4. LONG LIFE PAVEMENTS

Working Group
Leader: Ian van Wijk  2I/C: Nigel Preston  Group: Greg Stephenson, Hugo van Loon, Rob Vos

Tour scope: Long life pavements

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, a process that can be achieved by limiting cumulative distribution of asphalt strain, which is widely accepted in the literature (mainly NCAT test track findings).

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

Feedback from
Feedback directly related to long-life pavements was obtained from

- The French Administration (IFSTTAR & SETRA) and LCPC (in France)
- The University of Delft and the Rijkswaterstaat (in the Netherlands)
- The Highways Agency and Transport Research Board (in the UK)
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- Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt) and German Asphalt Pavement Association (DAV) (in Germany).
- Colas (in France), Kraton polymers (in the Netherlands) and BP (in Germany)
- The 5th Euroasphalt and Eurobitumen (E&E) congress proceedings (in Turkey).

Background

Many papers at the E&E congress dealing with thin asphalt (functional) surfacings referred to long-life, sustainable or durable pavements materials. They are not pertinent to the discussion. It is therefore important to clearly define what is meant by long-life pavements (LLP). The formal European definition is given further on in this report. For the purpose of this discussion, the design of LLP covers:

- The thickness design (a function of the design traffic, design period or threshold strain and material properties)
- Structural properties of bituminous material used (mainly as base since this layer determines the structural life).
The findings from a 2010 AAPA study tour to the USA and work by the European Long-Life Pavement Group (ELLPAG), and recent Austroads reports are relevant to this discussion and the salient issues are summarised below.

**Findings from 2011 AAPA Study Tour to the USA**

An AAPA tour to the USA in 2010 studied, amongst others, Perpetual Pavement, PP (the marketing term used in the USA to describe long-life pavements, LLP) concepts.

The main observations were:

- 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 and that
  - 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
- If the pavement structure is sufficiently thick so that the FEL is not exceeded a long life or so called "Perpetual Pavement" becomes a reality. The field calibration of asphalt fatigue is difficult since a distinction can often not be made between structural (bottom-up) and top-down cracking.
- Typical FEL values obtained from various sources during the visit
  - 90 to 300 µm with average of 125 µm (Thompson)
  - 75 to 200 µm for a 95% lower prediction limit and the higher values related to SBS polymer modified materials (NCHRP report 646)
- Thickness design methods in the USA are moving away from weighted Mean Annual Pavement Temperature toward dynamic modulus at a selected range of temperatures to match seasonal effects.
- The USA Mechanistic Empirical Pavement Design Guide (MEPDG) has been updated and includes the FEL concept. The Auburn University NCAT developed PerRoad and PerRoad Express pavement design programs provide an approach to designing perpetual pavements. However, these programs currently (in 2010) do not form part of accepted design practice in the USA.
- “Rich bottom” or high fatigue asphalt base layers is widely being researched.
- The concept of effective crack healing is not accepted by all researchers.
- There was general agreement that pavement support conditions should be sound and that material and construction quality control should be effective.

The following recommendations were made

- Australian flexible pavement design practice should investigate the opportunities for inclusion of Fatigue Endurance Limits into local practice.
• Contact should be maintained with US colleagues to facilitate the above through industry, State Road Authority, academia, consultants, ARRB personnel and the Austroads Pavement Structures Reference Group.

• Existing laboratory tools in Australia should be used to facilitate comparison of local products to allow comparison with USA materials proven on their major highways and accelerated test facilities.

• A “library” of the performance Australian pavement materials should be developed to provide input into local predictive models.

• AAPA should include, as part of its technology development program, the conversion of PP / Long life design packages to SI units and, through partnerships with SRA / ARRB / consulting fraternity, the modification of Australian design methods of tools such as CIRCLY.

**European experience**

Discussions about long-life pavements are not new in Europe and the UK. A large number of European countries have been involved in the sharing of information and in related research since the 1990s.

The European Long-Life Pavement Group (ELLPAG) was established in 1999 as a FEHRL (a registered International Association formed in 1989 as the Forum of European National Highway Research Laboratories) and Conference of European Directors of Roads (CEDR) Working Group. Core membership of the Group comprises representatives of research institutes (FEHRL members) and the UK Highways Agency. ELLPAG is chaired and co-ordinated by TRL (UK). The objectives of ELLPAG are:

• In the short term - to carry out state-of-the-art reviews of the current European knowledge on the design and maintenance of long-life fully-flexible, semi-rigid and rigid pavements.

• In the medium turn – to undertake a series of workshops/seminars to promote the understanding and use of long-life pavements in Europe.

• In the long term - to produce a user-friendly comprehensive Best Practice Guidance note on long-life pavement design and maintenance for all the common types of pavement construction used in Europe.

A long-life pavement was defined by the Group as “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”.

Also relevant is the definition of deterioration or failure as “ whatever the network manager considers important, e.g. significant cracking or (progressive) deformation in the structural layers of a fully-flexible pavement”.

