Comments on the Australian Structural Pavement Design Procedure for Lightly Bound Cemented Materials

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Designing for Reuse and Resilience

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1. Aim – Why comment?

- We as consultants have an obligation to
  - Have a reasonable understanding of the design procedures/guidelines we use
  - Add to the industry by making suggestions for improvement
- This is by no means a critique of the design procedures
- Lightly Bound cemented(LBC) material is of particular importance since
  - Few structural design procedures available
  - The design differences are obvious and significant
  - Widely used in some areas
  - Insitu stabilisation promoted as sustainable (6,000 tonnes/km of raw material saved) But an ineffective design can off-set all the sustainability benefits.

2. Definitions

- Cemented/cementitiously stabilised
  - Cement, lime, slag, flyash added
  - Prone to cracking due to fatigue and shrinkage
- Modified - UCS (28-day) of <1 MPa (1.5 MPa)
  - Improve performance (reducing plasticity), no significant increase in structural stiffness
  - Characterised as unbound materials and modelled in the same manner
  - Modulus of <500 MPa, layered, anisotropic, 0.35
- Lightly bound - UCS (28-day) of 1 to 2 MPa
  - Exhibit behaviour between modified granular materials and more heavily bound cemented materials
  - Modulus of <600 MPa, nonlayered, anisotropic, 0.35
- Heavily bound - UCS (28-day) of >2 or 3 MPa (4 MPa in glossary), > 3% cement
  - Design based on flexural strength (like concrete)
  - Modulus of >2,000 MPa, nonlayered, isotropic, 0.2

3. Use & design

- Cemented materials
- Lightly bound cemented (LBC) materials

Use & design – Cemented materials

- Higher volume, composite pavements, cemented or LMC as subbase
- Austroads (Australia and NZ), subbase with >175 mm asphalt cover
- British (hydraulically bound, UCS >10 MPa), South Africa (C3, UCS> 1.5 MPa), India (CTB, UCS>4.5 MPa; CTSB, UCS 0.75 to 1.5 MPa), Germany, France,
  US PCA
- Design procedures
  - International: Some version of flexural strength (modulus of rupture)/tensile stress (= stress ratio)
  - Austroads, tensile strain

