High Modulus Asphalt (EME2) Pavement Design in Queensland

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ABSTRACT

Enrobés à module élevé (EME), which means high modulus asphalt, was developed in France over 30 years ago, and has been used internationally for a wide range of heavy duty applications. It is primarily intended to reduce the thickness of full depth asphalt pavements whilst still providing sound pavement performance through a combination of high modulus, and superior fatigue, deformation and moisture resistance.

EME2, which is the highest class of EME in the French standards, is being introduced into Queensland through a collaborative effort involving Transport and Main Roads (TMR), ARRB Group, the Australian Asphalt Pavement Association (AAPA) and its members, and Brisbane City Council (BCC). In addition, the implementation into Queensland leverages off related projects by Austroads and other Australian road agencies.

An extensive research program was carried out under the TMR-ARRB National Asset Centre of Excellence (NACoE) project P9 for the development of structural design procedures for pavements containing EME2. This included the positioning and function of EME2 layers in typical Queensland pavement designs, procedures to characterise the modulus of EME2 at different temperatures and loading conditions, and the development and validation of transfer functions for pavement structures containing EME2. While the French design system for flexible pavements directly applies inputs from performance-based mix design, immediate implementation of such a system in Queensland was inhibited as the existing Austroads pavement design methodology does not make such links. The research project investigated the technical solutions to overcome these issues; this paper summarises the technical basis of the implementation process.

Based on the background information collected in the research project, Technical Note 142 was drafted and published, which is intended to facilitate the timely implementation of EME2 on TMR projects. This paper also provides practical guidance on the design of pavements incorporating EME2.

Keywords: EME2, high modulus asphalt, mechanistic pavement design, performance-based asphalt mix design

1. INTRODUCTION

Using current material characterisation and design procedures, full depth asphalt pavements in Queensland typically comprise around 400 mm of asphalt for the most heavily trafficked roads. While such pavements require minimal maintenance during the life of the pavement, there is a significant initial capital cost incurred which is unfavourable in a budget-constrained environment.

Current Austroads pavement design procedures indirectly require asphalt pavements in Queensland to be thicker than those in other Australian states owing to the prevailing environmental and traffic conditions. This is mainly due to assumptions associated with asphalt properties (i.e. stiffness and fatigue) and durability effects in certain traffic and environmental climates. As a result, asphalt pavements in Queensland are thicker, and therefore more expensive, than pavements designed for the same traffic conditions in other Australian states.

The introduction of enrobés à module élevé (EME), or high modulus asphalt, into Queensland is one of the technologies being actively considered to reduce the initial cost of infrastructure.
High modulus asphalt is primarily intended to reduce the thickness and cost of full depth asphalt pavements whilst still providing sound pavement performance through a combination of high modulus, and superior fatigue, deformation and moisture resistance.

An extensive research program was carried out under the TMR-ARRB National Asset Centre of Excellence (NACoE) project P9 for the development of structural design procedures for pavements containing EME2. This included the positioning and function of EME2 layers in typical Queensland pavement designs, procedures to characterise the modulus of EME2 at different temperatures and loading conditions, and the development and validation of transfer functions for pavement structures containing EME2. While the French design system for flexible pavements directly applies inputs from performance-based mix design, immediate implementation of such a system in Queensland was inhibited as the existing Austroads pavement design methodology does not make such links. The research project investigated the technical solutions to overcome these issues; this paper summarises the technical basis of the implementation process, and recommends an interim pavement design procedure to facilitate the implementation of the technology into Queensland.

2. RELATED RESEARCH

The EME2 technology transfer is a complex issue and implementation of the complete system is covered by various research projects. The French technology is being introduced into Queensland through a collaborative effort involving Transport and Main Roads (TMR), ARRB Group, the Australian Asphalt Pavement Association (AAPA) and its members, and Brisbane City Council (BCC). In addition, the implementation into Queensland leverages off related projects by Austroads and other Australian road agencies.

While this paper primarily focuses on pavement design, other related projects include:

- TMR-ARRB NACoE project – Characterisation of asphalt fatigue at Queensland pavement temperatures
- Austroads project – Improved design methods for asphalt pavements
- Austroads project – High modulus high fatigue asphalt (EME) technology transfer.

