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NATIONAL
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OF EXCELLENCE

A new approach to asphalt pavement design

Part 1

TODAY'S MODERATOR

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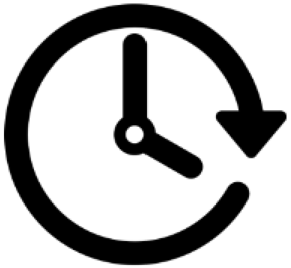
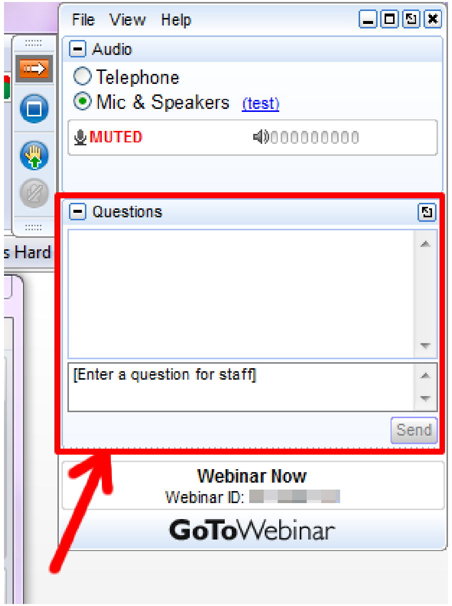
HOUSEKEEPING

Webinar is 90 mins each day



GOTOWEBINAR FUNCTIONS



Please type your questions here

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Australian Asphalt Pavement Association

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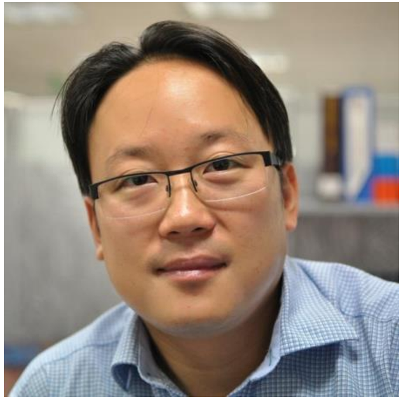

Introduction and overview

Peter Bryant

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AN INITIATIVE BY: arrb GROUP Queensland Government

Purpose of seminar

Release draft technical note for stakeholder feedback

Summarise background research

Facilitate understanding of content

Agenda

Topic	Presenter
1. Introduction and overview	Peter Bryant
2. Flexural modulus testing and master curves	Dr Erik Denneman
3. Flexural fatigue testing and mix-specific fatigue relationships	Dr Erik Denneman
4. Upper limit on design traffic	Dr Jeffrey Lee
Break	-
5. Improved method for consideration of multiple-axle group loads	Peter Bryant
6. Pavement design example	Peter Bryant
7. Implementation and stakeholder feedback	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

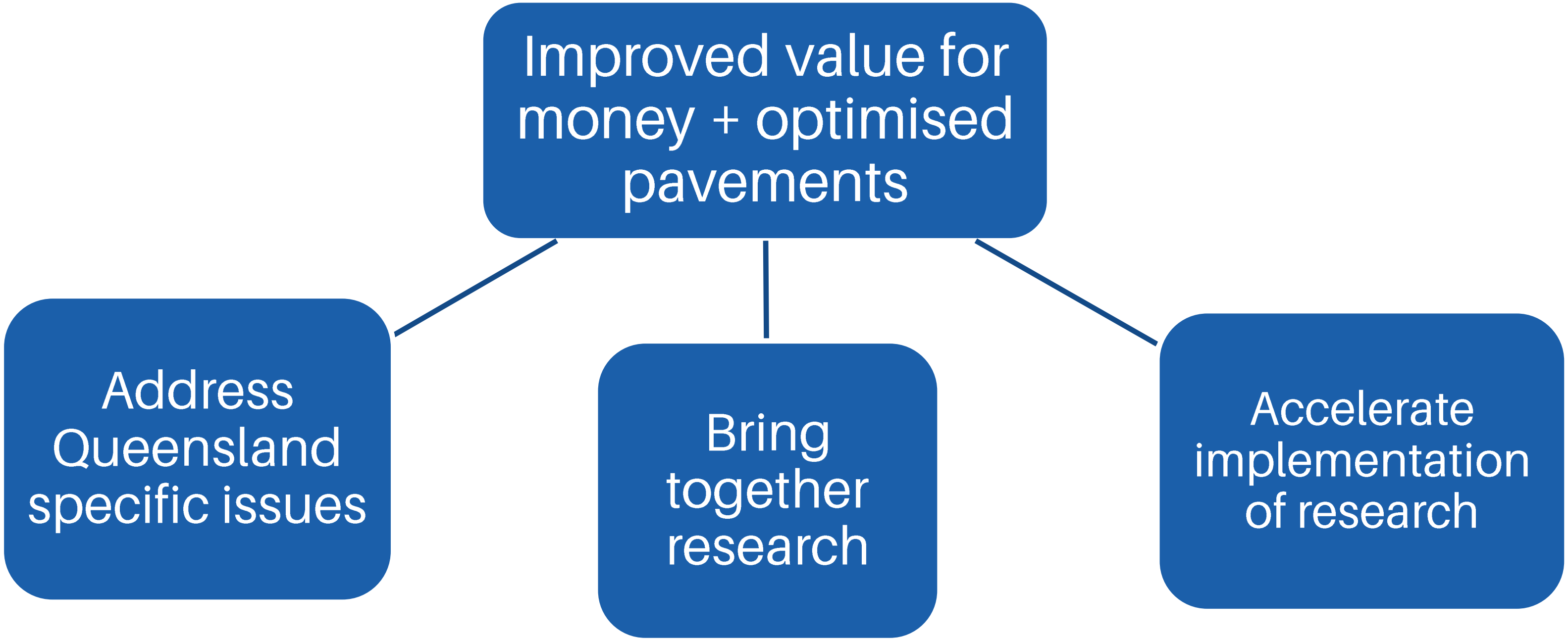
Austroads

- 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

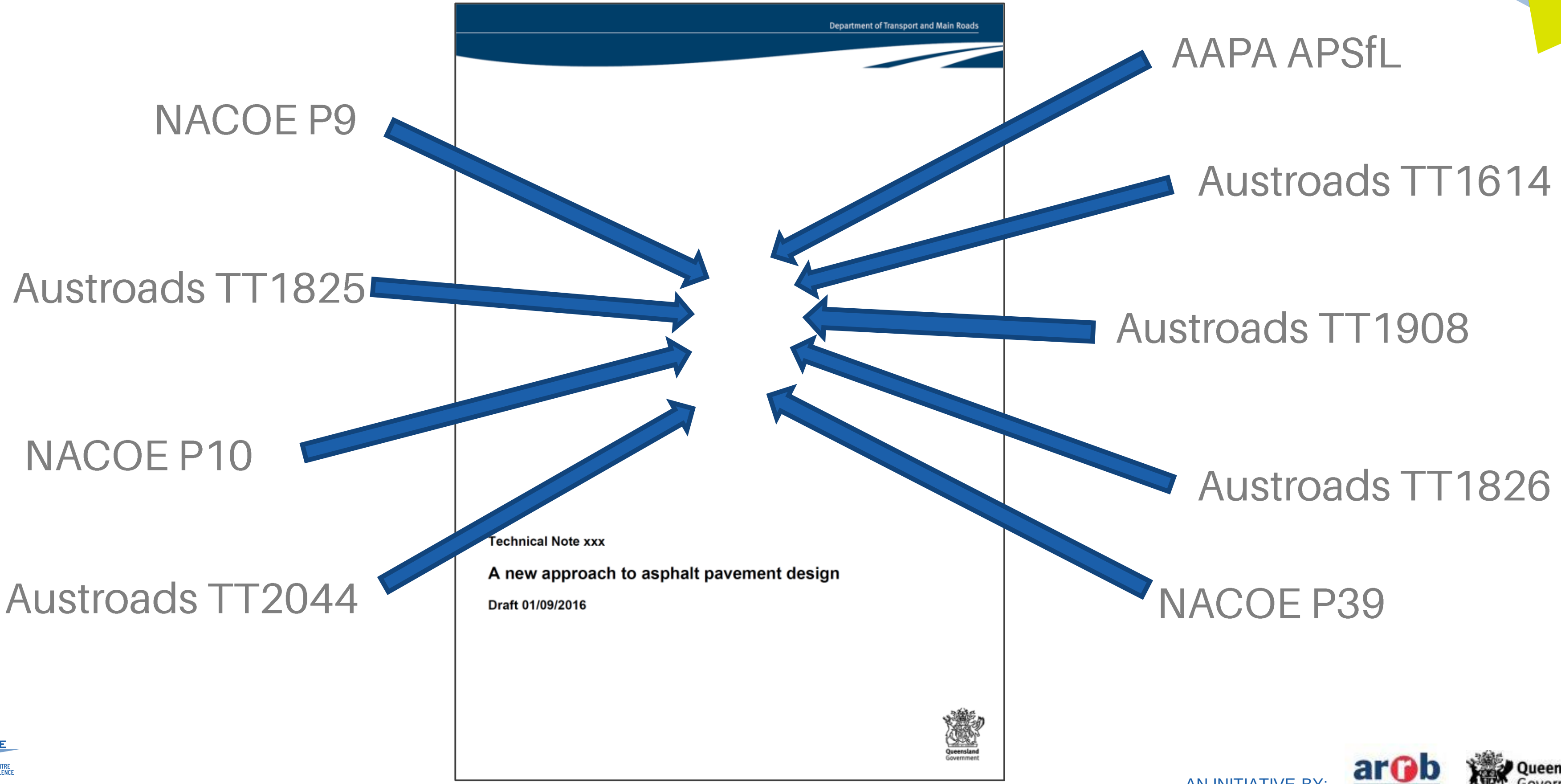
Australian Asphalt Pavement Association (AAPA)

