A new approach to asphalt pavement design

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AN INITIATIVE BY: ARRB GROUP Queensland Government

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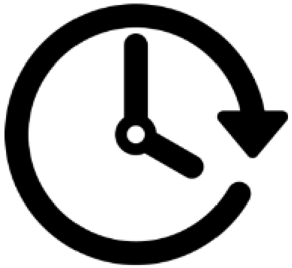
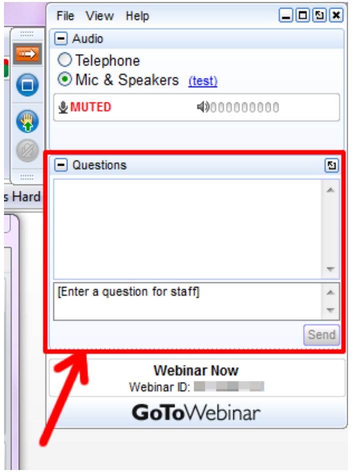
HOUSEKEEPING

Webinar is = 60 mins



GOTOWEBINAR FUNCTIONS



Please type your questions here

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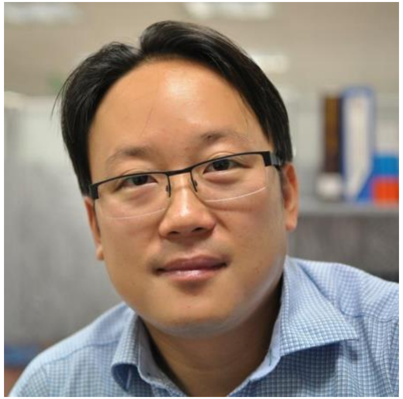

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Introduction and overview

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

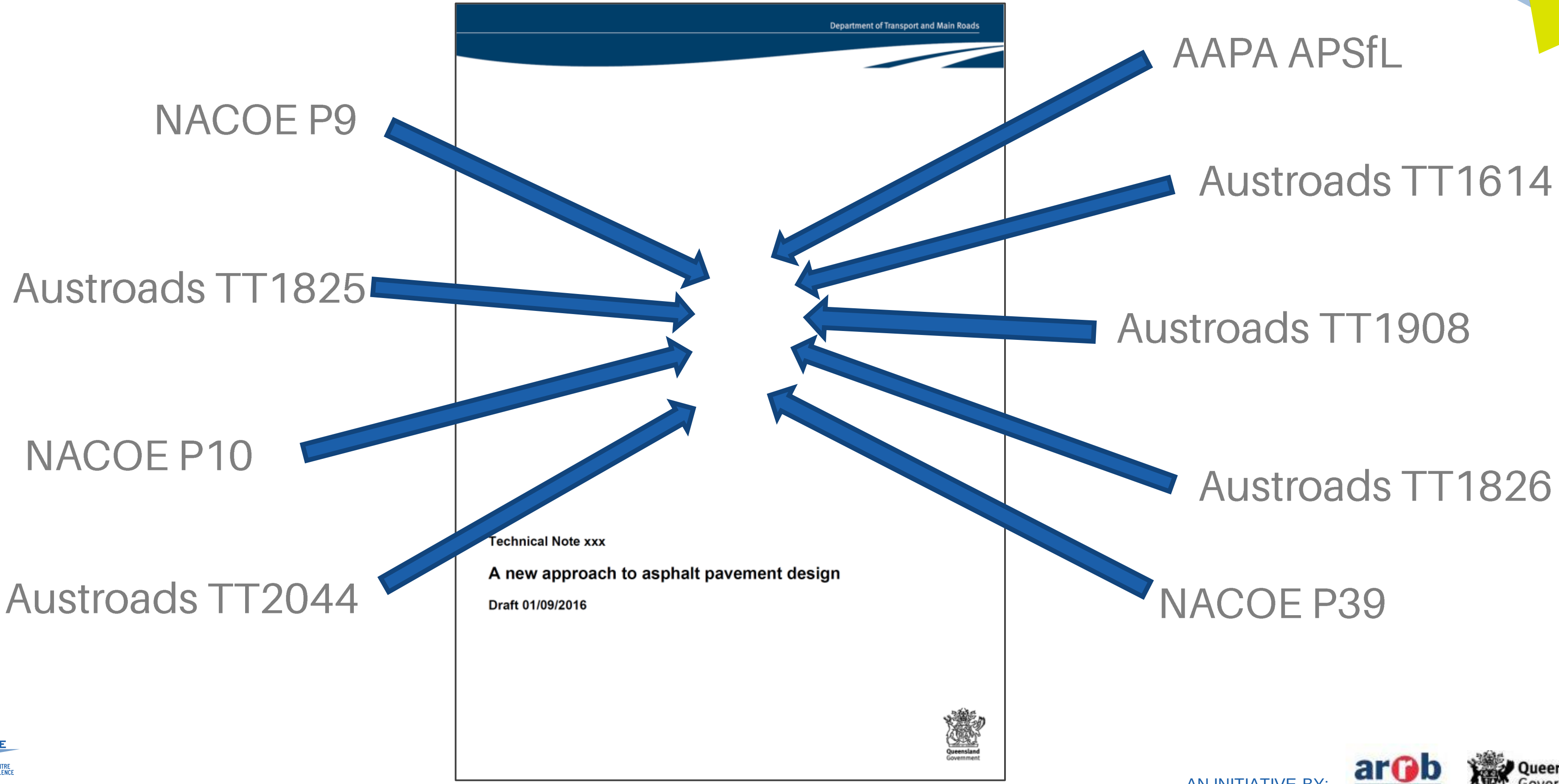
Austroads

- 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



Overview

Four key changes proposed

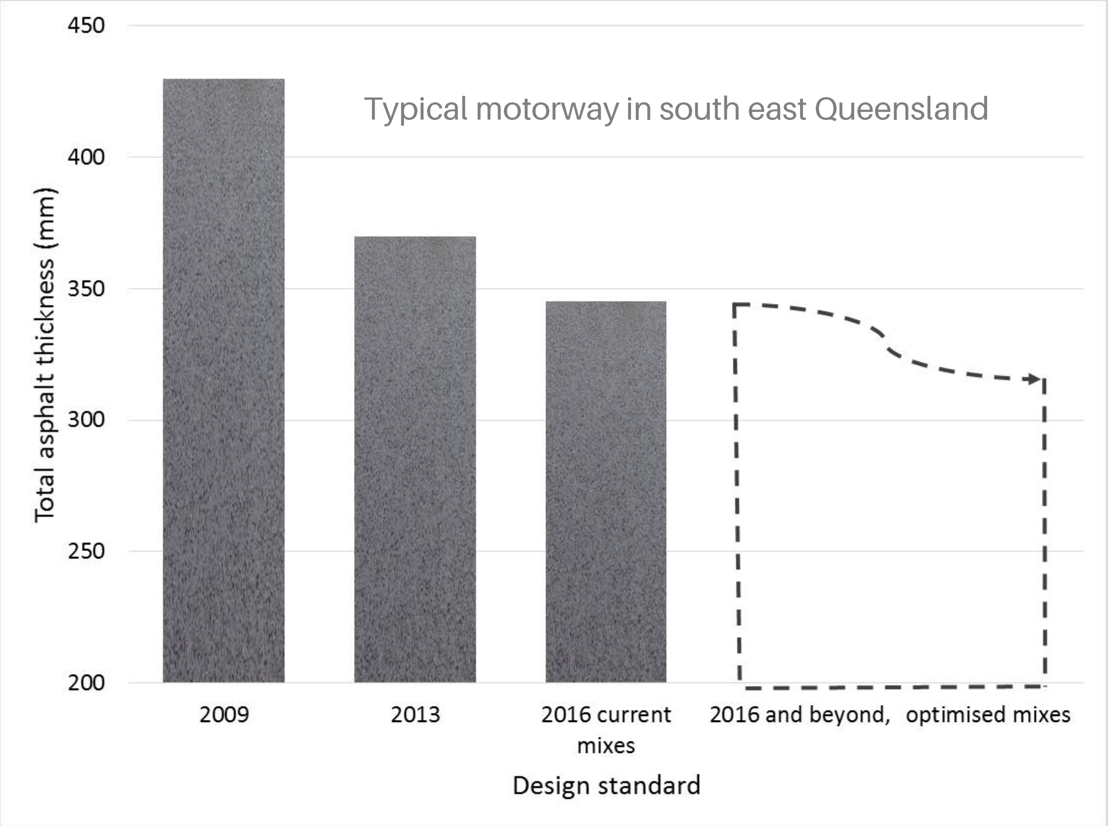
- Asphalt design modulus
- Asphalt fatigue relationship
- Upper limit on design traffic
- Multiple-axle group loads

