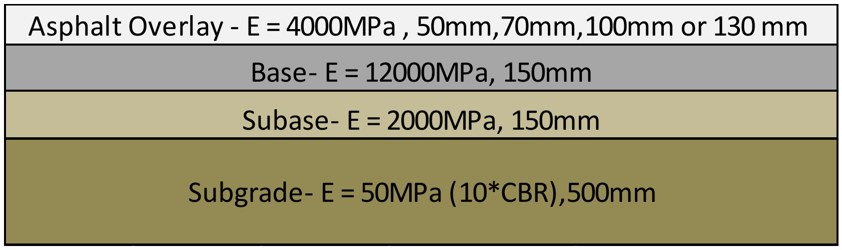


Figure 18: Type 2 of single slab design for modeling

Single slab model Type 2 had a maximum stress in the bottom of the 50mm layer with a tensile microstrain of 68 and the minimum in the 100 and 130 mm asphalt layers. The stress in the two thicker layers was minimal, having a tensile strain of 13 microstrains. The results are shown below in Table 6 with Figure 19 depicting the maximum stress that was present in the 50mm asphalt layer.

Table 6: Summary of Type 2 results for asphalt layer

Type 2		
Asphalt thickness	**Microstrain (AC)**	**Max tensile stress (MPa)**
50	68	0.27
70	35	0.14
100	13	0.05
130	13	0.05

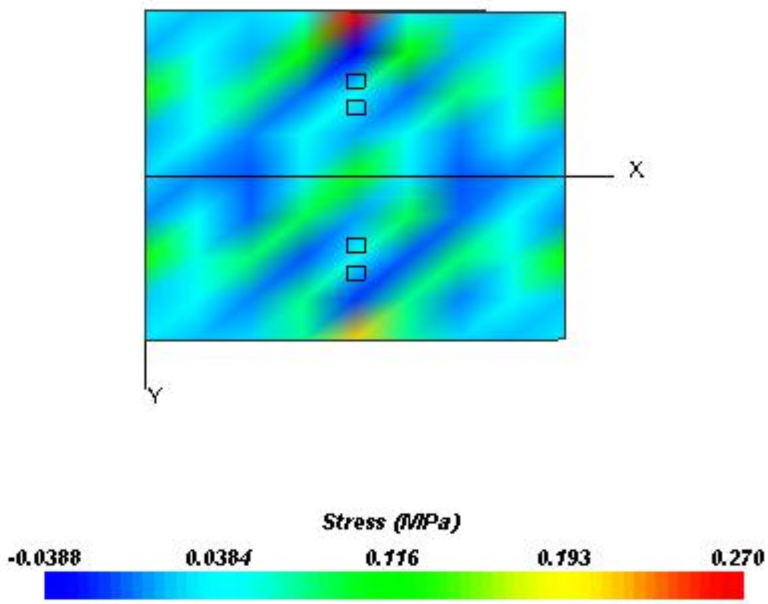


Figure 19: Type 2 max stress in the bottom of the 50 mm asphalt layer

Type 2 50mm overlay design would be considered at the threshold of the tensile strain limit (68 microstrains) although suitable theoretically it would be expected to have cracking close to the wheel path and the edge of the lane.

Type 3 had a maximum of 35 and minimum of 22 microstrains, respectively. For this pavement model with a thick concrete slab of 200mm, the minimum strain occurred in the second thickest (100mm) asphalt layer.

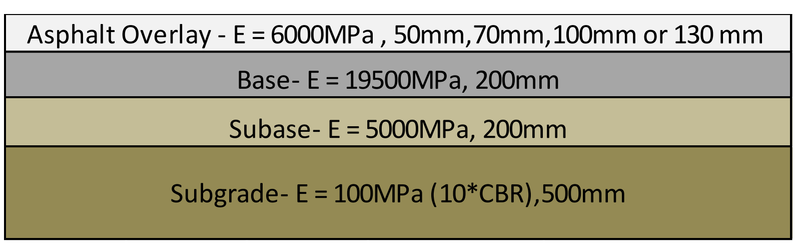


Figure 20: Type 3 of single slab design for modeling

Similar to Type 2, Type 3 had a maximum tensile strain in the top edge of the asphalt, resulting in 35 microstrains with a stress of 0.21MPa (Figure 21).

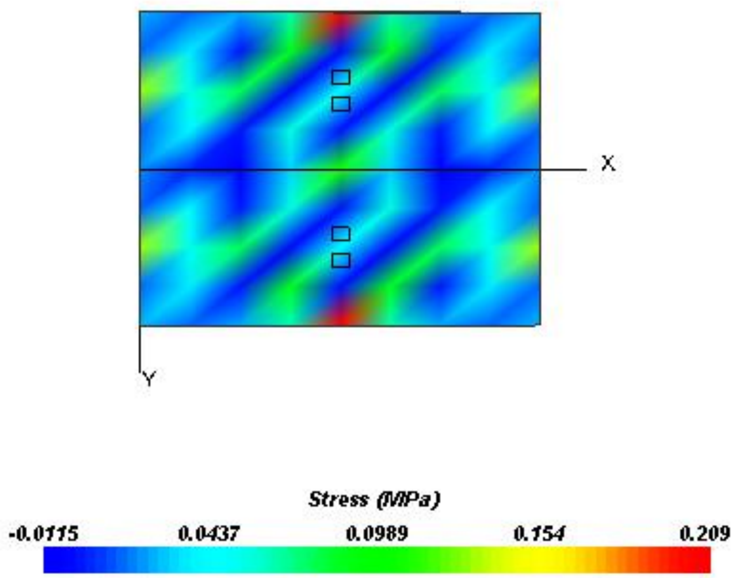


Figure 21: Type 3 max stress on top of 50mm asphalt layer

Table 7 below shows the results for the asphalt layers simulated in Type 3 pavement configuration.

Table 7: Summary of Type 3 results for asphalt layer

Type 3		
Asphalt thickness	**Microstrain (AC)**	**Max tensile stress (MPa)**
50	35	0.21
70	25	0.15
100	22	0.13
130	25	0.15

The final design to be assessed was Type 4 below (Figure 22). This model configuration had a 250mm concrete slab with a modulus of 8000MPa. The results from the modeling process showed a maximum tensile strain of 29 microstrains in the 50mm asphalt layer and a minimum 16 microstrains in the 100mm layer.

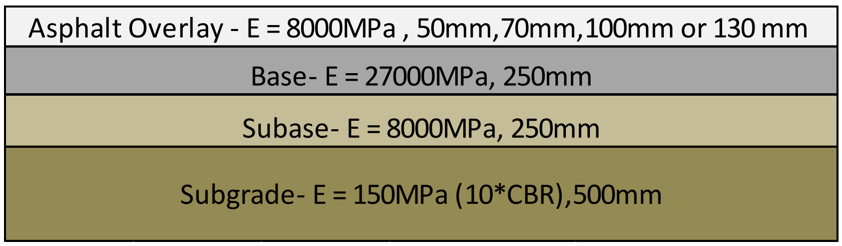


Figure 22: Type 4 of single slab design for modeling

Table 8 shows the results for model Type 4 in combination with the maximum stress output in the top of the asphalt when it was 50 mm thick and the 70,100 and 130mm layers having a similar strain of 17 microstrains.

