Long Life Pavements
1. Long life pavements
   - Experience, design systems, use, durability & performance

2. High performance asphalt & binders
   - High modulus asphalt (EME, HiMA), modifiers

3. Sustainability
   - RAP/WMA, bitumen substitutes, carbon calculators & energy analysis
     climate change impacts, societal concerns

4. Health & Safety
   - Construction of road works, health considerations for bitumen
     and asphalt products

5. Procurement Systems
   - Proprietary products (Avis Technique, HAPAS, etc.), “green” procurement,
     REACH, responsible sourcing, PPP and contract models
Overview of reasons

• A revision to the Austroads pavement design guide is required to keep flexible pavements competitive against rigid pavements.

• The proposed revision will take into account the ‘perpetual pavement concept’ underpinned by the asphalt fatigue endurance limit and healing which is widely accepted in the literature (mainly NCAT test track findings).

➢ Need for revision of design to include LLP and FEL concepts

• A number of issues hinder implementation in Australia, e.g.
  o evidence of successful implementation by Road Authorities
  o proven structural and material design procedures
  o appropriate laboratory testing and criteria (moduli and fatigue properties)
  o specification, construction and quality control requirements.

• European performance data will facilitate the validation and calibration of the limiting cumulative distribution of asphalt strain for long life pavements.

➢ What can we learn from them?
Topic 1: Long life pavements

Questions

• Usage and performance records (evidence of successful implementation)
  o Examples and case studies
  o Composition, traffic, deflection history
  o Typical maintenance

• Design aspects (proven structural design procedures)
  o Design procedures
  o Most appropriate approach - mechanistic or catalogue
  o Prioritisation of focus – design models or construction

• Material properties (proven material design procedures)
  o Types of materials typically used
  o Relevant material properties
  o Measurement of material properties
  o Laboratory curing and testing
  o Incorporation of “non standard” materials, e.g. PMB, EME, RAP
Topic 1: Long life pavements

Questions

• **Fatigue & healing** *(appropriate laboratory testing and criteria)*
  - Definition of fatigue/failure
  - Fatigue testing and the determination of endurance limit
  - Correlation between laboratory test results and field performance
  - Effect of binder type on fatigue/endurance
  - Healing of asphalt mixes – testing, effect of traffic loading frequencies

• **Contract and construction** *(specification, construction and quality control requirements)*
  - Initial construction cost – flexible vs. rigid
  - Specification requirements in D&C contract

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Definition

- Long-life (fully flexible) pavements, LLP or Perpetual pavements, PP
- “well designed and well constructed pavement where the structural elements last indefinitely provided that the designed maximum individual load and environmental conditions are not exceeded and that appropriate and timely surface maintenance is carried out”
- No structural cracking, only surface cracks (top-down) - surfacing materials and designs excluded
- Fatigue endurance limit (FEL)

![Likelihood of Pavements Being Long Life Graph]

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Background

- AAPA 2010 study tour to the USA
- European Studies, European long-life pavement group, ELLPAG
- Austroads publications
AAPA 2010 study tour

- The concept of PP or LLP has been accepted in the USA, but not widely implemented.
- The Fatigue Endurance Limit (FEL) is an accepted concept and full scale field trails at NCAT have provided evidence that a FEL exists
  - FEL is not a single value, e.g. the distribution of the strains (percentage below and above) affects the performance
  - Laboratory FEL may not directly translate to the FEL in the field
- Australian flexible pavement design practice should investigate the opportunities
- Use existing laboratory tools in Australia to compare with proven USA materials
- Quantify the performance Australian pavement materials
- Modification of the Australian design procedure (CIRCLY)
European experience – ELLPAG

- 2004 report with summary of situation in member countries and recommendations
- LLP and FEL accepted, but not explicitly used in design
- Recommendations for further research not yet implemented
- The 100msa80 designs - average asphalt layer thickness of 295mm (195mm to 350mm).
European experience – ELLPAG

Designs for a heavy traffic threshold vs Other conventional designs for maximum traffic

- Thickness (mm)
- Surface course, Binder course, Base

Countries compared: UK long-life pavement, US perpetual pavement, Germany, Denmark, Finland, Norway, Poland, Italy, Sweden, Hungary, Australia, Switzerland, Netherlands, Greece, Belgium, France.

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Austroads publications

• The latest Austroads, GUIDE TO PAVEMENT TECHNOLOGY PART 2: PAVEMENT STRUCTURAL DESIGN (2012) “There is increasing recognition of the notion that asphalt mixes have endurance strain limits for asphalt fatigue, such that below a given applied strain repeated cycles of loading no longer result in fatigue damage..... Currently, field performance information is insufficient to incorporate a strain endurance limit.... future research will enable this concept to be incorporated in the mechanistic design process.”

