A new approach to asphalt pavement design
TODAY’S MODERATOR

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HOUSEKEEPING

Webinar is = 60 mins
GOTOWEBINAR FUNCTIONS

Please type your questions here
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Introduction and overview

Peter Bryant
Contributing research projects

National Asset Centre of Excellence (NACOE)

- P10 Cost-effective design of asphalt pavements at Queensland pavement temperatures
- P39 Long life pavement alternatives for Queensland
- P9 Cost-effective design of thick asphalt pavements: high modulus asphalt implementation

Austroads

- TT1614 Pavement wear effects of heavy vehicle axle groups
- TT1825 Strategic review of pavement design practice
- TT1826 Improved design procedures for asphalt pavements
- TT1908 High modulus asphalt implementation
- TT2044 Encouraging pavement design innovations

Australian Asphalt Pavement Association (AAPA)

- Asphalt pavement solutions for life (APsfL)
Draft technical note

Technical Note xxx
A new approach to asphalt pavement design
Draft 01/09/2016

AN INITIATIVE BY:
Overview

Four key changes proposed

Asphalt design modulus
Asphalt fatigue relationship
Upper limit on design traffic
Multiple-axle group loads
Outcomes

Example inputs:

80,000 vehicles per day
10% heavy vehicles
4% annual growth
1.52x10^8 ESA (30 years)

50 mm SMA14
50 mm AC14M(A5S)
X mm AC20M(C600)
150 mm improved layer
Subgrade design CBR 7%
Flexural modulus

Erik Denneman
What we used to do
What we will be doing

25 °C, 10 Hz
fr = 1.58 Hz
E* = 4995 MPa
Why we will be doing it

- Better represents flexural modulus over range of temperatures and frequencies
- Higher modulus at elevated temperatures/low vehicle speeds
- Realistic modulus at low temperatures
Why we are doing it

![Graph showing frequency vs. modulus for different materials including AC10 30% RAP AGPT, DG20HM AGPT, EME2 AGPT, AC10 30% RAP Flexural, DG20HM Flexural, EME2 flexural, AC10 30% RAP ITT 25C, DG20H ITT 25C, and EME2 ITT 25C.]
Why we are doing it

– Higher modulus leads to reduced pavement thicknesses
– Mix specific master curves open doors to innovation (competitive advantage for high performance mixes)
– Reduce risk
Background

- Austroads guide to pavement technology (AGPT) uses flexural modulus for asphalt pavement design
- Flexural modulus for AGPT designs estimated from resilient modulus
- Shell (1978) design method used flexural modulus
- Shell nomographs estimate flexural modulus (master curve)
- Austroads AP-R511-16 recommends reintroduction of measured flexural modulus (master curve) as basis for design
Test method

• Four point bending
Test method

- AGPT/T274 replaces AGPT/T233
- Changes w.r.t. modulus include:
  - Use of small strain
  - temperature and frequency sweep
  - Sinusoidal wave shape
  - Construct E* master curve

AUSTROADS TEST METHOD AGPT/T274

Characterisation of Flexural Stiffness and Fatigue Performance of Bituminous Mixes
What is complex modulus $|E^*|$
Test method

- Developing a master curve for pavement design
  - Temperature and frequency sweep over as wide a range as possible, e.g.:
  - 0 °C, 10 °C, 20 °C, 30 °C and 40 °C
  - 0.1 Hz, 0.5 Hz, 1 Hz, 3 Hz, 5 Hz, 10 Hz, 15 Hz, 20 Hz, 30 Hz
Master curve construction

![Graph showing master curve construction with different temperatures and shifted data points.](image-url)
Master curve construction

- **Sigmoidal model**
  \[ \log |E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log f_r}} \]

- **Reduced frequency**
  \[ f_r = a(T) \times f \]

- **Temperature shift factor**
  \[ \log_{10}(a_T) = a(T - T_{ref})^2 + b(T - T_{ref}) \]
Mix specific master curves

![Graph showing specific master curves for different mixes. The x-axis represents frequency [Hz] with values ranging from 1.0E-03 to 1.0E+05. The y-axis represents E* [MPa] with values ranging from 1000 to 100000. The graph compares the performance of Mix 1 DG 20HM, Mix 2 EME2 D14, Mix 3 DG14HS, Mix 4 AC14M, and Mix 5 AC20H.](image-url)
Incorporating default values
## Use of default values

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<thead>
<tr>
<th>Asphalt mix type</th>
<th>Binder Type</th>
<th>Volume of binder (%)</th>
<th>$E_{25}$ (MPa)</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\delta$</th>
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<td>-4.188</td>
<td>1.191×10⁻⁵</td>
<td>-0.0951</td>
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</table>
Mix specific fatigue model

