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A new approach to asphalt pavement design

Part 2

AN INITIATIVE BY: arrb GROUP Queensland Government

TODAY'S MODERATOR

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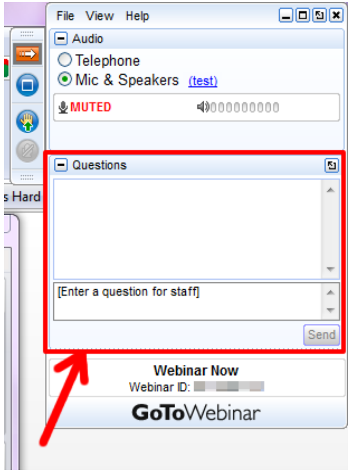
GOTOWEBINAR FUNCTIONS



Please type your questions here

Improved consideration of multiple-axle group loads

Peter Bryant

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Austroads research

The influence of multiple-axle loads on pavement performance

- Rapidly growing freight task
- Trend towards innovative heavy vehicles

Increased focus on the way pavement designers estimate performance under different loads

Significant outcome

Current	Proposed
Strains under standard axle	Strains under every axle

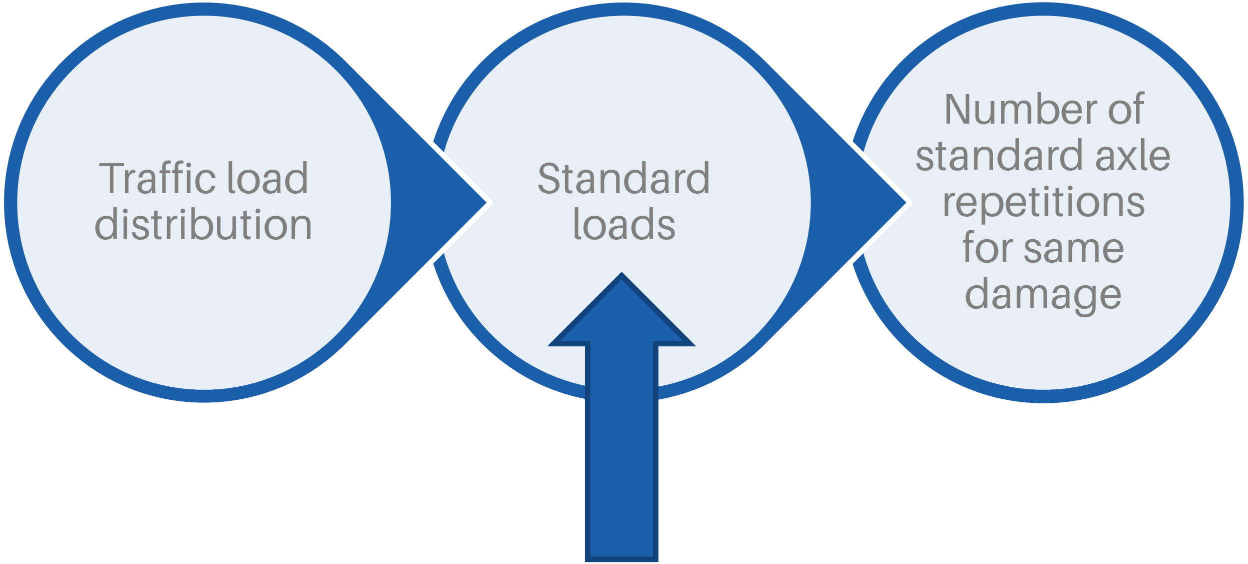
Austroads TT1614 - Pavement wear effects of heavy vehicle axle groups (Dr Michael Moffatt)

Traffic load distribution

Axle Group Load (kN)	Axle group type and proportion (%)					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	0.1	0.6				
20	3.7	3.6		0.4		
30	15.7	16.5	0.3	1.4	0.2	
40	12.4	18.7	1.4	2.6	0.4	
50	19.7	16.7	3.3	3.3	1.5	0.3
60	32.4	14.7	2.6	5.8	4.3	1.8
220				0.6	5.6	5.9
230				0.4	5.2	5.7
240				0.1	3.8	6.2
250				0.1	2.4	5.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
Proportion of each axle group type (%)	36.1	16.6	1.9	30.2	15.1	0.1

SAST	Single axle with single tyres
SADT	Single axle with dual tyres
TAST	Tandem axle group with single tyres
TADT	Tandem axle group with dual tyres
TRDT	Tri-axle group with dual tyres
QADT	Quad axle group with dual tyres

Current Austroads method



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

Standard axle repetitions

$$Standard\ axle\ repetitions(SAR5) = \sum \left(\frac{axle\ group\ load}{standard\ load} \right)^5$$

Table 7.5: Loads on axle groups with dual tyres which cause same damage as Standard Axle

Axle group type	Load (kN)
Single axle with dual tyres (SADT)	80
Tandem axle with dual tyres (TADT)	135
Triaxle with dual tyres (TRDT)	181
Quad-axle with dual tyres (QADT)	221

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)

Moffatt recommendation

Determine the pavement damage resulting from:

- Each axle load and group within the traffic load distribution.