Table 8: Summary of Type 4 results for asphalt layer

Type 4		
Asphalt thickness	**Microstrain (AC)**	**Max tensile stress (MPa)**
50	28	0.23
70	17	0.14
100	16	0.13
130	17	0.14

Although a minimal difference between the bottom and top of the asphalt layer the maximum stress was found in the top of the 50mm asphalt layer around the wheel loading, when modeling Type 4 configuration, depicted below in Figure 23.

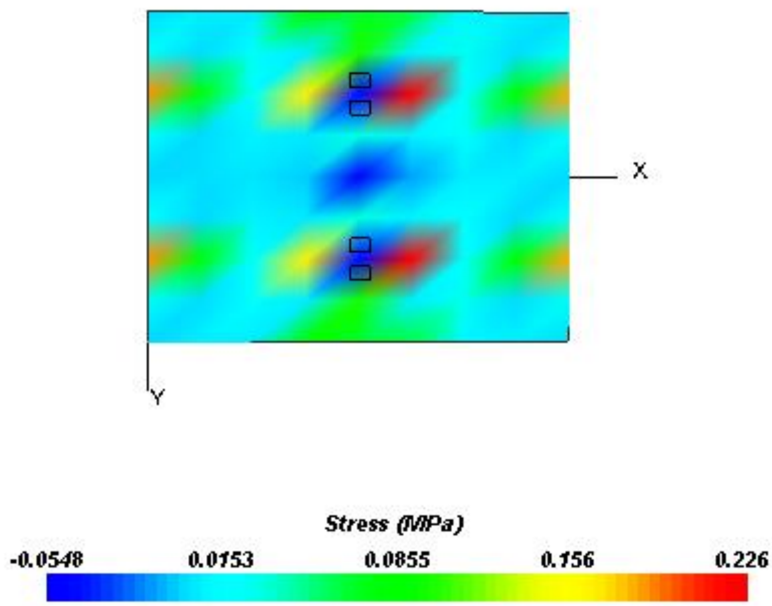


Figure 23: Max tensile stress in top 50mm overlay for Type 4 model

5.4 Summary of single slab asphalt layer

Results indicate the maximum tensile strain occurs in the 50mm asphalt layer for 3 of the 4 model types. Type 1 configuration (Figure 16) had the maximum tensile stress at the top of the 70mm layer. This may be that the stress is predominately being transferred the layers on Type 1 due to the thin layers present. The 50mm overlay for this study was modeled to test the limits of the design even though it is recommended a minimum of 70mm for this type of asphalt. Figure 24 below summarises the results for the single slab asphalt tensile microstrains, the dashed line marks the allowable strain for unlimited repetitions keeping the asphalt below its limit of fatigue (Shen and Carpenter, 2005).

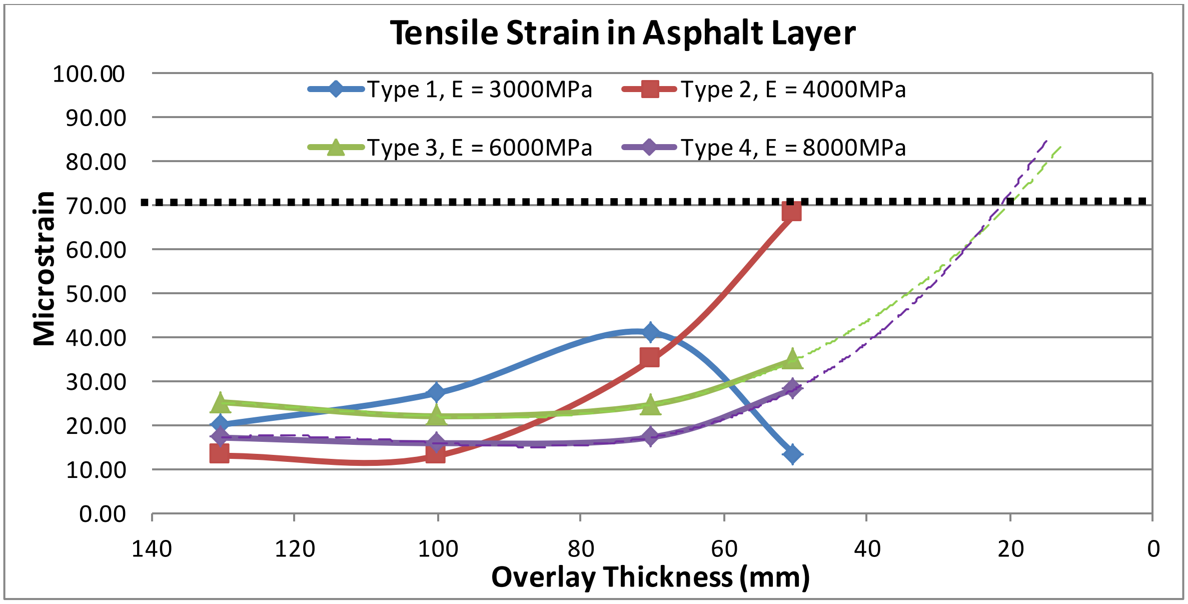


Figure 24: Summary of tensile strain results present in asphalt layer (single slab4 layer model)

Results for the majority of the simulations performed (markers on the line) show that the strain tends to flatten out around the 70mm mark, particularly for Type 3 and 4 which had concrete slabs 200mm and 250mm with a firm base. Types 3 and 4 demonstrated a point between 130 and 80mm where the strain change is minimal. This suggests that in regards to tensile strain, an 80mm overlay would perform similarly to a 130 mm overlay, meaning a substantial material saving and limited height change for cross falls and change of gutter heights etc. Type 2 shows a similar trend although starts to increase prominently around 100mm. Type 1 has a substantially low amount of strain in the 50mm layer, which may indicate that layer is not adding a structural element with a majority of the stress continuing through to the lower layers.

5.5 Deflection and stress of concrete slab with overlay

Type 1 single slab model with the properties given in Figure 16 resulted in a minimal stress change throughout the concrete slabs, even with the varying asphalt thicknesses. The only significant change existed in the 70mm overlay, where the stress increased by 0.2 MPa. Using the maximum tensile stress present in each of the slabs with varying asphalt thicknesses the stress ratio was calculated, which is shown in Table 9 below with the maximum deflection.

Table 9: Summary of stress and deflection in slab of Type 1 with asphalt overlay

Type 1			
Modeled asphalt E = 3000 MPa, concrete slab E = 12000 MPa			
Asphalt overlay thickness	**Max tensile stress (Concrete)**	**Slab stress ratio (Concrete)**	**Max deflection (Concrete)**
mm	**MPa**	**Tensile stress/ Tensile strength**	**mm**
50	0.43	0.11	0.955
70	0.67	0.17	0.992
100	0.43	0.11	0.984
130	0.43	0.11	0.998

The results of the slab stress ratio range from 0.1-0.17, indicating that the stress would be well below 0.5. Therefore all of the configurations for Type 1 would be able to withstand unlimited amounts of this loading and stress. The deflection had minimal change throughout the models of Type 1, close to 1 mm for all. Figure 25 below shows the simulation results from the maximum tensile stress that was present in the base of the slab when a 70 mm overlay was modeled.

