HIGH MODULUS ASPHALT: THE FRENCH EXPERIENCE
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International Technical Manager
CONTENT

- Background
- Mix design
- Pavement design: road pavements
- Pavement design: airport pavements
- Manufacturing and placing
- Developments
- Conclusions
BACKGROUND

- 1980
- A COLAS invention
- GBTHP
- Very high performance road base asphalt
- $E^* = 16000 \text{ Mpa (15°C 10 Hz)}$
- $\varepsilon_6 = 160 \times 10^{-6} \text{ µs (10°C 25 Hz)}$
BACKGROUND

- 1988
- Technical advice
- GBTHP
- Very high performance road base asphalt
- \( E^* = 16000 \text{ Mpa (15°C 10 Hz) } \)
- \( \varepsilon_6 = 160 \times 10^{-6} \mu \text{s (10°C 25 Hz) } \)
BACKGROUND

- Oct. 1992
- French Standard
- NF P 98140
- Updated in Nov. 1999
BACKGROUND

- Oct. 1992
- French Standard
- NF P 98140
- Updated in Nov. 1999
- 2 types of EME
- Focus on EME2:
  - \( E^* > 14000 \text{ Mpa} (15^\circ \text{C} 10 \text{ Hz}) \)
  - \( \varepsilon_6 > 130 \times 10^{-6} \text{ } \mu \text{s} (10^\circ \text{C} 25 \text{ Hz}) \)
BACKGROUND

- A few words about the French asphalt mix design method
- 4 levels of performance based tests
  - Water resistance
  - Resistance to permanent deformation
  - Stiffness modulus $E^*$
  - Fatigue resistance $\varepsilon_6$
BACKGROUND

- A few words about the French asphalt mix design method
- 4 Levels of performance based tests:
  - Water resistance
  - Resistance to permanent deformation
  - Stiffness modulus E*
  - Fatigue resistance

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**BACKGROUND**

- A few words about the French asphalt mix design method
- 4 levels of performance based tests:
  - Water resistance
  - Resistance to permanent deformation
  - Stiffness modulus $E^*$
  - Fatigue resistance

<table>
<thead>
<tr>
<th>Level</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Compactability test (gyratory)</td>
</tr>
<tr>
<td></td>
<td>Duriez test</td>
</tr>
<tr>
<td>Level 2</td>
<td>Rutting test</td>
</tr>
<tr>
<td>Level 3</td>
<td>Modulus test</td>
</tr>
<tr>
<td>Level 4</td>
<td>Fatigue test</td>
</tr>
<tr>
<td></td>
<td>Formulation selected</td>
</tr>
</tbody>
</table>

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BACKGROUND

- Water resistance EN 12697-12
- Compressive strength on core after 8 days of immersion
BACKGROUND

- Resistance to permanent deformation: EN 12697-22
- Determination of rut depth
BACKGROUND

- Stiffness modulus $E^*$ EN 12697-26
- Sinusoidal dynamic deflexion $15^\circ C$ 10 Hz
- Direct tension $15^\circ C$ 0.02 s
BACKGROUND

- Fatigue resistance (EN 12697-24)
- Determination of strain level for 1 million cycles $\varepsilon_6$ (10°C 25 Hz)
BACKGROUND

- 1994
- The French Design Manual for Pavement Structures
BACKGROUND

- 1994
- The French Design Manual for Pavement Structures
- English version in 1997
BACKGROUND

- 1997
- An updated Avis Technique
- COLBASE S

- \( E^* = 16000 \text{ Mpa (15°C 10 Hz)} \)
- \( \varepsilon_6 = 145 \times 10^{-6} \mu\text{s (10°C 25 Hz)} \)
BACKGROUND

- 1998
- The French guide for new pavement structure (SETRA/LCPC)
BACKGROUND

- 1998
- The French guide for new pavement structure (SETRA/LCPC)

Road base asphalt: 21 cm

EME: 15 cm

- 29%
BACKGROUND

- 2008
- European Standard EN 13108-1
- EME2

- AC Ø base binder
  - $S_{min} = 14000$, $\varepsilon_{6-130} = 3\%$ and $V_s = 6\%$
**Mix design**

- An appropriate combination of
  - Aggregates
  - Bitumen

- An appropriate gradation
  - The standard does not provide with any specification
  - The main aim is to reach a dense mix: void content between 3 & 6% when tested with the gyratory compactor (80 to 120 revolutions depending on the maximum aggregate size)

- An appropriate bitumen
  - A « hard » bitumen
  - A high bitumen content
Mix design

- The characteristics of the bitumen will provide the mix with its modulus (and rutting resistance)
- The bitumen content will provide the mix with its fatigue properties (and water resistance)
MIX DESIGN

