SESSION 6 — REPORTS FROM 1997 AAPA STUDY TOUR

Design and Performance of Heavy Duty Asphalt Pavements

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DESIGN AND PERFORMANCE
OF HEAVY DUTY ASPHALT PAVEMENTS

8th INTERNATIONAL SOCIETY OF ASPHALT PAVEMENTS (ISAP) CONFERENCE
— SEATTLE, INCLUDING THE AAPA STUDY TOUR OF USA AND CANADA

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Summary
This paper provides an overview of relevant information from papers presented at the Eighth ISAP conference held at the University of Washington in Seattle, USA, from August 10 to 14, 1997 and observations made and information presented and/or received on the subsequent Australian Asphalt Pavement Association (AAPA) study tour of the USA and Canada.

The design of heavy duty asphalt pavements in Australia is based on a mechanistic design method where a linear elastic model is used to determine critical horizontal strains at the bottom of bound layers (usually the determining factor for pavement thickness) and the vertical strain in the subgrade. The method is heavily reliant on fatigue performance relationships derived from laboratory test data and validated by accelerated loading tests to predict the structural life of bound pavement layers and deformation of the subgrade.

It would appear that Australian pavements designed by the mechanistic method result in similar thicknesses as those designed by different mechanistic/empirical methods in other parts of the world but there is growing evidence that these relationships are under predicting the fatigue life of bound pavement layers.

Whilst there is adequate laboratory test data and accelerated loading test results available around the world there does not appear to be a strong correlation established between accelerated test results and actual field performance which is essential if realistic performance relationships are to be derived.

The modes of pavement distress in both Europe and North America are usually rutting, environmental cracking, wear or ravelling, delamination and brittle fracture of the wearing course rather than fatigue cracking or structural failure of the bound layers. The UK design method is designed to avoid structural (or fatigue) damage altogether which has some merit on very heavily trafficked freeways. Opportunity exists for the sharing and exchange of accelerated pavement test data and performance data on actual “in service” aged heavy duty pavements to assist with validation of the Austroads asphalt fatigue performance relationship.

A mechanistic approach to the design of pavements in the USA is incorporated in the Strategic Highway Research Program (SHRP) pavement distress prediction models. Unfortunately these models contained deficiencies which lead to incorrect values or incorrect conclusions in a number of aspects. A complete review of the models is to be undertaken which is scheduled for completion by year 2005. The aims of the SHRP prediction models for prediction of fatigue cracking, rutting thermal cracking, and new model for prediction of reflection cracking, has the general support of the Federal Highway Administration (FHWA) and asphalt industry groups to eventually replace the largely empirically based AASHTO pavement design method which was developed after the 1962 AASHTO road test.

Heavy duty thick asphalt pavements (particularly those with cement bound sub-bases) appear to be performing very well and can be readily rehabilitated periodically by surfacing milling and overlay with new generation rut resistant and durable asphalt surfacing such as Stone Mastic Asphalt or Open Graded Friction Course incorporating Polymer Modified Binders and mineral fibres.
1. INTRODUCTION

Since 1986, a mechanistic approach to the design of heavy duty asphalt pavements has been used in Australia which is largely based on the asphalt fatigue performance relationship developed in the 1960s by the Shell oil company. Fatigue performance relationships for cement bound sub-bases and the various asphalt layers are used to predict the fatigue life for pavements comprising one or more bound layers. Another performance relationship is used to predict the vertical deformation of the subgrade.

The visco-elastic behaviour of asphalt is built into the asphalt fatigue performance relationship and was validated by accelerated loading trials conducted by the Accelerated Loading Facility (ALF) trials at Mulgrave in Victoria (Jameson et al 1991).

The Austroads asphalt fatigue performance relationship seems to deliver the desired result in terms of overall pavement thickness, however there is a growing indication that the relationship, having been based largely upon laboratory tests, is under predicting fatigue life in comparison with actual observed performance in the field. It is accepted that laboratory fatigue tests are more severe than field accelerated loading tests mainly due to sample variation and lack of rest periods between load pulses. Sizeable shift factors (8 to 13 times) are applicable to convert laboratory performance of materials to field performance under accelerated loading (Maccarone et al, 1997). Accelerated pavement testing is indicating longer fatigue lives for asphalt (particularly thin layers) than the fatigue lives predicted by the fatigue performance relationships. This has been confirmed to some extent by preliminary information from accelerated loading trials undertaken at Dandenong in Victoria in 1997, other similar accelerated loading trials undertaken in other countries, and from the lack of observed fatigue cracking in aged heavy duty thick asphalt pavements.