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%



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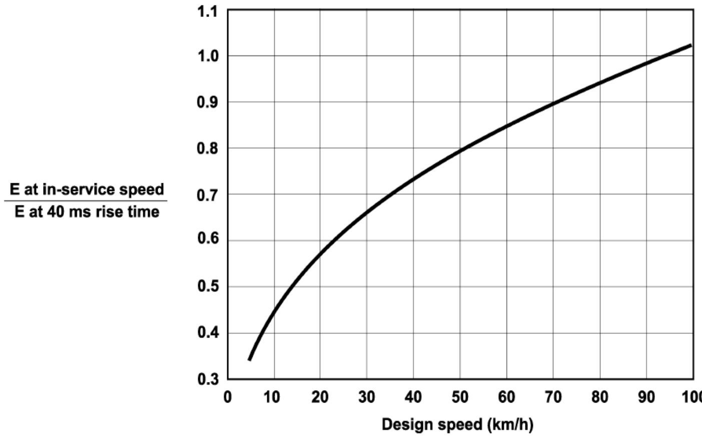
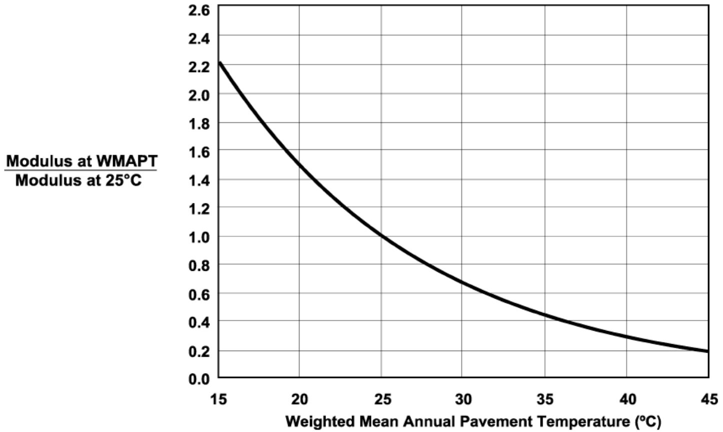
Flexural modulus

Erik Denneman

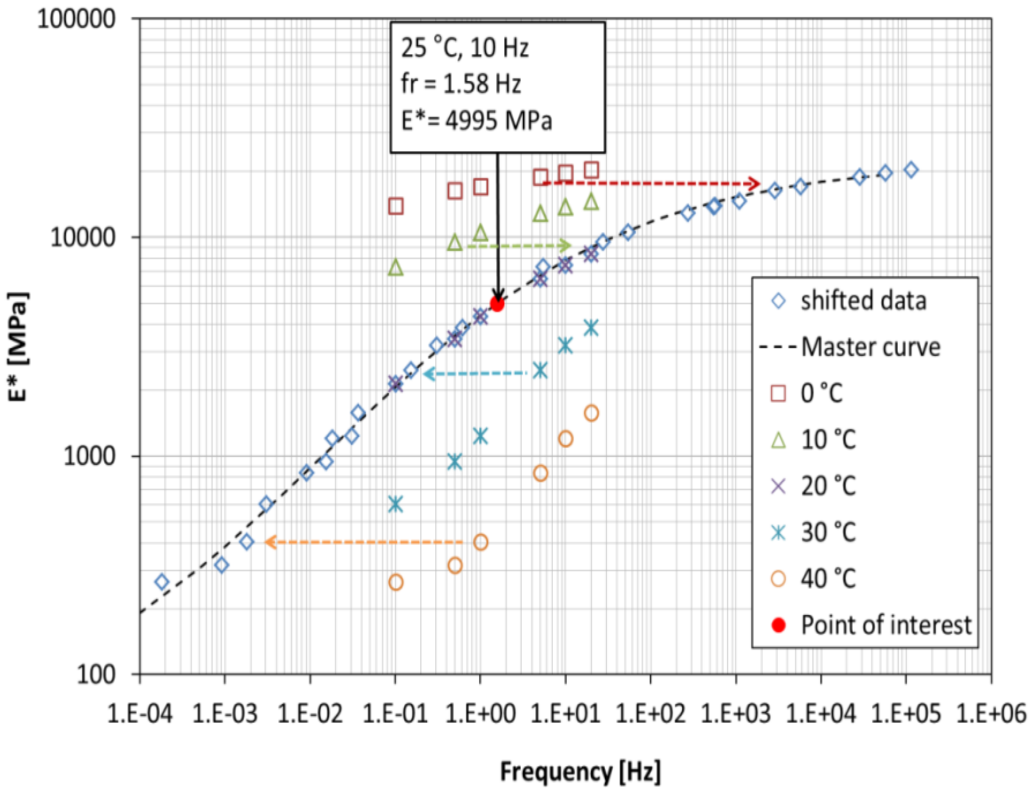
AN INITIATIVE BY: ARRB Group, Queensland Government