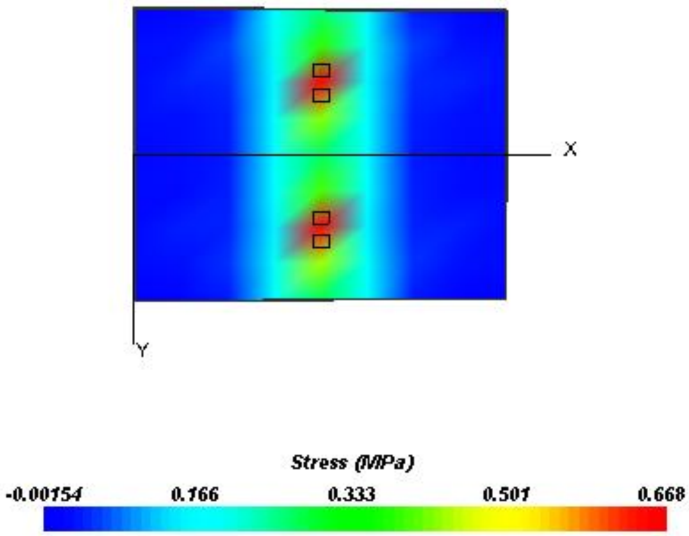


Figure 25: Type 1 max tensile stress in base of slab with 70mm overlay

Type 2 single slab model configuration (Figure 18) had the same material properties and geometry as Type 1, with the exception of a thicker subgrade of 500 mm. The results indicate that there is minimal difference in tensile stress among all four Type 2 models, with the tensile stress averaging 0.65 MPa in the base of the concrete slab. Table 10 below shows the stress and maximum deflection with the calculated stress ratio.

Table 10: Summary of tensile stress and deflection in slab of Type 2 with asphalt overlay

Type 2			
Modeled asphalt E = 3000 MPa, concrete slab E = 12000 MPa			
Asphalt overlay thickness	**Max tensile stress (Concrete)**	**Slab Stress ratio (Concrete)**	**Max deflection (Concrete)**
mm	**MPa**	**Tensile stress/ Tensile strength**	**mm**
50	0.67	0.17	0.504
70	0.66	0.17	0.8
100	0.64	0.17	1.232
130	0.54	0.14	1.246

Despite minimal change in stress with varying overlay thicknesses, the deflection steadily increases as the asphalt thickness increases. The deflection ranges from 0.5 mm to almost 1.3 mm, the minimum when an overlay of 50 mm was modeled and the maximum when the 130 mm overlay was modeled. Figure 26 below shows the stress in the slab of Type 2 model when a 130 mm asphalt overlay was simulated with maximum deflection also occurring in the area of maximum stress.

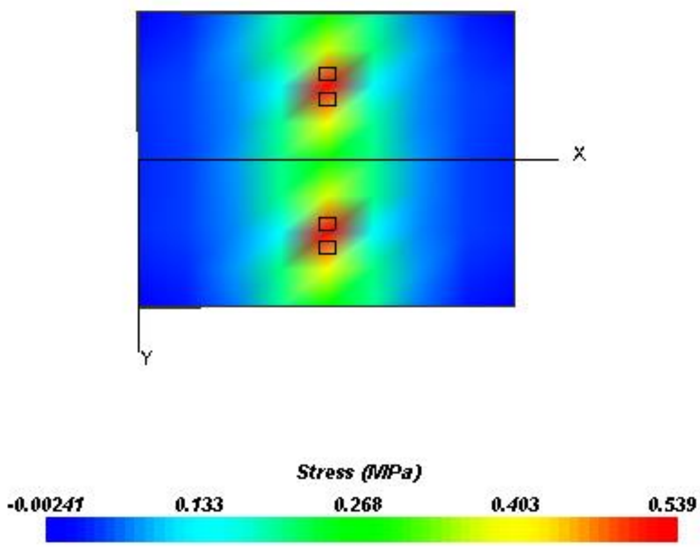


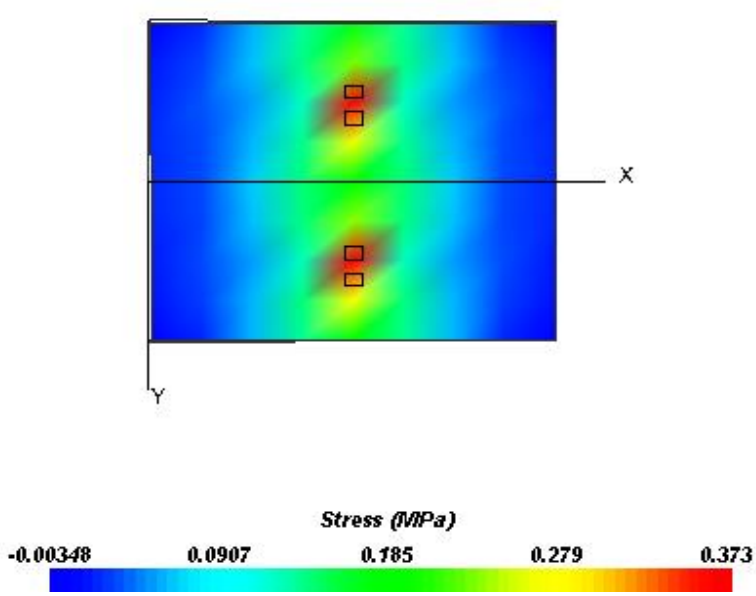
Figure 26: Type 2 model with 130mm overlay where maximum tensile stress occurred in base of concrete slab

Type 3 single slab model (Figure 20) had the same amount of stress in the base of the concrete slab when all four layer thicknesses were modeled for this configuration. The tensile stress was approximately 0.4 MPa with a stress ratio of 0.08. A summary of the results below in Table 11 indicates minimal change in the deflection amongst the different simulations for the single slab model Type 3, all of which are approximately 1mm.

Table 11: Summary of tensile stress and deflection in slab of Type 3 with asphalt overlay

Type 3			
Modeled asphalt E = 6000 MPa, concrete slab E = 19500 MPa			
Asphalt overlay thickness	**Max tensile stress (Concrete)**	**Slab stress ratio (Concrete)**	**Max deflection (Concrete)**
mm	**MPa**	**Tensile stress/ Tensile strength**	**mm**
50	0.39	0.08	0.994
70	0.38	0.08	0.999
100	0.37	0.08	1.077
130	0.36	0.08	1.095

Figure 27 below is the stress distribution in the base of the slab when a 100mm overlay was present with the maximum tensile stress of 0.37 MPa below the wheel load. This type of stress distribution was typical for the other Type 3 models.