Two alternatives considered:

- Calculate strains under each axle group, or
- Calculate strains under each individual axle

Improved method

Step 1

- Define pavement structure

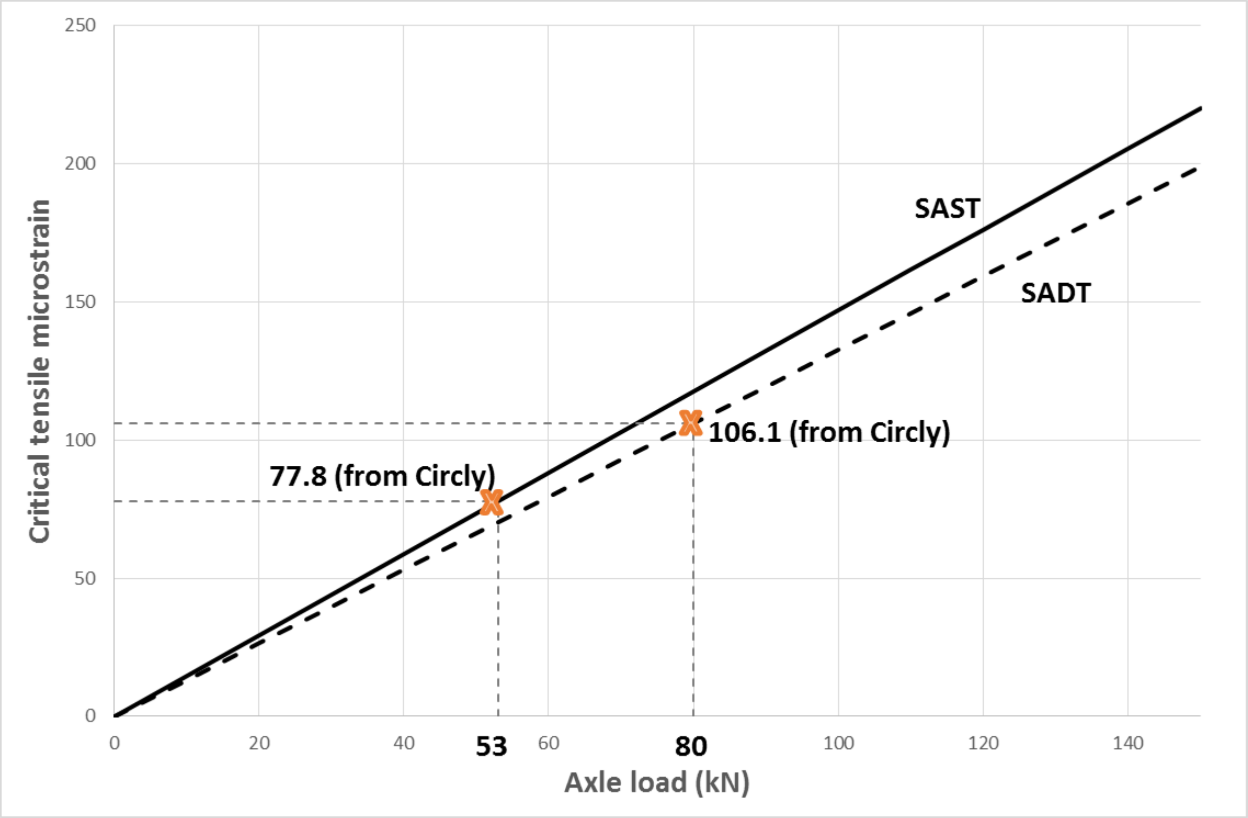
Step 2a

- 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 (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