The Austroads model used for the mechanistic design of pavements with one of more bound layers assumes that fatigue cracks commence at the bottom asphalt layer and propagate to the surface. There is now evidence to suggest that due to age hardening of the top asphalt layers and uneven stress distribution under tyres, cracking has been observed to commence at the top and propagate downwards particularly when the asphalt pavement is more than 150 mm thick.

The fatigue life of asphalt is defined as the number of load repetitions required to reduce the asphalt stiffness to half its initial value however when this point is reached. It has been observed that fatigue cracks are not always visible, indicating that the reduction in stiffness could be due to micro cracking rather than crack propagation.

It is fundamental that the predominant failure modes of pavement materials is well understood if the mechanistic pavement design procedure is to be further enhanced.

This paper provides an overview of relevant information from papers presented at the Eighth ISAP conference held at the University of Washington in Seattle, USA, from August 10 to 14, 1997 and observations and information presented on the subsequent Australian Asphalt Pavement Association (AAPA) study tour of the USA and Canada. This information may provide assistance in planning the future direction of pavement research and possible enhancements to the Austroads mechanistic pavement design procedure.

2. UNITED KINGDOM (UK)

Pavement Design

The UK has been building heavy duty asphalt flexible pavements since the 1950s. The older pavements were of lesser thickness (150 to 200 mm of asphalt) but the current long life pavement designs comprise a minimum of 200 - 300 mm of asphalt base, a 250 - 300 mm sub-
base of cement bound material (or lean mix concrete), and a lower sub-base of 250 mm of granular material (Nunn, 1997).

The UK empirical pavement design charts for heavy duty asphalt pavements require a minimum asphalt thickness of 200 mm to prevent reflection cracking from the highly bound cemented granular sub-base which is higher than the value of 175 mm adopted in Victoria (Figure 1).

![Performance Studies](image)

Figure 1 - UK Design Curves for Flexible Pavements

**Performance Studies**
The heavy duty asphalt pavements studied have not suffered serious structural damage where the surface has been properly maintained. There are numerous cases where measured deflections have decreased over time because of age hardening of the asphalt layers. Visual observation of some cracked sections of asphalt pavement over 200 mm thick indicated fatigue cracking of the total asphalt thickness but after detailed investigation these cracks were found to be limited to the top 100 mm. No evidence could be found to support the theory that fatigue cracking propagates from the bottom layer of asphalt in an upward direction.

Areas where strength deterioration had occurred was found to be attributed to poor quality materials or poor standard of construction rather than traffic loading. It appears that age hardened thick heavy duty asphalt pavements can suffer surfacing cracking to a depth of up to 100 mm without losing significant strength.

The main form of cracking observed on the heavy duty UK pavements is thermal or longitudinal cracking mainly confined to the wearing course. The cement bound material (highly bound material is called lean mix concrete in the UK) in current specifications requires a compressive strength ranging from 10 to 15 MPa at 7 days. A minimum ratio of the 28 day flexural strength to the calculated stresses (thermal and traffic loading) of 1.5 is specified to ensure that there will not be fatigue or structural failure in the cement bound layer. (Victorian specifications only require a minimum cement content of 3 % and the sub-base is predicted to fatigue crack before the end of the design life of the pavement).

Crack inducement techniques are used for high strength cemented material to induce shrinkage cracks to form at 2 to 3 m intervals to avoid wider uncontrolled shrinkage cracks forming which are more likely to propagate through the asphalt pavement layers (Parry et al, 1997).

The UK experience acknowledges the importance of regular monitoring of the performance of heavy duty pavements in order to continually validate pavement design practices.
3. UNITED STATES OF AMERICA

Pavement Design

All States in the USA generally use the AASHTO Pavement Design Guide for the design of heavy duty pavements. The method considers variations in stiffness of materials by assigning structural coefficients to layers based on various material strength tests. Many States have their own supplementary provisions and adopt structural coefficients based on material availability, climate, local conditions and past performance. The AASHTO method was developed from the AASHTO road test undertaken in 1962 with revisions in 1986 and 1993. The determination of pavement thickness is largely empirically based.

A typical interstate highway design for a heavy duty asphalt pavement consists of 200 to 300 mm of asphalt, a 100 mm thick layer of permeable granular material or a lightly bound open graded drainage asphalt (1.5 to 2% binder content) and a 250 to 500 mm granular sub-base.

Most agencies and industry groups acknowledge the FHWA needs to develop a reliable mechanistic pavement design procedure.