Funding was obtained in 2002 for phase 1 (short term as mentioned above) which covered the review of the current knowledge on the design/maintenance of long-life fully flexible pavements. As a result, ”A guide to the use of Long-life Fully- Flexible Pavements” (FEHRL Report 2004/1 ELLPAG PHASE 1), was produced in 2004 that covered the definition, new pavements, assessment and upgrading, maintenance, economic analysis and research needs. The components directly
relevant to the 2012 AAPA Study Tour Report are the design and maintenance. The situation among the participating countries was summarised in the report as:

- Many countries permit the design of pavements for periods in excess of 20 years, e.g. France, Germany, The Netherlands, Hungary and the UK.
- Fatigue endurance limits (FEL) had not been established, but values of 70 µm and 50 µm have been mentioned in the UK and the Netherlands, respectively.
- For heavily trafficked pavements, design traffic can be expressed in traffic class, cumulative traffic (with or without a capped level) and traffic flows derived at a certain time in the life of the pavement.
- No special provision is generally made for the treatment of the subgrade for long-life pavements. A number of approaches are used, such as minimum bearing capacity, specific strength, superior modulus, classes of support (in cases depending on traffic level) and minimum capping layer thickness.
- Some countries use special surfacings and fatigue resistant lower layers. The best example is France where high modulus and modified binder layers are regularly used.
- Only one country (the UK) applied a maximum asphalt layer thickness based on a notional threshold strain below which structural deterioration is unlikely to occur.
- In general improved quality and quality control are required during construction.
- Maintenance entails treatments to restore the functional characteristics rather than improve the structural capacity, e.g. inlays, resurfacing, surface patching, surface dressing and rejuvenation of the surfacing.
- Maintenance of LLP is important and best practice (e.g. the Netherlands, the UK, Austria and Hungary) involves
  - The measurement of the relevant condition parameter (mainly cracking and surface deterioration)
  - Appropriate warning and intervention levels (to initiate interventions)
  - Pavement management systems and prediction models (to process information and prepare intervention programs)
  - Appropriate maintenance actions
  - Whole of life analysis with financial, environmental and safety considerations

The following recommendations were made in the FEHRL Report 2004/1 ELLPAG PHASE 1 for further research:

- Develop monitoring methods to accurately determine the degree of surface deterioration in long-life pavements.
- Conduct research to identify the rate of deterioration and to quantify the risk of sudden, unforeseen developments in deterioration occurring in such a way that the structure of the pavement may be affected.
- Identify intervention levels for non-structural deterioration.
- Develop an integrated maintenance strategy of monitoring and treatment so that the whole-of-life costs of long-life pavements after construction are minimised.
Although these recommendations had been made in 2004 none of them have yet been developed further.

**Austroads reports**

Two recent Austroads reports, and also the 2012 Austroads Guide, contain information relevant to the discussion of LLP:

- **Austroads AP T199-12, Development of a Nonlinear Finite Element Pavement Response to Load, 2012.** One of the pavement design areas identified for improvement was that related to the ability to predict asphalt fatigue life of thin (<150 mm) asphalt layers as feedback from “experienced engineers” was that the current method under-estimates the life of thin asphalt layers. Nonlinear finite element theory (APADS software) was used instead of the linear elastic model (CIRCLY software) to compare strains at the bottom of the asphalt layer. The results indicated that the multi-layer theory calculated different strains than those using the finite element theory and that the differences depended on the asphalt thickness and subgrade CBR, i.e.
  - For 50 mm asphalt, the APADS calculates higher strains than CIRCLY for cases where the subgrade CBR is more than 2%
  - For 100 mm asphalt, the APADS calculates higher strains than CIRCLY for cases where the subgrade CBR is more than 6%
  - For 150 mm asphalt, the APADS calculates lower strains than CIRCLY

- **Austroads AP-T131/09, Asphalt Fatigue Endurance Limit, 2009.** The report contains findings of field studies by Ross, AAPA and Tsoumbanos which confirmed the findings by Nunn on UK roads that the pavements were in “sound structural condition and meeting functional requirements despite many having, at the time, already exceeded the design life predicted” (p.19). Tsoumbanos specifically found that “three of the four sites selected for detailed investigations generally exhibited behaviour expected of long-life pavements based on asphalt thicknesses typically exceeding 210 mm, cracking mostly limited to the top 40 to 60 mm of the asphalt, deflection testing identifying very strong pavement structures, and no structural intervention during service life to date” (p16).

- **The latest Austroads, GUIDE TO PAVEMENT TECHNOLOGY PART 2: PAVEMENT STRUCTURAL DESIGN (2012)** addresses the endurance limit, i.e. “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. For instance, as a result of the work by Nunn et al. (1998) the UK procedure for design of asphalt pavements was revised to include a minimum asphalt thickness, corresponding to minimum threshold pavement strength, for the most common asphalt mixes beyond which the pavement should have a very long but indeterminate structural life, so-called long-life pavement structures. Currently, field performance information is insufficient to incorporate a strain endurance limit for use with the Equation 11 fatigue relationship. It is anticipated that future research will enable this concept to be incorporated in the mechanistic design process.”
From the references above it is clear that there is a general acceptance (in the USA, Europe, the UK and Australia) of the merits of LLP and that a FEL is relevant, but specific structural design procedures and design criteria have not yet been developed to a point where they are routinely used.

1. Usage and performance records

The objectives of this component of the study tour were to obtain information about:

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

Information gathered

ELLPAG Phase 1 report contains valuable information on the utilisation of long-life fully flexible pavements in Europe and the UK. Figure 1 depicts the designs for maximum traffic volumes in each of a number of countries (and the USA), with only 3 countries utilising heavy traffic thresholds.