What we used to do



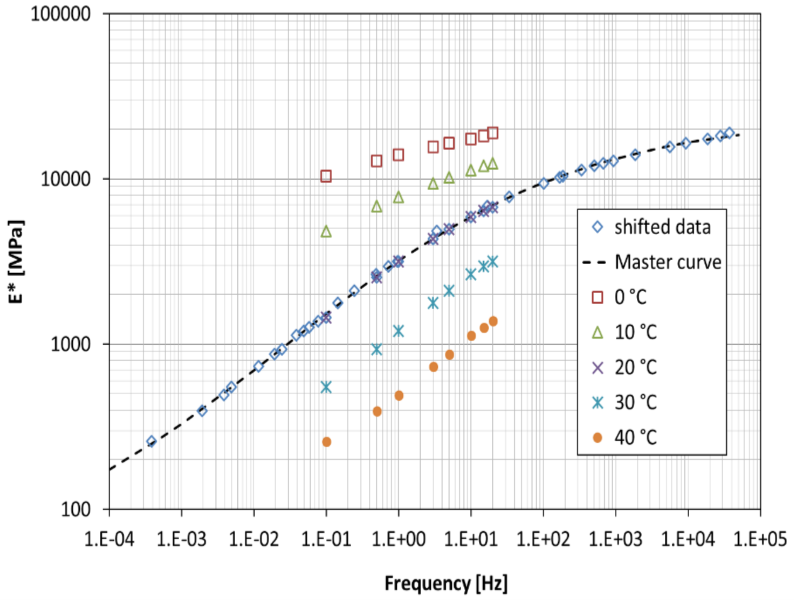


What we will be doing

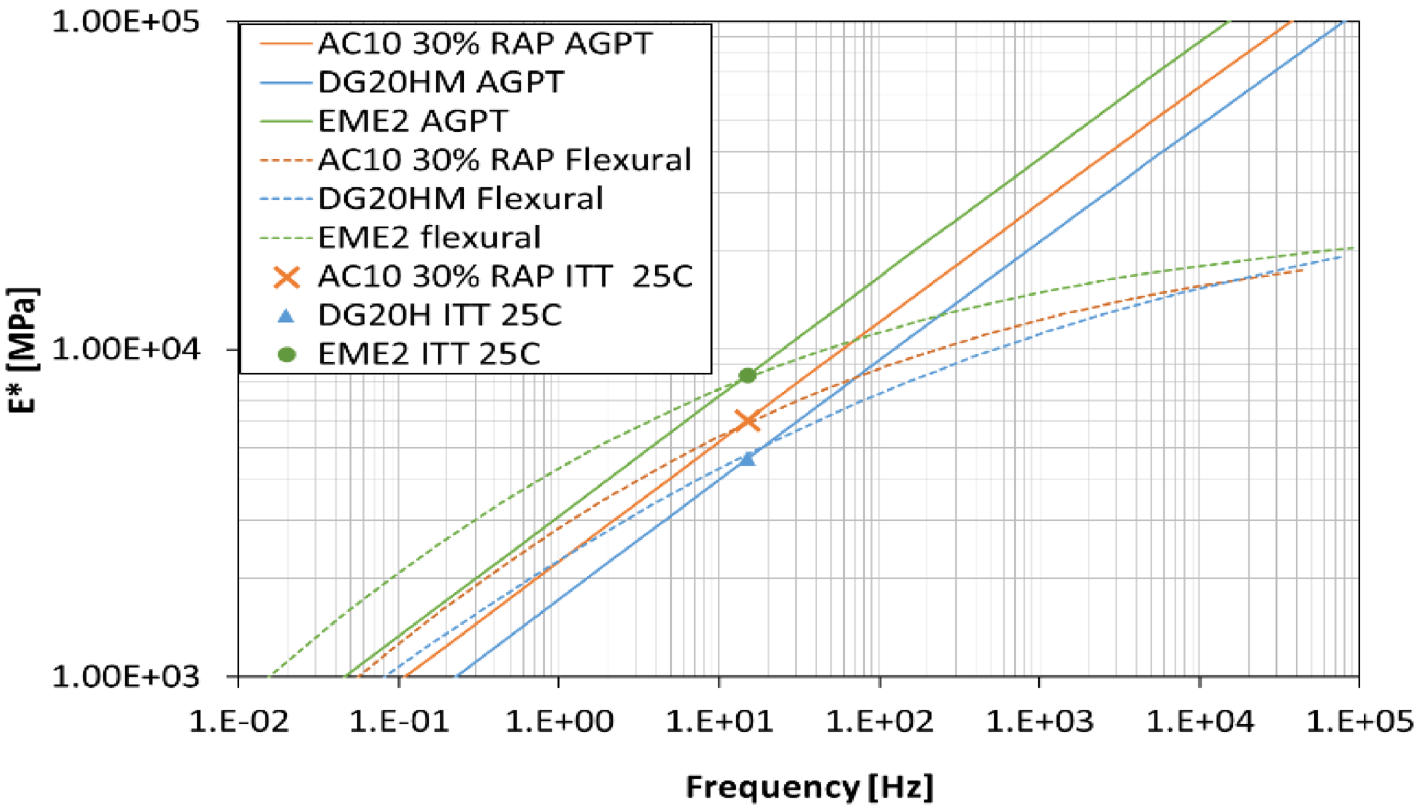


Why we will be doing it

- 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



Why we are doing it

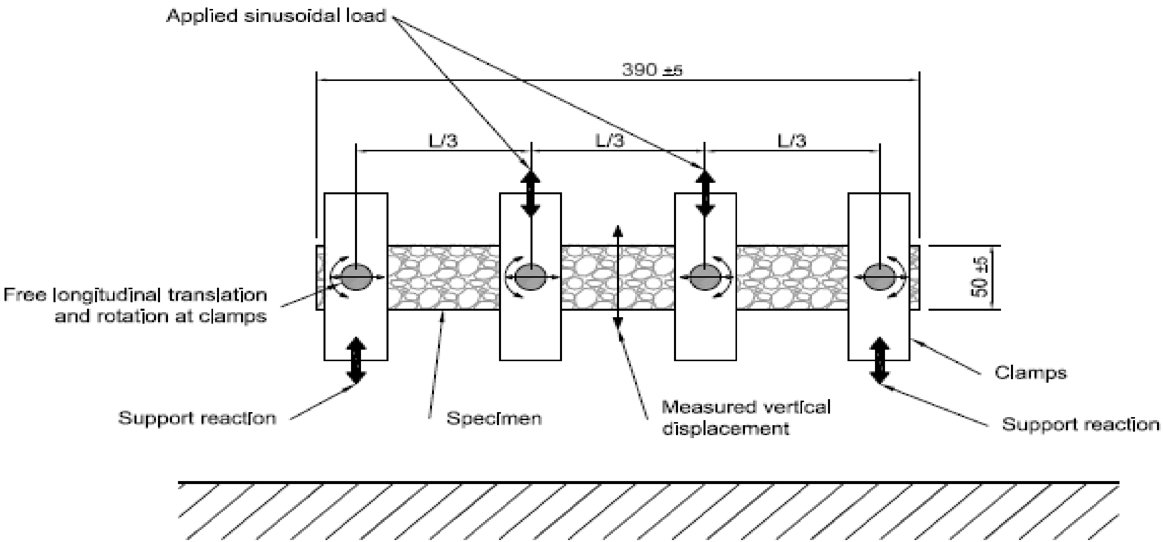
- Higher modulus leads to reduced pavement thicknesses
- Mix specific master curves open doors to innovation (competitive advantage for high performance mixes)
- Reduce risk

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

Austroads

Characterisation of Flexural Stiffness and Fatigue Performance of Bituminous Mixes

1. Preface

This asphalt test method was prepared by the Pavement Structures Working Group and the Asphalt Research Working Group on behalf of Austroads. Representatives of Austroads, ARRB Group and the Australian Asphalt Pavement Association have been involved in the development and review of this test method.

2. Foreword

This test method should be read in conjunction with the European Standards EN 12697-24:2012, *Bituminous mixtures – Test methods for hot mix asphalt – Part 24: resistance to fatigue* and EN 12697-26:2012, *Bituminous mixtures – Test methods for hot mix asphalt – Part 26: stiffness*, published by the European Committee for Standardization. This Austroads method provides instructions on conducting tests in accordance with these European Standards, while complying with Austroads specimen preparation methodology and test conditions.

3. Scope

The test method specifies procedures for the characterisation of the stiffness and fatigue behaviour of bituminous mixtures using a four-point bending test configuration. The test procedure to characterise the complex modulus is contained in Section 10 of this Austroads test method. The procedure to determine the fatigue performance is described Section 11. Section 12 contains a method to develop a complex modulus master curve from modulus results obtained using the method in Section 10. The tests are performed on compacted bituminous material under a sinusoidal displacement-controlled loading on prismatic specimens.

The modulus and fatigue characterisation tests can be run independently, or can be run consecutively on the same specimen, with the fatigue test following the modulus test.

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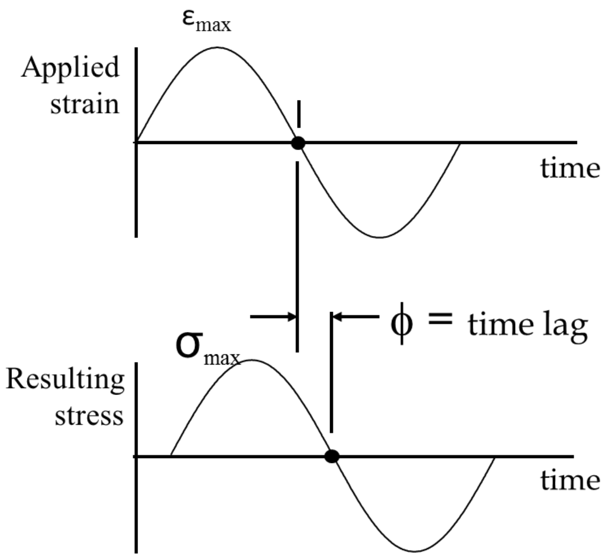
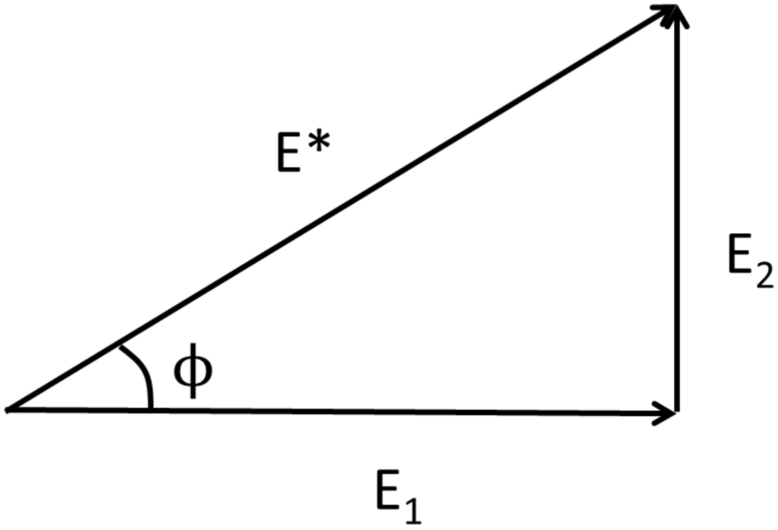
What is complex modulus |E*|