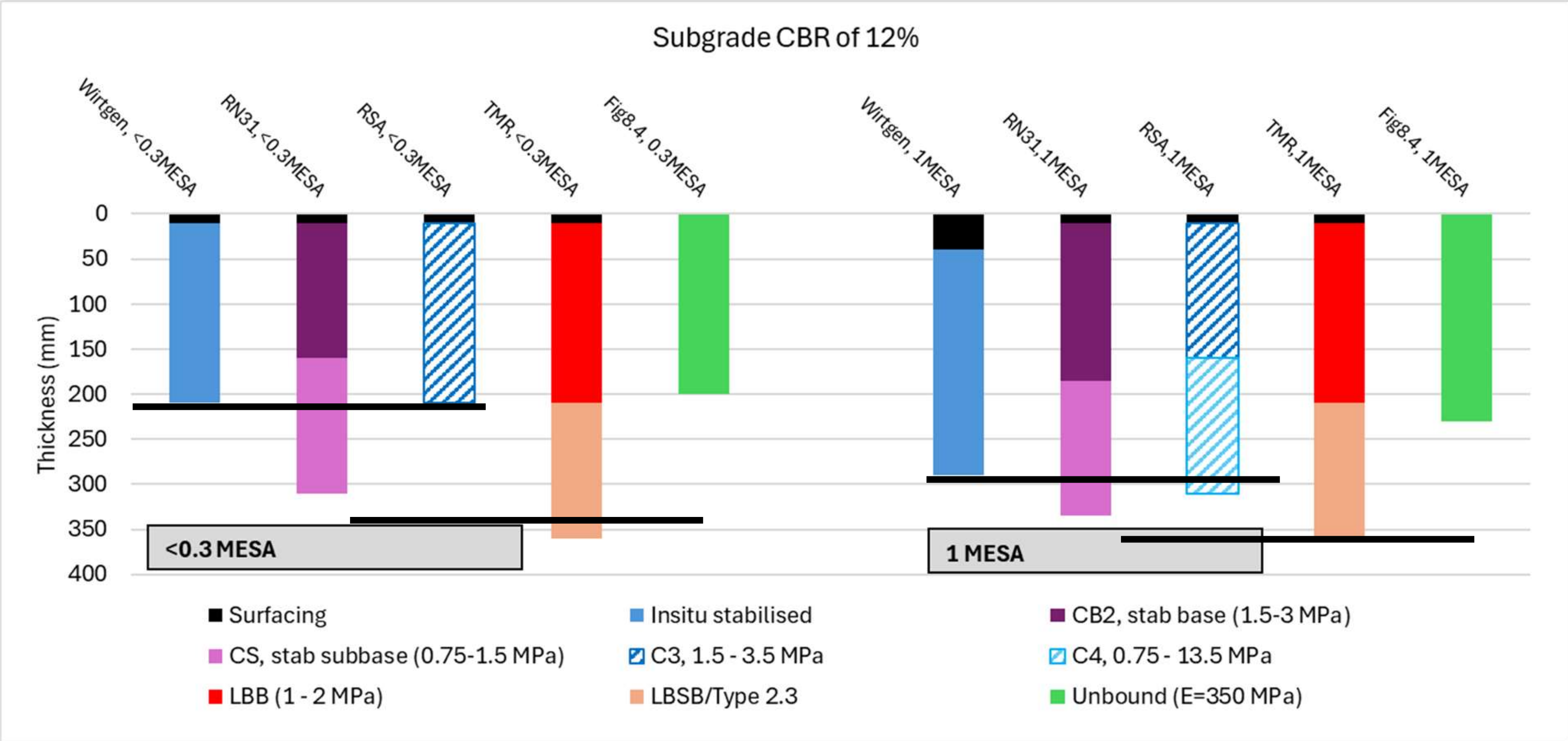
Use & design – Lightly bound materials

- In general, lower volumes
- TMR: Lightly bound base with sprayed seal with subbase (SLBB), up to 1,000 ESAs/day
- South Africa: Cemented base only <03E+05 ESAs and with cemented subbase <1E+07 ESAs (about 1,200 ESAs/day).
- UK ORN 31: On subgrade CBR 10% up to 1.5 MESA but with cemented subbase
- Design procedures
  - AP-R640-20: "*no method to design for the fatigue cracking of LBC layers*"
  - Waka Kotahi (NZTA T19-2020)
  - South African
  - Empirical - ORN31 (UK, Tropical areas), Wirtgen

4. Design procedures

- Road Note 39, Wirtgen – no specific structural design procedure (catalogue)
- AGPT02 and TMR
- Waka Kotahi (NZTA)
- South Africa