![Figure 1: Pavement designs for national maximum design traffic levels (ELLPAG Phase 1 report)](image)

European designs for 1E+08 ESAs are shown in Figure 2. This shows a large variation (to be expected given the differences in traffic loading patterns, type of asphalt and the environment). As reference a typical full depth asphalt design for 1E+08 ESAs in Queensland (Brisbane region with WMAPT of 33°C) comprises 50 mm surfacing, 50 mm binder layer, 270 mm asphalt base on a working platform (subgrade CBR of 5%). This gives a total thickness of asphalt of 370 mm, which is slightly higher than thicknesses in the UK, France and Germany (but at a higher temperature).
None of the road authorities visited could provide very detailed information about the usage or performance (e.g. examples and case studies, traffic, deflection history and typical maintenance).

Figure 3: Photographs depicting the cracking from the UK study

The British approach is based on research by Nunn in the 1990s (initially reported in TR 250) which showed that thick (>250 mm), well built flexible pavements did not deteriorate structurally as previously expected. For such pavements, rutting was confined to the upper surface layers and
cracking initiated at the surface (with no evidence of “bottom-up” fatigue cracking) as shown in Figure 3.

This study resulted in the British LLP design now limiting the thickness to that which would be required for 80 MESA (8E+07 ESA), which would result in a maximum thickness of 320 mm for hard bitumen base (EME2) or 380 mm for soft bitumen base (DBM50/HDM). The bituminous base is typically supported by a foundation layer, Class 2 (E ≥ 100 MPa) or better, and 150 mm bound subbase. The maintenance is normally an asphalt overlay with the thickness determined by the pavement deflections and expected traffic loading.

A deflection of less than 0.25 mm (at 20°C) is considered to indicate a long-life pavement in Britain. The Highways Agency indicated that 80% of the fully flexible motorways and 20% of the All-Purpose Truck Roads (APTR) meet the long-life deflection and thickness criteria.

Deflection measurements (previously with the Deflectograph and now with the Travel Speed Deflectometer, TSD) on the British road network are done annually (covering about a third of the network per annum), but the deflection histories were not available for the assessment of the identified long-life pavements. In the Netherlands FWD deflections are only done on project level.

The Dutch refer to long-life pavements as “eternal” pavements, i.e. pavements that are strong enough not to fail until functional repair is done. Functional repairs are defined as overlays to replace surfacings and to correct deformation. This is normally done at 10 to 15-year intervals (open grade asphalt which is replaced every 11 years in the slow lane and 15 years in the fast lane). A typical design comprises:

- 50 mm porous asphalt (with no waterproofing layer below)
- HMA base of 230 to 300 mm (4.5% bitumen, 6% voids, E= 8,500 MPa at 20°C)
- 2% cement modified base of 250 to 300 mm (cement concrete waste, E = 400 to 500 MPa)
- Typical subgrade CBR of 10%

Typical German designs for high traffic loading (>32 MESA) comprise a 120 mm binder and surfacing layer on a 220 mm base layer supported by an appropriate foundation.

The French are currently monitoring 58 pavement sections, including 3 sections with thick asphalt which could be considered LLPs. Information reported include age, cross-section, drainage, pavement structure, details of asphalt mix designs, rehabilitation, cumulative traffic since construction (but using a method different from Austroads), Deflectograph deflections and condition.

**Conclusions**

- LLP is accepted in Europe and the UK as pavement design option and considered important enough to have created the ELLPAG to investigate. A report was published in 2004 with a summary of the situation in the UK and Europe and recommendations for further research, but none of these recommendations have yet been implemented.
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- Most information on the past performance of full depth asphalt pavements comes from UK studies in the 1990s. No documented recent case studies could be made available by the agencies visited.
- Maintenance, involving the replacement of the surfacing layer only, is important for the performance of LLPs and should be based on a sound selection and design methodology.
- Long-life pavements are designed in the UK (maximum design traffic loading of $8 \times 10^7$ ESA), Germany (maximum design traffic loading of $3.2 \times 10^7$ ESA) and the Netherlands (standard low maintenance design for their traffic loading) by applying some form of limiting criteria. However, the formal theoretical models with limiting criteria (e.g. fatigue endurance level) are not used.
- High modulus asphalt base layers are used in France to produce long-life pavements. The fatigue relationships have been developed for these materials and are used in a mechanistic design process.

2. Design aspects

The objectives of this component of the study were:
- To evaluate the design procedures
- To determine the most appropriate approach - either mechanistic or catalogue-based
- Prioritisation of focus – either design models or construction

From the Highways Agency presentation

Information gathered

The Highway Agency uses either a series of graphs limiting the thickness to that of a pavement for a loading of $8 \times 10^7$ ESAs (HD26/6 and TR 250, see Figure 4) or a mechanistic procedure (TR1132,
e.g. fatigue criteria of 79 µm and shift factor). The latter (use of shift factor) is only used where there is a departure from the standards, but this does not seem to happen often. The BISAR program is used in the analysis with bituminous layer design stiffnesses (moduli) at a reference condition of 5 Hz and 20°C (e.g. 2,500 MPa for the surface course). Subgrade design properties are defined as moduli (measure with Light FWD). The maintenance actions selected are in line with design, i.e. no structural failures, only replacement and / or rejuvenation of the surfacing.

Figure 4: UK Highways Agency design

Dutch pavement thickness design method has been adapted to the harmonised European Standards for asphalt and follows a fundamental approach of fatigue failure for asphalt concrete (tensile strains at the bottom of the layer), shear failure of the road base (stress/strength ratio), fatigue and compressive failure of cemented layers (tensile stresses at the bottom and compressive stresses on top of the base) and permanent deformation of the subgrade. The reliability is 85%. Other material properties are specified to control resistance to permanent deformation and water resistance of the asphalt concrete.