$$Damage_{ij} = \frac{Expected\ repetitions_{ij}}{Allowable\ repetitions_{ij}}$$

Improved method

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

Improved method

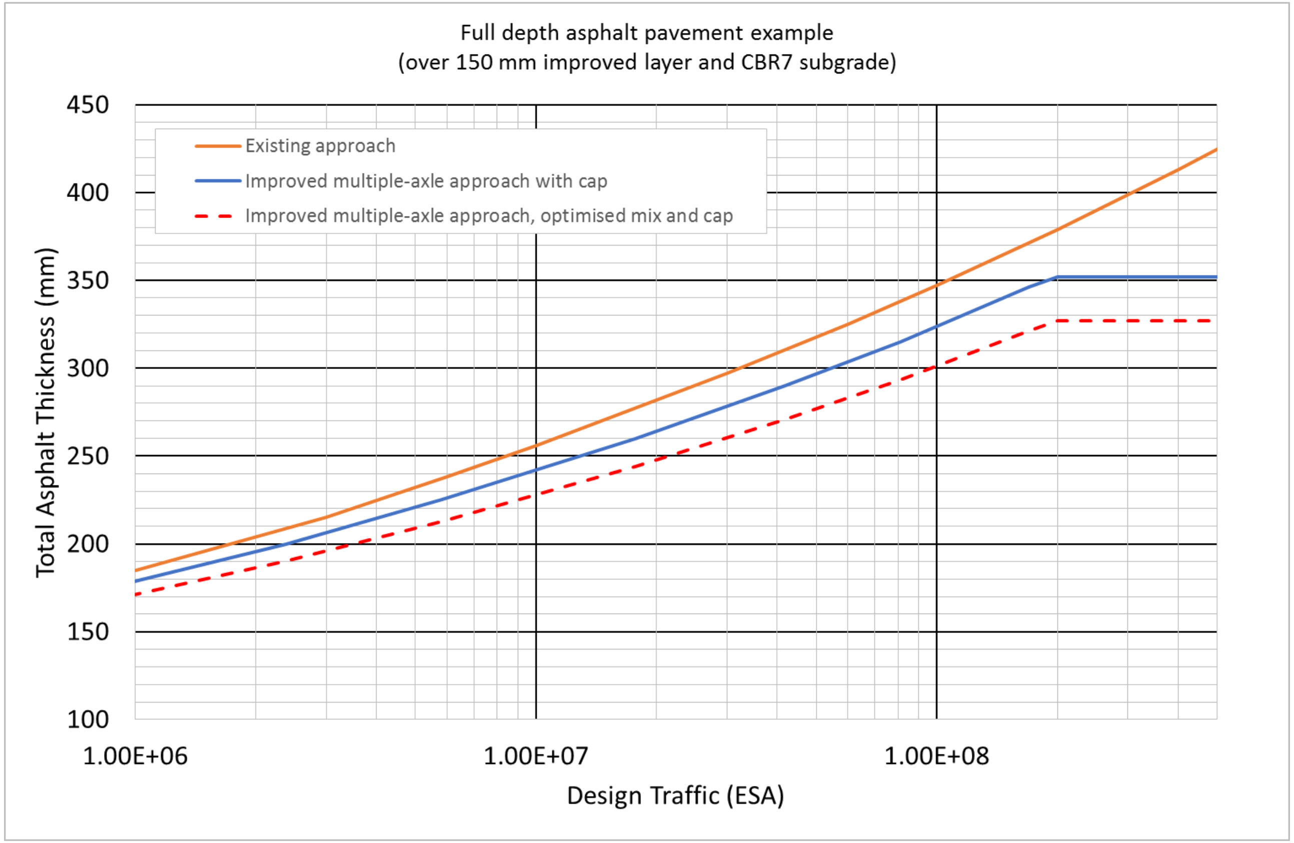
Loss of surface shape

- Current Austroads Guide uses standard axle repetitions (SAR7)
- New method uses equivalent standard axles (ESA)
- Performance equation updated to reflect difference between ESA and SAR7