Examples – Lightly bound pavement designs



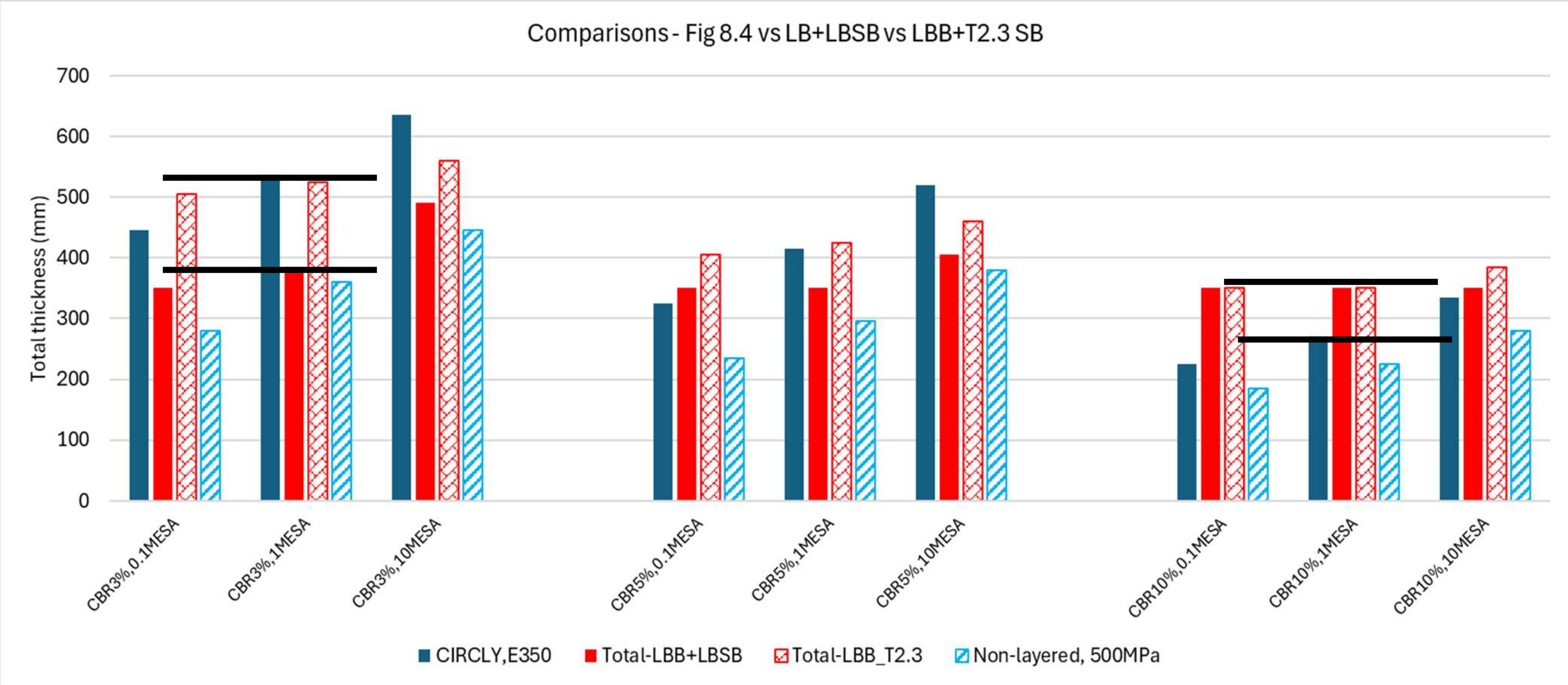
Design procedures – Cemented, AGPT02

- The first phase (= the allowable number of ESA load repetitions to cemented material fatigue)
  - Power value = 12 (8 to 20)
  - Only E>2,000 MPa
- The second phase (=allowable number of ESA load repetitions to unacceptable permanent deformation after cemented material fatigue)
  - Modulus of 500 MPa (or a fifth of the original modulus if smaller)
  - Poisson's ratio of 0.35, anisotropic and no sublayering
  - Not allowed to be used by all agencies

Design procedures – Lightly bound (LBC)

- Austroads/TMR
  - Base: failure = the allowable number of ESA load repetitions to macro-cracking
  - Base: Unlayered, anisotropic, ≤ 600 MPa, min 150 MPa below, min 200 mm.
  - Subbase: Unlayered, anisotropic, 240 to 600 MPa
- Waka Kotahi
  - Max tensile stress <50% of the flexural strength
- South African
  - Phase 1: Effective fatigue (Change of modulus after shrinkage cracking to the effective granular phase) = f(tensile strain, strain at break, material properties, thickness)
  - Phase 2: Granular (All layers in an equivalent granular state).
  - (Advanced) Crushing = f(vertical compressive stress, UCS, material properties)

Examples – A ustroads/TMR/NZ designs



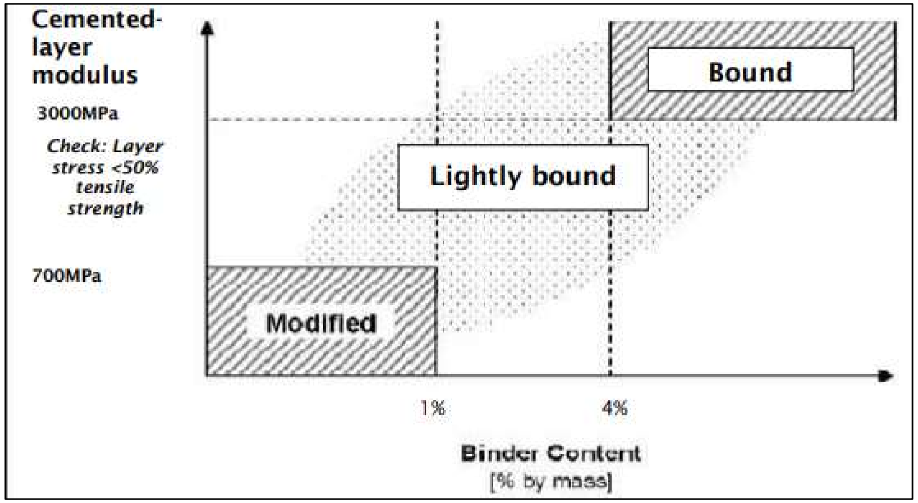
5. Relevant studies

- NZTA
- Austroads

Studies – Waka Kotahi (NZTA)

RR461 (2011), RR498 (2013)