- Asphalt pavement solutions for life (APSfL)

NACOE project goals



Draft technical note



Overview

Four key changes proposed

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

Asphalt design modulus

Current

Presumptive values from indirect tensile test

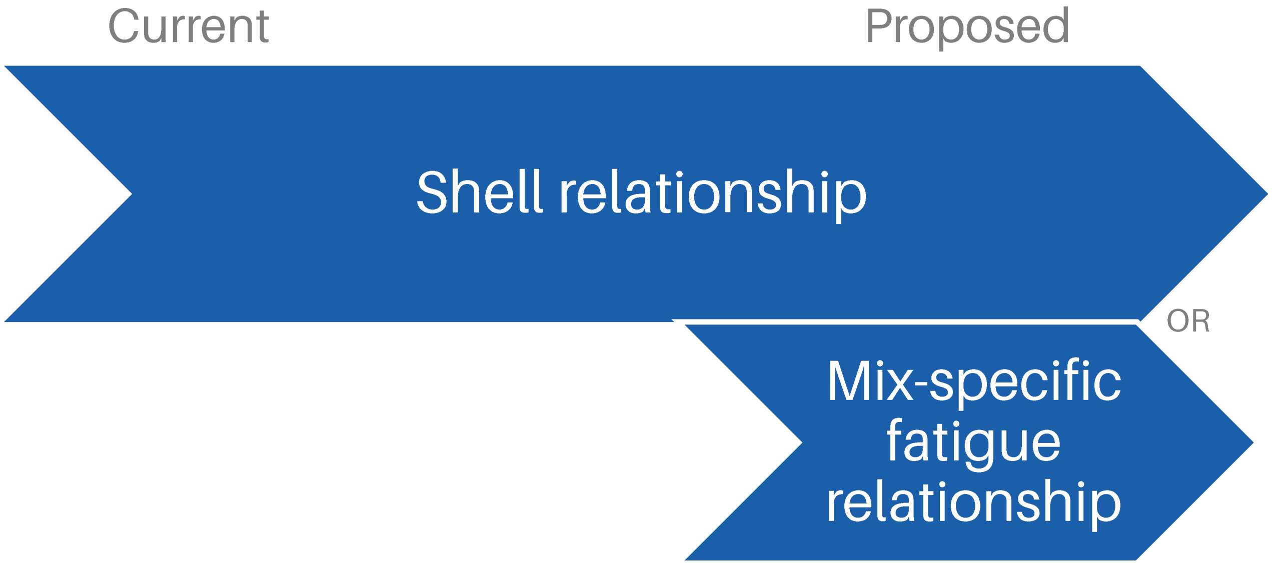
Proposed

Presumptive flexural modulus master curve

OR

Mix-specific flexural modulus master curve

Asphalt fatigue relationship



Upper limit on design traffic

Current

Thickness unlimited

Proposed

Thickness capped by an upper limit on design traffic

Multiple-axle group loads

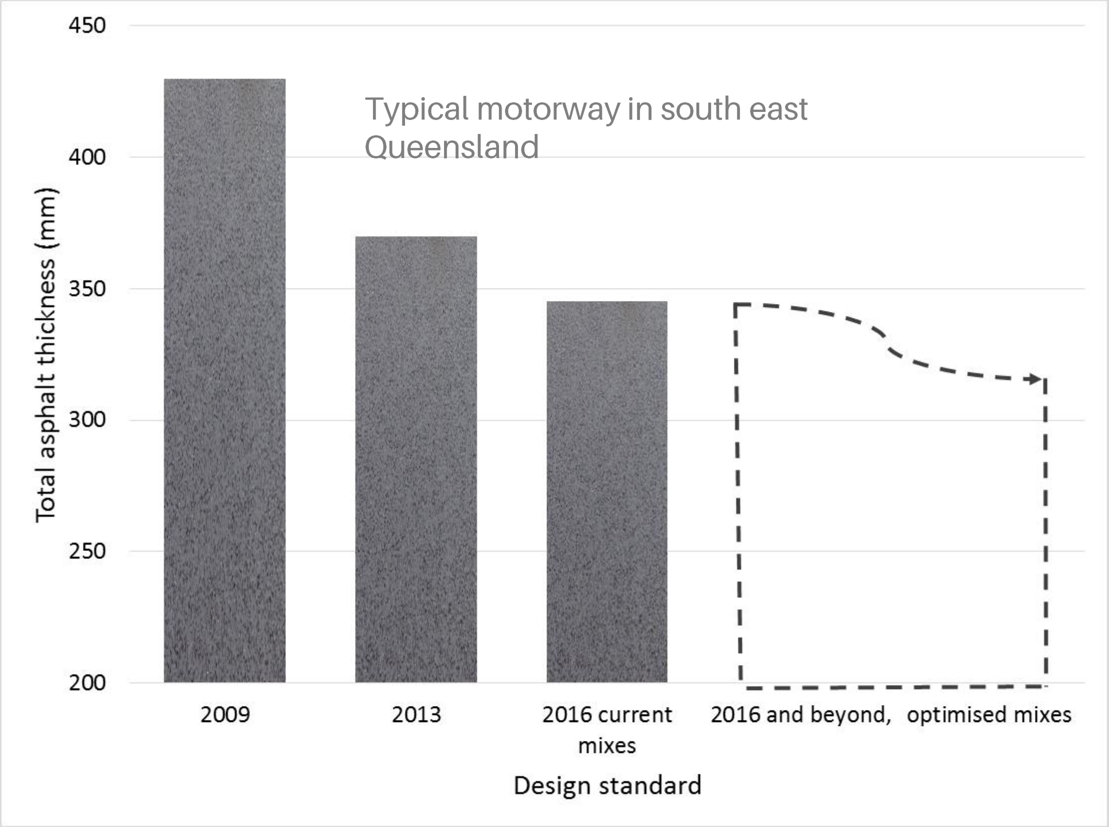
Current	Proposed
Strains under standard axle	Strains under every axle

Outcomes

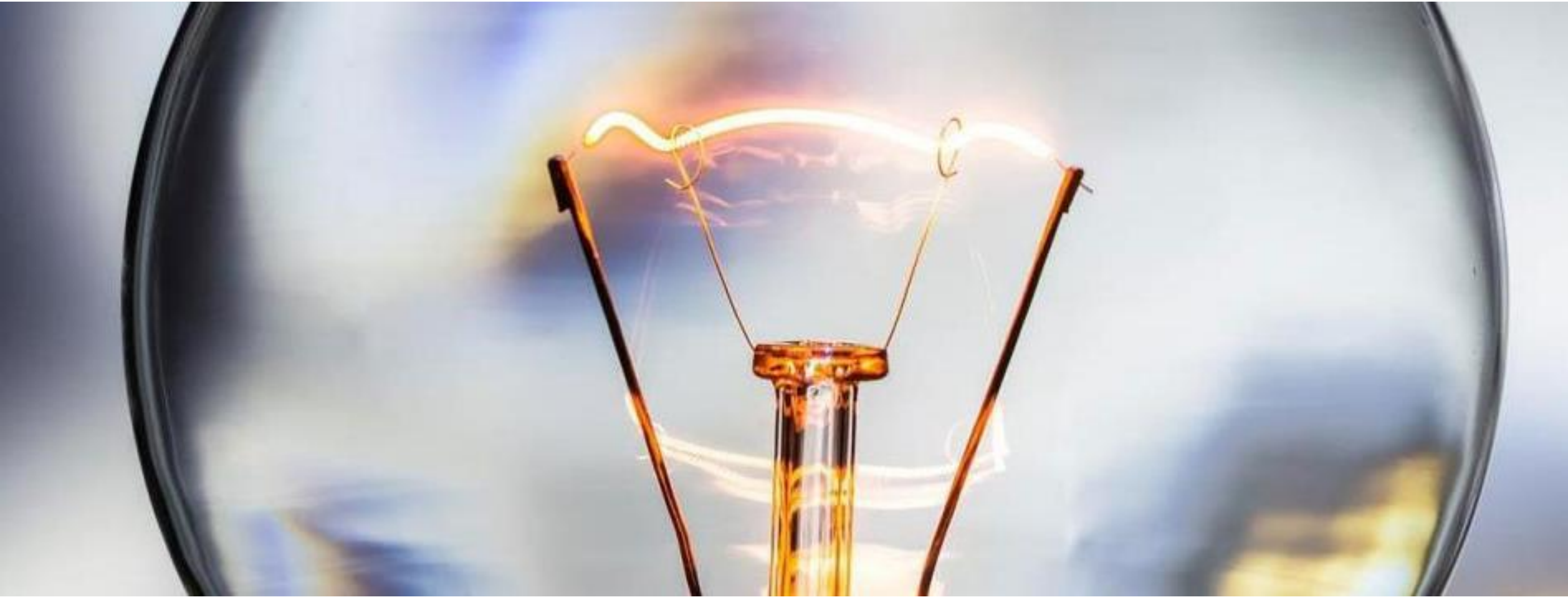
Example inputs:

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

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



QUESTIONS?