The approach used in the design of long-life pavements entails the following considerations (see Figure 5)

- Pavement is designed to be free from structural deterioration by keeping the stresses and strains below fatigue limits. Specific fatigue limits were not made available, but laboratory values specified for the HMA base layer material (were indicated as appropriate) to be used.
- Materials must be insensitive to deterioration from climate, environment, endogenous processes, etc.
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- Overlaying will further reduce stresses and strains. The overlay is also used to correct defective profiles.
- No special material is used as HMA base, but requirements set in terms of rutting, failure and stiffness.
- The BISAR M-E program is used for non-standard designs. Laboratory determined asphalt fatigue relationships are multiplied with a factor of 10 (4 for healing and 2.5 for other factors) to be used in the M-E design, but these non-standard designs are not often done.

![Fatigue damage curve](image)

**Figure 5: Dutch design approach**

The German designs are presented as catalogues in the pavement design manual in 7 categories ranging from $<3E+05$ ESA to $>3E+07$ ESAs (see example in Figure 6).

![German design catalogue](image)

**Figure 6: Example for German design**
Only one paper (from Denmark) at the E&E congress touched on the long-life pavements by means of a case study, while a few papers addressed fatigue testing and a number of papers covered aspects of the long-life of pavement surfacing materials. None of these papers presented specific thickness design methods.

The ELLPAG group identified 3 options for the development of design procedures for LLP, i.e.
- The extrapolation of current design curves (thicker pavements using conventional materials),
- The recognition that above a certain strength (threshold strength), pavement wear does not accumulate,
- The use of improved materials and/or design to prevent the expected modes of deterioration occurring (e.g. use of an anti-fatigue layer as the lower base layer).

The use of improved materials and preventing expected modes of failures was identified as the preferred option as shown in Figure 7.

Figure 7: The preferred way approach to developing a long-life design method (ELLPAG Phase 1 report)

Mr Brian Ferne (from TRL, and the coordinator of ELLPAG Phase 1) provided useful further insights into issues related to the design of LLPs, i.e.

- Threshold levels seem to exist, but have not been defined. Threshold levels determined in the laboratory and in accelerated loading facilities do not necessarily apply to the real network, i.e. there is a mismatch between lab and field performance.
- There is uncertainty about the relevance of the traditional parameters, i.e. horizontal strain at bottom of asphalt and vertical strain at top of subgrade, to predict pavement life. Horizontal tensile strain below the HMA may not be the governing stress/strain, i.e. failure is not caused by bending.
- Top down cracking develops due to change in viscosity with depth and not loading.
- Validated M-E models do not exist for the design of LLP in Europe and the UK. Development of these models should include an assessment of existing pavement performance.
Conclusions

- There is general acceptance of the concept of a threshold value, but it has not been defined.
- Validated M-E models do not exist for the design of LLP in Europe and the UK. As a consequence there is no uniform design method. Horizontal tensile strains below the HMA may not be the governing strains since failure of thick layers may not be caused by bending.
- The conversion of laboratory test results to field performance is problematic. The use of existing pavement performance to calibrate the models was suggested as the most effective way of calibrating models or developing laboratory–field conversions.
- The focus in Europe for future development is on improved materials and related design.
- The preference of the road authorities visited seemed to be for catalogue design rather than M-E designs for routine LLP designs.

3. Material Properties

This component of the study had as objectives:

- 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

Information gathered

A significant amount of work is being done by various road agencies and bitumen suppliers to improve of the structural and durability properties of asphalts and bitumens.

More work has, arguably, been done in France than any other European country on the use of high modulus asphalts, i.e. “Enrobés à Module Elévé” (EME) with a proven track record of more than 20 years. The EMEs have excellent deformation resistance and outstanding waterproofing properties. In France it is produced with 0/10 mm, 0/14 mm and 0/20 mm aggregate and target binder content of around 5.7%. It has a high modulus (14,000 MPa at 15°C and 10 Hz) with a high resistance to fatigue (130 µm at 10°C and 25Hz). Tables 1 and 2 contain the French classifications and specifications for the standard (GP) and the high modulus (EME) mixes. Saving in thickness of up to 35% can be expected if an EME is used instead of a GB material.

Table 1: French classification
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Table 2: French specifications

<table>
<thead>
<tr>
<th>Type of mix</th>
<th>GB Class 2</th>
<th>GB Class 3</th>
<th>GB Class 4</th>
<th>EME Class 1</th>
<th>EME Class 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size (mm)</td>
<td>≤ 11</td>
<td>≤ 10</td>
<td>≤ 9</td>
<td>≤ 10</td>
<td>≤ 6</td>
</tr>
<tr>
<td>Binder Content (%)</td>
<td>≥ 0.65</td>
<td>≥ 0.7</td>
<td>≥ 0.7</td>
<td>≥ 0.7</td>
<td>≥ 0.75</td>
</tr>
<tr>
<td>Water sensitivity</td>
<td>≤ 10</td>
<td>≤ 10</td>
<td>≤ 10**</td>
<td>≤ 7.5**</td>
<td>≤ 7.5**</td>
</tr>
<tr>
<td>Rut depth (60°C, 100 mm)</td>
<td>≥ 9,000</td>
<td>≥ 9,000</td>
<td>≥ 11,000</td>
<td>≥ 14,000</td>
<td>≥ 14,000</td>
</tr>
<tr>
<td>Fatigue – service life (10^6 cycles)</td>
<td>≥ 80 \times 10^4</td>
<td>≥ 90 \times 10^5</td>
<td>≥ 100 \times 10^4</td>
<td>≥ 100 \times 10^4</td>
<td>≥ 130 \times 10^6</td>
</tr>
</tbody>
</table>