- Basically, the stiffness $E^*$ of the mix will depend on the stiffness $G^*$ of the binder
- A 10/20 might be suitable (e.g. Netherlands)
- A 10/20 might not be suitable (e.g. Czech Republic)
- A 20/30 might be suitable (e.g. South Africa)
Mix Design

- Basically, the stiffness modulus of the mix will depend on the stiffness of the binder
- A 10/20 might be suitable (e.g. Netherland)
  - Pen 19 G* 82 MPa
- A 10/20 might not be suitable (e.g. Cesch Rep.)
  - Pen 18 G* 35 MPa
- A 20/30 might be suitable (e.g. South Africa)
  - Pen 28 G* 80 MPa
- Bitumen used for EME:
  - Straight run bitumen (e.g. Netherland)
  - Propane bitumen (e.g. South Africa)
  - Blown bitumen (available in Australia)
Mix Design

- Basically, the stiffness modulus of the mix will depend on the stiffness of the binder
- A 10/20 might be suitable (e.g. Netherland)
- A 10/20 might not be suitable (e.g. Cesch Rep.)
- A 20/30 might be suitable (e.g. South Africa)
- A (SBS) modified bitumen will provide the mix with improved fatigue resistance
MIX DESIGN

A summary of this history

<table>
<thead>
<tr>
<th></th>
<th>GB2</th>
<th>GB3</th>
<th>GB4</th>
<th>EME1</th>
<th>EME2</th>
</tr>
</thead>
<tbody>
<tr>
<td>E* (Mpa)</td>
<td>9000</td>
<td>9000</td>
<td>11000</td>
<td>11000</td>
<td>14000</td>
</tr>
<tr>
<td>ε6 (µs)</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>130</td>
</tr>
</tbody>
</table>

- Binder pen ↓
- Binder content ↑
- Pavement thickness ↓

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PAVEMENT DESIGN: ROAD PAVEMENTS

- How to make the best use of the characteristics measured in the laboratory taking into account the actual service conditions?
PAVEMENT DESIGN: ROAD PAVEMENTS

- How to make the best use of the characteristics measured in the laboratory taking into account the actual service conditions?
- 1st step
PAVEMENT DESIGN: ROAD PAVEMENTS

- How to make the best use of the characteristics measured in the laboratory taking into account the actual service conditions?

- 2nd step

\[ \varepsilon_{t,\text{ad}} = \varepsilon (NE, \theta_{eq}, f) k_r k_c k_s \]
PAVEMENT DESIGN: ROAD PAVEMENTS

- How to make the best use of the characteristics measured in the laboratory taking into account the actual service conditions?
- 2nd step

\[ \varepsilon_t < \varepsilon_{t,ad} \]
\[ \varepsilon_z < \varepsilon_{z,ad} \]
PAVEMENT DESIGN: ROAD PAVEMENTS

- $k_r$: related to the calculated risk chosen
- $k_c$: adjustment between calculation results and actual behaviour
- $k_s$: potential unconsistency of the subgrade

$k_c$ is a coefficient which adjusts the results of the computation model in line with the behaviour observed on actual pavements of the same type. For bituminous pavements, the values chosen for the coefficient of adjustment according to the nature of the bituminous material are specified in Table VI.4.2.

<table>
<thead>
<tr>
<th>Material</th>
<th>$k_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>road base asphalt concrete, GB</td>
<td>1.3</td>
</tr>
<tr>
<td>bituminous concrete, BB</td>
<td>1.1</td>
</tr>
<tr>
<td>high modulus asphalt concrete, EME</td>
<td>1</td>
</tr>
</tbody>
</table>

$$
\varepsilon_{\text{t,ad}} = \varepsilon (\text{NE, } \theta_{\text{eq}}, t) k_r k_c k_s
$$
### Tableau F.6 — Caractéristiques mécaniques minimales et maximales de EB-GB à retenir pour le dimensionnement dans le cadre de l’approche fondamentale

<table>
<thead>
<tr>
<th>Classe</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeurs minimales</td>
<td>Module à 15 °C – 10 Hz ou 0,02 s (MPa)</td>
<td>9 000</td>
<td>9 000</td>
</tr>
<tr>
<td>$q_s$ (µd déf)</td>
<td>80</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Valeurs maximales</td>
<td>Module à 15 °C – 10 Hz ou 0,02 s (MPa)</td>
<td>11 000</td>
<td>11 000</td>
</tr>
<tr>
<td>$q_s$ (µd déf)</td>
<td>90</td>
<td>100</td>
<td>115</td>
</tr>
<tr>
<td>Valeurs à appliquer fortuitement</td>
<td>$-1/b$</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>$S_N$</td>
<td>0,3</td>
<td>0,3</td>
<td>0,3</td>
</tr>
<tr>
<td>$k_C$</td>
<td>1,3</td>
<td>1,3</td>
<td>1,3</td>
</tr>
</tbody>
</table>