AN INITIATIVE BY:

Flexural modulus

Erik Denneman

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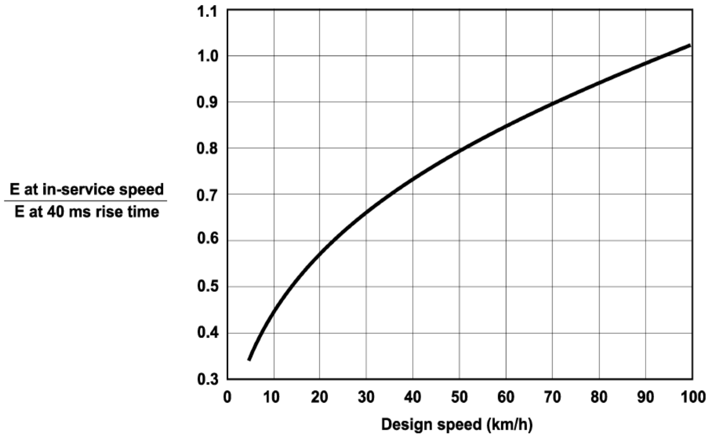
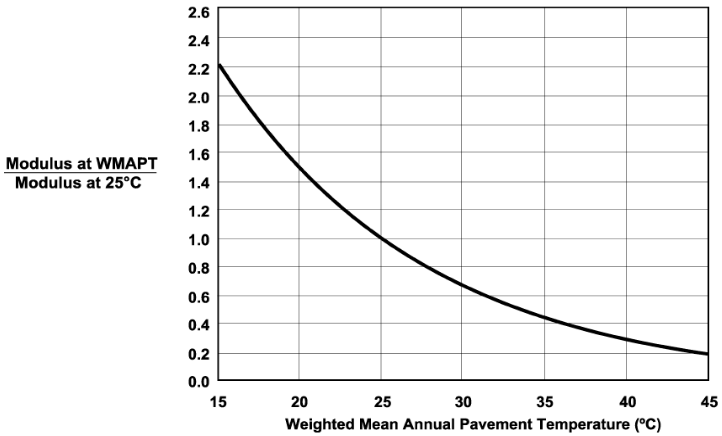
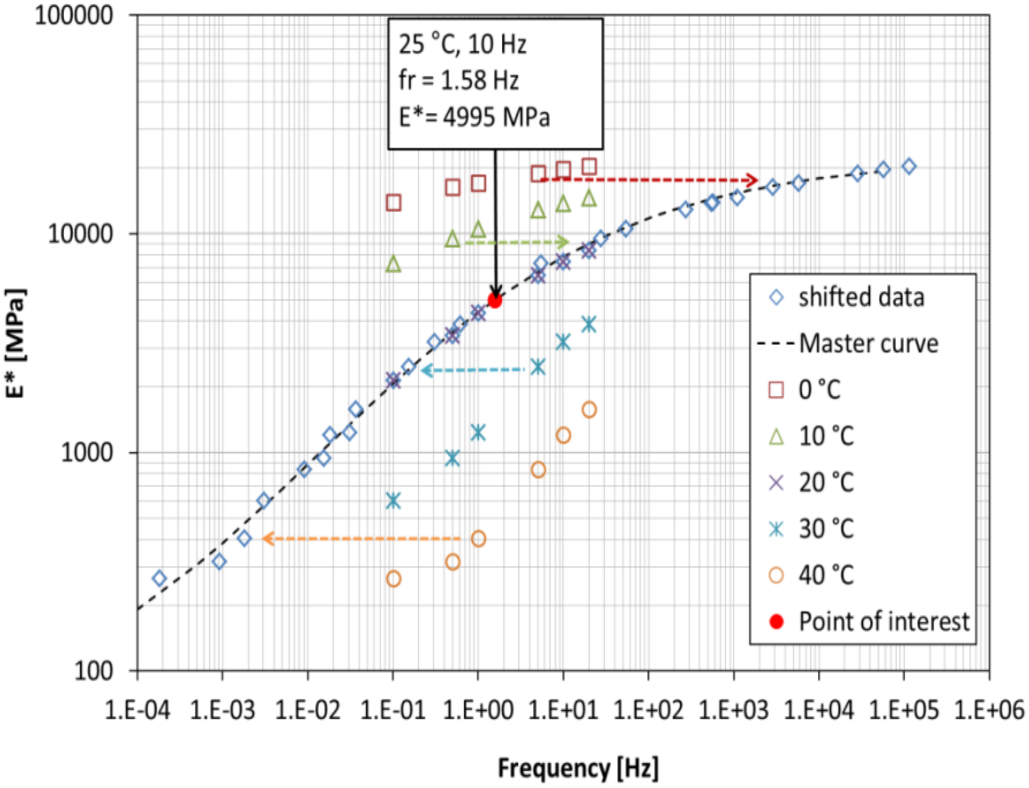
What we used to do



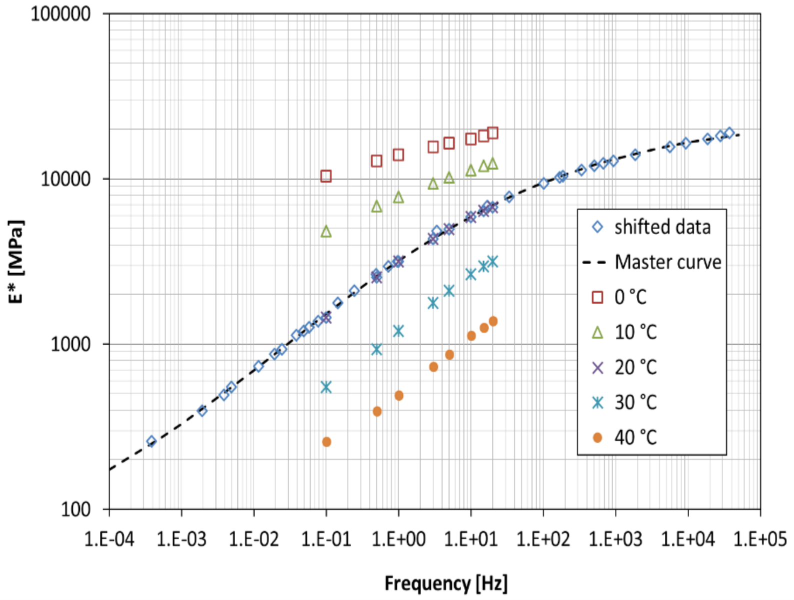


What we will be doing

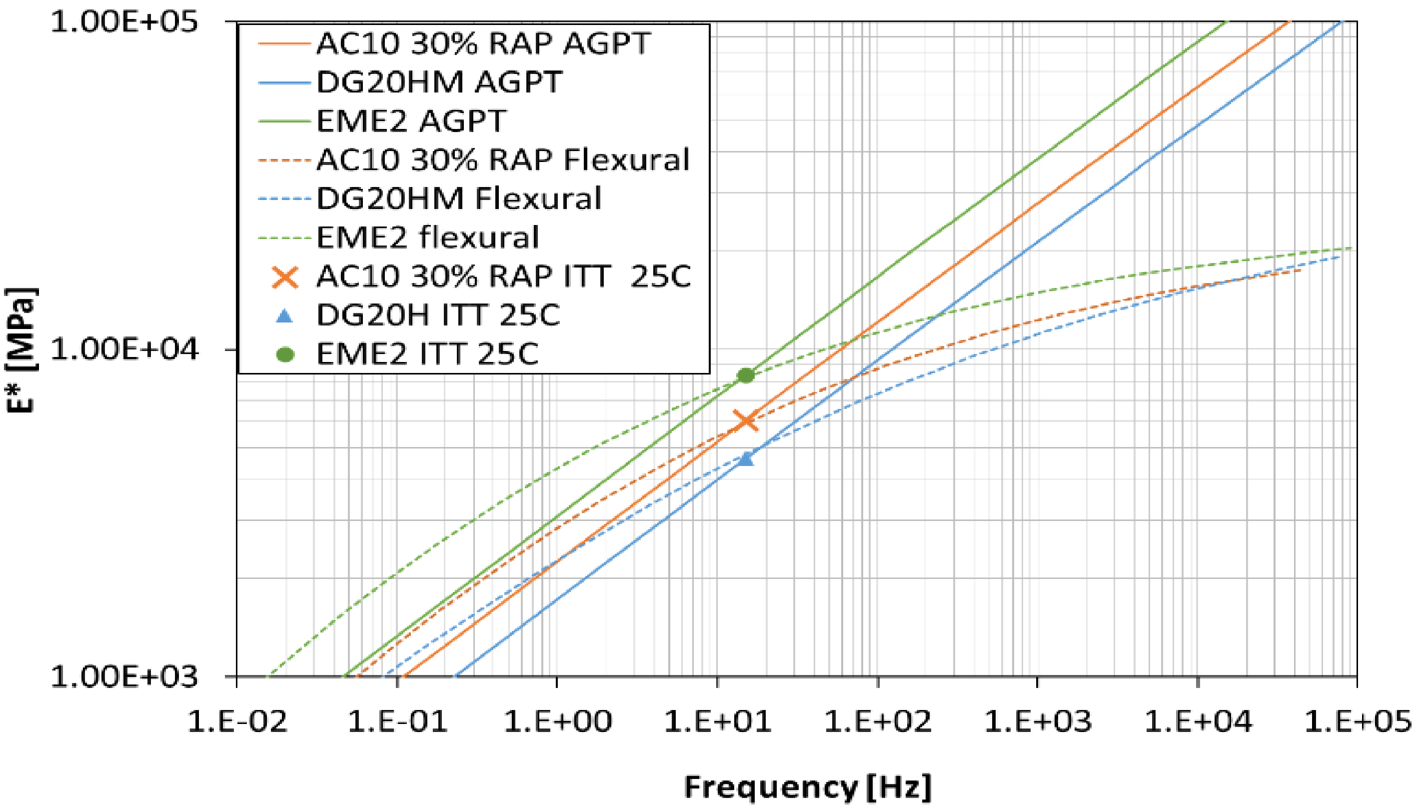


Why we will be doing it

- Convenient way of calculating flexural modulus at any combination of temperature and loading speed
- 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