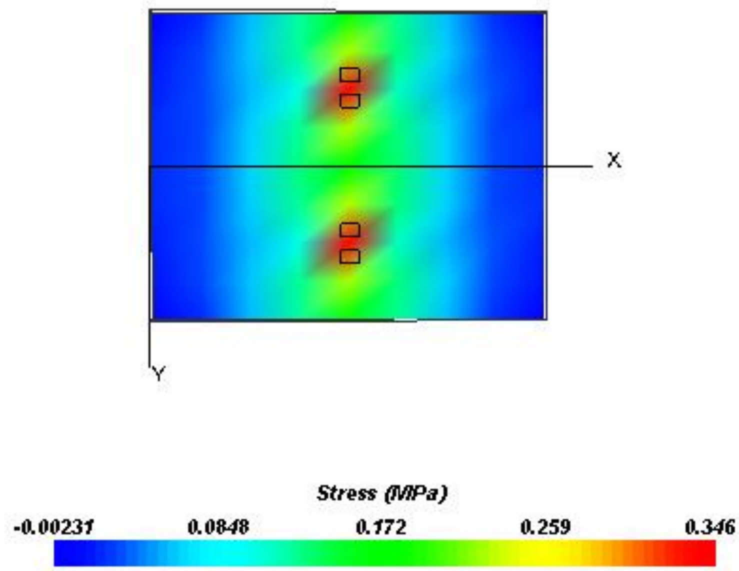


The final design modeled was Type 4, with the configuration and material properties depicted earlier in Figure 22. Type 4 had a similar stress in the slab as Type 3, using a 50 mm on top, however as the overlay increased to 70 mm and onwards the tensile stress in the concrete slab decreased. The stress present in the base of the slab reached a minimum of 0.26 MPa when both the 100 mm and 130 mm overlay was simulated, as shown in the summary below (Table 12). The slab stress ratio averaged 0.06 and the deflection in the slab averaged just over 1 mm for all the configurations modeled for Type 4.

Table 12: Summary of tensile stress and deflection in slab of Type 4 with asphalt overlay

Type 4			
Modeled asphalt E = 8000 MPa, concrete slab E = 27000 MPa			
Asphalt overlay thickness	**Max tensile stress (Concrete)**	**Slab stress ratio (Concrete)**	**Max deflection (Concrete)**
mm	**MPa**	**Tensile stress/ Tensile strength**	**mm**
50	0.35	0.07	1.023
70	0.28	0.06	1.071
100	0.26	0.06	1.053
130	0.26	0.06	1.116

Figure 27 below is the stress present in the base of the concrete slab with a 50 mm overlay. This was also typical for the 70,100 and 130 mm overlay model, however increasing thickness of overlay slightly decreased stress in the base of the concrete slab.



. Figure 27: Stress in base of concrete slab of Type 4 with 50mm overlay

The stress in the base of the concrete slab was in a uniform direction along the line of the axle loading for all the models. This coincided with the maximum deflection between the dual wheels. This is due to the way the slabs are deflecting in the central location along the Y axis, shown below in Figure 28, with the two pairs of twin rectangles indicating the wheel loading position.

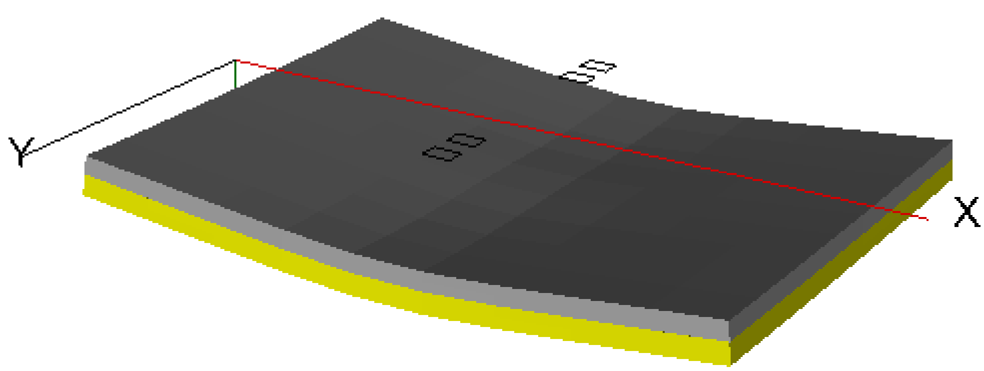


Figure 28: Typical deflection for slab and asphalt layer (x 500 scale factor, Type 4 with 130mm overlay)

The deflection shape in Figure 28 above resulted in the maximum amount of tension in the concrete base under the loading point and maximum compression along the edges of the top face of the concrete slab.

5.6 Deflection and stress of concrete slab before and after overlay

Comparing the stress in the base of the concrete slab before and after an asphalt layer was modeled on top shows a great reduction in the stress applied to the slab when an overlay is present. Figure 29 below shows the stress ratio comparisons for the four models with and without overlay.

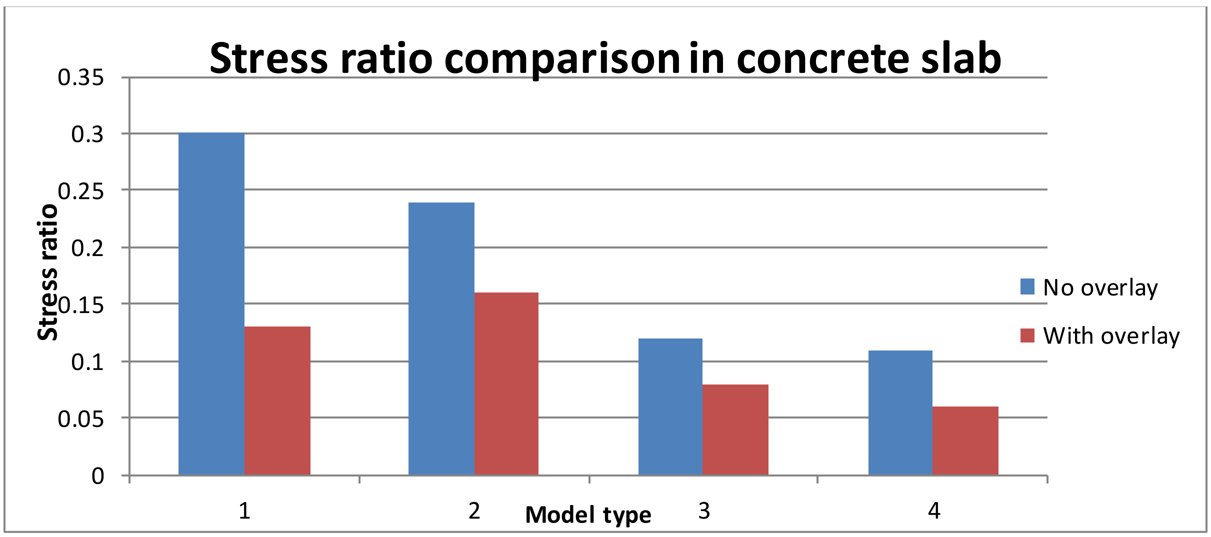


Figure 29: Summary of stress reduction in base of slab after overlay

The stress ratio is a direct result of the stress present in the base of the slab when the load is applied. These results show that the stress in the concrete slab is significantly reduced when an asphalt overlay is applied. For this study, there was a minimum of a 40% stress reduction in Type 1 and the maximum of 67% for Type 2 and 3, with an average amongst all the pavements modeled of 58%. Table 13 below shows these results, highlighting the difference in tensile stress, deflection and stress ratio in the concrete slab with an overlay and without.