The French design method for EME mixes are depicted in Figure 8.
EMEs were introduced in UK in 2006 and the standard French specification is used. The EMEs are not always more cost-effective than “traditional asphalts” due to high binder contents, but the design charts are considered to be conservative estimates of properties and thus under-estimate the structural benefits of the EMEs. Binder properties are considered to be critical. The UK Highways Agency recommends a 10/20 grade bitumen as binder for use in EME base/binder course asphalt mixtures, targeting a penetration of 15-20, and in accordance with EN 13924 (as elaborated in Annex A of the Draft Specification Requirements given in TRL Report 636). During production of the EME2, the binder content must not be less than 0.3% below the design target binder content, nor more than 0.6% above. The target binder contents are 5.6% for EME2 0/10, 5.4% for EME2 0/14 and 5.2% for EME2 0/20. EME2 must be compacted on a subbase with an initial minimum foundation surface stiffness modulus of 120MPa.

Currently PMBs are not accounted for in UK design methodology.

The Dutch do not specify non-standard materials for as HMA base. The properties typically specified in design and construct (D&C) contracts are:

- Creep/permanent deformation (triaxial test) – maximum of 1.4 mm (local roads) and 0.2 mm (high traffic volume roads)
- Fatigue at $10^6$ cycles (4 point bending test) – maximum strain values of 100 µm (local roads) and 90 µm (high traffic volume roads)
- Stiffness at 20°C and 8 Hz (4 point bending, frequency sweep) – minimum of 4,500 MPa (local roads) and 7,000 MPa (high traffic volume roads) and maximum of 11,000 MPa (local roads) and 14,000 MPa (high traffic volume roads)
- Water resistance – Indirect tensile strength (ITS) ratio
Typical properties for binder (base) and wearing courses in Germany (German Standard 2012) are:

- **Binder Course (base) AC 22 BS and AC 16 BS**
  - Bitumen, 25/55-55 or 30/45 or 10/40-65
  - Wheel tracking not specified but must be documented
  - Voids 3.5% to 6.5%
  - Binder content, 4.2% (AC 22 BS) and 4.4% (AC 16 BS)
  - Grading according to TL Asphalt-StB 07

- **Wearing course (SMA8S or SMA 11S), 2.5 to 3% voids (Marshall 50 blows), 6.6% (SMA11) and 7.2% (SMA8) binder, fibres added.**

### Conclusions

- The benefits of higher quality (in terms of higher modulus, better deformation resistance, longer fatigue life and/or durability) material is recognized.
- Large amount of work is done both in Europe and the UK to develop and utilise higher quality HMA materials, e.g. EMEs.
- No uniform European/UK design procedure exists for the non-standard materials, but all use the similar structural properties, e.g. stiffness, fatigue and deformation resistance.
- RAP is widely used in standard mixes, but not in high modulus and/or high fatigue resistant mixes.
- Laboratory fatigue properties specified in France and in the Netherlands range between maximum strain values of 90 and 100 µm for conventional asphalt mixes and 130 µm for EME2 mixes (for the specified test method and temperatures).

### 4. Fatigue and healing

The objectives of this component were to investigate European and UK views and experiences related to:

- 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

### Information gathered

Fatigue testing was not discussed in any detail during any of the visits to the road authorities and TRL, except as mentioned as one of a number of tests conducted and by Prof Molenaar (Delft
University). Four different tests (Figure 9) are used by European and UK road agencies to determine the fatigue resistance, i.e.

- 4 point bending – used in Netherlands
- 2 point bending – used in France and Belgium
- Indirect tension – used in the UK
- Direct tension

![Fatigue tests used in Europe and the UK](image)

**Figure 9. Fatigue tests used in Europe and the UK**

In addition to the different tests, the sample test temperature and loading pattern also differ from country to country. The standard measurement of fatigue is when a stiffness of 50% of the original is reached. These differences and the consequences thereof were highlighted by Prof Andre Molenaar (Delft University) in his presentation in which he conveyed the following:

- Fatigue resistance is a specimen, not a material property.
- Reported applied strains are depended on how test is performed (full sine vs. half sine).
- Reported number of load repetitions to failure is depending on the type of test (4 point, 2 point, indirect tension and direct tension), slab dimensions and if the test is load or displacement controlled.
- Strain under which no fatigue develops, could be around 37 to 44 µm at 10 million cycles and 20°C (depending on slab thickness).
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- Reported endurance limits are in fact specimen properties.
- Substantial adjustments are needed to convert laboratory tests to field performance (confirming Ferne’s views reported earlier). A factor of 10 (4 to convert from laboratory to field performance and another 2.5 to accommodate for the effects of healing) as shown in Figure 10.