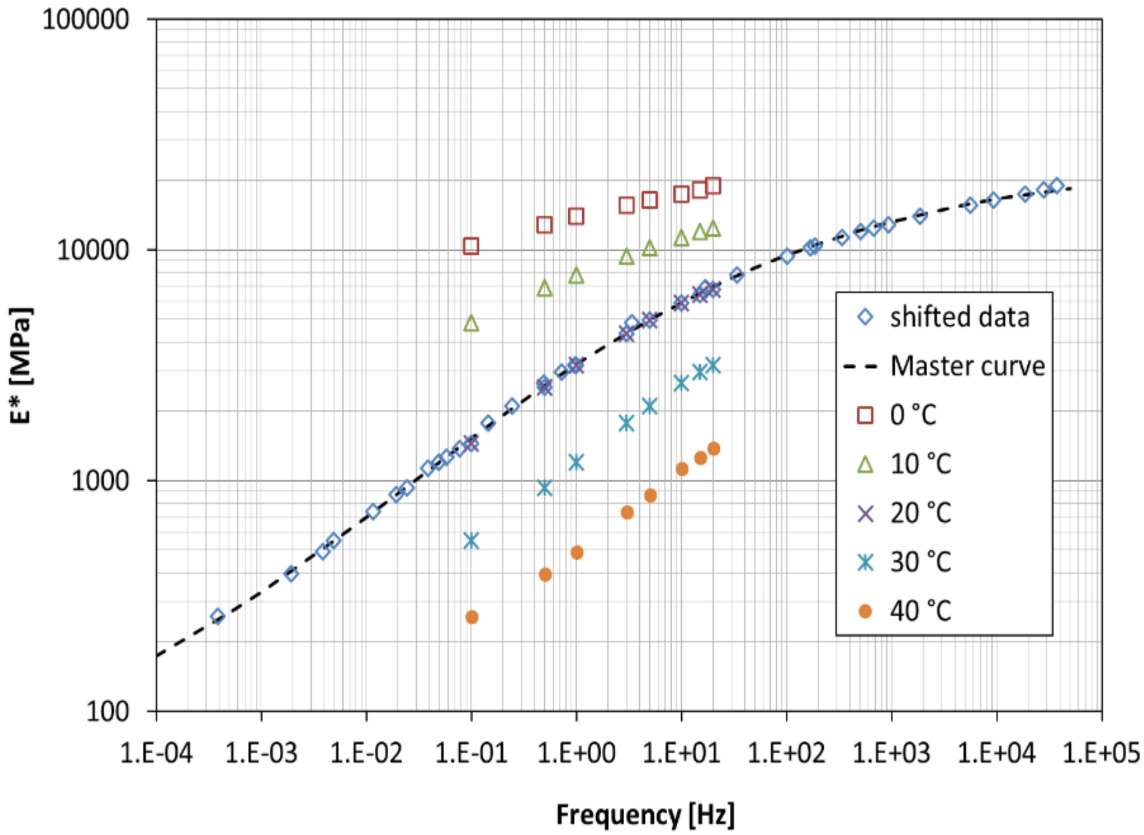




Test method

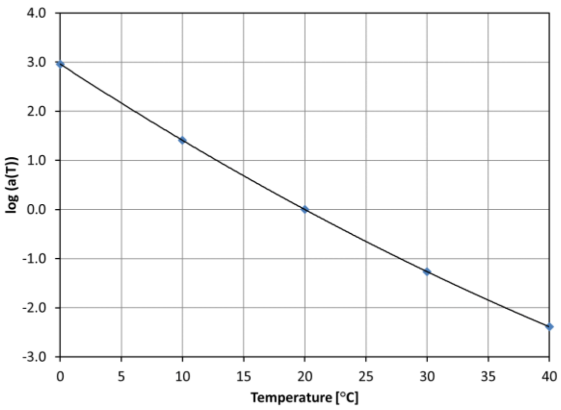
- Developing a master curve for pavement design
  - Temperature and frequency sweep over as wide a range as possible, e.g.:
  - 0 ^{0}C, 10 ^{0}C, 20 ^{0}C, 30 ^{0}C and 40 ^{0}C
  - 0.1 Hz, 0.5 Hz, 1 Hz, 3 Hz, 5 Hz, 10 Hz, 15 Hz, 20 Hz, 30 Hz

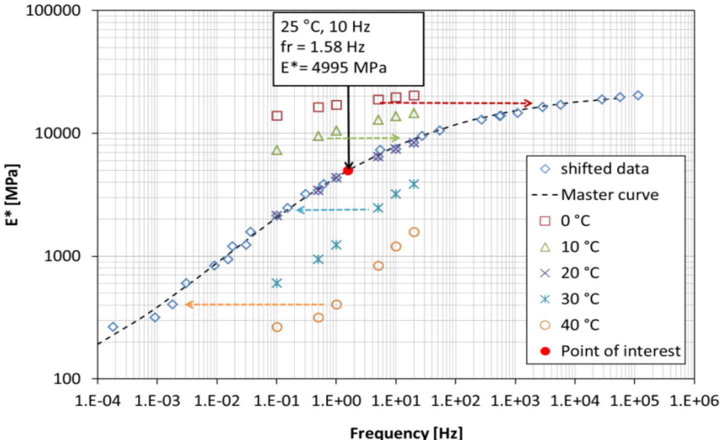
Master curve construction



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 $$\log_{10}(a_T) = a(T - T_{ref})^2 + b(T - T_{ref})$$





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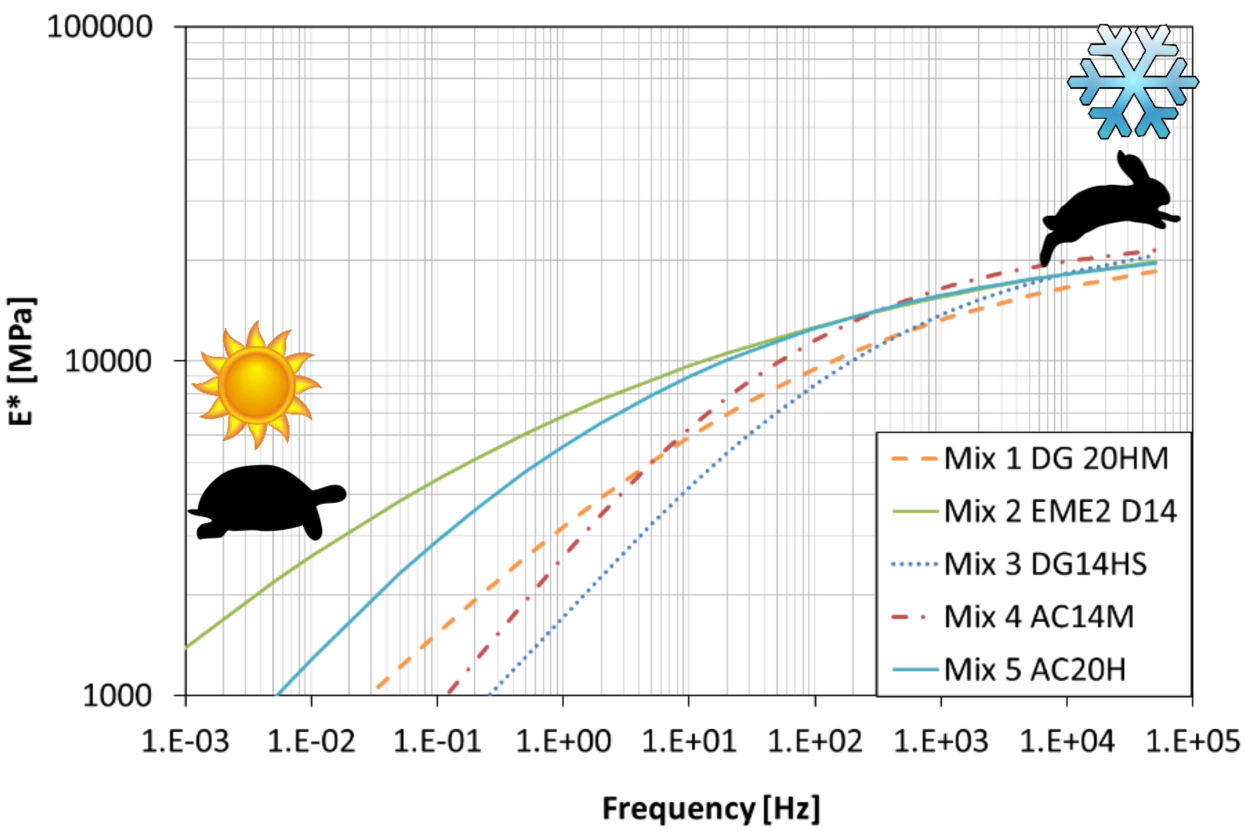
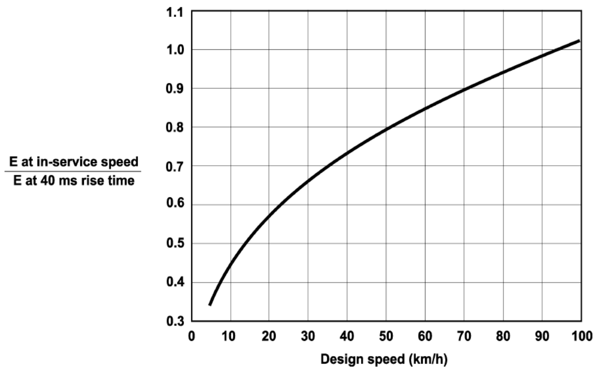
arrb GROUP