- No clear distinction in behaviour
  - unbound → modified → bound
- Bound: 3 to 4% cement, very little rutting, significant loss in stiffness (to that of 1% cement)
- The CAPTIF test and field study: Austroads tensile strain criterion appeared to produce inappropriate results for New Zealand conditions, and the South African approach appears to produce more appropriate results



Studies – Austroads

R462-13, R463-14, R640-20

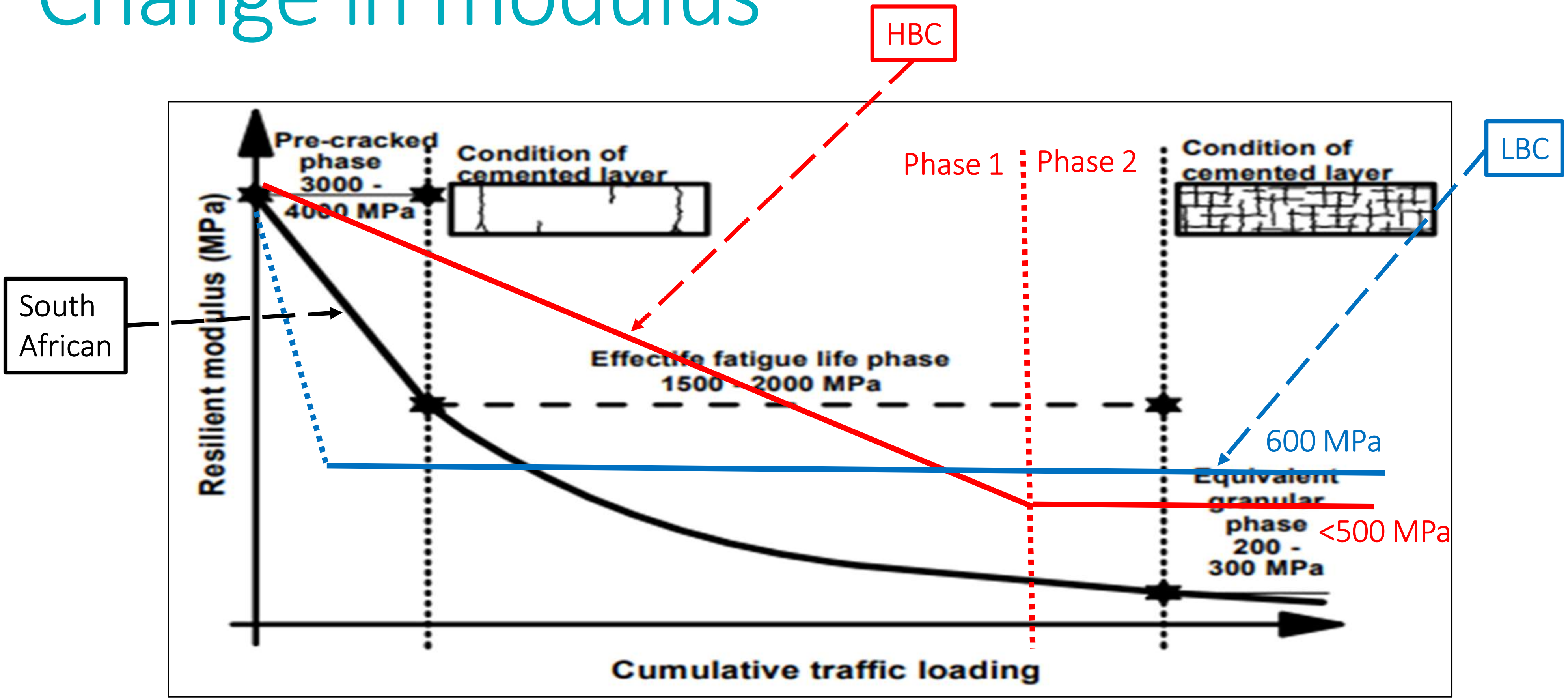
- Austroads (2017) - a method to predict the fatigue life of HBC layers, but none the fatigue cracking of LBC layers.
  - If used, LBC fatigue lives are so low that excessive LBC thicknesses would be required
  - Only consider the Austroads post-cracking phase of LBC life
- Weakly cemented materials are susceptible to crushing
- Low incidence of block/ladder cracking on LBC pavements
- Design procedure
  - From laboratory testing, a procedure was developed to predict the fatigue of LBC materials, this being an extrapolation of the current method for HBC materials
  - To avoid crushing and to maintain load transfer across micro-cracks, limits are placed on the quality granular materials used in LBC materials
  - LBC materials may be used as subbase (no need to inhibit macro-cracking)