Superpave™ Prediction Models for Pavement Design

Superpave™ is one of the outcomes of the Strategic Highway Research Program (SHRP). New binder grading specifications, binder test methods, and mix design specifications are now being implemented by the FHWA. The series of mathematical prediction models developed by SHRP for prediction of rutting, fatigue cracking and thermal cracking are yet to be incorporated into Superpave™. The inputs for these models include material performance criteria determined from sophisticated performance type laboratory tests, environmental information, traffic loading and a number of “shift factors” to account for differences between laboratory and field performance such as aging and healing properties. Unfortunately, these models have not given realistic answers in a number of areas.

An expert review committee has been established at the University of Maryland to review and validate the Superpave™ prediction models by 2005 including a new model to predict propagation of reflection cracking (Witczak 1997).

Whilst the Superpave™ prediction models require major review and validation, the overall concept of suitable models to predict fatigue life, rutting, thermal and reflection cracking is generally supported by government agencies and industry throughout the USA. Mike Butcher from DoT, South Australia, is the Australian representative on this committee.

Field Performance of Heavy Duty Asphalt Pavements

Unfortunately, there appears to be a shortage of long term data available on the field performance of pavements the USA. Observation of heavy duty asphalt pavements in various States indicates that fatigue failures are not common. The principal modes of distress on these pavements are rutting, thermal or environmental cracking, spalling of joints, brittle fracture of wearing courses, delamination, pavement wear and shape loss. The usual treatment for these modes of distress are cold planing, regulation and overlay with more durable asphalt surfaces such as Stone Matrix Asphalt (SMA) incorporating both Polymer Modified Binders and mineral or cellulose fibres (about 6 % polymer modified binder content and 0.3% mineral fibres are commonly used in SMA).

Overlays in the USA are generally restricted (at least in the first instance) to maximum of 100 mm to avoid raising of guard railing. Normally, rutted and cracked asphalt is removed by cold planing and 60 mm asphalt regulation and 40 mm of wearing course is applied. Some states determine the depth of overlay by redesigning of the pavement by the current AASHTO method. Falling Weight Deflectometer tests results are sometimes used to back calculate the stiffness of existing materials as inputs to the redesign. Occasionally Universities are engaged to carry out mechanistic analysis of pavement designs for some States.
Treatment of aging concrete pavements is a problem in some States. When the riding quality becomes unacceptable, concrete pavements are resurfaced with 60 mm of asphalt binder course and 40 mm of Stone Matrix Asphalt (SMA) wearing course. The SMA seems to be more resistant to reflection cracking and subsequent erosion. In extreme cases, concrete pavements are rubbelised using a resonant breaker or broken up and reseated with impact hammers. A new pavement design is produced using the rubbelised concrete as a granular sub-base layer with 100 mm of open graded drainage asphalt (1.5 - 2% binder content) and 200 mm of dense graded asphalt pavement is added to complete the reconstruction. This treatment requires guard rails to be raised and the clearance to overpass structures checked and the pavement regraded at these locations if necessary. Most of the interstate highways have a wide formation with a concrete invert drains without kerb and channelling so raising the level is not considered a major problem.

Accelerated Loading Tests
There are a number of accelerated loading facilities in the USA. The facilities either visited on tour or described in various papers presented at the ISAP conference are :-

- Three Australian designed Accelerated Loading Facilities (ALF). Two machines are located at the FHWA - Turner Fairbanks Highway Research Centre in Maryland, and the third belongs to the US Army Core of Engineers in Louisiana. Up to 80 kN dual or single wheel loads are applied over a 12 m strip of pavement in one direction only at 20 km/hr to yield 9120 load repetitions/day. (Figure 2)

- Two South African designed Heavy Vehicle Simulators (HVS) are located at the University of California - Berkeley which are capable of applying single wheel loads up to 200 kN in both directions over an 8 m strip at 8 km /hr to yield 18 000 load repetitions per day. (Figure 3)

- WesTrack near Reno in Nevada (mostly funded by the FHWA but constructed and operated by several universities and private industry) is a single lane 3 km oval track with 910 m straight sections with semicircular ends which is trafficked by driverless trucks towing two trailers to impart a total of 10.3 standard 89 kN axle repetitions per truck pass. Four trucks are used at a test speed of 64 km/hr to impart a total of 11666 axle repetitions/day. Up to 26 asphalt test sections can be constructed on the straights all of which are tested simultaneously. No test sections are placed on the curved ends. (Figure 4)

- The Texas Mobile Load Simulator (TxMLS) located at the University of Texas in Austin has six full tandem axles of 151.1 KN each mounted on a chain to form a vertical loop so that it continuously trafficks a 31 m long by 4 metre wide long test pad at 18 km/hr imparting about 7000 tandem axle repetitions per day. The machine is 31 m long 4.5 m wide and 6 m high and tests both wheel paths concurrently. (Figure 5)
Figure 3 - Heavy Vehicle Simulator (HVS) at the University of California - Berkeley