The objectives of the Austroads research can be summarised as follows:

- investigate the mix design methodology of EME2 asphalt mix, based on available international literature
- investigate requirements and local availability of aggregate type, aggregate grading, and hard penetration grade binder
- provide input for implementation of the EME2 technology in Australia
- provide a comprehensive characterisation of EME2 mix using Australian test methods, including workability, moisture sensitivity, rutting resistance, stiffness and fatigue resistance
- develop tentative specification framework for road agencies for designing EME2 mixes.

The above Austroads projects therefore provide a comprehensive input into the mix design part of the EME2 implementation.

3. MIX DESIGN

A brief description of the EME2 mix design procedures is provided in this section. While mix design is not the primary focus of this paper, a general understanding and appreciation it is important due to the linkages between mix design and pavement design in the French system.

A nationally consistent approach to mix design, including interim specification limits, has been developed [1]. This methodology is based on the French approach [2,3], which has been adapted to accommodate Australian test methods. The mix design methodology for EME2 is performed based, and comprises the following main steps:
1. Particle size (100% by mass passing the 19.0 mm sieve for a 14 mm nominal size mix)
2. Richness modulus (conceptually similar to binder film thickness, and results in a minimum binder content)
3. Workability using gyratory compaction (maximum air void content after the specified number of gyrations)
4. Moisture resistance (stripping potential)
5. Permanent deformation resistance (wheel tracking)
6. Flexural modulus (4-point bending, although the indirect tensile modulus is also tested as a design aid)
7. Fatigue resistance (4-point bending).

Further details on the test methods and interim specification limits are included in the Queensland EME2 pilot technical specification PSTS107 [4] and the related Austroads report [1].

In addition to the mix design testing, EME2 requires the use of a binder that meets minimum and maximum limits for penetration and softening point, and minimum viscosity requirements. Two different classes of binder can be used in France. These are 15/25 and 10/20 penetration grade binders. The asphalt and bitumen industry in Australia currently supports the use of 15/25 grade binder, and this grade has been adopted in Queensland.

Stiffness and fatigue properties are input values into the mechanistic pavement design. In the French system, mix-specific stiffness and fatigue characteristics are used for pavement design. It is important to highlight that in the current Austroads pavement design procedure the fatigue properties obtained from the mix design cannot be directly translated into transfer functions for the determination of pavement thickness. Instead, a single transfer function is typically used which was developed for mixes which are significantly different to EME mixes [5]. The utilisation of this function introduces a disconnection between mix performance in the laboratory and the field. This was one of the considerations for this project, and is discussed further in Section 5.

4. PAVEMENT DESIGN

4.1 French pavement design

4.1.1 Overview

In the French context, the design of pavement structures should be conducted according to the French Technical Guide [6] which has recently been updated and published in the French standard NF P 98-086 [7]. Both documents provide the background and general principles of the mechanistic pavement design. They cover the different aspects affecting pavement performance and the design; these are the traffic loading, environment, climatic conditions, underlying bearing capacity, pavement materials and the work quality considerations.

However, for typical pavement design configuration the mechanistic pavement design approach has been used to develop a catalogue of pavement structures [8] which provides an alternative comprehensive and straightforward thickness design option for relatively standard situations. It provides the same outcomes as the mechanistic pavement design; however, it saves the multi-step process.

The design is carried out by comparison of the following:

- the mechanical magnitudes (strains, deformations) representative of the behaviour of the structure of pavements under a reference axle, and calculated using a linear elastic model
- the allowable values of these same magnitudes, a function of the mechanical resistance of the materials bearing repeated loads with which various adjustment ratios are associated, taking into account, in particular, the probabilistic nature of the pavement design process and the discontinuities of the rigid pavements.
The stresses calculated in the pavement must therefore be lower than or equal to the allowable stresses; the minimum thickness of the layers is determined by successive repetitions of calculations in order to adhere to this criterion. The structure resulting from the mechanical calculation is then subjected to a frost/thaw check; this is not considered in the Australian context. Also, the thicknesses of the layers are adjusted to incorporate the technological constraints of the layer thickness.