$$N = \left[\frac{9150}{\mu\varepsilon}\right]^7$$

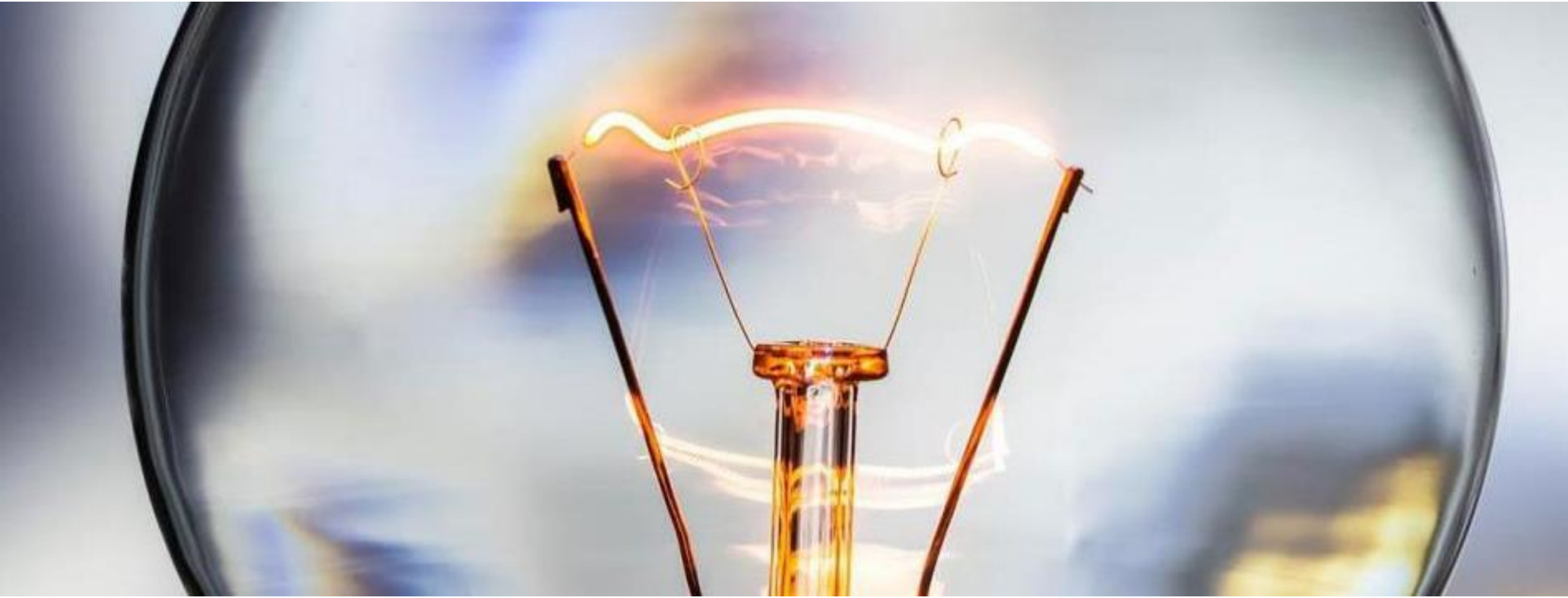
Where:
N = allowable repetitions (ESA)
$\mu\varepsilon$ = vertical compressive microstrain under standard axle

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?



Full depth asphalt pavement design example

Peter Bryant

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Introduction

Presumptive design modulus for the surfacing and intermediate courses

Mix-specific design modulus and mix-specific fatigue relationship for the base asphalt

Improved method for the consideration of multiple-axle group loads

Design inputs

Parameter	Value
Annual average daily traffic (AADT)	70,000
Direction factor (DF)	0.5
Percentage of heavy vehicles (%HV)	10.0
Lane distribution factor (LDF)	0.65
Design period	30 years
Heavy vehicle growth rate	3%
Reliability	95%
Weighted mean annual pavement temperature (WMAPT)	32°C
Heavy vehicle speed	80 km/h
Traffic load distribution	Table E3

Design traffic (N_{DT})

$$N_{DT} = 365 \times AADT \times DF \times \%HV/100 \times LDF \times CGF \times N_{HVAG}$$

$$= 365 \times 70{,}000 \times 0.5 \times 10.0/100 \times 0.65 \times 47.6 \times 2.63$$

$$= 1.04 \times 10^{8}$$ Heavy vehicle axle groups (HVAG)

Design traffic

Axle Group Load (kN)	Axle group type and proportion (%)					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	0.1	0.6				
20	3.7	3.6		0.4		
30	15.7	16.5	0.3	1.4	0.2	
40	12.4	18.7	1.4	2.6	0.4	
50	19.7	16.7	3.3	3.3	1.5	0.3
60	32.4	14.7	2.6	5.8	4.3	1.8
70	13.8	11.4	9.9	7.5	6.5	2.8
80	1.9	7.3	13.3	7.9	6.9	3.4
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
130	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150		0.1	1.1	6.8	4.6	3.4
160			0.9	7.5	4.3	3.4
170			0.5	6.8	4.4	3.6
180				5.5	4.6	3.4
190				3.3	4.4	2.5
200				1.8	4.8	5.3
210				0.9	5.4	5.2
220				0.6	5.6	5.9
230				0.4	5.2	5.7