Table 13: Summary of stress and deflection in concrete slab before and after an asphalt overlay

Overlay single slab				No overlay multiple slab		
Type 1						
Asphalt , E = 3000 MPa	Max tensile stress	Slab Stress ratio	Deflection	Max tensile stress	Stress ratio	Max deflection
Layer thickness (mm)	MPa	Stress/T Strength	Concrete	MPa	Stress/T Strength	mm
50	0.432	0.112	0.955	1.02	0.3	1.2
70	0.668	0.173	0.992			
100	0.433	0.112	0.984			
130	0.428	0.111	0.998			
Type 2						
Asphalt , E = 4000 MPa	Max tensile stress	Slab Stress ratio	Deflection	Max tensile stress	Stress ratio	Max deflection
Layer thickness (mm)	MPa	Stress/T Strength	Concrete	MPa	Stress/T Strength	mm
50	0.67	0.17	0.504	0.92	0.24	1.4
70	0.66	0.17	0.8			
100	0.64	0.17	1.232			
130	0.54	0.14	1.246			
Type 3						
Asphalt , E = 6000 MPa	Max tensile stress	Slab Stress ratio	Deflection	Max tensile stress	Stress ratio	Max deflection
Layer thickness (mm)	MPa	Stress/T Strength	Concrete	MPa	Stress/T Strength	mm
50	0.39	0.08	0.994	0.57	0.12	0.64
70	0.38	0.08	0.999			
100	0.37	0.08	1.077			
130	0.36	0.08	1.095			
Type 4						
Asphalt , E = 8000 MPa	Max tensile stress	Slab Stress ratio	Deflection	Max tensile stress	Stress ratio	Max deflection
Layer thickness (mm)	MPa	Stress/T Strength	Concrete	MPa	Stress/T Strength	mm
50	0.35	0.07	1.023	0.52	0.11	1.25
70	0.28	0.06	1.071			
100	0.26	0.06	1.053			
130	0.26	0.06	1.116			

Similar to the stress reduction when an asphalt overlay is used, there was also a reduction in the deflection of the slab for Type 1, 2 and 4. Type 3 appears to have a greater deflection when an overlay is used. Despite the maximum stress present in the base of the modeled slabs being below potential fatigue limits, there are alternatives to further reduce this. Skewing of the repaired joints similar to that pictured below (Figure 30) will transfer and disperse the wheel load among two different sections of the slab. This reduces the overall load applied to one join edge, and may help to further reduce the stress and deflection in both the asphalt and concrete slab.

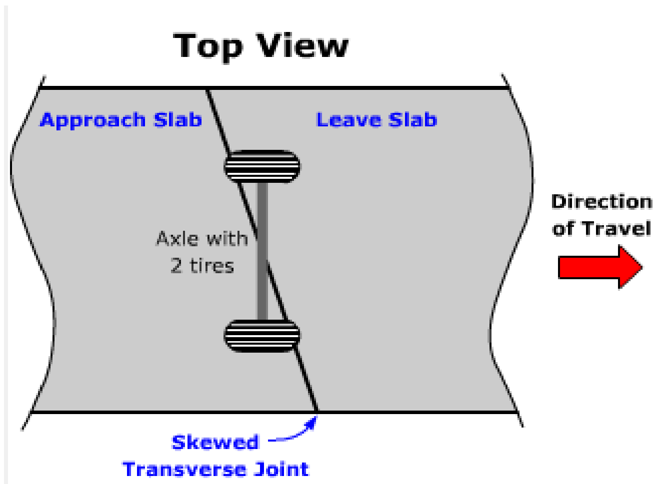


Figure 30: Skewing of concrete section

6.0 Summary

The initial modeling was designed to imitate multiple slab repairs along a section of road, to assess the effect the multiple joints had on the 'repaired' concrete slabs. The models had a subgrade thickness ranging from 300-500mm, subbase and concrete slab varied from 100-250mm. Although the top layer could not be modeled due to the limitations of the program used, it was apparent that in most cases, if repaired correctly to the original strength of the pavement, all modeled types would withstand unlimited repetitive loading. The maximum stress ratio found was 0.3 in Type 1, however this is below the recommended 0.5 maximal for unlimited repetitions. This requires further investigation, as the properties of the existing subbase and subgrade may cause excessive stress throughout the pavement layers. Therefore Type 2, 3 and 4 may be more suitable for rehabilitation. Furthermore, the stress around the traverse joints of the slabs also requires further investigation if heavier vehicles, greater than 80kN, are going to be using these pavement models.

The next stage of modeling was a four layer pavement system with the same material properties as the initial set of models, but included a fourth layer of a high modulus overlay. The varying thicknesses of the additional asphalt overlay ranged from 50-130mm. Each layer varied in strength which can be seen in Figures 16-22. The key focus of the project was the modulus of the asphalt overlay. From literature moduli it is known to have a vast range (SAMI, 2015), but for this study it ranged from 3000 MPa (low end of high modulus) to 8000 MPa (upper limit). The results from the project indicate that a 50mm asphalt layer does not act as a structural layer for the pavement and a large percentage of the stress is directly transferred to the lower layers beneath the asphalt. Further to this, the project highlights that for all the simulations conducted, an overlay of 70mm would be suitable, although pavement configurations Type 1 and 2 may be better suited to a slightly thicker overlay.

7.0 Conclusion

This project aimed to initiate further investigation into this relatively new form of rehabilitating pavement in Australia, specifically analysing how the existing rigid pavements in Australia would react to an overlay with an elevated modulus. Although the project used a simplified simulation process, these initial results are promising and indicate high modulus overlay may be a viable option for rigid pavement improvement without the need for complete reconstruction. With increasing traffic volumes and an ever growing population, particularly in our capital cities existing pavement designs from 30 plus years ago are not coping. A form of rehabilitation for pavements is needed to handle the extra loading that pavements are under in the modern day. As complete reconstruction of our road system is not a feasible option for government bodies, asphalt overlay with a high modulus may assist in alleviating the pressure on the aging concrete pavements.

8.0 Further Work

As the use of asphalt overlay with an elevated modulus to rehabilitate cracked concrete pavement is relatively new to Australia, extensive research is still required in this area. The project was to initiate this process and further work should include:

- Alternate program for modeling so that a multiple repaired slab can be simulated beneath a single asphalt layer.
- A cost analysis comparing it to other current forms of pavement rehabilitation.
- Geotextile grid reinforcing that may improve resistance to tensile strain in the asphalt.
- Laboratory and field testing of different blends of asphalt with an elevated modulus.

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10.0 Appendices

Appendix A - Project Specification

Title: Design of asphalt overlay for concrete pavements

Major: Civil Engineering

Supervisor: Dr. Andreas Nataatmadja

Enrolment: ENG4111 – EXT S1, 2016

ENG4112 – EXT S2, 2016

Project Aim: Assess different asphalt overlay designs on top of cracked concrete pavements and provide guidance on the application of asphalt overlays.

Programme: Issue A, 16th March 2016;

1. Conduct literature review of current asphalt overlay practices and analysis 2 to 3 case studies of previous overlays that have rehabilitated existing concrete pavements.