The pavement structures are evaluated using the following calculations:

- fatigue failure of the base of bituminous layers: strain $\varepsilon_t$ at the base of the bituminous layers must remain lower than the allowable value $\varepsilon_{t,\text{allow}}$ calculated according to Eq. 1
- the permanent deformation of the unbound layer (subgrade or improved subgrade, referred to as the foundation): the reversible vertical deformation $\varepsilon_z$ on the surface of the unbound layers must remain lower than the limit value $\varepsilon_{z,\text{allow}}$.

Only asphalt fatigue is discussed further in this paper.

4.1.2 Pavement design and allowable strain
In the French general mechanistic pavement design method, the allowable asphalt strain (as a function of the mix type) and the calculated strain (as a function of the pavement model) are compared.

The allowable strain in the asphalt base layer $\varepsilon_{t,\text{allow}}$ is calculated according to Eq.1.

$$\varepsilon_{t,\text{allow}} = \varepsilon_6(10^\circ\text{C}; 25\text{Hz}) \times \frac{E(10^\circ\text{C}; 10\text{Hz})}{E(\theta_{eq}; 10\text{Hz})} \times \left(\frac{NE}{10^6}\right)^b \times k_c \times k_r \times k_s$$

where

$\varepsilon_6(10^\circ\text{C}; 25\text{Hz})$ = the fatigue resistance of the asphalt mix, determined at $10^6$ loading cycles; in France the test is carried out according to EN 12697-24, Annex A [9] at $10^\circ\text{C}$ and 25 Hz

$b$ = is the slope of the fatigue line (-1 $< b < 0$)

$E(10^\circ\text{C}; 10\text{Hz})$ = stiffness of the asphalt material at $10^\circ\text{C}$ and 10 Hz, tested according to EN 12697-26, Annex A [10]

$E(\theta_{eq}; 10\text{Hz})$ = stiffness of the asphalt material at the equivalent temperature $\theta_{eq}$ and 10 Hz, tested according to EN 12697-26, Annex A [10]

$NE$ = traffic loading in equivalent standard axles

$k_c$, $k_r$, $k_s$ = coefficients as discussed below.

The value $k_c$ is a coefficient which adjusts the results of the model in line with the behaviour observed on actual pavements. The value of $k_c$ depends on the asphalt type, and a value of 1.0 is used for EME.

The value $k_r$ is a coefficient which adjusts the allowable strain according to the calculated risk of failure. The value of $k_r$ depends on the standard deviation (e.g. scatter) of the thickness and the fatigue performance from laboratory testing.

The value $k_s$ is a reduction coefficient to take into account the effect of a lack of uniformity in the bearing capacity of a soft soil layer (the foundation in French terms) underneath the treated or modified layers. The value of $k_s$ depends on the bearing capacity (surface modulus) of the formation level. A value of 1.0 is used for foundations under EME pavements which are typically designed with a foundation modulus of at least 120 MPa [8].
4.1.3 Material characterisation in the design procedure

High modulus mixes (EME) are characterised according to the fundamental approach. In the foreword to French standard NF EN 13108-1 [3] concerning mixes, the minimum values for modulus E and for fatigue $\varepsilon_6$ are established by the class of the material, which is reproduced in Table 1. These values are used to carry out a pre-pavement design before obtaining the results of tests carried out in a laboratory on the material in question.

Characteristics greater than these minimum values for modulus E and for fatigue $\varepsilon_6$ may be taken into account in the pavement design, provided that these characteristics were in fact obtained during the mix design on materials developed with the actual worksite components and within the required air voids contents. These characteristics must not, however, exceed the maximum values for the class in question (Table 1).