Figure 4 - Layout of the WesTrack Road Testing Facility near Reno in Nevada

Figure 5 - Scale Model of Texas Mobile Load Simulator (TxMLS) at University of Texas - Austin
At the Turner Fairbanks Highway Research Centre most of the ALF testing has been related to rutting of mixes associated with the new Superpave™ binder grading system however some work has been being carried out to validate the Superpave™ fatigue performance prediction models. The test was undertaken on pavement with 150 mm of asphalt over 300 mm of crushed rock in the open without temperature control.

HVS testing has been recently been undertaken by the University of California for Caltrans to evaluate the performance of two pavements with and without an asphalt drainage layer in accordance with the Caltrans pavement design and overlay design procedures. The first section comprises 140 mm of asphalt, 140 mm of crushed rock base, 230 mm of Granular sub-base over clayey gravel sub-grade with a CBR of 10. The second section was the same as the first except that 76 mm of crushed rock base was substituted with the asphalt drainage layer.

Of particular interest was the comparison between predicted performance and actual performance on the first pavement in fatigue where the fatigue life of the pavement significantly exceeded the predicted fatigue life 12 to 50 times (earlier fatigue failure resulted to some extent by slippage between asphalt layers). This testing was carried out under cover at 20°C.

Two of the significant recommendations to Caltrans as a result of the trial were that a heavier tack coat should be applied between asphalt layers to improve bonding and the compaction standard for asphalt should be increased to reduce air voids and achieve a longer expected pavement life. Rutting was found to be confined to the top 75 mm of asphalt. (W Nokes et al - 1997)

The WesTrack test was set up to validate Superpave™ asphalt mix designs and to examine the effect of mix and/or construction variability on the asphalt performance. Rutting and fatigue data was gathered from the various sections and is to be used to compare with laboratory test data. There are some unexpected results in regard to performance of the Superpave™ mixes. Analysis is continuing. (J Epps - 1997)

The TxMLS testing is still in the analysis stage and some good examples of fatigue cracking of a 50 mm asphalt surfacing have occurred (D.H Chen et al, 1997). The test pavements include one section comprising 50 mm of asphalt surfacing, 300 mm of lime treated gravel base, 150 mm lime stabilised sandy clay sub-grade and another section with 200 mm of asphalt pavement in lieu of the 50 mm of asphalt surfacing. Only the former has been tested to date. (There are also two untested sections of 200 mm thick jointed concrete pavement, one section is founded on a 100 mm of permeable asphalt drainage layer, over 150 mm of lime stabilised sandy clay sub-grade and the other is founded directly on untreated sandy clay sub-grade). On the first test section with 50 mm of asphalt surfacing, transverse cracks predominate and whilst information is still subject to detailed analysis, it has been suggested that there has been strain reversal occurring in the longitudinal direction but not in the transverse direction (F Hugo et al, 1997).

4. CANADA

Pavement Design
Ontario Province has developed a mechanistic/empirical model (OPAC 2000) which predicts both loss of life due to traffic effects and loss of life due to environmental effects (H Ze et al - 1997). The program is an empirical mechanistic approach where structural coefficients are determined for the materials, and elastic layer analysis is undertaken to predict subgrade deflection. The program has an economic analysis module which also considers vehicle exhaust emissions associated with traffic delays caused by disruption of traffic during future rehabilitation work. The traffic model predominates on primary roads and the environmental model predominates on secondary roads. Layer thicknesses on the trial pavements are automatically optimised by the program and costs can also be estimated. The models have
been calibrated from extensive long term performance data in various regions. (Haas et al 1997)

The mode of distress on Canadian heavy duty asphalt pavements is normally rutting, reflection and thermal cracking and shape loss. Asphalt fatigue is not a common occurrence.

Ontario Province has 94% flexible pavements, 5% composite pavements and 1% concrete pavements.