Traffic load distribution

$N_{DT} = 1.04 \times 10^8$ HVAG

Axle Group Load (kN)	Expected repetitions by axle group type					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	3.75E+04	1.04E+05				
20	1.39E+06	6.22E+05		1.26E+05		
30	5.89E+06	2.85E+06	5.93E+03	4.40E+05	3.14E+04	
40	4.66E+06	3.23E+06	2.77E+04	8.17E+05	6.28E+04	
50	7.40E+06	2.88E+06	6.52E+04	1.04E+06	2.36E+05	3.12E+02
60	1.22E+07	2.54E+06	5.14E+04	1.82E+06	6.75E+05	1.87E+03
70	5.18E+06	1.97E+06	1.96E+05	2.36E+06	1.02E+06	2.91E+03
80	7.13E+05	1.26E+06	2.63E+05	2.48E+06	1.08E+06	3.54E+03
90	1.13E+05	7.94E+05	3.04E+05	2.04E+06	8.64E+05	7.80E+03
100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
120		1.04E+05	2.61E+05	1.85E+06	7.69E+05	5.82E+03
130		5.18E+04	1.01E+05	2.10E+06	7.54E+05	6.03E+03
140		3.45E+04	2.96E+04	2.04E+06	7.38E+05	5.62E+03
150		1.73E+04	2.17E+04	2.14E+06	7.22E+05	3.54E+03
160			1.78E+04	2.36E+06	6.75E+05	3.54E+03
170			9.88E+03	2.14E+06	6.91E+05	3.74E+03
180				1.73E+06	7.22E+05	3.54E+03
190				1.04E+06	6.91E+05	2.60E+03
200				5.65E+05	7.54E+05	5.51E+03
210				2.83E+05	8.48E+05	5.41E+03
220				1.88E+05	8.79E+05	6.14E+03
230				1.26E+05	8.17E+05	5.93E+03

Expected repetitions

Fatigue assessment - Step 1

- Select pavement structure and characterise all materials

Pavement structure

Course	Thickness (mm)	Description
Surfacing	50	SMA14 - presumptive master curve – 1300 MPa
Intermediate	50	AC14M(A5S) - presumptive master curve – 1500 MPa
Base	X (= 230 mm for this iteration, excludes tolerance)	AC20M(C600) - mix-specific master curve and fatigue relationship
Improved layer	150	Lightly stabilised unbound granular
Select fill	170	Design CBR 10%
Existing subgrade	-	Design CBR 3%

AC20M(C600) design modulus

- Master curve (T_{ref} = 25°C, 5% air voids)

Parameter	α	β	γ	δ	a	b
Value	2.579	-0.6292	-0.6704	1.742	2.156x10^{-3}	-0.1157

$$\log_{10}|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log_{10} f_r}}$$

$$f_r = \alpha_T \times f_{T274}$$

80 km/h

$$f_{T274} = \frac{V}{2\pi}$$

32°C

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

E^* = 3749 MPa (@ 5% air voids)

E^* = 3515 MPa (@ 6% air voids)

Design modulus = 3500 MPa

Fatigue assessment - Step 2

- Determine critical tensile strains under each axle

CIRCLY output

Axle type	Axle load (kN)	Critical tensile microstrain
Single axle with single tyres	53	77.8
Single axle with dual tyres (Standard Axle)	80	106.1

Linear scaling

Axle Group Load (kN)	Critical microstrain under each individual axle					
	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
110		145.9	80.8	73.0	48.6	36.5
120		159.2	88.1	79.6	53.1	39.8
130		172.4	95.4	86.2	57.5	43.1
140		185.7	102.8	92.9	61.9	46.4
150		199.0	110.1	99.5	66.3	49.7
160			117.5	106.1	70.7	53.1
170			124.8	112.8	75.2	56.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fatigue assessment – step 3

- Determine the allowable load repetitions

Allowable axle group repetitions

3500 MPa

Strain under single axle from step 2

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

Converts from allowable single axles to allowable axle groups

Parameter	c_1	c_2	c_3	c_4	c_5
Value	0.37663	-9.3728	75.086	-151.67	-5.0209

Allowable load repetitions

Axle Group Load (kN)	Allowable axle group load repetitions					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	1.57E+12	2.62E+12				
20	4.85E+10	8.07E+10		1.31E+12		
30	6.33E+09	1.05E+10	1.03E+11	1.71E+11	8.74E+11	
40	1.49E+09	2.49E+09	2.42E+10	4.04E+10	2.06E+11	
50	4.87E+08	8.11E+08	7.91E+09	1.32E+10	6.72E+10	2.14E+11
60	1.95E+08	3.25E+08	3.17E+09	5.27E+09	2.69E+10	8.56E+10
70	8.99E+07	1.50E+08	1.46E+09	2.43E+09	1.24E+10	3.95E+10
80	4.60E+07	7.66E+07	7.47E+08	1.24E+09	6.35E+09	2.02E+10
90	2.55E+07	4.24E+07	4.13E+08	6.88E+08	3.51E+09	1.12E+10
100						09
110						09
120		1.00E+07	9.75E+07	1.62E+08	8.29E+08	2.64E+09
130		6.69E+06	6.52E+07	1.09E+08	5.55E+08	1.76E+09
140		4.61E+06	4.50E+07	7.49E+07	3.82E+08	1.22E+09
150		3.26E+06	3.18E+07	5.30E+07	2.70E+08	8.60E+08
160			2.30E+07	3.83E+07	1.96E+08	6.22E+08
170			1.70E+07	2.82E+07	1.44E+08	4.59E+08
180				2.12E+07	1.08E+08	3.44E+08
190				1.62E+07	8.25E+07	2.62E+08