**TABLE 1 Minimum and maximum mechanical characteristics for EME to be retained for the pavement design within the context of the fundamental approach**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Class</th>
<th>EME1</th>
<th>EME2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum values and conventional values</td>
<td>Modulus at 15 °C – 10 Hz or 0.02 s (MPa)</td>
<td>14 000</td>
<td>14 000</td>
</tr>
<tr>
<td></td>
<td>$\varepsilon_6$ (microstrain)</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>Maximum values</td>
<td>Modulus at 15 °C – 10 Hz or 0.02 s (MPa)</td>
<td>17 000</td>
<td>17 000</td>
</tr>
<tr>
<td></td>
<td>$\varepsilon_6$ (microstrain)</td>
<td>115</td>
<td>145</td>
</tr>
<tr>
<td>Values to be applied inclusively</td>
<td>$S_N$ (residual standard deviation from laboratory fatigue test)</td>
<td>0.3</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>$k_c$</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: NF P 96-086 [7].

EME2 is the class of EME being implemented in Queensland and Australia.

In the French method, both the modulus and fatigue properties are adjusted to suit the temperature environment for the project being designed. The method can be used over a fairly broad range of positive temperatures, based on the calculation that the approximate value for the dependency of the modulus E and the strain $\varepsilon_6$ can be obtained from Eq. 2 [6].

$$\varepsilon_6(\theta) \times E(\theta)^n = \text{constant} \tag{2}$$

where

$$\varepsilon_6(\theta) = \text{fatigue resistance of the asphalt mix, determined at } 10^6 \text{ loading cycles at the equivalent temperature } \theta$$

$$E(\theta) = \text{stiffness of the asphalt material at the equivalent temperature } \theta$$

$$n = \text{material constant.}$$

In the absence of results of fatigue tests for a given material at different temperatures, a mean value of 0.5 can be selected for $n$ and the equation can be re-organised as in Eq. 3.

$$\varepsilon_6(\theta_i) = \varepsilon_6(10^\circ C; 25Hz) \times \frac{E(10^\circ C; 10Hz)}{E(\theta_i; 10Hz)} \tag{3}$$
Eq. 3 provides a good model and estimation of the fatigue properties at different temperatures. By using Eq. 3, the fatigue properties at any given equivalent temperatures could be readily calculated, given that the standardised fatigue test at 10 °C, 25 Hz and a temperature-frequency sweep for flexural stiffness has been completed.

Structural design is performed at a constant temperature, referred to as the equivalent temperature $\theta_{eq}$. This temperature is such that the cumulative damage undergone by the pavement over a year, for a given temperature distribution, is equal to the damage that the pavement would undergo with the same traffic but for a constant temperature $\theta_{eq}$ [6].

The calculation for the equivalent pavement temperature is based on fundamental mechanics and considers real pavement structure responses and asphalt fatigue properties. The calculation requires detailed input on the pavement temperature distribution. When real and accurate data can be obtained for the pavement structure for a certain climatic environment, it could provide reliable input into the mechanistic pavement design.

4.1.4 Pavement support, categories of the subgrade (formation)

According to the French design manual for pavement structures [6] (the Manual) the pavement foundation is built up from two parts:

- subgrade, usually the top 1 m of the natural ground, cut or imported material
- an overlying capping layer.

For the pavement structural design, the formation is characterised by its expected long-term behaviour:

- the behaviour of the subgrade over the depth of the top part of the earthworks (1 m)
- the nature of the materials chosen for the capping layer and its thickness.

The design method is adjusted by taking the mechanical characteristics that correspond to the most unfavourable moisture conditions for the pavement; seasonal variations are ignored. The Manual provides examples of how to increase the bearing capacity of the subgrade by applying different material properties and thicknesses for the capping layer; by using this method in the pavement design, the subgrade and capping layer are treated together as the semi-infinite layer. Typical treatments in the French Manual for common subgrades include 500 to 800 mm selected unbound fill, or 300 to 500 mm in situ or plant-mixed stabilised soil. Such treatments are required to provide a semi-infinite design bearing capacity of at least 120 MPa under EME pavements.