Erik Denneman
What we used to do

- Austroads
  - Lab to field + reliability factor

- Shell
  - \[ \varepsilon_{fat} = (0.856 \cdot V_b + 1.08)S_{mix}^{-0.36} \cdot N_{fat}^{-0.2} \]

\[ N = RF \left[ \frac{6918 (0.856 V_b + 1.08)}{E^{0.36} \mu \varepsilon} \right]^5 \]
What we will be doing

\[ \ln(N_f(50)) = c_1 \cdot \ln^3(E) + c_2 \cdot \ln^2(E) + c_3 \cdot \ln(E) + c_4 + c_5 \cdot \ln \varepsilon \]
Why we are doing it

- Encourage use and development of mixes with superior fatigue performance
- Mix specific fatigue models open doors to innovation (competitive advantage for high performance mixes)
- Reduce pavement design thickness
- Reduce risk
Why we are doing it

![Graph showing required base thickness vs. design temperature WMAPT in °C, with data points for different locations such as Ballarat, VIC, Melbourne, VIC, Toowoomba, QLD, Brisbane, QLD, Townsville, QLD, and Broome, WA. The graph compares TMR supplement and Mix specific model results.]}
Background

- Design method AGPT uses Shell (1978) laboratory model to characterise fatigue performance of asphalt mixes
- Shell laboratory based on mean performance of 12 mixes
- Provided that suitable test conditions are used, the general laboratory model can be replaced with mix specific model
- To allow this, AGPT/T233 replaced by AGPT/T274
Test method

- AGPT/T274 replaces AGPT/T233
- Changes w.r.t. fatigue include:
  - Sinusoidal wave shape!
  - 18 specimens per result
  - Improved calculation of engineering properties

- Results from AGPT/T233 not to be used with TechNote
Test method

- Developing a mix specific fatigue model for pavement design
  - Test a minimum of 27 beams equally divided over 3 temperatures
  - 9 beams per temperature: 10 °C, 20 °C, 30 °C
  - three strain levels per temperature
Laboratory model fitting

\[ N_{lab} = \exp\left[ c_1 \cdot \ln^3(E) + c_2 \cdot \ln^2(E) + c_3 \cdot \ln(E) + c_4 + c_5 \cdot \ln(\mu \varepsilon_{lab}) \right] \quad (7) \]

where

- \(N_{lab}\) = number of cycles to failure in the laboratory flexural fatigue test
- \(E\) = flexural modulus (MPa) at the test frequency and test temperature, determined from the master curve (Equation 1)
- \(\mu \varepsilon_{lab}\) = strain in laboratory flexural fatigue test (µm/m)
- \(c_1 - c_5\) = fitting parameters
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Laboratory to field prediction

Lab to field + reliability factor

Mix specific lab model

\[ N = RF \times EXP[c_1 \cdot ln^3(E_d) + c_2 \cdot ln^2(E_d) + c_3 \cdot ln(E_d) + c_4 + c_5 \cdot ln(\mu\varepsilon)] \]

where

\( N = \) allowable number of repetitions of the load

\( E_d = \) design flexural modulus as determined in Section 3 (MPa)

\( \mu\varepsilon = \) tensile strain produced by the load, determined by mechanistic design (\( \mu m/m \))
Upper limit on design traffic

Jeffrey Lee
Key Fatigue Endurance Limit (FEL) studies

- Shen and Carpenter (University of Illinois)
- NCHRP 9-44A (Arizona State University)
- TRL (Nunn et al)
- Austroads Publication AP-T131/09
- AAPA APSfL
- Austroads TT 2044

On going research in this studies, and consensus has not arrived yet.
AN INITIATIVE BY:

**APSfL suggested equation**

\[
FEL = \frac{8.2}{U_l} [k_1 \cdot 21625 \cdot Smix^{-0.65} + k_2]
\]

- \(k_1\) = confidence level adjustment factor
- \(k_2\) = mix adjustment factor
- \(U_l\) = upper 97.5\(^{th}\) single load (ton)
- \(S_{mix}\) = asphalt mix stiffness (MPa)
A discussion paper titled “Asphalt Fatigue Endurance Limits: Guide Implementation Options” was circulated to Austroads Pavement Structure Working Group in June 2016. It reviews the current AAPA APSfL method, and outlined the following options:

- Option A – APSfL method to estimate ELS from asphalt modulus
- Option B – NCHRP 9-44A method to calculate ELS from modulus
- Option C – NCHRP 9-44A estimating ELS from temperature and mix volumetrics
- Option D – Limiting design traffic loading
- Option E – modify fatigue relationship to allow for healing at elevated temperature
Design examples