• Austroads AP T199-12, Development of a Nonlinear Finite Element Pavement Response to Load, 2012. Finite element vs. elastic layer calculation of stresses and strains.

• Austroads AP-T131/09, Asphalt Fatigue Endurance Limit, 2009. “sound structural condition and meeting functional requirements despite many having, at the time, already exceeded the design life predicted “
Q1: Usage and performance records

- Examples and case studies
- Composition, traffic, deflection history
- Typical maintenance
Usage and performance records

- Initiated in the UK: study by Nunn (1990s) – no structural defects > 250 mm bound layer
- Very little further specific information
- Concept widely accepted, but implemented differently by the road authorities
  - UK (chart) and Germany (catalogue) – traffic limits, i.e. 80 mesa and 3.2 E+07 ESA
  - France – high modulus layers
  - Netherlands – standard design
- Importance of structured maintenance - replacement of the surfacing layer
Usage and performance records

For $1E+08$ ESAs

- Sweden
- Greece
- UK study
- Portugal
- Austria
- Spain
- Netherlands
- UK
- Belgium
- France
- QLD, 25C, CBR5%
- Germany
- QLD, 32C, CBR5%

Asphalt thickness (mm)
Q2: Design aspects

• To evaluate the design procedures
• To determine the most appropriate approach - either mechanistic or catalogue-based
• Prioritisation of focus – either design models or construction
Design aspects

- No formal mechanistic – empirical designs
- Graphs and catalogues
- Use BISAR for special cases
Long life pavement design (TRL 250)
Dutch approach

- First intervention level: 15% fatigue damage (% of road length)
- Second intervention level: 20% fatigue damage (% of road length)

- Residual "life" is indicated between the first and second intervention levels.
- The graph shows the progression over years or traffic.
- An 85% reliable curve is indicated.
- A 50% reliable curve is also indicated.
Design aspects

European design development preference

- Extrapolation: 3%
- Threshold strength: 14%
- Improved materials/design: 83%
Design aspects

- General acceptance of the concept of a threshold value, but it has not been defined.
- Horizontal tensile strains below the HMA may not be the governing strains - failure of thick layers may not be caused by bending.
- Conversion of laboratory test results to field performance is problematic.
- Use of existing pavement performance to calibrate the models.
- The preference for catalogue design rather than M-E designs for routine LLP designs.
Q3: Material properties

- Types of materials typically used
- Relevant material properties
- Measurement of material properties
- Laboratory curing and testing
- Incorporation of “non-standard” materials, e.g. PMB, EME, RAP
## Material properties

- France – high modulus bases, EME
- UK – EME and conventional
- Germany – conventional and modified
- Netherlands – conventional

<table>
<thead>
<tr>
<th>Type of mix</th>
<th>Grit factor, (Void %)</th>
<th>Water sensitivity, F/R ratio</th>
<th>Rut depth, (60°C-100 mm)</th>
<th>Stiffness modulus (15°C-100 Hz) in MPa</th>
<th>Fatigue – admissible strain (@1 million de cycles)</th>
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<td>GB Class 2</td>
<td>≤ 11</td>
<td>≥ 0.65</td>
<td>≤ 10*</td>
<td>≥ 9,000</td>
<td>≥ 80.10^{-6}</td>
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<td>≥ 9,000</td>
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<td>≤ 10**</td>
<td>≥ 11,000</td>
<td>≥ 100.10^{-5}</td>
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<td>EME Class 1</td>
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<td>≤ 7.5**</td>
<td>≥ 14,000</td>
<td>≥ 100.10^{-5}</td>
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<tr>
<td>EME Class 2</td>
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<td>≥ 0.75</td>
<td>≤ 7.5**</td>
<td>≥ 14,000</td>
<td>≥ 130.10^{-5}</td>
</tr>
</tbody>
</table>
Material Properties

Mix design of EME

- Workability
- Water resistance
- Rutting resistance
- Modulus
- Fatigue resistance

Level 1 + Level 2
General requirement

Level 3 + Level 4
Fundamental Approach
In EN 13108-1

Level 1

Level 2

Level 3

Level 4

>14 000 MPa
15° C 10Hz

>130 μdefs (10° C 25Hz)
Material properties

- The benefits of higher quality (in terms of higher modulus, better deformation resistance, longer fatigue life and/or durability) - recognized.
- Large amount of work is done both in Europe and the UK
- No uniform European/UK design procedure exists for the non-standard materials
- Similar structural properties, e.g. stiffness, fatigue and deformation resistance.
- Laboratory fatigue properties specified in France and in the Netherlands –
  - 90 and 100 µm for conventional asphalt mixes
  - 130 µm for EME2 mixes (for the specified test method and temperatures).
Q4: Fatigue and healing