4.1.5 Typical pavement structures

Table 2 compares the heavy duty (GB3) and high modulus (EME2) pavement structures as outlined in the French catalogue [8]. The table shows that significant pavement thickness reduction can be achieved when using the EME2 mix type. For example, for traffic category TC730, and foundation class PF3 (120 MPa), a total asphalt thickness of 410 mm is required when conventional GB3 heavy duty asphalt is used in the base. For the same situation, except using EME2 in the base, the total asphalt thickness is reduced to 330 mm, equating to a reduction of approximately 20% in total asphalt thickness. The base asphalt thickness is reduced by approximately 25%, from 310 mm to 230 mm.
TABLE 2 Comparison of GB3 (heavy duty asphalt) and EME2 (high modulus asphalt) pavement structures based on the French catalogue

<table>
<thead>
<tr>
<th>Traffic category</th>
<th>Total pavement thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PF3, Ev2 = 120 MPa</td>
</tr>
<tr>
<td></td>
<td>GB3 pavement structure</td>
</tr>
<tr>
<td>TC8(_{30})</td>
<td>94 million HV (75 million ESA)</td>
</tr>
<tr>
<td>Surface course</td>
<td>GB3 pavement structure</td>
</tr>
<tr>
<td>Base course, GB3</td>
<td>120</td>
</tr>
<tr>
<td>Base course, GB3</td>
<td>120</td>
</tr>
<tr>
<td>Base course,</td>
<td>Total 450</td>
</tr>
<tr>
<td>EME2 pavement</td>
<td>40</td>
</tr>
<tr>
<td>structure</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>130</td>
</tr>
<tr>
<td>TC7(_{30})</td>
<td>38 million HV (30 million ESA)</td>
</tr>
<tr>
<td>Surface course</td>
<td>GB3 pavement structure</td>
</tr>
<tr>
<td>Base course, GB3</td>
<td>100</td>
</tr>
<tr>
<td>Base course, GB3</td>
<td>100</td>
</tr>
<tr>
<td>Base course,</td>
<td>Total 410</td>
</tr>
<tr>
<td>EME2 pavement</td>
<td>40</td>
</tr>
<tr>
<td>structure</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>140</td>
</tr>
<tr>
<td>TC6(_{30})</td>
<td>14 million HV (11.3 million ESA)</td>
</tr>
<tr>
<td>Surface course</td>
<td>GB3 pavement structure</td>
</tr>
<tr>
<td>Base course, GB3</td>
<td>90</td>
</tr>
<tr>
<td>Base course, GB3</td>
<td>90</td>
</tr>
<tr>
<td>Base course,</td>
<td>Total 360</td>
</tr>
<tr>
<td>EME2 pavement</td>
<td>40</td>
</tr>
<tr>
<td>structure</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>110</td>
</tr>
<tr>
<td>40 (\text{mm})</td>
<td>60 (\text{mm})</td>
</tr>
<tr>
<td>60 (\text{mm})</td>
<td>110</td>
</tr>
<tr>
<td>90 (\text{mm})</td>
<td>120</td>
</tr>
<tr>
<td>110 (\text{mm})</td>
<td>130</td>
</tr>
<tr>
<td>130 (\text{mm})</td>
<td>130</td>
</tr>
</tbody>
</table>

Source: LCPC-Setra (1998) [8].

5. TRANSFERRING THE FRENCH PAVEMENT DESIGN PROCEDURES TO QUEENSLAND

Successful EME2 technology transfer requires the development of an applicable and reliable pavement design methodology in Queensland so that the full benefits of the EME2 technology can be realised.

There were three options considered for pavement design using EME2. While developing the strategy for implementation, it should be emphasised that the introduction of a new technology always requires periods of transition. The three options are summarised as options 1, 2 and 3.

5.1 Option 1: Improved Austroads method

Option 1 recommends utilising the pavement design method described in the Austroads Guide [11] with an updated transfer function for asphalt fatigue. In Austroads project TT1826: Improved design procedures for asphalt pavements, there is work currently underway for an updated methodology. The first step in coupling the asphalt mix design and pavement design
is that the default general laboratory fatigue life model should be replaced with a mix-specific model [12]. A possible utilisation of this methodology is provided in Eq. 2. However, the laboratory-to-field shift factors, as indicated in Eq. 2, have to be validated for Australian conditions. Also, the provided equation has to be simplified and re-arranged to be compatible with CIRCLY calculations.