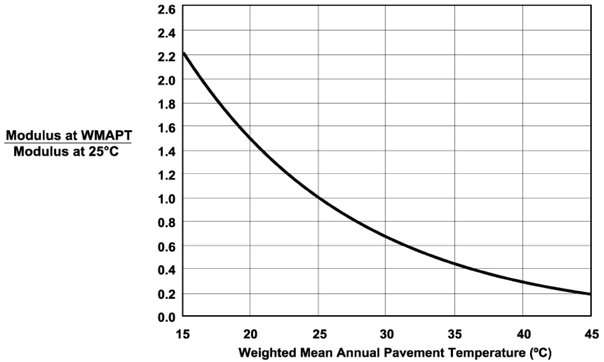
Queensland Government

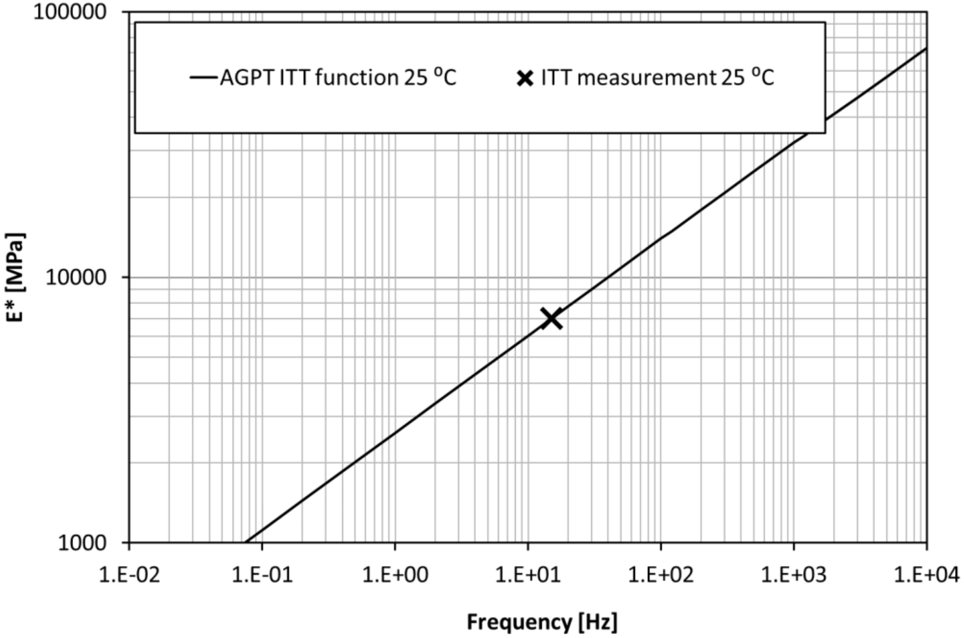
Mix specific master curves



Incorporating default values







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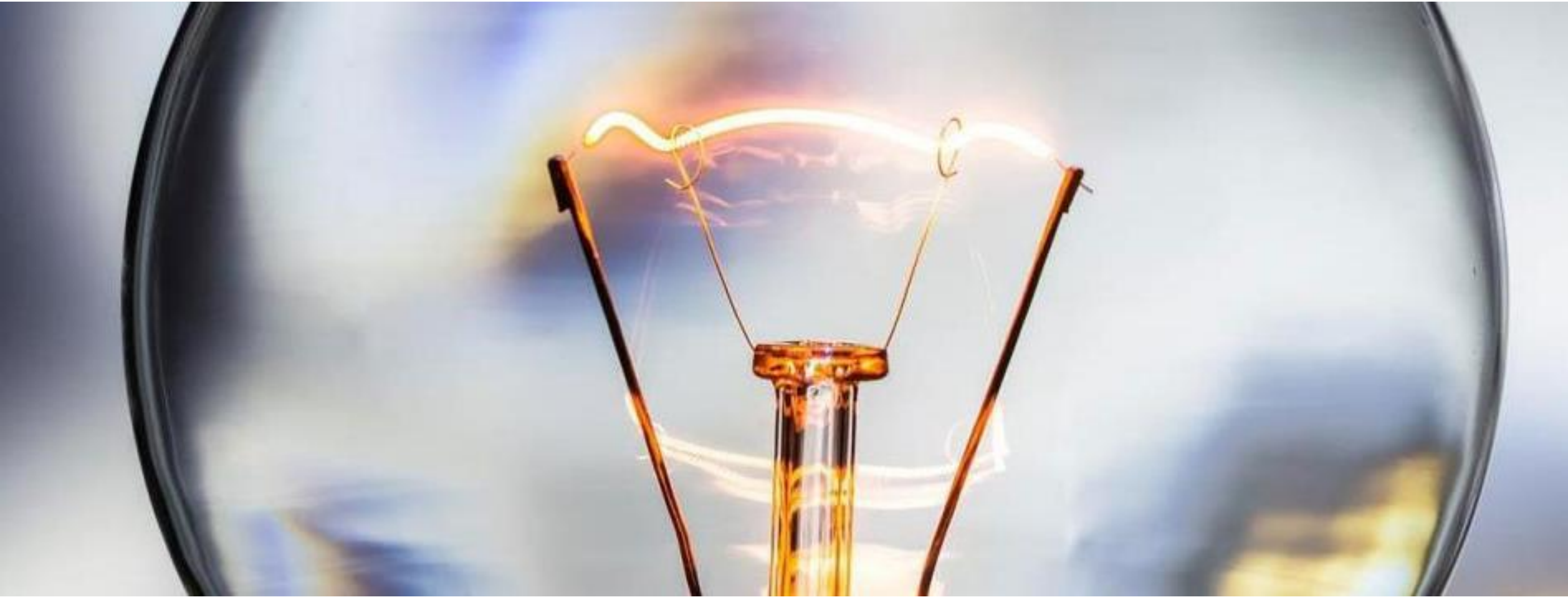
Use of default values

Asphalt mix type	Binder Type	Volume of binder (%)	E_{r25} (MPa)	α	β	γ	δ	a	b
SMA14	A5S	13.0	2400	15.3	0.0	-0.0958	-4.700	1.191×10^{-5}	-0.0951
AC10M	C320	11.5	3500	15.3	0.0	-0.0958	-4.536	1.191×10^{-5}	-0.0951
AC10M AC10H	A5S	11.5	2200	15.3	0.0	-0.0958	-4.738	1.191×10^{-5}	-0.0951
AC14M	C320	11.0	4500	15.3	0.0	-0.0958	-4.427	1.191×10^{-5}	-0.0951
AC14M AC14H	C600	11.0	5400	15.3	0.0	-0.0958	-4.348	1.191×10^{-5}	-0.0951
AC14M AC14H	A5S	11.0	2800	15.3	0.0	-0.0958	-4.633	1.191×10^{-5}	-0.0951
AC20M	C320	10.5	4800	15.3	0.0	-0.0958	-4.399	1.191×10^{-5}	-0.0951
AC20M AC20H	C600	10.5	5800	15.3	0.0	-0.0958	-4.317	1.191×10^{-5}	-0.0951
EME2	15/25	13.5	7800	15.3	0.0	-0.0958	-4.188	1.191×10^{-5}	-0.0951

QUESTIONS?



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Mix specific fatigue model

Erik Denneman

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What we used to do

- Austroads

$$N = RF\left[\frac{6918\,(0.856\,V_b + 1.08)}{E^{0.36}\mu\varepsilon}\right]^5$$

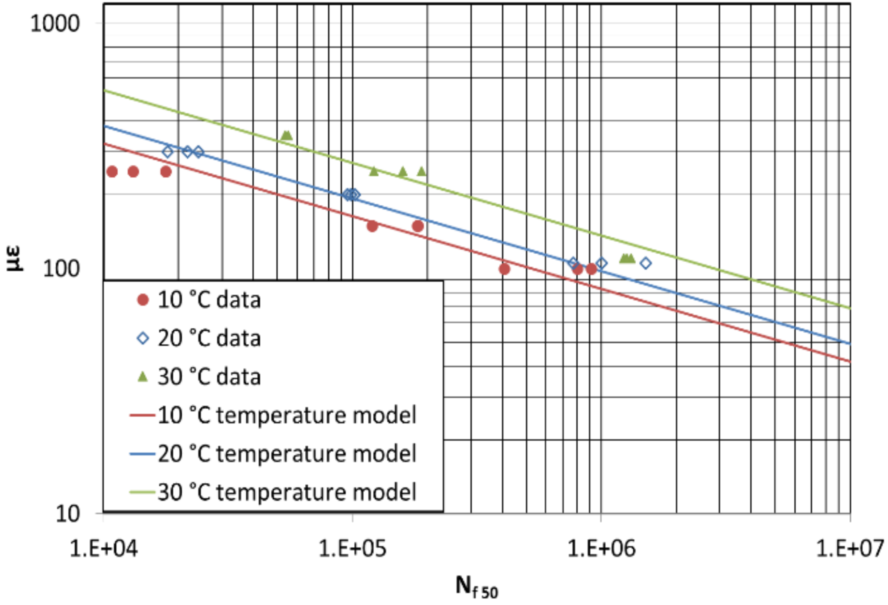
- Shell

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

Lab to field + reliability factor

Shell laboratory model

What we will be doing

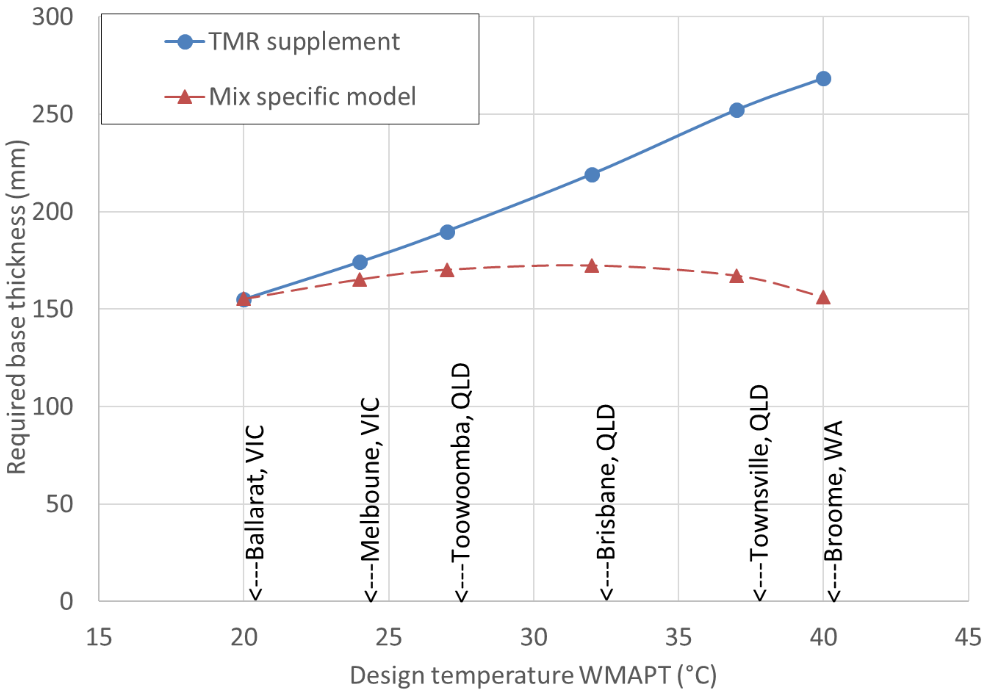


$$\ln\left(N_{f\,(50)}\right) = c_1 \cdot ln^3(E) + c_2 \cdot ln^2(E) + c_3 \cdot \ln(E) + c_4 + c_5 \cdot \ln\varepsilon$$