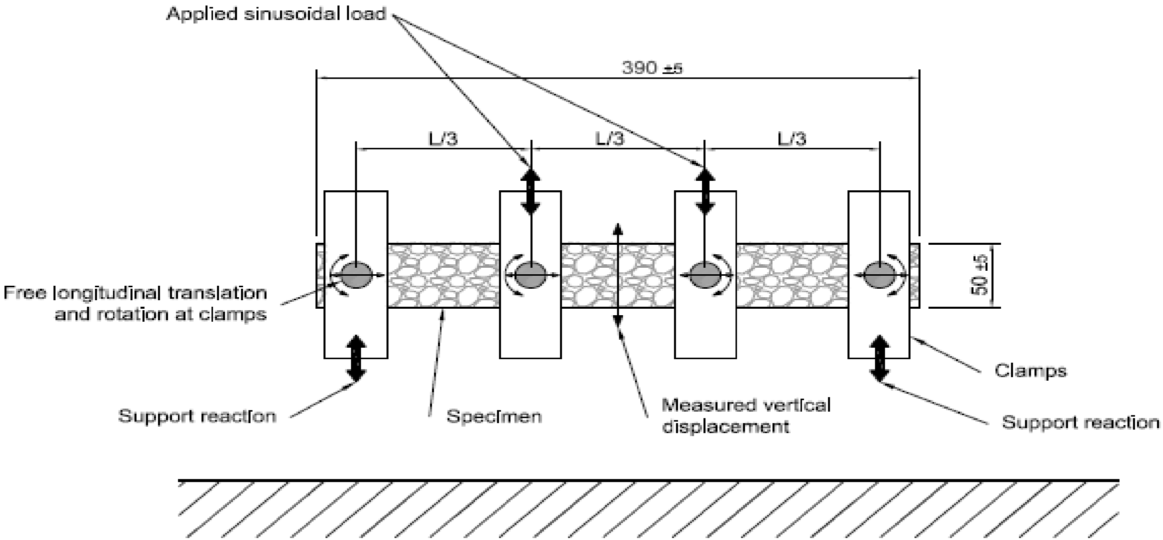
- Higher modulus leads to reduced pavement thicknesses
- Mix specific master curves open doors to innovation (competitive advantage for high performance mixes)
- Reduce risk

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.

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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.

Contents

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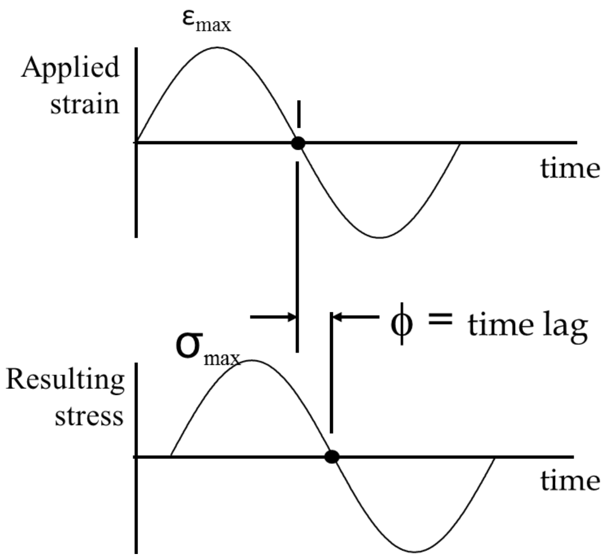
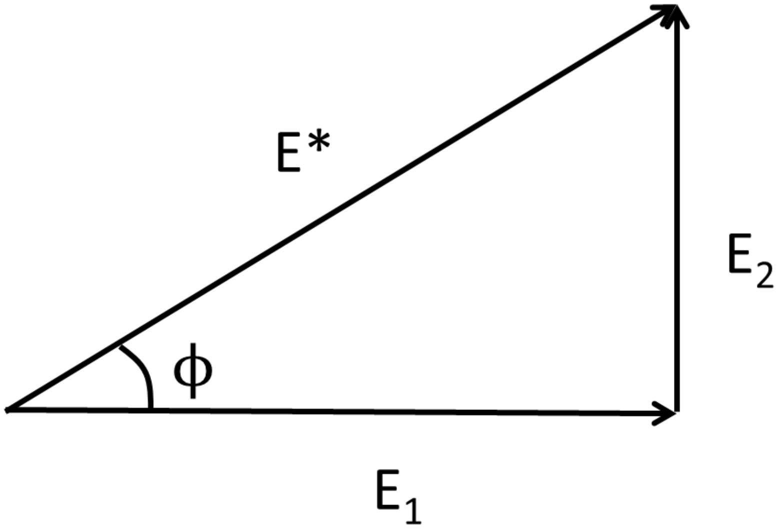
What is complex modulus |E*|