2. Identify case studies of effective overlay rehabilitations to form the basis of a design for project.

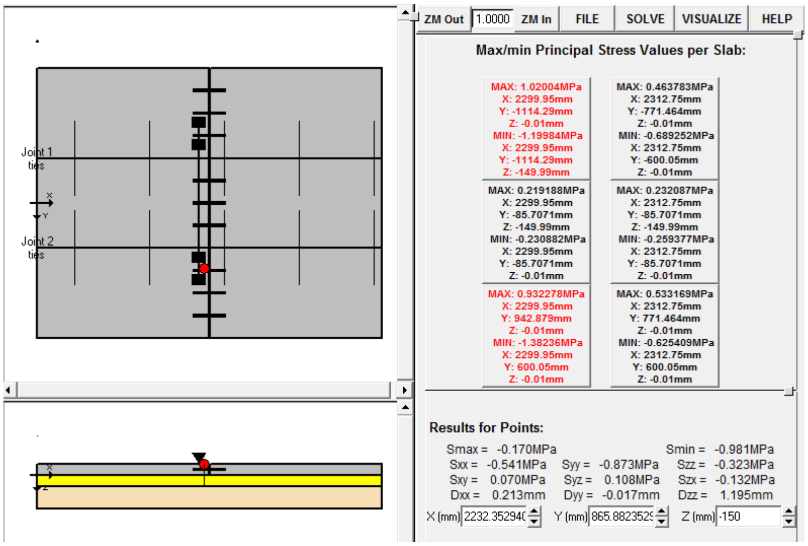
3. Simulate designs using the 3D finite-element program EverFE taking into consideration, loading conditions, material characteristics, subgrade support, pavement deflection.

4. Analyse data gathered from simulations and select an appropriate design taking into consideration the factors in stage 3.

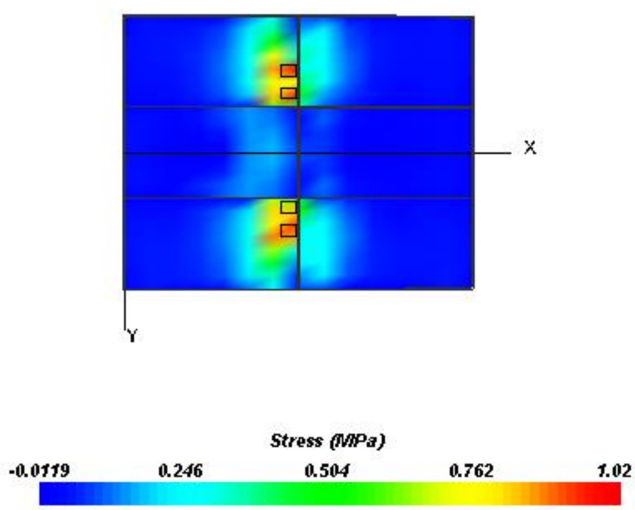
5. If a successful design is obtained the main results will look to contribute to the understanding of high modulus overlay for the Australian Pavement Community

Appendix B - EverFE Output Result (Multiple slab model)