Additionally, in the current Austroads method the design reliability is incorporated in the reliability factor (RF), which represents a combination of a laboratory-to-field shift factor and a material safety factor [12]. These two measures are clearly separated in the French design method.

While this option represents a possible future direction, it is not currently mature enough for immediate adoption for implementation of EME2 in Queensland.

5.2 Option 2: The French method (in full)

The second option considered was to use the French method as outlined in Section 4. While this option would be possible, it differs significantly from the current Austroads procedures and would not be straightforward for immediate implementation. Differences are not only in asphalt fatigue modelling, but in other areas including traffic modelling and calculations, material characterisation, temperature modelling, and foundation materials and design. On this basis it was concluded that immediate implementation would more practically be achieved by using the existing Austroads procedure and benchmarking designs with those using the French methodology. This option is discussed in Section 5.3.

5.3 Option 3: Current Austroads method (benchmarked against the French method)

Option 3 uses the current pavement design method as outlined in Austroads [11] and TMR Pavement Design Supplement [13]. By the application of the current Austroads [11] methodology as an interim measure, the utilisation of EME2, within the existing pavement design framework, is facilitated. Unlike Options 1 and 2, immediate implementation is possible. The trade-off with this approach however is that the full benefits of EME2 may not be realised as this methodology only uses the volumetric properties and one performance parameter, i.e. the stiffness of the EME2 mix. Therefore, the designer may not be prompted to develop the most cost-effective mix and pavement design. This is not considered to be a significant deterrent for interim use.

Benchmarking of the interim procedure with the French procedure has demonstrated that it results in realistic outcomes relative to existing heavy duty asphalt pavements. As the interim method can be readily applied within the current Austroads pavement design framework, it allows direct comparison with conventional pavement options.

To adopt this method, presumptive stiffness and binder volumes needed to be determined. The recommended values were determined from an analysis of data for currently available Australian EME2 mixes, and a French EME2 mix that was produced in France and tested in Australia.

A large number of specimens, extracted from the Queensland EME2 trial and manufactured in the laboratory, were tested for resilient modulus according to AS 2891.13, using the standard test temperature of 25 °C. Specimens were then subjected to the resilient modulus test at 15, 32 and 40 °C. The temperatures of 15 and 40 °C were selected to cover the range of typical temperature environments in Australia where EME2 may be used, while 32 °C is the weighted mean annual pavement temperature (WMAPT) for Brisbane. Based on this data, it was found that the temperature correction as described in Austroads [11] is valid for EME2 mixes.

Individual test results were then corrected to 4.5% air voids; the reason behind this step is that EME2 mixes in the laboratory design phase should be compacted to an air voids content between 3 and 6% for performance-based tests. The applied 4.5% air voids content
High Modulus Asphalt (EME2) Pavement Design in Queensland – Peer Reviewed Paper

represents the average of this range. The 10th percentile of the large number of test results was then calculated, which is summarised in Table 5.

Although the performance-based mix design and mechanistic pavement design is disconnected at this stage, the above approach allows that the minimum performance requirement of 14,000 MPa for EME2 mixes (4-point bending test, 15 °C, 10Hz) is translated to normally used pavement design characterisation (resilient modulus, 40 ms rise time, 32 °C). It should be noted that EME2 mixes have to meet the design criteria as outlined in PSTS107 [4]; the values in Table 5 are presumptive values for pavement design and they do not represent specification requirements for EME2 mix design.

In order to assess the applicability of the binder volume in the asphalt mix, a sensitivity analysis was performed on this property by using Monte Carlo simulation (MCS). Austroads [11] requires using the binder volume when calculating the fatigue properties. Calculations were performed according to TMR Test Method Q321. The variables were selected according to Table 3. It was assumed that the variables have triangular distribution.

TABLE 3 Input selected for the MCS analysis

<table>
<thead>
<tr>
<th>Property</th>
<th>Minimum</th>
<th>Likeliest</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder content in EME2 (m%)​1</td>
<td>5.6</td>
<td>6.0</td>
<td>6.4</td>
</tr>
</tbody>
</table>

1: Mass % by total mass of asphalt mix.