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



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

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AUSTROADS TEST METHOD AGPT/T274

Austroads

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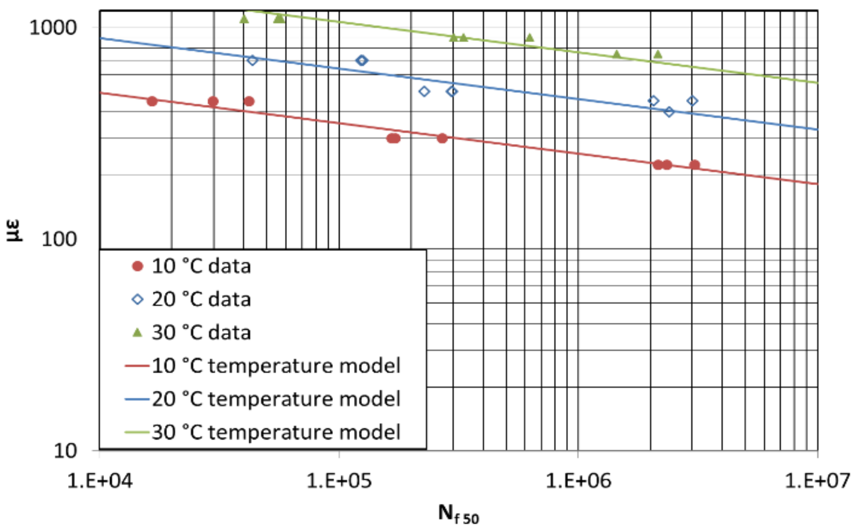
Test method

- 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 ^{0}C, 20 ^{0}C, 30 ^{0}C
  - three strain levels per temperature



Laboratory model fitting

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

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

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 (µm/m)

Upper limit on design traffic

Jeffrey Lee

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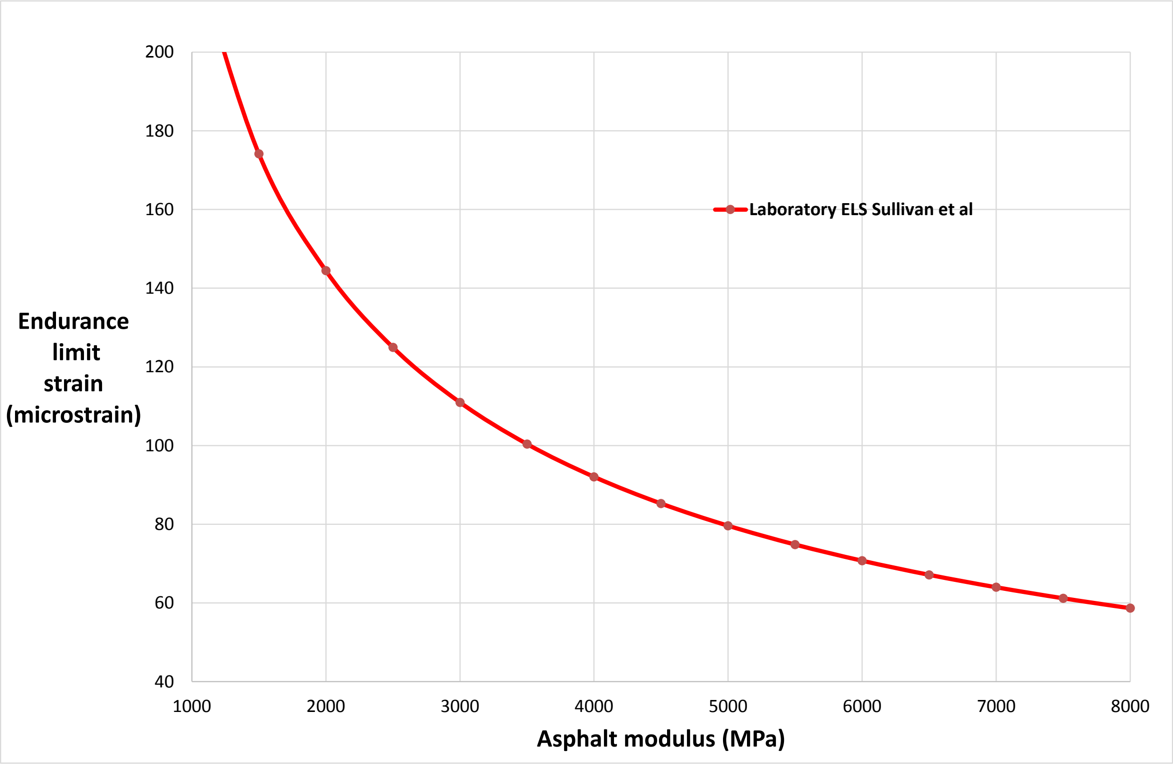
Key Fatigue Endurance Limit (FEL) studies

- 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.

AAPA APSfL – Fatigue Endurance Limit



APSfL suggested equation

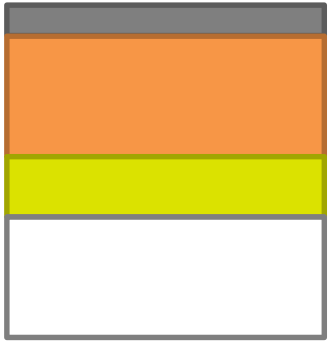
$$FEL = \frac{8.2}{U_l}\left[k_1 21625\ Smix^{-0.65} + k_2\right]$$

k_1 = confidence level adjustment factor
k_2 = mix adjustment factor
U_l = upper 97.5th single load (ton)
S_{mix} = asphalt mix stiffness (MPa)

Austroads Project TT 2044

- 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* ⇐ **Interim approach recommended in Queensland**
  - *Option E – modify fatigue relationship to allow for healing at elevated temperature*

Design examples



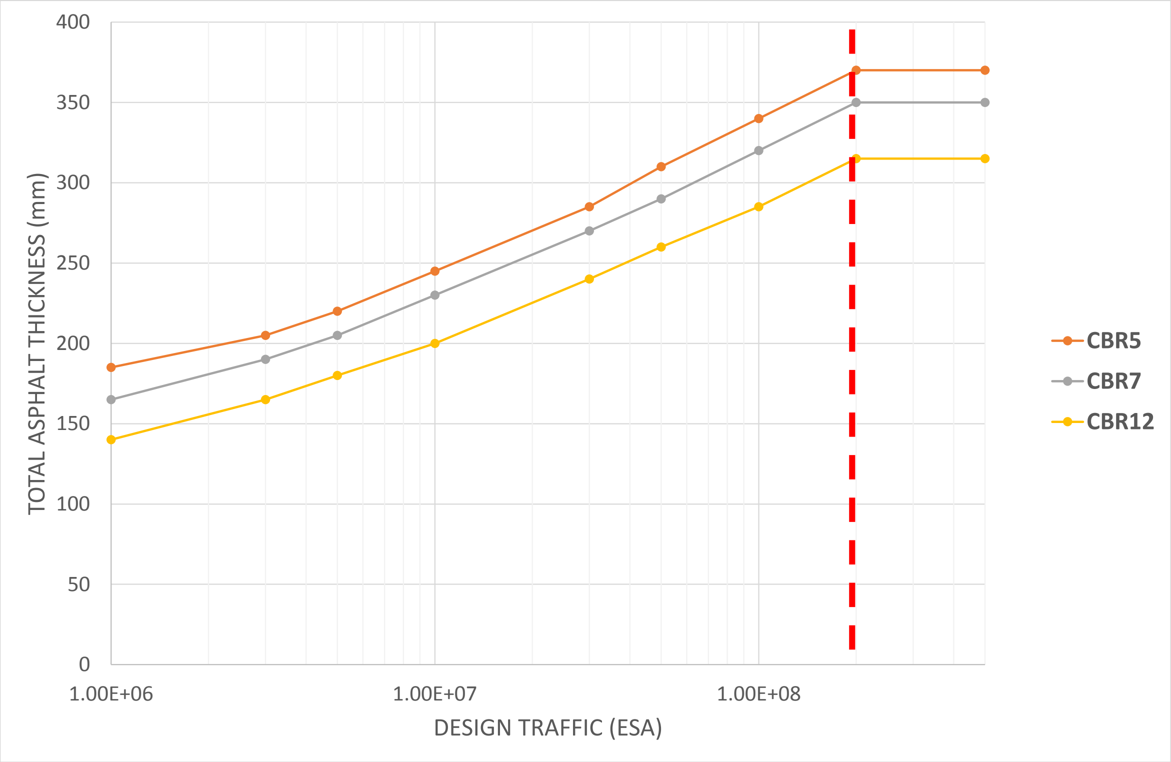
50 mm AC14M(C320)