Typical heavy duty pavement designs for a subgrade CBR of 3 % in Ontario Province consists of:

<table>
<thead>
<tr>
<th>Deep Strength Asphalt</th>
<th>Full Depth Asphalt</th>
<th>Composite</th>
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<tr>
<td>OGA 40 mm</td>
<td>OGA 40 mm</td>
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<tr>
<td>HD Binder 80 mm</td>
<td>HD Binder 80 mm</td>
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<tr>
<td>DG Base 120 mm</td>
<td>DG Base 270 mm</td>
<td>Concrete 250mm</td>
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<td>GGACDL 100 mm</td>
<td>GGACDL 100 mm</td>
<td>GGACDL 100 mm</td>
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<tr>
<td>Granular 550 mm</td>
<td>Granular 100 mm</td>
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The Gap Graded Asphalitic Concrete Drainage Layer (GGACDL) is place to overcome frost heave and freeze/thaw effects although it also serves to provide positive sub-surface drainage of the pavement. The drainage layer consists of a gap graded or open graded asphalt mix with 1.8 % binder content.

The composite pavements are usually dowelled jointed plain jointed concrete pavements with 100mm of asphalt surfacing to overcome noise and achieve a smoother riding quality. Some older concrete pavements are converted to composite pavements after diamond grinding. The asphalt over concrete usually cracks and requires further maintenance however some of these roads are being resurfaced with SMA incorporating Polymer Modified Binder (5.7 %) and Mineral Fibre (0.3%) which is more resistant to crack reflection and less likely to erode if reflection cracks propagate through to the surface.

Investigations have indicated that rutting of heavy duty asphalt pavements is confined to the upper 90 mm of pavement and is normally rehabilitated by cold planing and asphalt resurfacing often with SMA.

5. SOUTH AFRICA

Most heavy duty pavements in South Africa are designed as granular pavements with relatively thin asphalt surfacing ranging from 35 mm up to 130 mm as a result of maintenance overlays. The legal dual tyre single axle load in South Africa is now 9 tonnes and a 1994 survey indicated tyre pressures range from 720 kPa up to 1100 kPa. (M White et al 1997). In the Cape Region many of the existing pavements have cement treated base (CTB) up to 200 mm thick with compressive strengths ranging from 10 to 15 MPa. These pavements have generally performed reasonably well structurally over the design period, but reflection cracking of the asphalt surfacing and ingress of water has presented a major maintenance problem.

Rehabilitation of various sections of pavement with highly bound cement treated bases with badly cracked asphalt surfacing 100 mm thick have been treated by:
- Outer Lane - Asphalt is milled off and the CTB pulverised. Up to 10% sand and 20% crusher dust is added to improve grading. A surfacing of 50 mm of asphalt containing 50% RAP is applied.

- Inner Lane - A 20% Bitumen Crumb Rubber Strain Alleviating Membrane Interlayer is applied and surfaced with a gap graded asphalt with hot chippings rolled into the top to improve the surface texture (similar to hot rolled asphalt in the UK).

In the Transvaal area, pavements comprise thin asphalt surfacing on Lightly Cemented Pavements (LCPs) which appear to fail by rutting or crushing of the base layer which is evidenced by surface deformation from pumping of fines rather than any fatigue or structural failure. These pavements are rehabilitated by:

- For roads with a traffic loading of up to 10 million ESAs the CTB is cracked and seated then surfaced with a two application seal treatment.

- For more heavily trafficked roads a 150 mm granular overlay is constructed and surfaced with a two application seal. (The seal treatments have been shown to perform equally as well as a thin asphalt surfacing for similar loadings. (Steyn et al 1997)

There were no papers from South Africa specifically dealing with the design of new pavements however mechanistic analysis techniques were described in the design of rehabilitation treatments. These methods included the ELSYM5 computer program for back calculation analysis, and the South African Mechanistic Design Method (SAMDM) pavement design method “Jordan 1986” and the “MECDE3” program (NITRR, 1997).

**Accelerated Loading Testing**

The first South African Heavy Vehicle (HVS) Simulator was developed in 1970 which was a mobile machine capable of travelling to various new and rehabilitated pavements around the country. A total of three have been produced but two have been exported to the University of California - Berkeley to carry out pavement research work for Caltrans (F Rust et al). Initially the HVS testing was directed towards heavy duty pavements but lately the focus has been on the performance of marginal materials on lighter trafficked pavements.

The HVS has been used to provide major input to the SAMDM mechanistic design procedure, improvements to modelling deformation in pavement, improvements in modelling deflection bowls, comparison of HVS predicted behaviour with actual pavement performance, enhancement of PMS procedures and for the development of Large Aggregate Mixes for Bases (LAMBS) and Granular Emulsion Mixes (GEMS).

Sixteen years ago HVS testing was carried out on a pavement on a four lane road serving the Johannesburg International airport. This pavement has a 35 mm thick asphalt surfacing and carries 30,000 vpd. The pavement condition after HVS loading at the time of construction compared well to the assessed condition of the pavement after 16 years under road traffic in terms of material strengths, deflection and depth of rutting (Jooste et al 1997). This trial indicated that accelerated loading can simulate traffic damage on granular pavements with thin bituminous surfacing fairly well. Asphalt fatigue analysis did not form part of this trial.