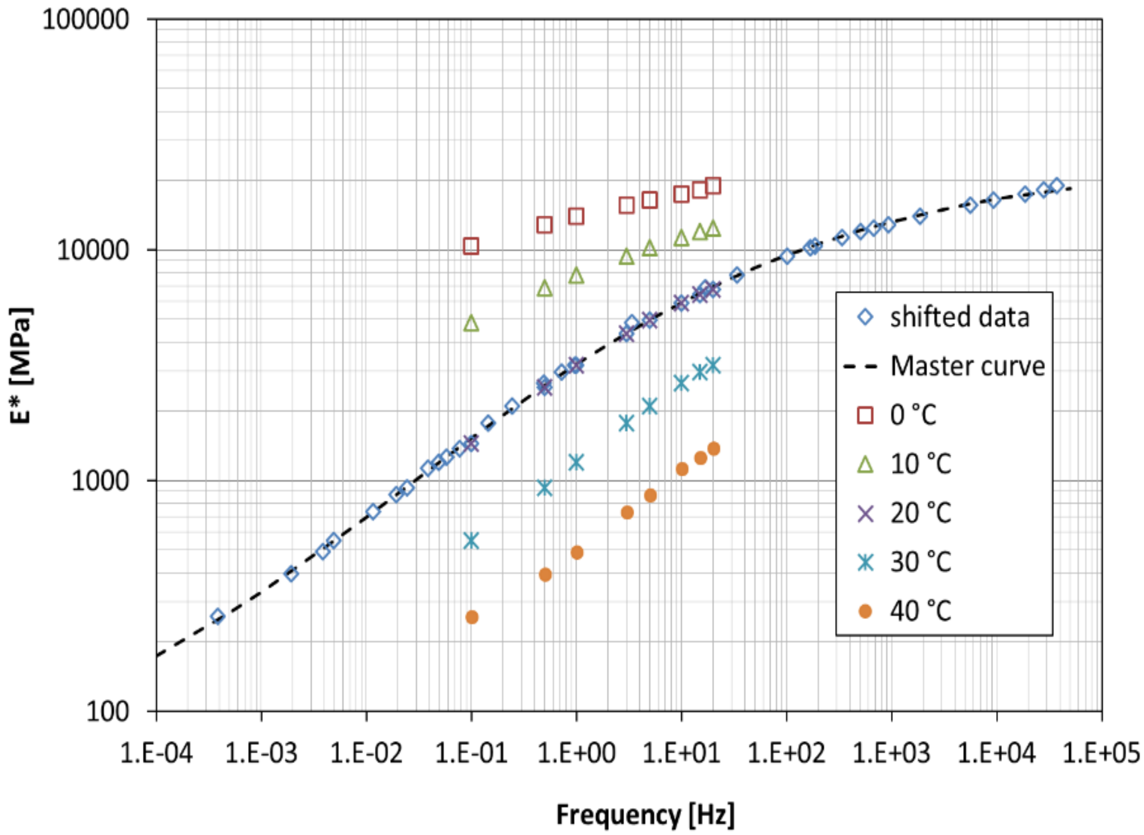
Test method

- 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

Results

Temperature (°C)	Frequency (Hz)	Flexural modulus for replicate specimens (MPa)					Statistics		
		15-227-1	15-227-3	15-227-4	15-228-1	15-228-2	Mean	STDEV	CoV
0	0.1	12,497	10,774	11,871	10,087	9,853	11016	1140	10.3%
	0.5	16,503	14,061	14,945	13,855	12,881	14449	1363	9.4%
	1	18,142	15,653	17,143	14,804	14,376	16024	1587	9.9%
	3	20,374	17,271	18,558	18,167	16,104	18095	1586	8.8%
	5	20,998	18,328	20,011	19,319	16,992	19130	1542	8.1%
	10	22,062	19,607	20,152	20,989	18,340	20230	1405	6.9%
	15	23,289	21,693	21,141	21,647	19,181	21390	1475	6.9%
	20	24,045	22,023	21,986	21,580	19,621	21851	1574	7.2%
10	0.1	4,564	4,410	4,250	4,075	3,913	4242	259	6.1%
	0.5	7,542	7,215	7,287	6,948	6,482	7095	403	5.7%
	1	8,776	8,850	8,363	8,320	7,474	8357	548	6.6%
	3	11,385	10,843	10,823	10,585	9,869	10701	550	5.1%
	5	12,496	11,872	11,684	11,699	10,854	11721	587	5.0%
	10	14,152	13,355	13,555	13,261	12,283	13321	676	5.1%
	15	14,923	14,373	14,121	14,183	13,180	14156	630	4.5%
	20	16,156	14,961	15,061	14,820	13,657	14931	888	5.9%
20	0.1	868	885	881	845	827	861	25	2.9%
	0.5	1,895	1,937	1,964	1,872	1,815	1897	58	3.1%
	1	2,919	2,603	2,600	2,757	2,784	2733	135	4.9%
	3	4,086	4,222	4,169	4,074	3,962	4103	99	2.4%
	5	4,910	5,044	5,011	4,870	4,713	4910	131	2.7%

Master curve construction



Master curve construction

- Sigmoidal model

$$log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log f_r}}$$

where:

f_r = reduced frequency

$\delta, \alpha, \beta, \gamma$ = fitting parameters

- Reduced frequency

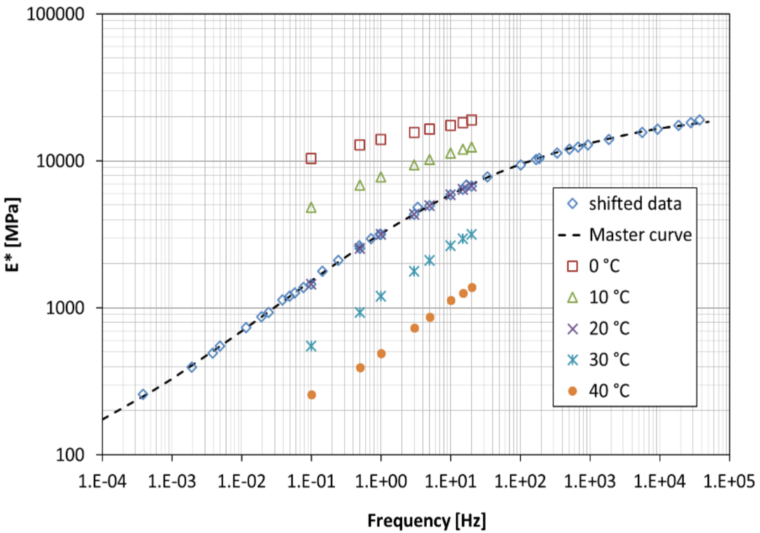
$$f_r = a(T) \times f$$

where:

f = frequency (Hz)

$a(T)$ = shift factor as a function of temperature (°C)

T = temperature (°C)



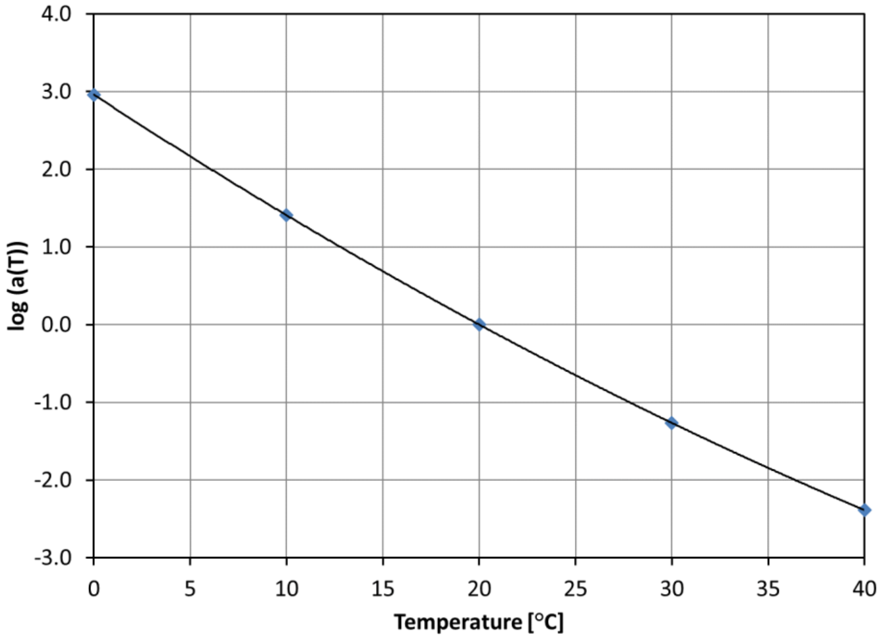
Master curve construction

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

where

a, b = fitting parameters

T_{ref} = Reference temperature



Master curve construction

- Curve fitting
  - Fitting parameters δ, α, β, γ, a, b determined by maximising coefficient of determination

$$log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log f_r}}$$

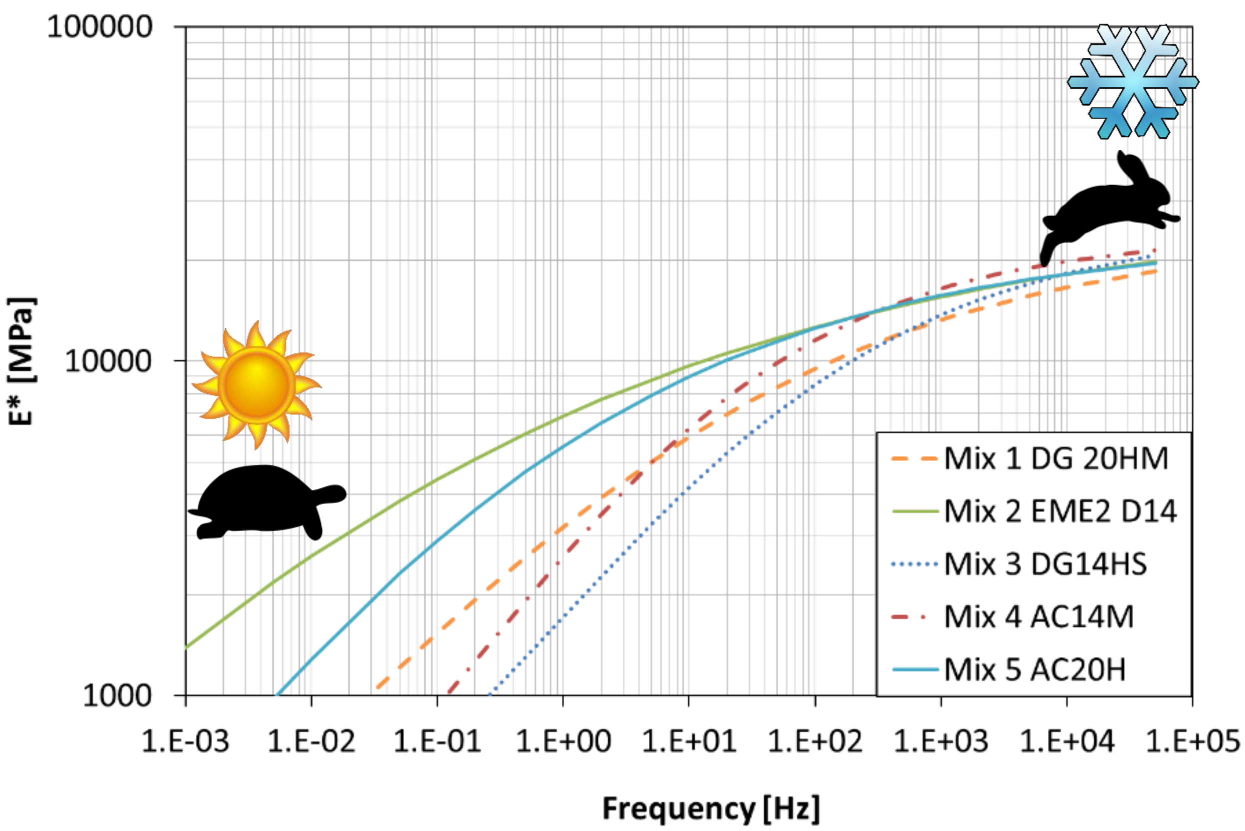
$$\log_{10}(a_T) = a(T - T_{ref})^2 + b(T - T_{ref})$$