6. Discussion

- Behaviour (change in modulus)
- Mode of failure
- Engineering properties
- Fatigue relationships – power of strain (n)

  $$\boldsymbol{N} = \left(\frac{\boldsymbol{constant}}{\boldsymbol{strain}}\right)^{\boldsymbol{n}}$$ *and definition of failure*
- Appropriate design procedure
- Observations

Change in modulus



Mode of failure

Figure 2.2: A fatigued cemented base pavement showing block cracking on a highway pavement in South Australia

46A 53.76 b

Deformation

Figure E.24 Mangatu Road 10.07km – alligator cracks

Type of cracking

- Block/ladder
- Crocodile/crushing

Material Properties – Australia and NZ

Property	Modified	Lightly bound	Cracked (phase 2)	Heavily bound/cemented	Comments
28-day UCS (MPa)	< 1 (1.5)	1 to 2		> 2 (3)	cylinder vs cube
Modulus (MPa)	500 max	Base: 430-600 Subbase: 240-600	500 max (or fifth of original)	>2,000/3,000	
Dry ITS (kPa)	150-350			>500	LBC – 350 to 500?
Poisson's ratio	0.35	0.35	0.35	0.2	HBC = same as concrete, LBC same as modified
Degree of anisotropy	2	2	2	1	LBC and cracked - anisotropic but not sublayered vs modified
Stress sensitivity/layer	Yes	No	No	No	
Failure observed	Deformation	Cracking&deformation (?)	Deformation?	Cracking – block/ladder	Relevance of modelling
Failure modelled	None	Macro cracking	None	Macro cracking	