The relative distribution is summarised in Figure 1 for the effective binder VB (which is a function of the binder content).

FIGURE 1 Relative distribution of VB for EME2

By using the above parameters, an extensive sensitivity analysis was undertaken, which determined total asphalt thickness reductions of around 20% (and base thickness reductions of 20-30%) for a wide range of design traffic (volumes, loadings and speeds), subgrade conditions and pavement temperatures. The reductions in thickness are similar to those outlined in the French system (Table 2). An example of the sensitivity analysis for a range of traffic loadings is provided in Figure 2, which shows EME2 thicknesses compared with conventional 20 mm dense graded asphalt (with both Class 320 and Class 600 bitumen). Other inputs in this specific analysis are as detailed for the case study in Section 6.
6. INTERIM PAVEMENT DESIGN PROCEDURE

6.1 Introduction

The recommended procedure to enable immediate implementation of EME is that detailed in Section 5.3 (Option 3). This section provides a practical guide to the design of EME2 pavements using the recommended method. The procedure should be read in conjunction with the Austroads Guide [11], the Pavement Design Supplement [13] and Technical Note 142 High Modulus Asphalt (EME2) Pavement Design [14] that was developed as an outcome of this research project.

The interim procedure is recommended for full depth asphalt pavements only. Consistent with the French pavement design catalogue, use of EME2 in pavements containing a cementitiously stabilised base or subbase is not recommended due to concerns regarding reflective cracking. Use of EME2 over a cementitiously treated improved layer (with unconfined compressive strength limited to 1.0 to 2.0 MPa at 7 days) is acceptable.

The French methodology also includes limits on layer thicknesses and subgrade support conditions. These too have been adapted for use in Queensland and are detailed in the following sections.

6.2 Typical pavement structure

The typical structure of a full depth asphalt pavement with an EME2 base is as shown in Table 4 (note that interlayer seals are not shown).

<table>
<thead>
<tr>
<th>Course</th>
<th>Description (typical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfacing</td>
<td>Dense graded, open graded or stone mastic asphalt</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Dense graded asphalt</td>
</tr>
<tr>
<td>Base</td>
<td>EME2 high modulus asphalt with thickness determined by mechanistic design</td>
</tr>
<tr>
<td>Improved layer</td>
<td>Minimum 150 mm Type 2.3 unbound granular material that has been cementitiously treated (refer to Section 5.4 for further details)</td>
</tr>
</tbody>
</table>
6.3 Subgrade evaluation and improved layer

To enable adequate compaction and future pavement performance, the French pavement design procedures includes minimum support conditions below the EME2 base. To achieve this within the Austroads framework, the following minimum support provisions are recommended:

- Improved layer comprising a minimum 150 mm thick layer of Type 2.3 unbound granular material that is treated with a cementitious stabilising agent to achieve an unconfined compressive strength of 1.0 to 2.0 MPa at 7 days.
- An additional thickness of select fill or unbound granular material (if required), based on the bearing capacity of the underlying subgrade material, to increase the pavement support to an adequate level for long-term pavement performance. Adequate support can be determined by using the Austroads unbound granular and selected subgrade sublayering procedures [11], ensuring that the modulus achieved at the top of the improved layer is not less than 150 MPa.

Where the design CBR of the existing in situ subgrade material is 7% or more, a 150 mm thick improved layer is typically adequate without the need for any additional underlying selected material, unless required to address other issues such as expansive material or excess moisture.

While this approach provides for a minimum amount of pavement support, which is generally less than typically adopted in France, more substantial treatments are likely to have benefits in terms of overall asphalt thickness reduction. Therefore, more substantial treatments should also be considered by the pavement designer in assessing project-specific alternatives.

To achieve adequate compaction of the asphalt layers, additional support may be necessary depending on the bearing capacity of lower layers at the time of construction. Proof-rolling of the improved layer and all other earthworks layers should be undertaken to confirm acceptable support has been achieved prior to the construction of overlying layers.

6.4 Asphalt design modulus and Poisson’s ratio

For the interim pavement design methodology, the presumptive design moduli as detailed in Table 5 should be used. A Poisson’s ratio of 0.4 is also applicable.