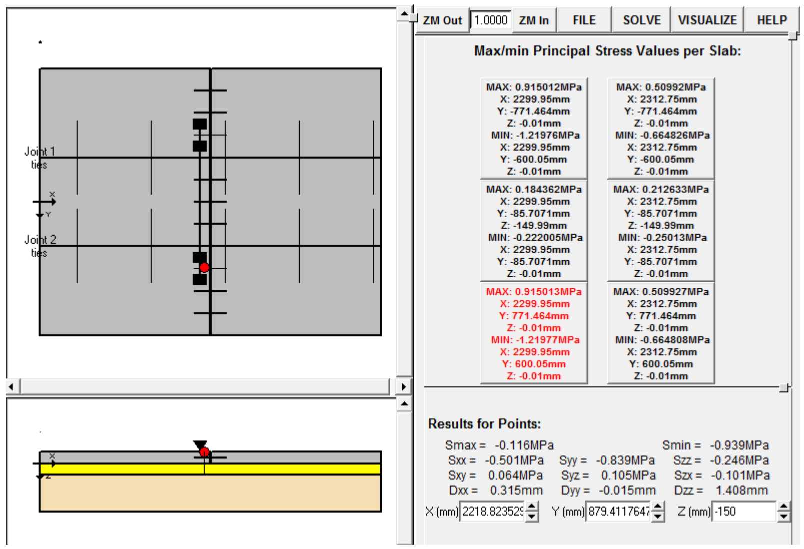
Type 1



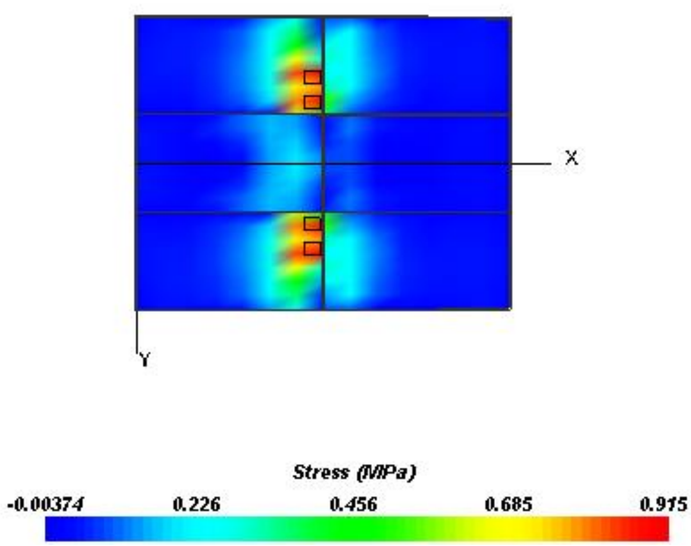
Type 1 stress in bottom of slab



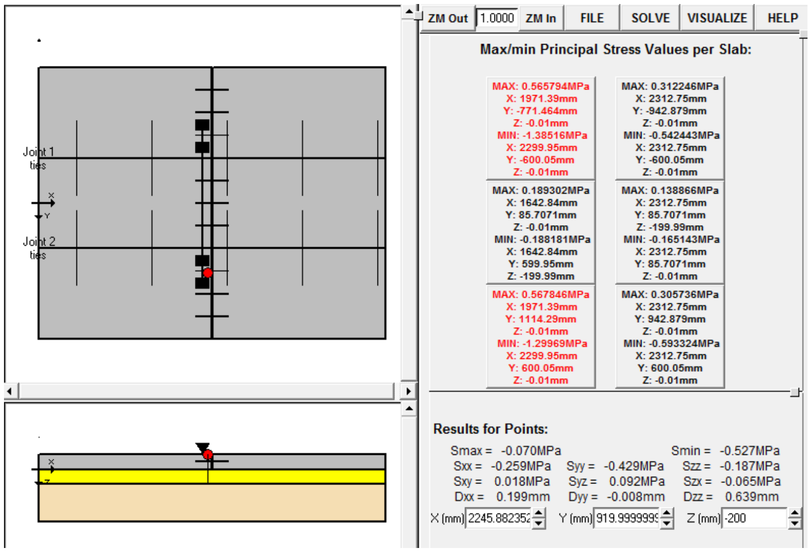
Type 2



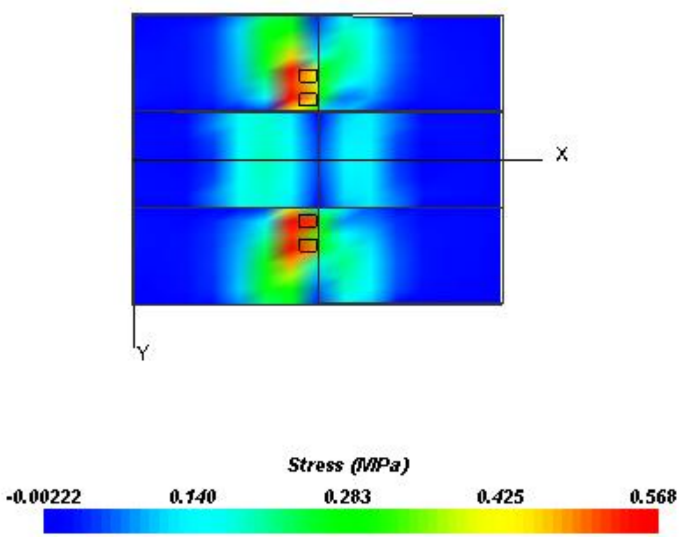
Type 2 stress in bottom of slab



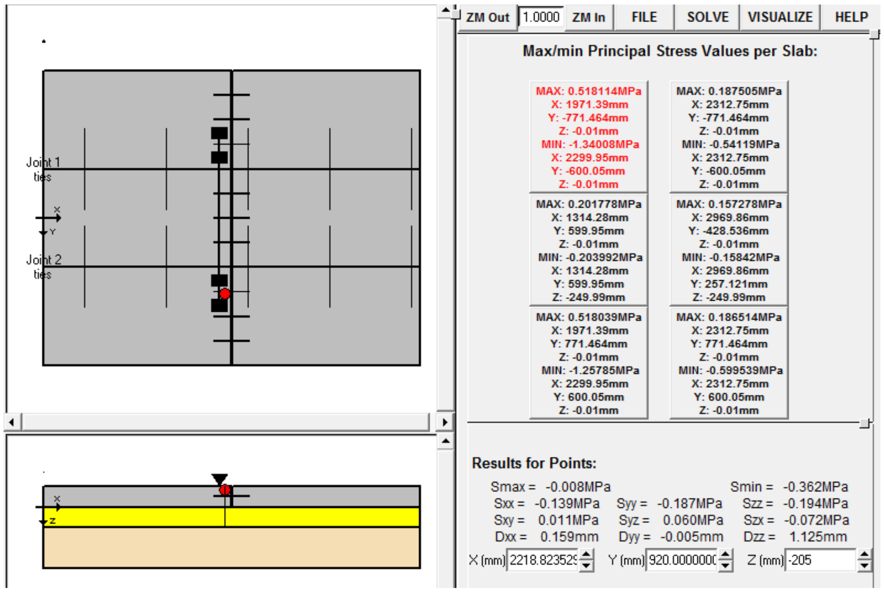
Type 3



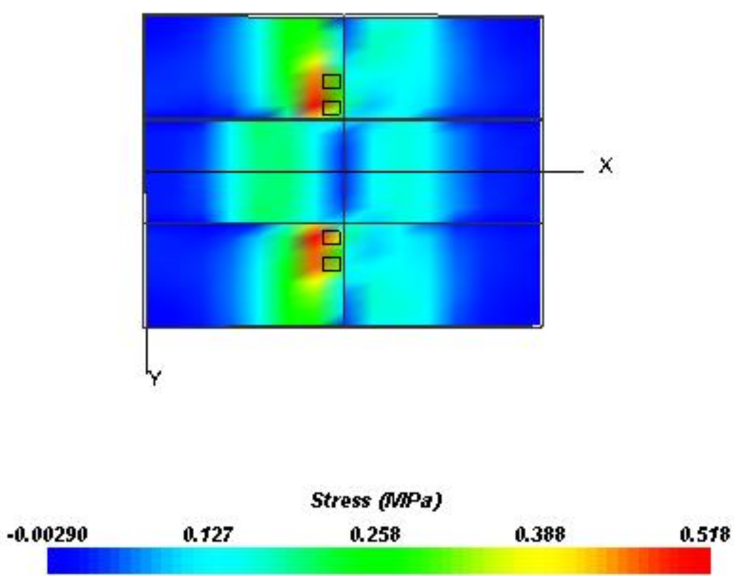
Type 3 stress in bottom of slab



Type 4

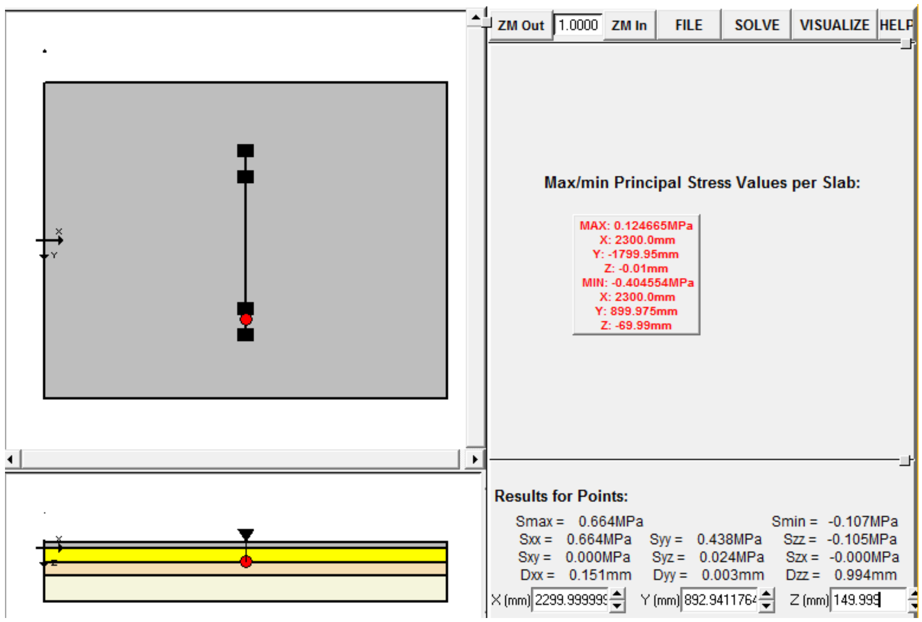


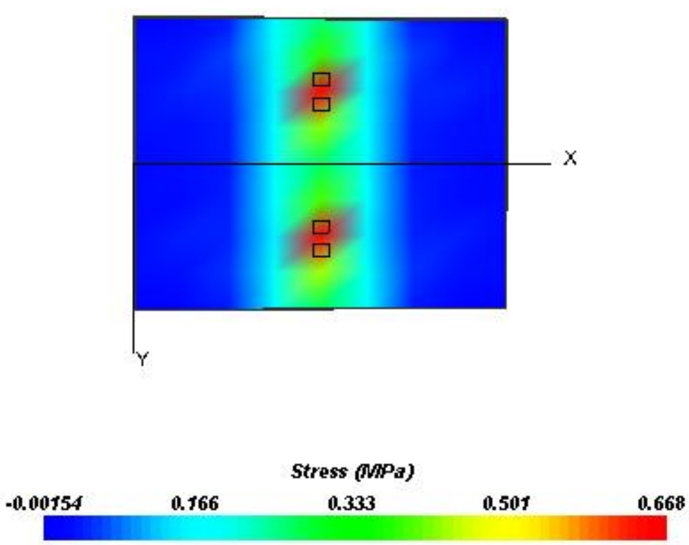
Type 4 stress in bottom of slab