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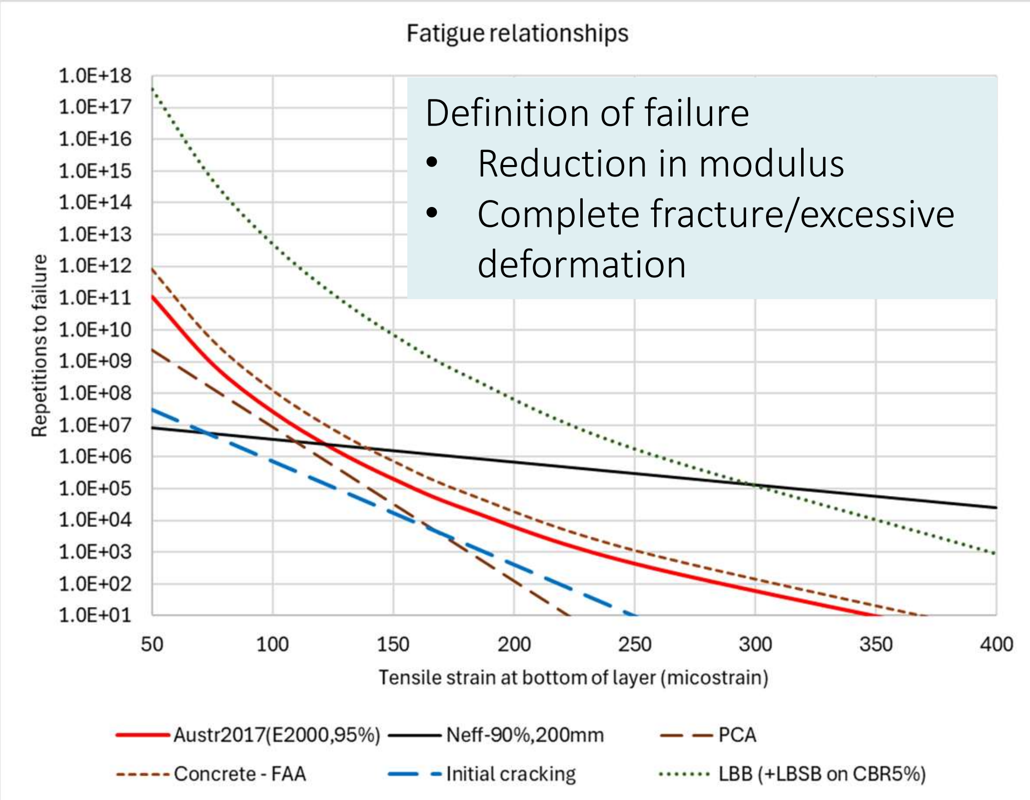
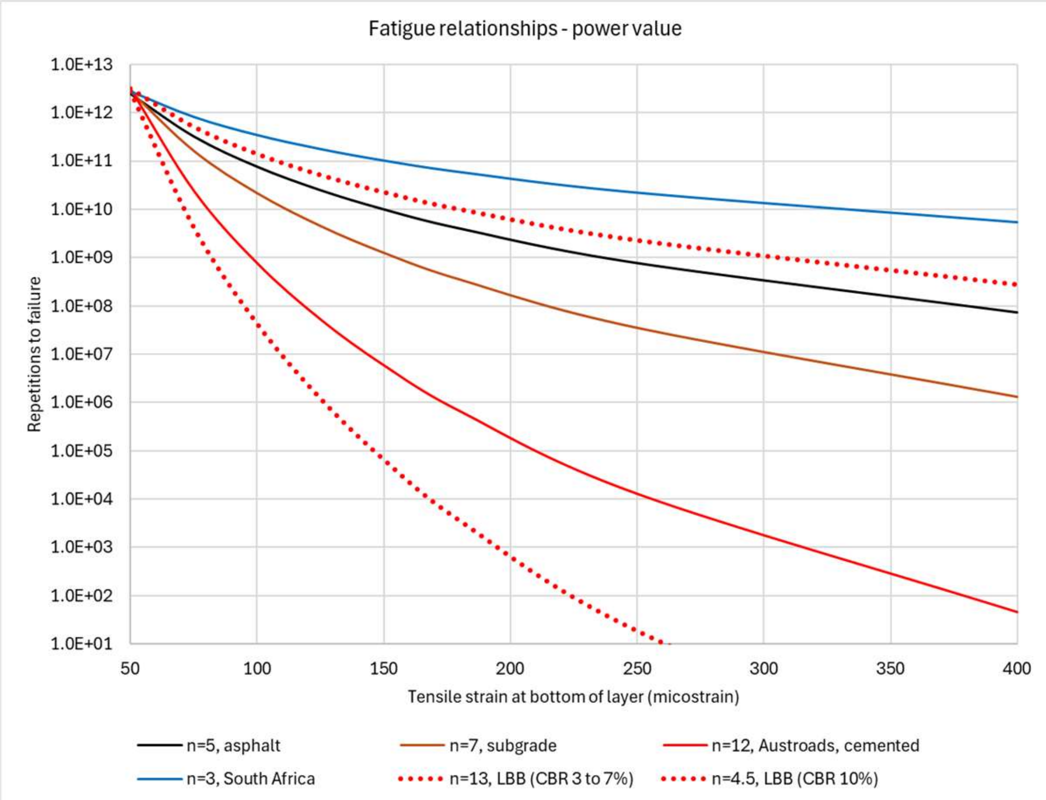
Fatigue relationships





Observations (1)

- Wealth of research information in Australia
  - AP-R462-13 and AP-R463-14 for cemented materials
  - AP-R640-20 for lightly bound materials
- For modified/lightly bound cemented (LBC) materials:
  - The Australian procedure is mainly based on lab testing (limited accelerated testing and some performance-based observations). The lab failure criterion is a percentage (<50%) of the original modulus.
  - The South African procedure is mainly based on the results of accelerated testing (some performance-based observations and very little lab testing). Failure is defined as reaching an equivalent granular state (and deformation).
  - The Waka Kotahi approach is based on deformation and ITS.
- All 3 approaches are valid within the appropriate contexts
- Austroads/NRTO research: Arguably the most recent and comprehensive

Observations (2)

- Modelling Properties
  - Only modified (UCS <1 to 1.5 MPa) is stress-sensitive (layered) but also anisotropic like LBC and cracked
  - Should there be a correlation between stress-sensitivity and degree of isotropy?
- Failure mode
  - Is there a difference between equivalent granular and post-cracked state?
  - Is macro-cracking (from fatigue induced micro-cracking) the appropriate mode of failure for LBC?
  - What about deformation/crushing?
- Fatigue relationships
  - Specifically, the power of strain value for LCM

7. Summary

- There is a high degree of uncertainty about the appropriate structural modelling of the LBC materials
- There are significant differences in design approaches
- All the approaches have merit and based on sound research/observations
- A need to further refine the LBC material design procedures to optimise designs and produce sustainability benefits
- Perhaps, a different approach – not from a concrete/cemented perspective – and input from developers of the other design approaches
- More performance-based observations

Thank you