<table>
<thead>
<tr>
<th>Asphalt mix type</th>
<th>Binder Type</th>
<th>Volume of binder (%)</th>
<th>Asphalt modulus at heavy vehicle operating speed (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EME binder (15/25 pen)</td>
<td>13.5</td>
<td>10 km/h</td>
</tr>
<tr>
<td>EME2</td>
<td>EME binder (15/25 pen)</td>
<td>13.5</td>
<td>2000</td>
</tr>
</tbody>
</table>

For other WMAPTs, Equation Q6.1 of the Pavement Design Supplement [13] is considered to be acceptable for temperature correction of these presumptive moduli.

6.5 Thickness design

The interim approach to thickness design is as per the existing mechanistic design procedures for full depth asphalt pavements, as detailed in Section 9 of the Austroads Guide [11] and the Pavement Design Supplement [13]. Consistent with the French requirements, the target thickness of each individual compacted layer of EME2 should be between 70 and 130 mm, which should be considered in establishing the pavement thickness.

7. CASE STUDY

The following example compares a full depth asphalt pavement comprising EME2 base asphalt with a conventional design comprising DG20HM (with Class 600 bitumen). The design inputs in Table 6 are based on a typical heavily trafficked road in South East Queensland. Materials
were modelled in accordance with the presumptive values detailed in the Pavement Design Supplement [13] and Table 5. Results are shown in Figure 3. It is evident from the results that a substantial reduction in base asphalt thickness is possible if EME2 is used. The conventional design (Option 1) with DG20HM base requires a base thickness of 250 mm, while the EME2 design (Option 2) only requires 190 mm, equating to a 24% reduction in base thickness. There is the additional benefit with the EME2 option in that the number of compacted layers is reduced from three to two.

**TABLE 6 Design inputs**

<table>
<thead>
<tr>
<th>Site conditions</th>
<th>Value</th>
<th>Design parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMAPT (°C)</td>
<td>32</td>
<td>Design traffic (ESA)</td>
<td>1.1 x 10⁸</td>
</tr>
<tr>
<td>Heavy vehicle speed (km/h)</td>
<td>80</td>
<td>SAR5/ESA</td>
<td>1.1</td>
</tr>
<tr>
<td>Subgrade design CBR (%)</td>
<td>7</td>
<td>SAR7/ESA</td>
<td>1.6</td>
</tr>
<tr>
<td>Subgrade expansive nature</td>
<td>low</td>
<td>Project reliability (%)</td>
<td>95</td>
</tr>
</tbody>
</table>

**FIGURE 3 Example pavement design results**

Notes:
1. Base asphalt thickness includes 10 mm construction tolerance.
2. Project-specific assessment is necessary to guide the decision on inclusion of the waterproofing seal, and priming and sealing the improved layer.

**8. CONCLUSIONS AND RECOMMENDATIONS**

The project has successfully developed an interim pavement design procedure to facilitate the immediate implementation of EME2 in Queensland. The recommended pavement design method aligns with the current Austroads procedure, and includes presumptive design inputs for stiffness and binder volume.

It has been demonstrated that thickness reductions using the interim procedure, relative to conventional asphalt mixes, are in line with the expected reductions based on the full French methodology.
The reduced pavement thickness that is possible from using EME2 brings a number of benefits, such as:

- reduced pavement cost – while EME2 mixes may be more expensive compared to conventional asphalt mixes due to the higher binder content, the reduced pavement thickness should outweigh the increased costs of the EME2 mix
- less paving operations (see Figure 3) – if a pavement can be built with less asphalt layers, there are shorter construction times and less interruption to traffic
- better solution in constrained urban environments – thinner mill and fill operations, and reduced overlay thickness in areas with clearance restrictions, such as underpasses.

It is anticipated that future improvements in Australian pavement design procedures for asphalt pavements will lead to pavement designs being linked directly to mix-specific performance-based testing undertaken during the mix design stage, which would be in line with the French pavement design system. Further research is required before such a development can be implemented into routine pavement design.

9. ACKNOWLEDGEMENTS

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10. REFERENCES