50 mm AC14M(C320)

X mm AC20M(C600)

150 mm Improved Layer

Design Subgrade (CBR 5, 7,12%)
Limiting design traffic

The recommendation is inline with the latest discussion in Austroads where limiting design traffics are:

- $2 \times 10^8$ ESA (WMAPT 26 – 34°C)
QUESTIONS?
Improved consideration of multiple-axle group loads

Peter Bryant
Multiple-axle group loads

Current

Strains under standard axle

Proposed

Strains under every axle

Austroads TT1614 - Pavement wear effects of heavy vehicle axle groups (Dr Michael Moffatt)
Current Austroads method

Traffic (axle) load distribution → Standard loads → Number of standard axle repetitions for same damage

Based on the peak surface deflection being the same as under a standard axle
However

For fatigue of bound materials (asphalt and cemented):

- The standard load for an axle group varies with thickness and modulus of the bound material, and the underlying pavement structure (Moffatt)

Research outcome:

- Determine the pavement damage resulting from each individual axle load within the traffic load distribution.
Improved method

Step 1
- Define pavement structure

Step 2a
- Calculate critical strains under:
  - Single axle with single tyres (53 kN)
  - Single axle with dual tyres (80 kN)

Step 2b
- Linearly scale the strains for all other load levels
Linear scaling of strains

![Graph showing linear scaling of strains with axle load and critical tensile microstrain.](image)
Resulting critical strains

<table>
<thead>
<tr>
<th>Axle Group Load (kN)</th>
<th>Critical microstrain under each individual axle (determined by linearly scaling Step 2a strains)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SAST</td>
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<tr>
<td>10</td>
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<tr>
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<td>80</td>
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<td>90</td>
<td>132.1</td>
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<tr>
<td>100</td>
<td>132.7</td>
</tr>
</tbody>
</table>

...and so on for higher axle group loads
Improved method

Step 3

• Calculate allowable repetitions of each axle group load / type combination \((N_{ij})\)

\[
N = RF \left[ \frac{6918(0.856V_b + 1.08) \times \frac{0.36}{E_d} \mu \varepsilon_{ij}}{E_d} \right]^5
\]

\[
N = RF \times \exp \left[ c_1 \cdot \ln^3 (E_d) + c_2 \cdot \ln^2 (E_d) + c_3 \cdot \ln (E_d) + c_4 + c_5 \cdot \ln \left( \mu \varepsilon_{ij} \right) \right]
\]

• Will give the allowable number of individual axle loads

• We want the allowable number of axle groups
Improved method

Step 3

• Calculate allowable repetitions of each axle group load / type combination (N_{ij})

\[
N_{ij} = \frac{1}{n} \times RF \left[ \frac{6918(0.856V_b + 1.08)}{E_d^{0.36} \mu \varepsilon_{ij}} \right]^5
\]

\[
N_{ij} = \frac{1}{n} \times RF \times EXP\left[ c_1 \cdot ln^3(E_d) + c_2 \cdot ln^2(E_d) + c_3 \cdot ln(E_d) + c_4 + c_5 \cdot ln(\mu \varepsilon_{ij}) \right]
\]

n = number of axles in the group
Improved method

Step 4
- Calculate damage for each axle group load (i) and axle group type (j) combination

Step 5
- Sum the damage for all combinations

\[
\text{Total damage} = \sum_{ij} \frac{\text{Expected repetitions}_{ij}}{\text{Allowable repetitions}_{ij}}
\]

Total damage must be \( \leq 1.0 \)
Outcomes

Full depth asphalt pavement example
(over 150 mm improved layer and CBR7 subgrade)

- Existing approach
- Improved multiple-axle approach with cap
- Improved multiple-axle approach, optimised mix and cap

<table>
<thead>
<tr>
<th>Design Traffic (ESA)</th>
<th>Total Asphalt Thickness (mm)</th>
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<tbody>
<tr>
<td>1.00E+06</td>
<td>150</td>
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<tr>
<td>1.00E+07</td>
<td>200</td>
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<tr>
<td>1.00E+08</td>
<td>250</td>
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</table>
QUESTIONS?
THANK YOU FOR YOUR PARTICIPATION TODAY

For further information, please contact:

<table>
<thead>
<tr>
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<th>Dr Erik Denneman</th>
<th>Dr Jeffrey Lee</th>
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<td>E: <a href="mailto:erik.denneman@aapa.asn.au">erik.denneman@aapa.asn.au</a></td>
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