Allowable repetitions

Axle Group Load (kN)	Expected repetitions by axle group type					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	3.75E+04	1.04E+05				
20	1.39E+06	6.22E+05		1.26E+05		
30	5.89E+06	2.85E+06	5.93E+03	4.40E+05	3.14E+04	
40	4.66E+06	3.23E+06	2.77E+04	8.17E+05	6.28E+04	
50	7.40E+06	2.88E+06	6.52E+04	1.04E+06	2.36E+05	3.12E+02
60	1.22E+07	2.54E+06	5.14E+04	1.82E+06	6.75E+05	1.87E+03
70	5.18E+06	1.97E+06	1.96E+05	2.36E+06	1.02E+06	2.91E+03
80	7.13E+05	1.26E+06	2.63E+05	2.48E+06	1.08E+06	3.54E+03
90	1.13E+05	7.94E+05	3.04E+05	2.04E+06	8.64E+05	7.80E+03
100		4.83E+05	3.02E+05	1.82E+06	8.48E+05	1.03E+04
110		3.28E+05	3.20E+05	1.85E+06	8.48E+05	7.90E+03
120						3
130						3
140		3.45E+04	2.96E+04	2.04E+06	7.38E+05	5.62E+03
150		1.73E+04	2.17E+04	2.14E+06	7.22E+05	3.54E+03
160			1.78E+04	2.36E+06	6.75E+05	3.54E+03
170			9.88E+03	2.14E+06	6.91E+05	3.74E+03
180				1.73E+06	7.22E+05	3.54E+03
190				1.04E+06	6.91E+05	2.60E+03
200				5.65E+05	7.54E+05	5.51E+03
210				2.83E+05	8.48E+05	5.41E+03
220				1.88E+05	8.79E+05	6.14E+03
230				1.26E+05	8.17E+05	5.93E+03

Expected repetitions

Fatigue assessment – steps 4 & 5

- Determine the damage for each combination and sum

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

Axle Group Load (kN)	Asphalt fatigue damage					
	SAST	SADT	TAST	TADT	TRDT	QADT
10	0.000	0.000				
20	0.000	0.000		0.000		
30	0.001	0.000	0.000	0.000	0.000	
40	0.003	0.001	0.000	0.000	0.000	
50	0.015	0.004	0.000	0.000	0.000	0.000
60	0.062	0.008	0.000	0.000	0.000	0.000
70	0.058	0.013	0.000	0.001	0.000	0.000
⋮		⋮			⋮	
220				0.024	0.022	0.000
230				0.020	0.026	0.000
240				0.006	0.023	0.000
250				0.008	0.018	0.000
TOTAL	0.99					

≤ 1.0, therefore pavement is OK

Loss of surface shape

- Using maximum vertical compressive strain in the subgrade, under a standard 80 kN axle

$$N = \left[\frac{9150}{\mu\varepsilon}\right]^7$$

Where:
N = allowable repetitions (ESA)
$\mu\varepsilon$ = vertical compressive microstrain under standard axle