HVS testing using 40 kN wheel loading carried out on LCPs indicates that the SAMDM mechanistic design procedure under predicts the fatigue life of thin asphalt surfacing (around 40 mm) thick by 30 to 400 times.
6. THE NETHERLANDS

Accelerated Pavement Testing
The LINTRACK accelerated loading facility at the Delft University in the Netherlands is a circular track, 20 m in diameter with a truck wheel (single or dual) travelling over the circular pavement at 20 km/hr. The load may be varied from 15kN up to 100 kN and can complete up to 15,000 load cycles per day. The track is covered but does not have temperature control and the pavement temperature varies from 0 to 30°C (Figure 6).

Figure 6 - LINTRACK - at Delft University in The Netherlands

LINTRACK has recently been used to undertake accelerated testing on asphalt pavements founded on a sand sub-grade (160 MPa back calculated modulus) to compare rutting and fatigue performance with predicted performance, examining predicted strains with measured strains and modelling of wheel loads using non uniform three dimensional stress distribution under the tyre. (J. Groenendijk et al, 1997). Two trials were undertaken; one with a 70 mm thick asphalt layer and another with a 150 mm asphalt layer and both were trafficked for 4 million 75 kN load cycles.

It was found that:

- the vertical subgrade strain correlated well with the Shell prediction model.
- The Dutch design procedure does not account for surface cracking and predicts a fatigue 3 to 5 times less than the observed life.
- the rutting performance correlated well with the criterion from the Shell Pavement Design Manual
- Visible cracking was restricted to surface cracking rather than structural cracking even though FWD testing indicated the possible existence of cracking at the bottom of the layer. (This is consistent with observed cracking on the heavy duty asphalt pavements in the Netherlands which puts into question the design assumption that fatigue cracking always commences at the bottom of the layer and propagates upwards)
- There was good correlation between measured strain and predicted strain.
- The vertical contact stress in at the edges of the tyre footprint can be up to three times the tyre pressure.
- Substantial increases in maximum strains occurred under repeated loading due to the accumulation of residual strains.
7. AUSTRALIA

Pavement Design
A typical heavy duty pavement comprises 200 to 250 mm of asphalt base, 150 to 180 mm of cement bound sub-base (resilient modulus of around 3500 Mpa), and a selected filling or capping layer with a CBR of between 5 and 10. These pavements are designed to carry the cumulative standard axle passes for a design period of 30 years.

The multi layer linear elastic model CIRCLY (Wardle) is used to determine critical horizontal strains in bound layers and vertical strain in the sub-grade. The critical strains, material stiffness and asphalt mix volumetric data is used in the asphalt fatigue performance relationship to predict the number of load repetitions to failure. (Failure being defined as fatigue cracking of 50 % of the layer). The Design Traffic Loading is multiplied by reliability factors between 4 and 6 to allow for variability of materials, construction and traffic volume. A reliability factor of 6 is used for heavy duty urban freeway pavements in Victoria which equates to a 97.5 % reliability design. This equates to 97.5% of the pavement remaining serviceable at the end of the design traffic loading estimated for a 30 year design life.

The cemented bound sub-base is assumed to fatigue crack during the “first life “ of the pavement as strains are higher in the cemented sub-base material than in the asphalt layers. After the cement bound layer is assumed to have cracked it is treated as a non stress dependent granular material resulting in much higher strains being transferred to the bottom of the asphalt layer marking the beginning of the “second life”. The end of the “second life” is achieved when fatigue cracking of the asphalt has occurred. At the end of the pavement life, it is assumed that both the cemented layer and asphalt have fatigue cracked and unless “intervention” overlays are placed to reduce strains in the asphalt prior to crack propagation, the pavement would require reconstruction.

A minimum thickness of 175 mm of asphalt is required to be placed over cement bound sub-base to prevent reflection cracks propagating through the asphalt layers from shrinkage cracks in the cement bound sub-base. This requirement has been challenged on occasions as being too conservative, however the UK experience suggests otherwise. (A minimum asphalt cover of 200 mm is specified for high strength cement bound sub-bases in the UK).

Australian pavements are of similar composition to the empirically designed pavements in other parts of the world for a design life of 30 to 40 years.