  - Easy to set up with MS Excel Solver

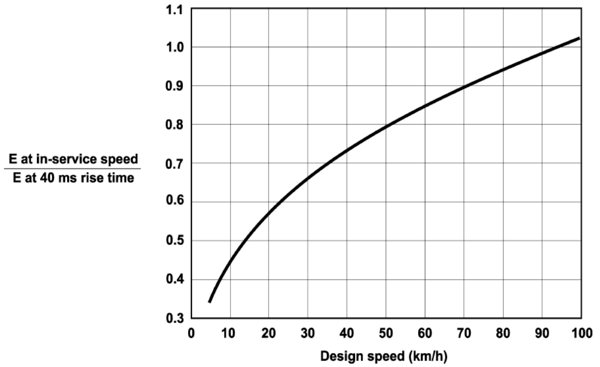
$$R^2 = 1 - \frac{\sum_i (y_i - z_i)^2}{\sum_i (y_i - \bar{y})^2}$$

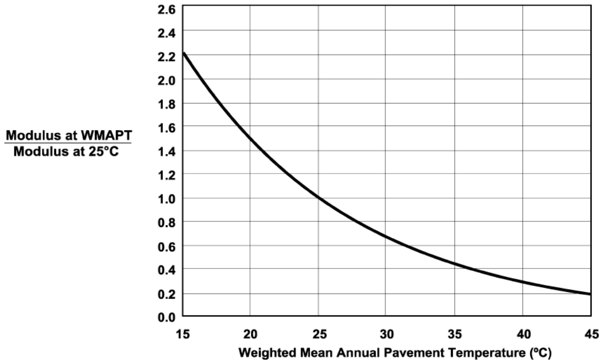
δ	α	β	γ	a	b	R^2	T_{ref} (°C)
2.699	1.579	-0.3386	-0.8926	2.873E-04	-0.1531	0.98	20