**Figure 10: Conversion of laboratory to field performance (Prof Andre Molenaar presentation)**

Further information on fatigue testing of asphalt samples were presented at the visit to BP (Figure 11) in Germany and in E&E congress papers. These emphasized the complexity of fatigue testing and the difficulty relating that to field performance.
As in the case of fatigue testing, healing was not discussed in depth with any of the road agencies visited. However, Prof Andre Molenaar reported on work done at the Delft University on healing of asphalt samples. The main conclusions in his presentation were:

- Healing entails the recovery in strength (fatigue) and not stiffness.
- Test properties (e.g. temperature, frequency, binder type) influence the quantification of the healing of stiffness and stiffness recovery is most likely due to thixotropy.
- Healing of asphalt mixtures is mainly a flow driven process.
- Long rest periods are beneficial but only at elevated temperatures.
- Temperature is more important than time in the healing process.
- Heating (strength recovery) of asphalt mixtures is limited.
- The healing of asphalts is complex to define and difficult to measure. It depends on a large number of factors, e.g. temperature, healing time and type of binder (Figure 12).

**Conclusions**

- A number of test devices, loading applications and test temperatures are used to determine failure resulting in differing fatigue values. Failure is generally defined as 50% of the original stiffness. Since difference test devices and protocols are used, the results must be used with
circumspection. Conversion from laboratory tests to field performance is problematic and no standard value or uniform conversion protocol exist (the Dutch use a value of 4).

- Fatigue tests have not been used to determine FEL values for use in the structural design, but minimum laboratory strain values for HMA bases are specified in France and the Netherlands.
- The healing of asphalts is complex to define and difficult to measure. While healing is accepted as occurring, standard test procedures and conversion factors have not yet been developed (a value of 2.5 is used in the Netherlands, but it can be as high as 40). Indications are that temperature is more important than time and healing only takes place at high temperature.

5. Contract and construction

Two specific aspects were addressed:

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

Information obtained

Contracting models were only explicitly discussed during the visit with the Rijkswaterstaat, while the importance of effective quality control in the construction of LLPs was raised in all the discussions. Neither were there discussions on initial construction cost comparisons. It is reasonable to assume that pavement option cost comparisons are done for all major projects, but that the outcomes would depend on the country, the traffic, etc. and not readily be transferable.

Types of functional contracts in the Netherlands

- *Performance contracts* for routine maintenance (grass mowing, cleaning of traffic signs, emptying garbage containers at service areas, etc.) (no design component)
- *Engineering & Construct contracts* for maintenance of wearing courses of pavements (limited design component)
- *Design & Construct contracts* (D&C) contractor has a design responsibility (new design, widening, strengthening); usually with 7 to 10 years of warranty
- *DBFM – contracts*; contractor is not only responsible for the design but also for the maintenance of his work for 20 to 30 years

Figures 13 and 14 display properties typically used by the Dutch Road Agency as performance criteria after construction and during the warranty period, respectively. These are applicable to the D&C contracts in the Netherlands.
### Performance assessment after construction

<table>
<thead>
<tr>
<th>property</th>
<th>assessment method</th>
<th>criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transversal slope</td>
<td>geodetical survey</td>
<td>according to:</td>
</tr>
<tr>
<td>Longitudinal evenness</td>
<td>Viograph</td>
<td>C5 - value &lt; 3%</td>
</tr>
<tr>
<td>Skid resistance</td>
<td>86% slip trailer</td>
<td>&gt; 0.40</td>
</tr>
<tr>
<td>Brake deceleration</td>
<td>Instrumented test vehicle</td>
<td>&gt; 5.2 m/s²</td>
</tr>
<tr>
<td>&gt; h over seams</td>
<td>straight edge</td>
<td></td>
</tr>
<tr>
<td>&gt; h at pavement edges</td>
<td>straight edge</td>
<td></td>
</tr>
<tr>
<td>layer thicknesses</td>
<td>cores</td>
<td>according to:</td>
</tr>
<tr>
<td>noise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- single layer PA</td>
<td>void content &amp; layer thickness</td>
<td>&gt; 20% &amp; ≥50mm</td>
</tr>
<tr>
<td>- twin layer PA</td>
<td>permeability test (Becker apparatus)</td>
<td></td>
</tr>
<tr>
<td>- thin wearing courses and thin inlays</td>
<td>verification of composition, compaction and layer thickness</td>
<td></td>
</tr>
<tr>
<td>raveling</td>
<td>visual inspection</td>
<td>no raveling</td>
</tr>
<tr>
<td>cracking</td>
<td>visual inspection</td>
<td>no cracking</td>
</tr>
</tbody>
</table>

**Figure 13: Performance criteria after construction**

### Performance assessment during warranty period

<table>
<thead>
<tr>
<th>property</th>
<th>assessment method</th>
<th>criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skid resistance</td>
<td>86% slip trailer</td>
<td>&gt; 0.38</td>
</tr>
<tr>
<td>Transversal evenness</td>
<td>ARAN laser rut depth measurement</td>
<td>rut depth &lt; 18 mm</td>
</tr>
<tr>
<td>Longitudinal evenness</td>
<td>ARAN IRI - measurement (D&amp;C)</td>
<td>IRI - value &lt; 3 m/km</td>
</tr>
<tr>
<td>Transversal slope</td>
<td>Aran slope measurement (D&amp;C)</td>
<td>no uniform criteria</td>
</tr>
<tr>
<td>Raveling</td>
<td>visual inspection</td>
<td>&lt; 20% stone loss/m² &lt; 25m/100m with 11-20% stone loss/m² no loss of deeper stones</td>
</tr>
<tr>
<td>Cracking</td>
<td>visual inspection</td>
<td>crack width &lt; 2 mm &gt; h over crack &lt; 11 mm less than 7 transversal cracks per 100m less than 30m longitudinal cracks per 100m connected cracks may not contain loose elements</td>
</tr>
<tr>
<td>Combined damage</td>
<td>visual inspection</td>
<td>moderate raveling + cracking may not have great extent</td>
</tr>
</tbody>
</table>

**Figure 14: Performance criteria during the warranty period**

**Conclusions**
There were limited discussions on contracts and contracting as it pertains to LLPs, but the contracting approach seems to be similar, in general, to that in Australia.