### Tableau F.7 — Caractéristiques mécaniques minimales et maximales de EB-EME à retenir pour le dimensionnement dans le cadre de l’approche fondamentale

<table>
<thead>
<tr>
<th>Classe</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeurs minimales et valeurs conventionnelles</td>
<td>Module à 15 °C – 10 Hz ou 0,02 s (MPa)</td>
<td>14 000</td>
</tr>
<tr>
<td>$q_s$ (µd déf)</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>Valeurs maximales</td>
<td>Module à 15 °C – 10 Hz ou 0,02 s (MPa)</td>
<td>17 000</td>
</tr>
<tr>
<td>$q_s$ (µd déf)</td>
<td>115</td>
<td>145</td>
</tr>
<tr>
<td>Valeurs à appliquer fortuitement</td>
<td>$-1/b$</td>
<td>5</td>
</tr>
<tr>
<td>$S_N$</td>
<td>0,3</td>
<td>0,25</td>
</tr>
<tr>
<td>$k_C$</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
PAVEMENT DESIGN: ROAD PAVEMENTS

- PF3: 120 Mpa
- TC6: 6.5 to 17.5 ESAL
- t°: 15°C

Road base asphalt: 21 cm
EME: 15 cm

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- 29%
Under such « hypothesis », the design criteria would be the vertical deformation of the subgrade.
**Pavement Design: Road Pavements**

- **PF3**: 120 Mpa
- **TC6**: 6.5 to 17.5 ESAL
- **t°**: 15°C

<table>
<thead>
<tr>
<th></th>
<th>GB3</th>
<th>EME2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kc</strong></td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>15°C</strong></td>
<td>21 cm</td>
<td>15 cm</td>
</tr>
<tr>
<td><strong>18°C (Sydney)</strong></td>
<td>22 cm</td>
<td>16 cm</td>
</tr>
<tr>
<td><strong>30°C (Bangkok)</strong></td>
<td>26 cm</td>
<td>18 cm</td>
</tr>
</tbody>
</table>

**Equation:**

\[
D_{eq} = \left[ \frac{\varepsilon_{eq}}{\varepsilon_{6(\theta_{eq})}} \right]^{1/b} \times 10^{-6} \sum_{i} n_{i} = \sum_{i} n_{i} \left[ \frac{\varepsilon_{i}}{\varepsilon_{6(\theta_{i})}} \right]^{1/b} \times 10^{-6}
\]
PAVEMENT DESIGN: ROAD PAVEMENTS

- In France, EME is a commonly used technique
- A technique that is used for both new construction and strengthening works
- The main difficulty is to source appropriate bitumen at an acceptable cost
- A major site: the « tamarin road » in the Réunion Island (Indian Ocean)
PAVEMENT DESIGN: ROAD PAVEMENTS

- A masterpiece: the « tamarin road » in the Réunion Island (Indian Ocean)
  - 200,000 T of EME
  - Basaltic local aggregates (high specific gravity)
  - Impact of the porosity: part of the bitumen is not « active »
  - B 20/30 from Engen (South Africa)
  - Impact of the binder content
    - 5.8%: 128 µs
    - 6.2%: 132 µs
PAVEMENT DESIGN: AIRPORTS

- In France, airport pavement design has been based on the use of structural numbers.
- Structural numbers:
  - Bituminous concrete: 2.0
  - Road base asphalt (GB): 1.5
  - Crushed graded material: 1.0 (reference)
- Structural numbers for « new » materials:
  - EME: 1.9
  - BBME: 2.5
PAVEMENT DESIGN: AIRPORTS

- Road base asphalt (GB) 1.5
- EME 1.9

<table>
<thead>
<tr>
<th>GB</th>
<th>Crushed graded material</th>
<th>EME</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 cm</td>
<td>x 1.5</td>
<td>= 15 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>: 1.9</td>
</tr>
</tbody>
</table>
PAVEMENT DESIGN: AIRPORTS

- Use on CDG (Paris) airport in 2002: runway 2
PAVEMENT DESIGN: AIRPORTS

- An existing concrete pavement
- Pavement design:
  - Linking concrete slabs
  - 2 cm SAMI: PMB sand asphalt
  - 7 cm EME (B20/30)
  - 6 cm BBME (PMB) high modulus asphalt concrete
MANUFACTURING AND PLACING

- Nothing very specific compared to conventional asphalt mixes
- Manufacturing temperature: 160 to 190°C
- Placing and compaction:
  - High bitumen content may lead to fating up
  - Specific care to the joints
  - The use of RAP eases compaction
  - Aim a low void content (spec: < 6%)
MANUFACTURING AND PLACING