For the very heavily trafficked urban freeways in Australia it would seem desirable to design these pavements to be totally resistant to fatigue cracking to avoid major structural damage occurring. Reconstruction of pavements under heavily trafficked urban facilities causes massive physical and community disruption costs. The approach taken by the UK seems be aiming to avoid this situation which appears to have some merit. If the Australian asphalt fatigue prediction relationship proves to be very conservative as current ALF testing at Dandenong is indicating, current Australian mechanistic design practice may be producing fatigue resistant pavements by chance. However if it is found that the existing fatigue performance relationship is accurately predicting fatigue life, consideration should be given to adopting a 50 year pavement design life on urban freeways or alternatively, adopting a cyclical deflection testing program to detect loss of stiffness so overlays can be applied well before structural damage occurs. (The difference between a 30 year design and a 50 year design would result in less than a 20 % increase in pavement thickness).

The older interstate highway pavements in the US are quite stiff in comparison with the older thin asphalt surfaced granular pavements that were commonly constructed in Australia up to the mid 1980s . These older pavement designs in heavily trafficked areas have exhibited some serious fatigue cracking of the surfacing (<100 mm thick) and is one of the principal modes of distress. Unfortunately, Australia has only a relatively short history of “in service” performance on the deep lift asphalt pavements which are comparable with current design standards. It
would be desirable if more “in service” performance data could be obtained from North America and Europe for similar pavements with a much longer history of performance. If reliable “in service” performance is not obtained, there is a tendency to place too much reliance on performance relationships derived from laboratory testing and a limited number of accelerated loading tests.

It is important that a better understanding of the structural failure mechanisms for heavy duty asphalt pavements is developed, particularly for planning of future overlays.

**Accelerated Loading Tests**

The first asphalt fatigue ALF trial was undertaken on a number of asphalt pavement configurations at Mulgrave (Victoria) from 1989 to 1991 to validate performance relationships used for asphalt and cement bound sub-base. After the trial was completed it was concluded that the Austroads fatigue performance relationship is valid if the condition of the pavement at the end of the pavement life if 50% fatigue cracking is considered acceptable. At the time this trial was undertaken a number of fatigue performance relationships were in existence and the Shell relationship on which the Austroads relationship was based, was found to be more conservative than some and less conservative than others. If a different level of cracking at the end of pavement life was considered desirable for different classes of road, then “shift factors” would need to be introduced into the relationship (Jameson et al 1991). Design reliability factors have been introduced since this time.

Austroads is currently conducting a further ALF trial to correlate asphalt fatigue performance in the laboratory (using the Flexural Beam Test) with field performance at Dandenong (Victoria) on a range of mixes incorporating different binders and gradations. The trial pavements consists of 75 mm of asphalt, 150 mm of crushed rock base founded on sand subgrade and was predicted to carry 50,000 cycles of an 80 kN dual wheel load using the Austroads fatigue performance relationship.

The ALF traffic loading achieved to the present time is 247,146 cycles with an 80 kN load, 161,487 cycles with a 90 kN load both at 20°C and a further 187,204 cycles with an 80 kN load at an average of 10.7°C with no evidence of fatigue cracking on the standard control mix (This equates to 11M ESAs). Possible reasons are that asphalt fatigue performance relationship is conservative, and/or there is a lack of understanding of asphalt failure mechanisms and/or a lack of understanding of the performance behaviour of the underlying crushed rock and sand subgrade.

Accelerated loading tests conducted in the USA and the Netherlands have achieved fatigue cracking of trial pavements up to 150 mm thick. If relevant data on pavement material properties, test conditions, asphalt mix volumetric data and traffic loading etc. could be obtained from these trials, the Austroads fatigue performance relationship could be used to compare predicted fatigue performance with actual performance at these sites. This may provide further evidence as to whether or not the Austroads fatigue performance relationship is consistently under predicting asphalt fatigue life as has been evidenced by the Dandenong ALF test so far. A study of the pavement compositions used in the various trials may give a clue as why a fatigue failure has not been achieved at the Dandenong site when prediction models indicate otherwise.

It would appear that bonding between bound pavement layers is an important issue as evidenced by an earlier Australian ALF trial on layered cemented materials and the results of the Caltrans HVS trial. Victorian practice is to prime the cement bound sub-base with cutback bitumen or bitumen emulsion and grit to cure the cemented material and to achieve a strong bond between the cemented material and the asphalt. There are some who consider this as unnecessary. This is an issue that requires more investigation and/or research.
8. DISCUSSION

This paper summarises some of the information obtained from papers presented at the ISAP conference and from visits to various agencies in the USA and Canada. There has been selective use of this information, to focus on that which is most relevant to Australia.

The information has been presented in a way that it will be useful for any review of the Austroads mechanistic pavement design procedure but at the same time provide an outline of the pavement design practices used in other countries. To do this most attention has been paid to the “in service” performance of deep lift asphalt pavements and information dealing with accelerated loading tests related to asphalt fatigue in particular.