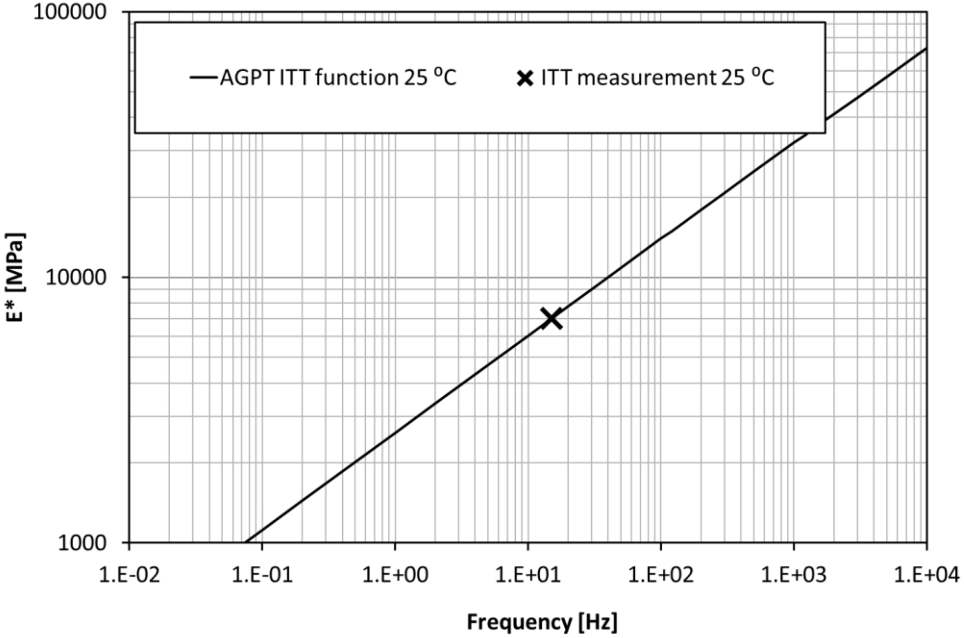
Mix specific master curves



Incorporating default values



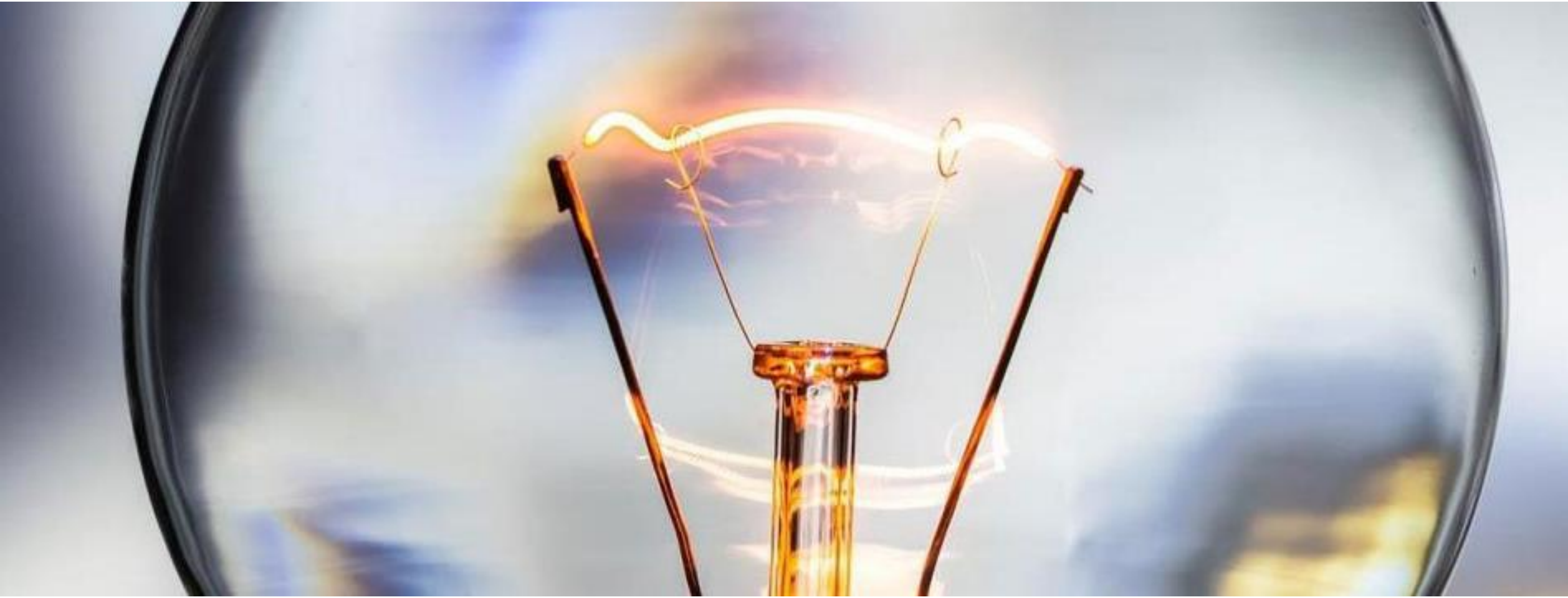




Use of default values

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

AN INITIATIVE BY: arrb GROUP Queensland Government

What we used to do

– Austroads

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

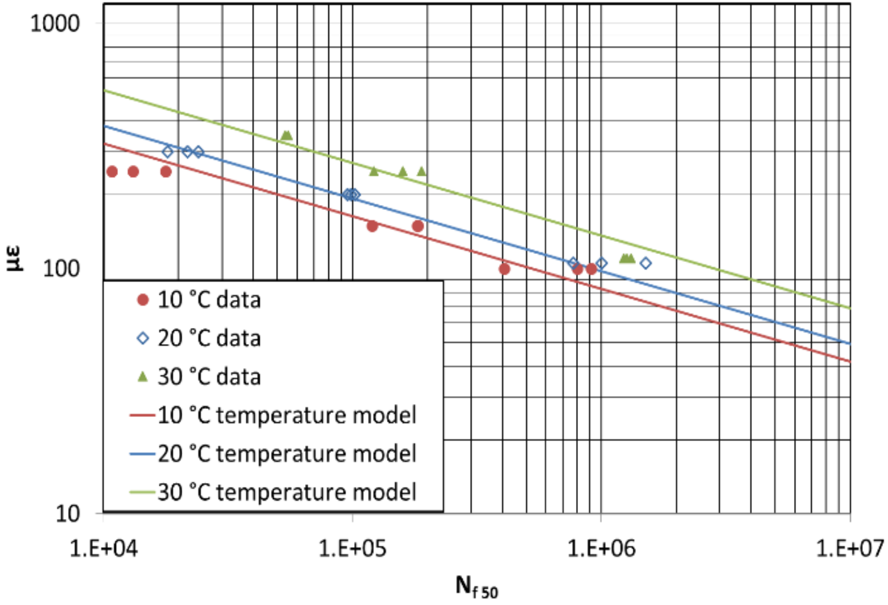
Lab to field + reliability factor

Shell laboratory model

– Shell

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

What we will be doing

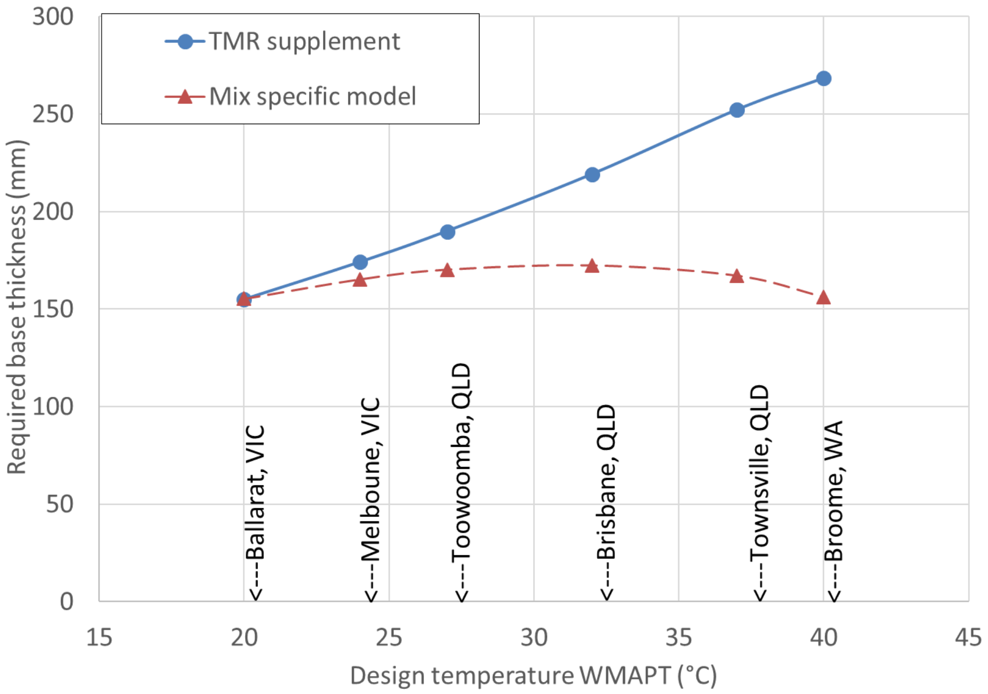


$$\ln\left(N_{f\,(50)}\right) = c_1 \cdot ln^3(E) + c_2 \cdot ln^2(E) + c_3 \cdot \ln(E) + c_4 + c_5 \cdot \ln \varepsilon$$

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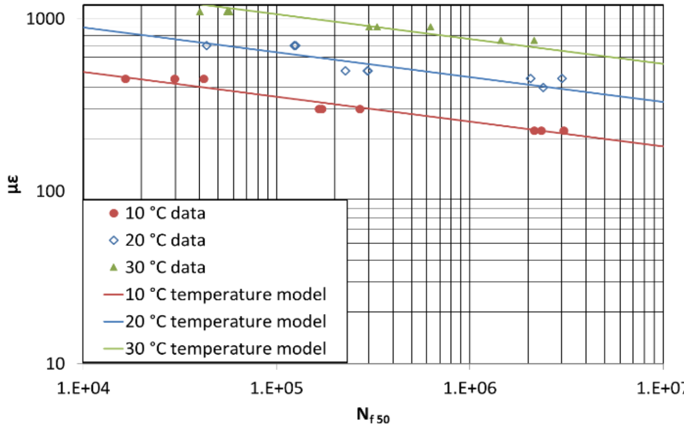
The modulus and fatigue characterisation tests can be run independently, or can be run consecutively on the same specimen, with the fatigue test following the modulus test.

Contents

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
  - All tests to exceed 10^4 cycles to failure
  - 22% of tests to exceed 10^6 cycles to failure
  - Test frequency: 10 Hz



Results

Sample #	Strain level (με)	$N_{f(50)}$	Temperature (°C)
15-117-1	225	2,156,300	10
15-117-3	225	2,335,610	10
15-207-3	225	3,058,506	10
15-116-3	300	269,987	10
15-116-4	300	171,201	10
15-116-5	300	165,405	10
15-077-5	450	16,543	10
15-116-1	450	29,646	10
15-116-2	450	41,882	10
15-077-1	400	2,400,313	20
15-077-2	450	2,061,922	20
15-077-2	450	3,000,000	20
15-024-4	500	227,279	20
15-024-5	500	297,033	20
15-056-5	500	296,222	20
15-076-2	700	125,469	20
15-076-4	700	123,706	20
15-076-5	700	43,381	20
15-213-1	750	3,000,000	30
15-212-3	750	2,147,917	30
15-212-5	750	1,450,242	30

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

Mix specific fatigue curve

- Laboratory model fitting
  - Fitting parameters c_1, c_2, c_3, c_4, c_5 determined by maximising coefficient of determination

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

  - Easy to set up with MS Excel Solver

$$R^2 = 1 - \frac{\sum_i (y_i - z_i)^2}{\sum_i (y_i - \bar{y})^2}$$

Mix name	n	c_1	c_2	c_3	c_4	c_5	σ_y
Example	27	0.388	-10.32	86.90	-175.3	-6.932	0.58

Laboratory to field prediction

Lab to field + reliability factor

Mix specific lab model

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

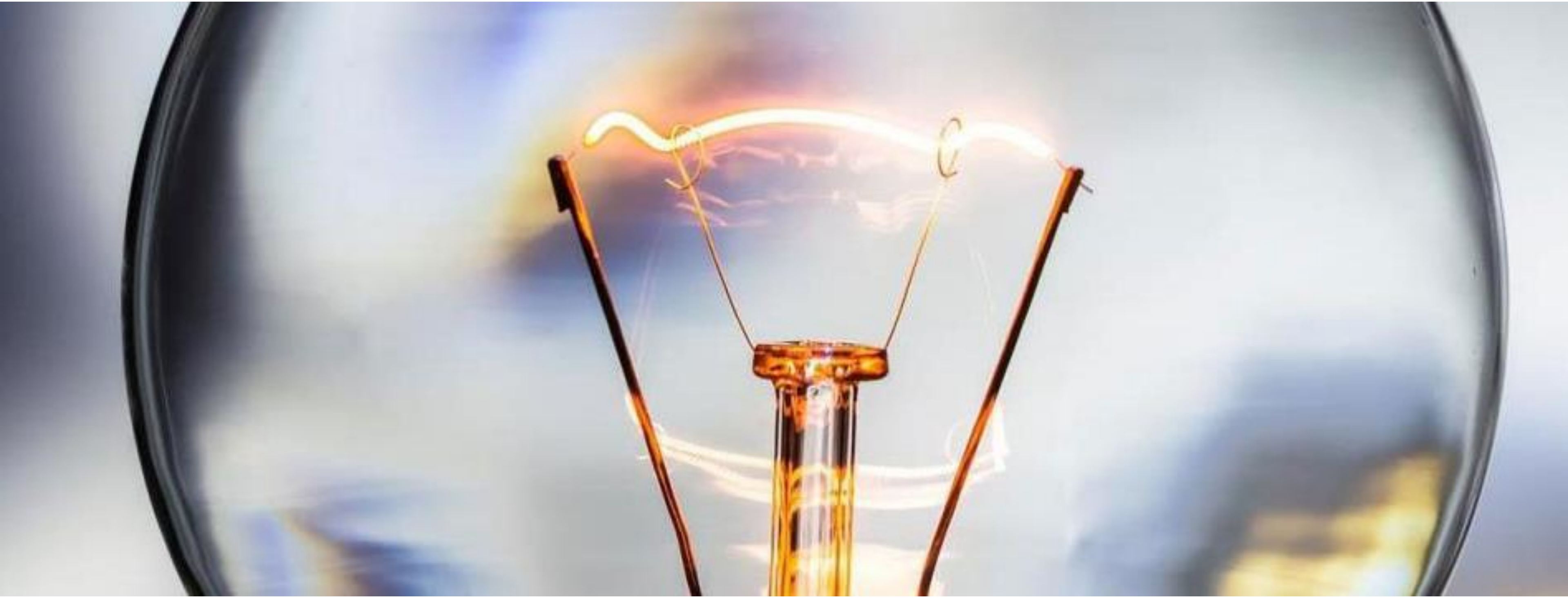
where

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)

QUESTIONS?



NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

Upper limit on design traffic

Jeffrey Lee

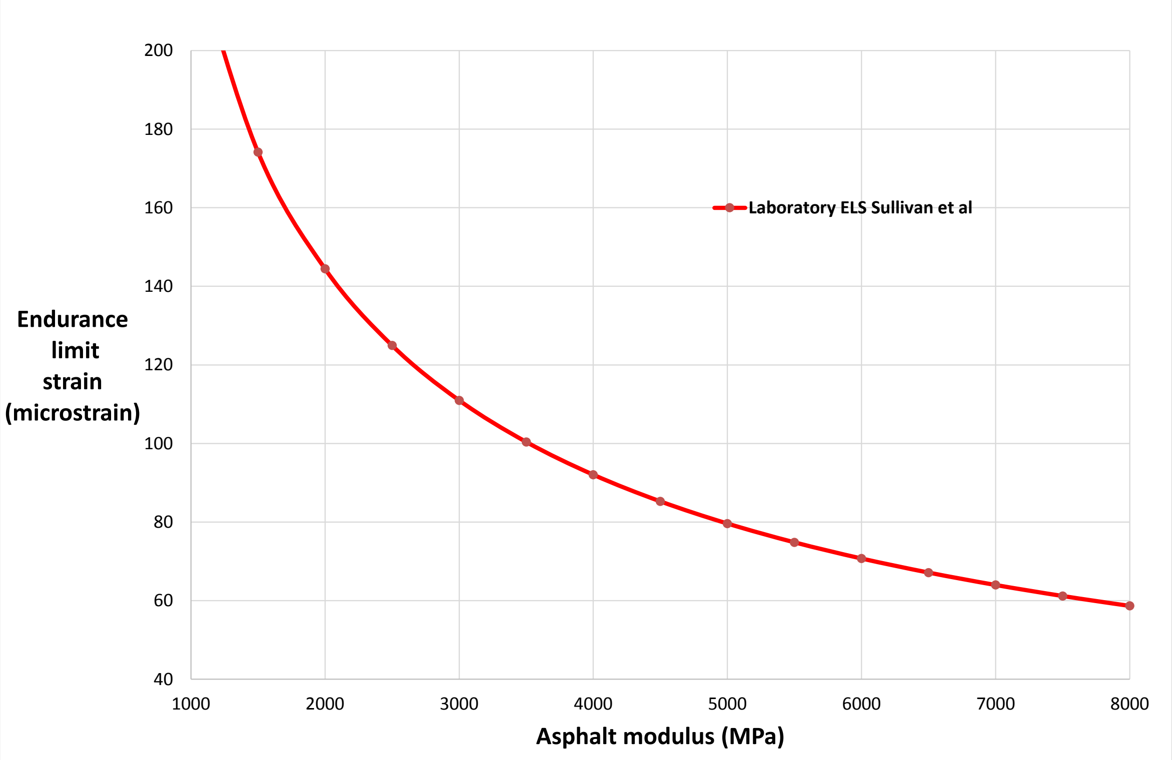
AN INITIATIVE BY: ARRB GROUP Queensland Government

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 APS-fL
- Austroads TT 2044

On going research in these studies, and consensus has not yet reached.

AAPA APS-fL – Fatigue Endurance Limit



$\underline{APSfL\ suggested\ equation}$

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

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)

FEL for different seasons

Observations

- FEL for winter is never the dominate criteria

- Depending on the particular situation, either the summer / WMAPT FEL control the design thickness
- Where the summer FEL is controlling the design, the thickness is usually within 5 – 10mm.

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 APS-fL method, and outlined the following options:
  - *Option A – APS-fL 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*

Austroads Project TT 2044

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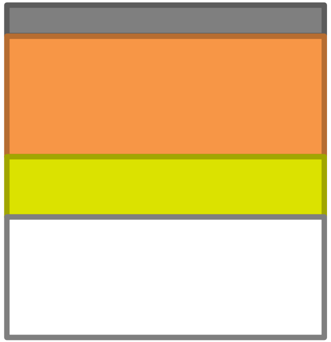
  - *Option D – Limiting design traffic loading* ← **Interim approach recommended in Queensland**
  - *Option E – modify fatigue relationship to allow for healing at elevated temperature*

Advantage of limiting design traffic

- Alternative methods require further development before they could be implemented
- *This option is simple to implement and is compatible with both the current AGPT02/12 and proposed changes*
- *This option can be implemented in the short term*
- *Not solely targeted at the perceived over-design at high temperatures*

Design examples



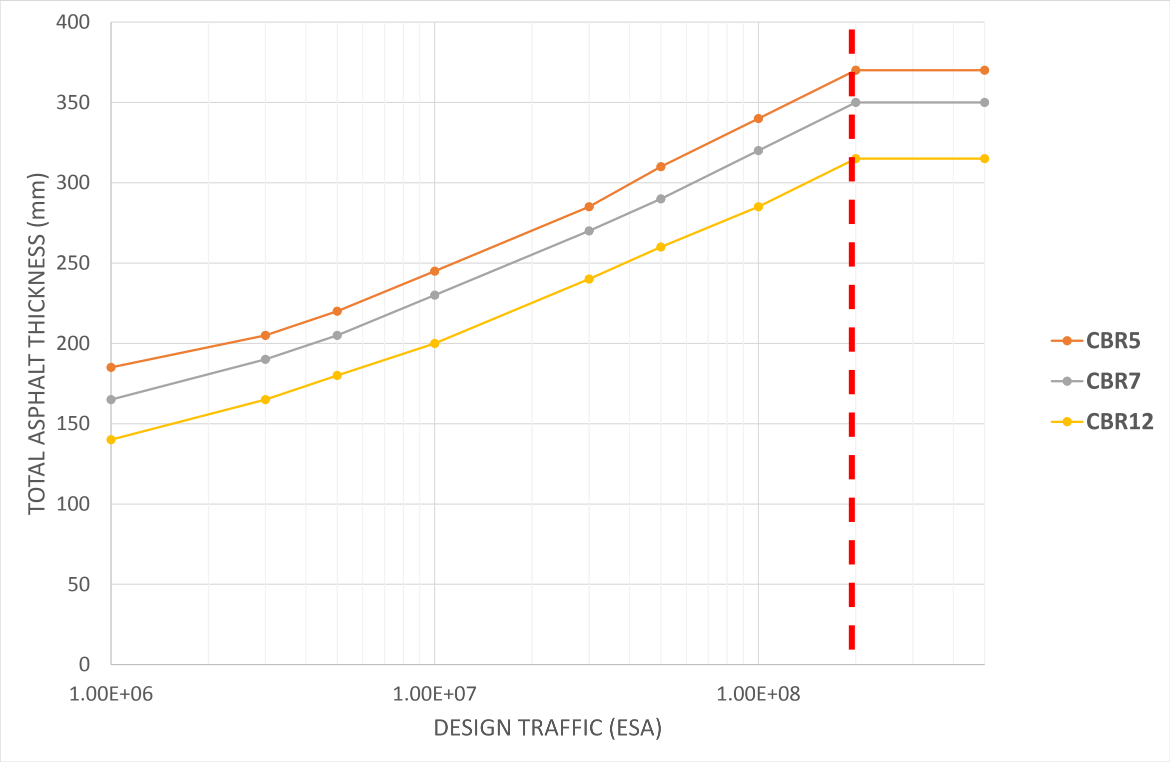
50 mm AC14M(C320)

X mm AC20M(C600)

150 mm Improved Layer

Design Subgrade (CBR 5, 7,12%)

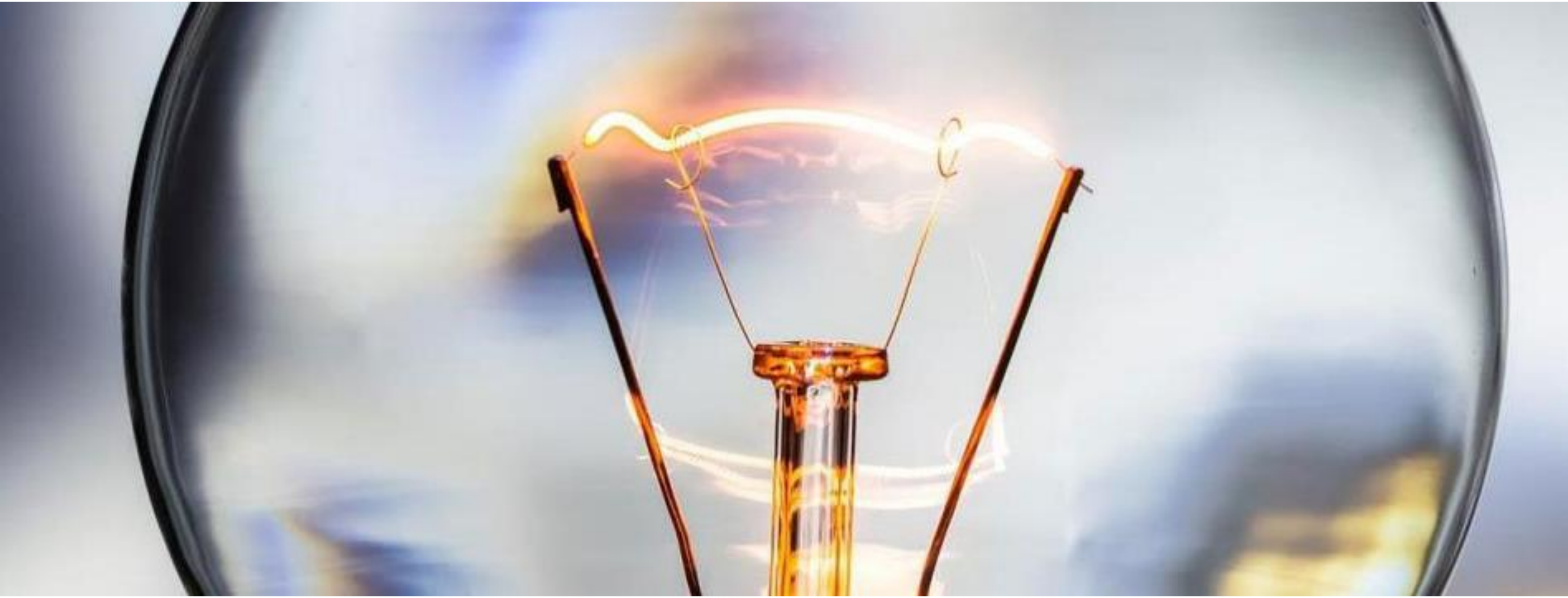
Limiting design traffic



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

- $2x10^8$ ESA (WMAPT 26 – 34°C)

QUESTIONS?



HOUSEKEEPING

Part 2 (tomorrow): 90 mins

9.00 to 10.30 am AEST