- First warm EME has been used in Dec. 2007 (city of Meaux)
- Morning temperature: -1°C
- Manufacturing temperature: 140°C
MANUFACTURING AND PLACING

- A (warm) thin overlay was placed on the EME base course
DEVELOPMENTS (OUTSIDE FRANCE)

- Preliminary remark:
- Pavement design methods vary (empirical, rationnal, combination)
- Testing methods vary
- Local conditions vary
  - Temperature, axle load, traffic
DEVELOPMENTS (OUTSIDE FRANCE)

- Example: modulus assessment

- Sinusoidal dynamic deflection
  - Appendix A
    - 15°C 10 Hz
    - 2 PB-TR

- Impulsion
  - Appendix B
    - 20°C 8Hz
    - 3-4 PB-PR

- Direct Tension
  - Appendix C
    - 20°C 124ms
    - IT-CY

- Appendix D
  - 15°C 0.02s
  - DTC-CY

Correlation between value
DEVELOPMENTS (OUTSIDE FRANCE)

- Local assessment needs to be made:
  - Testing methods
  - Performances

- Example in South Africa: testing methods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>French test method</th>
<th>Selected South African equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>EN 12697 - 31: Gyratory compactor</td>
<td>ASTM D6926: SUPERPAVE gyratory compactor</td>
</tr>
<tr>
<td>Durability</td>
<td>EN 12697 - 12: Duriez test</td>
<td>ASTM D4867: Modified Lottmann test</td>
</tr>
<tr>
<td>Permanent deformation</td>
<td>EN 12697 - 22: Wheel tracker</td>
<td>AASHTO 320-03 SUPERPAVE shear test</td>
</tr>
<tr>
<td>Dynamic modulus</td>
<td>EN 12697 - 26: Flexural beam</td>
<td>AASHTO TP 62 dynamic modulus</td>
</tr>
</tbody>
</table>
DEVELOPMENTS (OUTSIDE FRANCE)

- Local assessment needs to be made:
  - Testing methods
  - Performances
- Example in South Africa: performances

Table 2: Tentative performance criteria for HiMA bases

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Method</th>
<th>Performance requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Class 1</td>
</tr>
<tr>
<td>Workability</td>
<td>Gyratory compactor, air voids after 45 gyrations</td>
<td>ASTM D6926</td>
<td>≤ 10%</td>
</tr>
<tr>
<td>Moisture sensitivity</td>
<td>Modified Lottman</td>
<td>ASTM D4867</td>
<td>Refer to existing HMA value</td>
</tr>
<tr>
<td>Permanent deformation</td>
<td>RSST-CH, 55C, 5á000 repetitions</td>
<td>AASHTO T 320</td>
<td>≤ 1,1% strain</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>Dynamic modulus test at 10Hz, 15°C</td>
<td>AASHTO TP 62</td>
<td>&gt; 14 GPA</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Beam fatigue test at 10 Hz, 10C, to 70% stiffness reduction</td>
<td>AASHTO T 321</td>
<td>&lt; 310 for 10 E6 repetitions</td>
</tr>
</tbody>
</table>
DEVELOPMENTS (OUTSIDE FRANCE)

- Local assessment needs to be made:
  - Pavement design
- Example in the United Kingdom
Pavement Design
DEVELOPMENTS (OUTSIDE FRANCE)

Same Traffic and subgrade

DBM50 : 320 mm
EME 2 : 260 mm

- 60 mm
DEVELOPMENTS (OUTSIDE FRANCE)

- Poland
- Morocco
  - First worksite in 2000
  - Often used on highways
  - Mix design includes RAP 25%
- Mauritius
DEVELOPMENTS (OUTSIDE FRANCE)

- Mauritius

Several road projects since 2010

Triolet bypass

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DEVELOPMENTS (OUTSIDE FRANCE)

- Mauritius
  - SSR international airport
DEVELOPMENTS (OUTSIDE FRANCE)

- Mauritius
  - SSR international airport
- Runway overlay and parallel taxiway works
  - Owner: Airports of Mauritius
  - Engineer: Jacobs (UUK) and Gibb (Mauritius)
- Design system: FAARFIELD
- Alternatives main goal: to save materials
- Basic design (new taxiway)
DEVELOPMENTS (OUTSIDE FRANCE)

- Basic design (new taxiway)
- Alternative design
  - 105 mm thickness saving
CONCLUSIONS

- EME is a fully reliable technique that has been used for more than 20 years.
- Developments outside France have confirmed its efficiency.
- The selection of the right binder is a crucial issue.
- Development should include a careful study of its mechanical characteristics, to be used in the pavement design model.

All of you are more than welcome to visit our main lab facilities and worksites in progress.