X mm AC20M(C600)

150 mm Improved Layer

Design Subgrade (CBR 5, 7,12%)

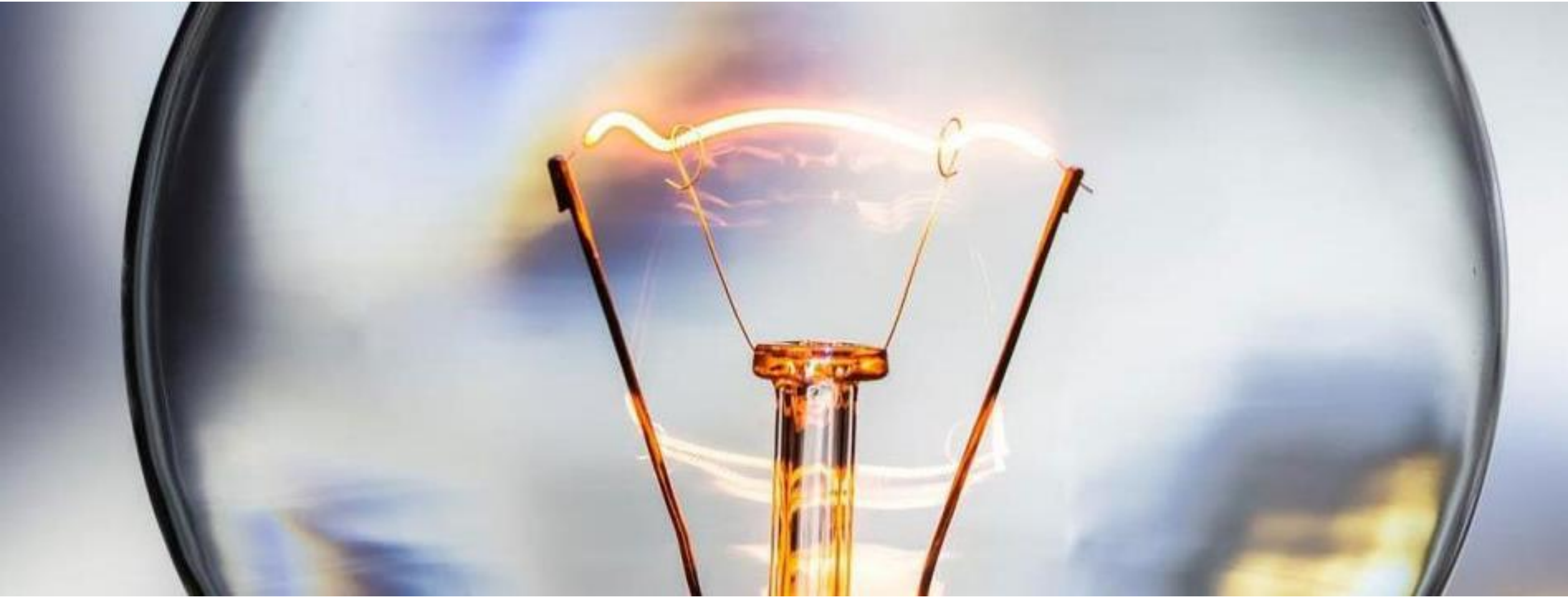
Limiting design traffic



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

- 2×10^8 ESA (WMAPT 26 – 34°C)

QUESTIONS?



Improved consideration of multiple-axle group loads

Peter Bryant

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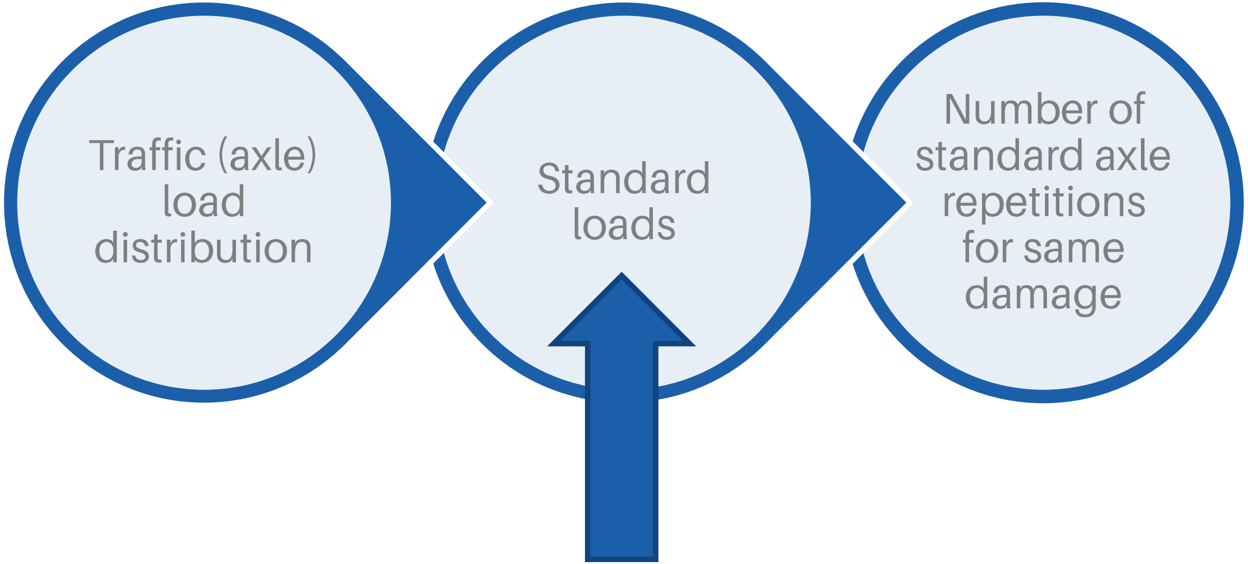
AN INITIATIVE BY: arrb GROUP Queensland Government