Information on typical contracts in the Netherlands was obtained. The D&C contracts have a warranty period of 7 to 10 years.

Summary and recommendations

Summary

- The concept of Long-life pavements (LLPs) is widely accepted in Europe and the UK, but only explicitly applied in the UK and Germany, while the pavement designs for high volume roads in the Netherlands are based on no structural defects during the design life (referred to as eternal pavements) and high modulus layers are used in France to increase the life of the pavements. Most information on the past performance of full depth asphalt pavements comes from UK studies in the 1990s. No documented recent case studies could be made available by the agencies visited.

- A group, ELLPAG was established to investigate LLP in Europe and the UK and produced a report in 2004 with a summary of the situation in the UK and Europe and recommendations for further research. A long-life pavement was defined by the Group as "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". The definition highlights the important elements of construction and maintenance in addition to the structural design. The
use of improved materials and/or designs to prevent the expected modes of deterioration occurring was identified by more than 80% of the group members as preferred design options. Unfortunately none of the recommendations have yet been developed any further.

- Long-life pavements are designed in the UK (maximum design traffic loading of $8\times10^7$ ESA), Germany (maximum design traffic loading of $3.2\times10^7$ ESA). The LLP designs are based, to a large extend, 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. However, validated M-E models do not exist for the design of LLP in Europe and the UK. As a consequence there is no uniform design method.

- Maintenance, involving the replacement of the surfacing layer only, is important for the performance of LLPs and should be based on a sound selection, asset management and design methodologies.

- A number of test devices, loading applications and test temperatures are used to determine failure resulting in differing fatigue values. Failure is generally defined as 50% of the original stiffness. Conversion from laboratory tests to field performance is problematic and no standard value or uniform conversion protocol exists. The use of existing pavement performance to calibrate the models was suggested as the most effective way of calibrating models or developing laboratory–field conversions. There is also recognition that horizontal tensile strains below the HMA may not be the governing strains since failure of thick layers may not be caused by bending.

- While healing is accepted as occurring, the definition and testing are complex and standard test procedures and conversion factors have not yet been developed (a value of 2.5 is used in the Netherlands, but it can be as high as 40). Indications are that temperature is more important than time and healing only takes place at high temperature.

- The benefits of higher quality (in terms of higher modulus, better deformation resistance, longer fatigue life and / or durability) material is recognized. Large amount of work is done both in Europe and the UK to develop and utilise higher quality HMA materials, e.g. EMEs, but no uniform European / UK design procedure exists for the non-standard materials, but all use the similar structural properties, e.g. stiffness, fatigue and deformation resistance. Also, RAP is widely used in standard mixes, but not in high modulus and / or high fatigue resistant mixes. Laboratory fatigue properties specified in France and in the Netherlands range between maximum strain values of 90 and 100 $\mu$m for conventional asphalt mixes and 130 $\mu$m for EME2 mixes (for the specified test method and temperatures).

- The latest Austroads, GUIDE TO PAVEMENT TECHNOLOGY PART 2: PAVEMENT STRUCTURAL DESIGN (2012) addresses the endurance limit, i.e. “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 for use with the Equation 11 fatigue relationship. It is anticipated that future research will enable this concept to be incorporated in the mechanistic design process.”

- 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.
Recommendations

- Australia would benefit from consideration of endurance strain levels in the design of flexible pavements and this should be further investigated (as also recommended after the 2010 AAPA study tour and some initiatives taken).

- Any local development should not rely on a significant amount of information from Europe and the UK as it is unlikely that the ELLPAG group will soon produce specific LLP design procedures. However, progress in the Europe and the UK should be monitored, with a specific focus on work being done at the TRL and Delft University.

- The best source of information to calibrate local models would be the performance of existing pavements, especially ones which had been rehabilitated (for which information on past traffic, pavement composition and failure mechanisms should be available).
Long life pavements - Questions & Responses

Usage and performance records
1. Examples and case studies
2. Composition, traffic, deflection history
3. Typical maintenance

Design aspects
1. Design procedures
2. Most appropriate approach - mechanistic or catalogue
3. Prioritisation of focus - design models or construction

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

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

Contract and construction
1. Initial construction cost - flexible vs. rigid
2. Specification requirements in D&C contract
Reference Material

List the presentations or other material gathered during the tour.

- FEHRL REPORT 2004/01 ELLPAG PHASE 1: A Guide to the Use of Long-Life Fully-Flexible Pavements
- HA design method 26/6 Design Manual for Roads and Bridges, 2006
- Richtlinie für die standardisierung des verbaues von erkehrsflächen, 2011 (in German)
- Pavement design manual (in French) - CATALOGUE DES STRUCTURES TYPES DE CHAUSSÉES NEUVES, 1998
- Austroads AP T199-12, Development of a Nonlinear finite Element Pavement Response to Load, 2012.
- Austroads AP-T131/09, Asphalt Fatigue Endurance Limit, 2009
1: Long Life Pavements

“Experience, design systems, use, durability and access to performance, data (deflections, materials, climate and traffic) for analysis”

BACKGROUND: Long life (or perpetual) pavements have been under discussion since the 1990s in many countries around the world. The objective is to design and construct a cost-effective pavement that would provide a sound structural foundation for long design periods (50 years or more). The basic design principle is to limit the strains in the structural asphalt layers to below a certain threshold level. The formal integration of long life pavement designs into standard pavement design methods seems to vary from country to country and accurate information about the extent of formal use is sketchy.