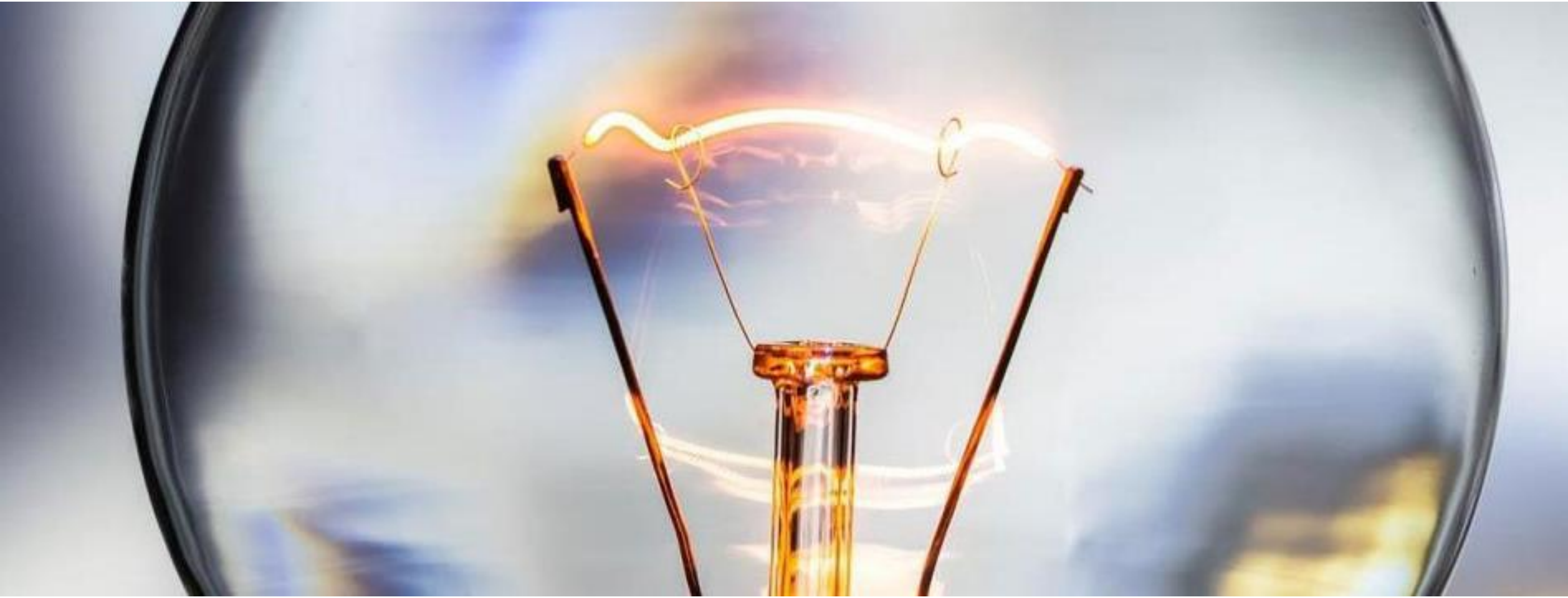
As shown in the draft technical note, N > design ESA, therefore pavement is acceptable

Comparison with existing design procedures

Course	Description	Thickness (mm) – technical note	Thickness (mm) – existing procedures
Surfacing	SMA14	50	
Intermediate	AC14M(A5S)	50	
Base	AC20M(C600)	**240**	**295**
Improved layer	Lightly stabilised unbound granular	150	
Select fill	Design CBR 10%	170	
Existing subgrade	Design CBR 3%	-	

Thickness includes tolerances

QUESTIONS?



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Implementation and stakeholder feedback

Peter Bryant

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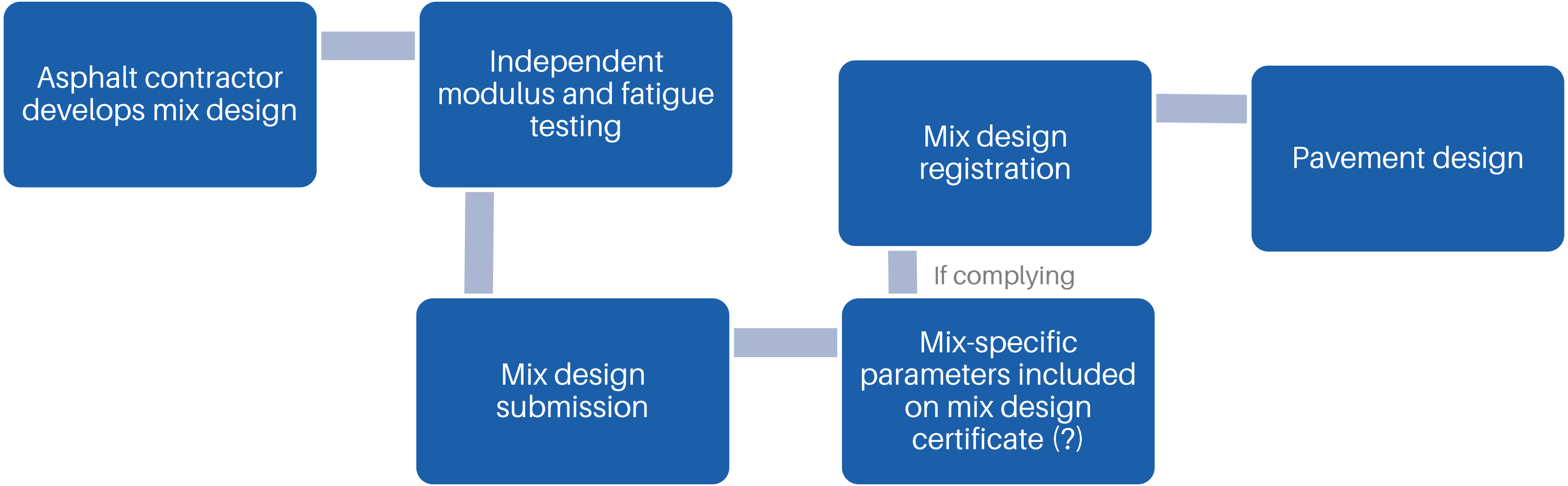
Risk mitigation