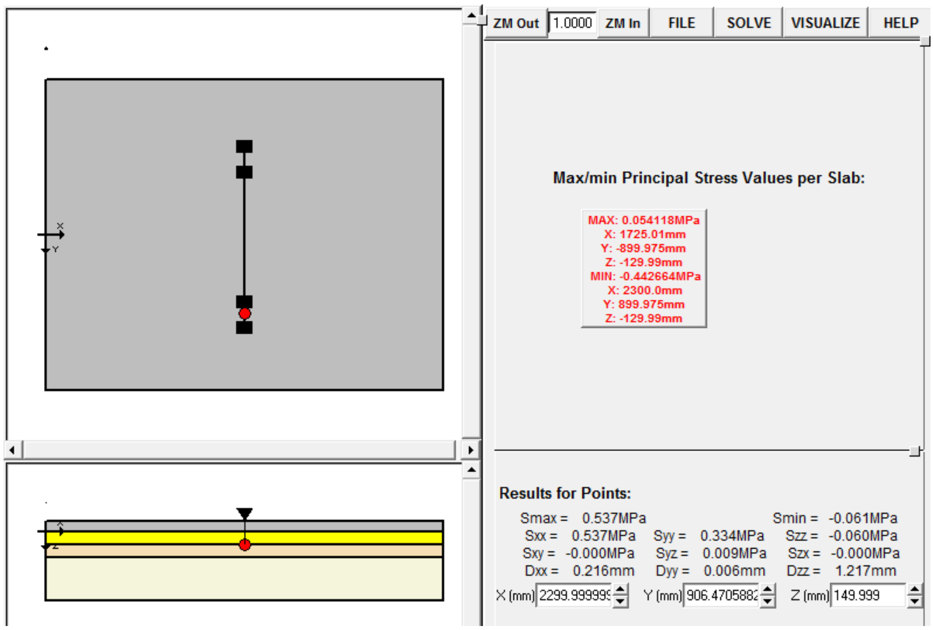
EverFE Output Results (Single slab with asphalt model)

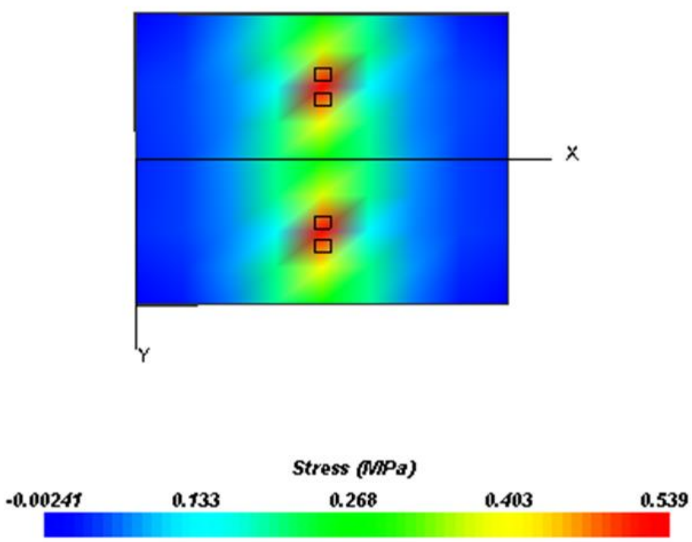
Type 1 slab results max stress in base of concrete slab modeling 70mm overlay



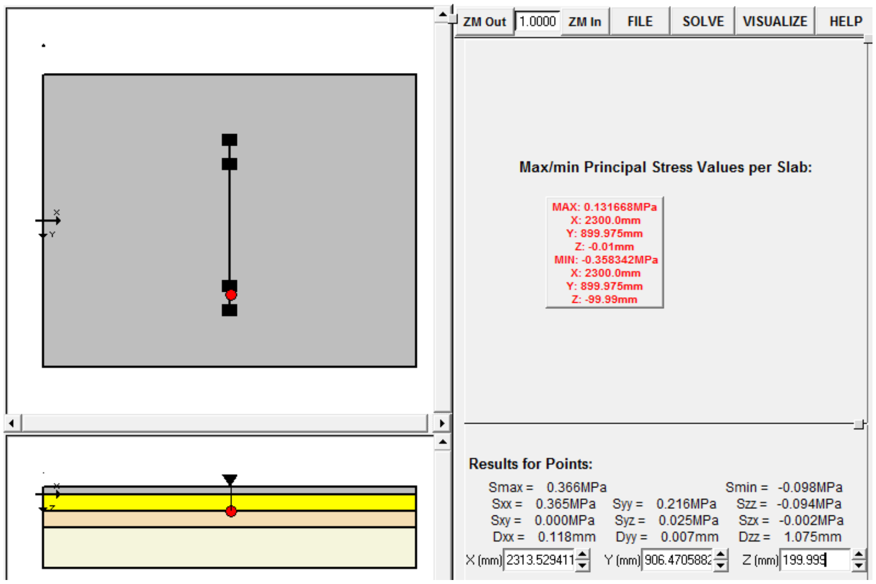


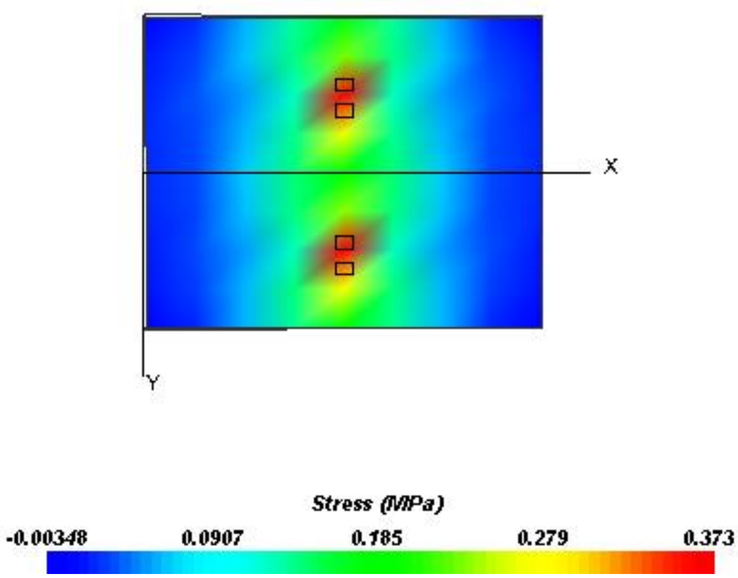
Type 2 slab results max stress in base of concrete slab modeling 130mm overlay





Type 3 slab results typical stress in base of concrete slab (100mm overlay)





Type 4 slab results typical stress in base of concrete slab (70mm overlay)