- Definition of fatigue/failure
- Fatigue testing and the determination of endurance limit
- Correlation between laboratory test results and field performance
- Effect of binder type on fatigue/endurance
- Healing of asphalt mixes – testing, effect of traffic loading frequencies
Fatigue and healing

Substantial corrections needed to match lab result with practice

![Graph showing fatigue and healing](#)

- Field fatigue
- Lab fatigue
- Shift factor (healing, lateral wander, damage propagation, stress redistribution etc. 2.5 - 40)

Factor of 2.5 to 40
Fatigue and healing

- Fatigue resistance is a specimen and test, not a material property.
- No standard test procedure in Europe and the UK
- Substantial adjustments are needed to convert laboratory tests to field performance - a factor of 10 used in the Netherlands (4 * 2.5)

- Loading type
- Sample size
- Temperature
- Loading cycle
- Controlled stress or strain
- Definition of failure – 40 or 50% of stiffness (strain control)
Fatigue and healing

- Effect load application
- Type
  - Strain controlled (>150 mm)
  - Stress controlled (<150 mm)
- Duration/frequency
  - 10 Hz, 0.1 sec/cycle
  - Wheel at 80 km/h, 0.045 sec/cycle
- Shape
  - Sinusoidal
  - Haversine
Fatigue and healing

- Healing entails the recovery in strength (fatigue) and not stiffness
- Healing (strength recovery) of asphalt mixtures is limited
- Long rest periods are beneficial but only at elevated temperatures
- Essentially a flow process
Fatigue and healing

- Difference test devices and protocols are used - difficult to compare results
- Conversion from laboratory tests to field performance is problematic and no standard value or uniform conversion protocol exist
- Fatigue tests have not been used to determine FEL values for use in the structural design.
- Minimum laboratory strain values for HMA bases are specified in France and the Netherlands.
- The healing of asphalts is complex and difficult to measure - temperature, healing time and type of binder
- Indications are that temperature is more important than time and healing only takes place at high temperature.
Q5: Contract and construction

- Initial construction cost – flexible vs. rigid
- Specification requirements in D&C contracts
Contract and construction

• There were limited discussions on contracts and contracting as it pertains to LLPs
• Approach seems to be similar to that in Australia
• The D&C contracts (Netherlands) have a warranty period of 7 to 10 years.
The concept of Long-life pavements (LLPs) is widely accepted in Europe and the UK

- UK and Germany - maximum traffic loading (80 and 32 million ESA)
- The Netherlands – standard design
- France - high modulus layers

A group, ELLPAG was established to investigate LLP in Europe and the UK and produced a report in 2004

- Research identified, but not yet conducted
- Preferred design option - The use of improved materials and/or designs
Summary

• The LLP designs are based on past experience and not on specific structural analyses, laboratory testing and material properties.

• The existence of a fatigue endurance limit (FEL), or threshold value, is recognized, but no specific values have been developed.

• Maintenance
  o Involves the replacement of the surfacing layer only
  o Important for the performance of LLPs and
  o Should be based on a sound selection, asset management and design methodologies.
Summary

• Fatigue testing
  o Results dependent on test device, loading applications, test temperatures and definition of failure
  o Conversion from laboratory tests to field performance is problematic – use the performance of existing pavements to calibrate
  o Horizontal tensile strains below the HMA may not be the governing strains for thick layers

• Healing
  o Accepted as occurring
  o Definition and testing are complex
  o Indications are that temperature is more important than time and healing only takes place at high temperature.
Summary

• Austroads,
  o “increasing recognition of ... endurance strain limits for asphalt fatigue
  o future research will enable this concept to be incorporated in the mechanistic design process.”

• Higher quality materials
  o The benefits of higher quality (in terms of higher modulus, better deformation resistance, longer fatigue life and / or durability) material is recognized.
  o Typical laboratory maximum strain values are
    • 90 and 100 µm for conventional asphalt mixes
    • 130 µm for EME2 mixes
Summary

• The findings were commensurate with those of the 2010 AAPA study tour to the USA, except perhaps that the concept of the FEL not being a single value did not come out as strongly.

• In essence
  o Very informative study tour – people, discussions, ‘real situation’
  o General acceptance that LLP and FEL should be implemented
  o More accurately quantify fatigue testing
  o Conversion to field performance
Summary

Single governing strain

Vs.

Distribution of strains
Recommendations

- Australia would benefit from consideration of endurance strain levels in the design of flexible pavements and should be further investigated.
- Progress in the Europe and the UK should be monitored, with a specific focus on work being done at the TRL and Delft University.
- However, any local development should not rely on a significant amount of information from Europe and the UK.
- The best source of information to calibrate local models would be the performance of existing pavements, especially ones which had been rehabilitated.