Inconsistent mix analysis	• Independent testing • Review and mix registration
Constructed mix substantially different to mix-specific design	• Additional compliance testing linked to mix design – resilient modulus currently proposed

Risk mitigation

Mixes with high modulus but poor fatigue properties	• If using mix-specific modulus, the mix-specific fatigue relationship must also be used
Overestimating field performance	• Maximum reduction in thickness for full depth asphalt pavements • Maximum increase in allowable loading for thin asphalt surfacings

Implementation



Consultation plan

1 September	• Release of draft technical note
5 October	• First round written comments due
October/November	• Consideration of comments and further stakeholder engagement (if needed)
December/January?	• Publication and implementation - tentative

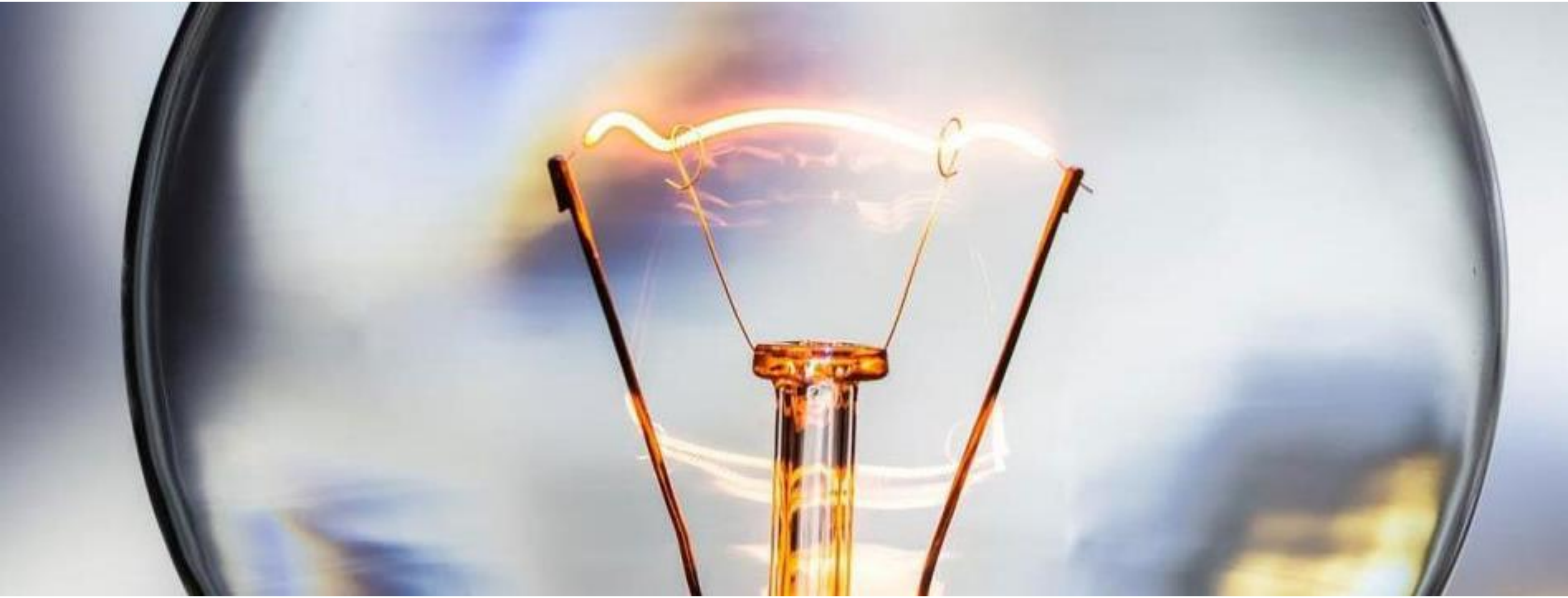
How to provide feedback

- Please provide feedback through your representative:

Stakeholder	Representative
Australian Asphalt Pavement Association	Rob Vos
Consult Australia	Stacey Rawlings
Transport and Main Roads	Pavement Reference Group representative

- Representatives and others send feedback to peter.n.bryant@tmr.qld.gov.au

QUESTIONS?



THANK YOU FOR YOUR PARTICIPATION TODAY

For further information, please contact:

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