9. CONCLUSIONS

There is some evidence that fatigue performance relationships using the calculated elastic strains at the bottom of bound layers tend to under predict fatigue life. This is evidenced by results obtained from a number of accelerated loading tests undertaken and the lack of fatigue cracking in heavy duty asphalt pavements where asphalt thicknesses exceed 200 mm. It would appear that the Austroads mechanistic design procedure produces designs for heavy duty pavements that are comparable with other mechanistic/empirical design methods used around the world even though fatigue life may be under predicted.

Crack formation and propagation mechanisms requires further research. The development of a performance prediction model for propagation of reflection cracking through asphalt layers from underlying cement bound layers or concrete pavement would be most useful. Use of crack inducement techniques for highly bound sub-bases requires further investigation in order to minimise the incidence of reflection cracking.

More research is required to confirm the importance of achieving strong bonding between asphalt layers and other bound materials. If reliable pavement prediction models are to be developed, pavement research needs to be directed towards achieving correlation between laboratory performance of materials, accelerated pavement testing and most importantly, long term “in service” performance. There does not appear to be a clear link between accelerated testing and long term "in service" pavement performance on deep lift asphalt pavements.

Greater opportunity should be taken to share and exchange sufficient raw data from the numerous accelerated pavement trials conducted around the world so better use can be made of this data as an additional mechanism for validation of pavement performance prediction models used by various agencies engaged in development or review of their mechanistic pavement design procedures.

There is some evidence to suggest that heavy duty asphalt pavements on some primary classes of road with very high disruption costs should not be designed for structural failure in fatigue. This could be overcome by adopting a significantly longer design life without causing prohibitive increases in initial capital costs. Alternatively, there could be a strong case made for cyclical structural testing of heavy duty pavements on very heavily trafficked roads to make sure intervention asphalt overlays are placed well before serious structural damage occurs.

It would appear from the ISAP conference papers published and observations made during the AAPA study tour of the US and Canada that heavy duty asphalt pavements, particularly those with cement bound sub-bases are performing very well. Pavement condition and good ride quality can be maintained by periodic resurfacing and asphalt overlays. New developments in Polymer Modified Binder Technology and use of mineral fibres means that heavy duty asphalt pavements can be provided with a much more durable, quiet and rut resistant surfacing such as Stone Mastic Asphalt and Open Graded Friction Course. These types of surfacing will no doubt enhance overall pavement performance and significantly reduce maintenance costs.
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11. REFERENCES

The following papers contained in the proceedings of the Eighth International Conference on Asphalt Pavements August 10 to 14, 1997 in Seattle Washington.

CHEN D.H. et al - Testing and Analysis of the TxMLS test Pads at Victoria, Texas (Texas USA)

EPPS.J. - WesTrack Full Scale Test Track : Interim Findings - ( Nevada USA)

GROENENDIJK.J. et al - Pavement Performance Modelling using LINTRACK - (Netherlands)

HAAS. R. et al - Pavement Design and Management Guide (Canada)

HE.Z. et al - Development of Performance Models for Ontario's New Mechanistic-Empirical Pavement Design Method - (Canada)

HUGO.F. et al - A Rational Evaluation of Pavement Performance Using the TxMLS Texas Mobile Load Simulator (Texas USA)

MACCARONE.S. et al - Permanent Deformation and Fatigue Properties of Polymer Modified Asphalt Mixes (Australia)

NOKES.W. et al - CALTRANS Accelerated Pavement Testing (CAL/APT) Program - Test Results 1993 - 1996 (California USA)

NUNN.M. - Long-Life Flexible Roads (United Kingdom)

PARRY.R. et al - UK Design of Flexible Composite Pavements (United Kingdom)

RUST.F. et al - The impact of the Heavy Vehicle Simulator (HVS) Test Program on Road Pavement Technology and Management (S. Africa)


WHITE.M. et al - The Rehabilitation of the N1 Freeway Between Cape Town and Paarl - ( S. Africa)
WITCZAK, M.W. - Superpave™ Support and Performance Models Management: Evaluation of the SHRP Performance Models System (Maryland USA)

Other References

AASHTO - Guide for Design of Pavement Structures - 1993 (USA)

Austroads - Guide to the Structural Design of Road Pavements - 1992 (Australia)

JAMESON et al - Australian Road Research Board (ARR 224) Full Depth Asphalt Pavement Fatigue Under Accelerated Loading: Mulgrave Victoria - ALF Trial 1989/91 (Australia)