Multiple-axle group loads

Current	Proposed
Strains under standard axle	Strains under every axle

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

Current Austroads method



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

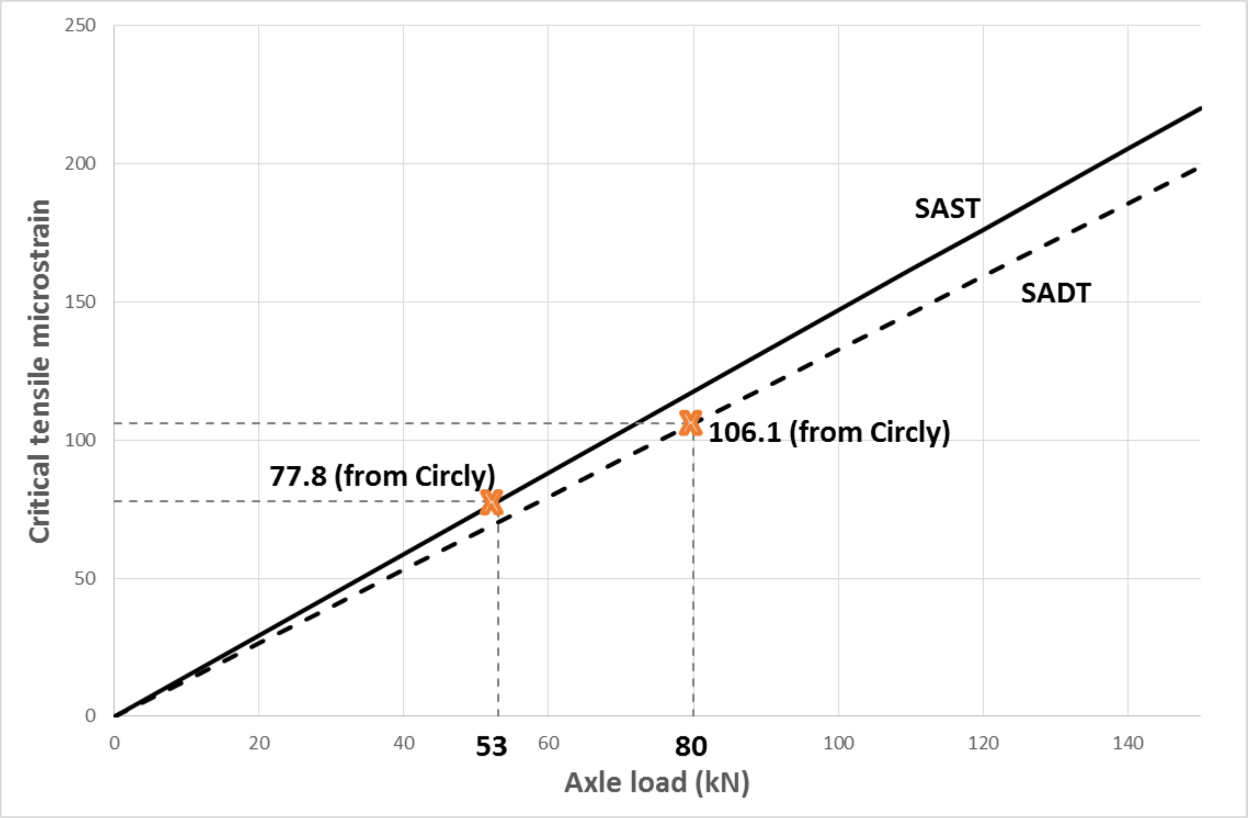
Step 2a

- 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



Resulting critical strains

Axle Group Load (kN)	Critical microstrain under each individual axle (determined by linearly scaling Step 2a strains)					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	14.7	13.3				
20	29.4	26.5		13.3		
30	44.0	39.8	22.0	19.9	13.3	
40	58.7	53.1	29.4	26.5	17.7	
50	73.4	66.3	36.7	33.2	22.1	16.6
60	88.1	79.6	44.0	39.8	26.5	19.9
70	102.8	92.9	51.4	46.4	31.0	23.2
80	117.5	106.1	58.7	53.1	35.4	26.5
90	132.1	119.4	66.1	59.7	39.8	29.8
100		132.7	73.4	66.3	44.2	33.2

…and so on for higher axle group loads

Improved method

Step 3

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

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

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

- 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 (Nij)

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

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

n = number of axles in the group

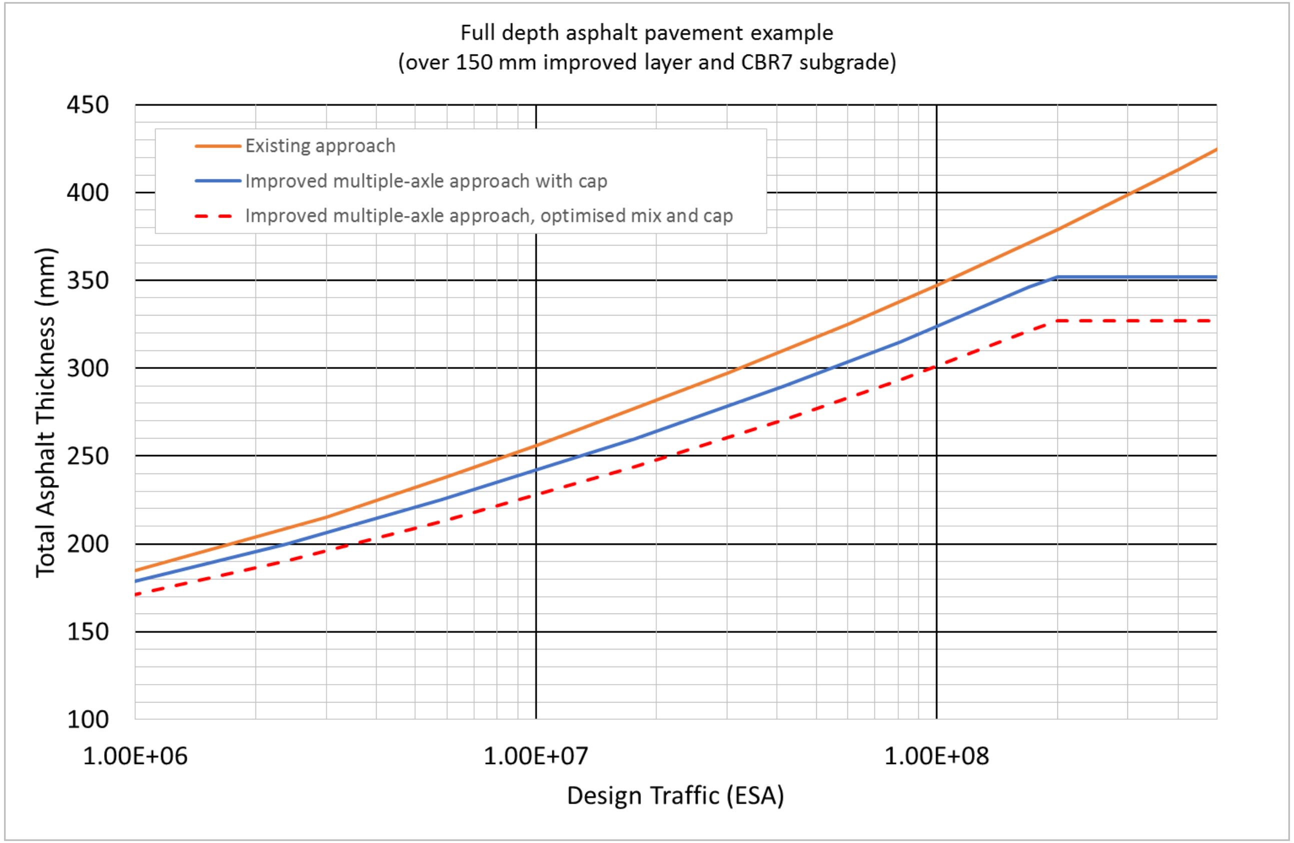
Improved method

Step 4	• Calculate damage for each axle group load (i) and axle group type (j) combination
Step 5	• Sum the damage for all combinations

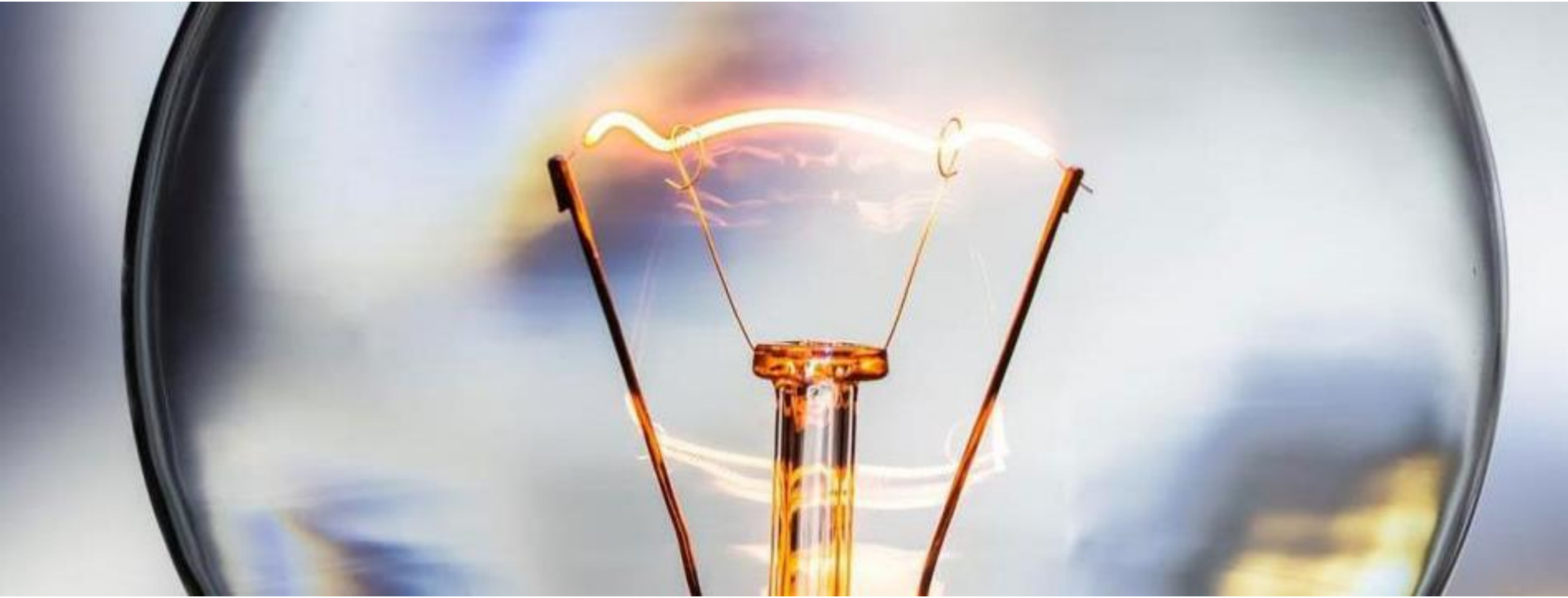
$$Total\ damage = \sum_{ij} \frac{Expected\ repetitions_{ij}}{Allowable\ repetitions_{ij}}$$

Total damage must be ≤ 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
Total Asphalt Thickness (mm)
450
400
350
300
250
200
150
100
1.00E+06
1.00E+07
1.00E+08
Design Traffic (ESA)

QUESTIONS?



THANK YOU FOR YOUR PARTICIPATION TODAY

For further information, please contact:

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