Some of the first recommendations on limiting bound pavement thicknesses were reported in the UK and considerable work has been done in Europe on material testing and structural evaluation. Australia has embarked upon research to incorporate long life concepts into the standard Australian pavement design procedures to take account of the ‘perpetual pavement concept’ underpinned by the asphalt fatigue endurance limit and healing which is widely accepted in the literature.

However, a number of issues hinder implementation in Australia, e.g.

- evidence of successful implementation by Road Authorities
- proven structural and material design procedures
- appropriate laboratory testing and criteria (moduli and fatigue properties)
- specification, construction and quality control requirements.

The study tour will involve interaction with a wide range of Road Authorities and research organisations and would contribute meaningfully to addressing the issues impeding the implementation of long life pavement designs in Australia.

... Ian van Wijk, Aurecon Consulting Engineers & Tour participant

An essential element of both the AAPA project and the soon to commence Austroads project is identifying a significant number of long life pavements which have been in service for at least ½ their design life. So we are looking for pavements that are at least 15 years old and preferably 30 years or more. Accordingly, it would be of considerable benefit if the study tour were able to prepare our way in sourcing this data. To provide at least some assurance these LLP are not fatiguing they need to have been periodically deflection tested over their lives.

... Geoff Jameson ARRB

AAPA has taken inspiration from the NCAT test track findings and consider the cumulative distribution of asphalt strain over the temperature / frequency spectrum offers a rational limiting
design criterion that can obviate the problems in modeling fatigue transfer functions, fatigue endurance limit, healing etc. We believe the analysis of the European performance data will facilitate the validation and calibration of the limiting cumulative distribution of asphalt strain for long life pavements.

... Ian Rickards AAPA consultant

Questions

Usage and performance records

1Q 1. Do you have examples of old LLP on heavily trafficked roads which have been periodically deflection tested over an extended period of time? No examples provided and there seems to be very little recent information available.

1Q 2. If so is it possible for AAPA/Austroads to obtain information about their pavement structure, past traffic loading and performance of these pavements and who would be best person to contact to obtain this data? N/A.

1Q 3. Are there case studies available on the benefits of using long life pavements? No specific case studies, but the FEHRL Report 2004/1 ELLPAG PHASE 1 contains useful information on the situation and views in Europe and the UK.

1Q 4. In what context are long life pavements used? What requirements are there for the pavement and foundation/subgrade as a whole? In countries where LLPs are used, they are used for high trafficked roads (> 8E+07 ESAs in the UK and >3.2E+07 ESAs in Germany). Pavement design procedures (mainly graphs and catalogues) and foundation/subgrade requirements are used.

1Q 5. What is a typical maintenance schedule for a long life pavement? Normal maintenance of the asphalt surfacing, e.g. reseal every 10 to 12 years. In addition efficient pavement maintenance management procedures are recommended.

Design aspects

1Q 6. Can you provide an example design of a long life asphalt pavement? Yes, see write-up.

1Q 7. What is the design procedure adopted for long life asphalt pavements in your country? Graph (in the UK), catalogue (in Germany) and standard design (in the Netherlands).

1Q 8. For how long has the current pavement design procedure been in place? Not specifically answered, but probably more than 5 to 10 years (in the UK).

1Q 9. What are the inputs to the mechanistic design procedure (e.g. moduli as a function of temperature and frequency, asphalt fatigue characteristics)? The mechanistic design procedure is only used in special cases (in the UK and the Netherlands). Then only stiffness (at a reference temperature) and "standard" fatigue relationship (i.e. same relationships that had been used for a large number of years) are used.

1Q 10. In multi layer construction how is the binder course and wearing course incorporated into the design process? In the UK as part of the bound layer for thickness design purposes and
in the Netherlands and Germany as layers with specified thicknesses on a bound base, i.e. thickness of base only determined (but considered to be structural layers). (Rephrase).

1Q 11. Is a catalogue of designs a more realistic solution (i.e. it recognises the enormous uncertainty in modeling; avoids the silliness of solutions which are designed primarily to give a commercial edge at bid time; it ensures parity in bids; it has an empirical basis)? Yes, that was the impression we got.

1Q 12. Certainly design models need to be refined for the long life pavement – the empirical evidence indicates designs are far too conservative and this is due to fatigue endurance and healing factors. Considering the complexity of the pavement structure and its environment, is it realistic to expect to hone the thickness design other than by climatic zone? This was not explicitly discussed, but no specific adjustments in the UK, the Netherlands (climate reasonably uniform) and German (but subgrade frost considered) design procedures.

1Q 13. In research where is the best bang for buck given extremely limited resources in Australia; a) refining and honing thickness design models or; b) refine construction detailing, specification and auditing to ensure high construction quality or; c) other? Not specifically discussed, but ELLPAG report 1 reports a preference for the use of improved materials and/or design to prevent the expected modes of deterioration occurring. High quality construction considered by all to be important.

Material properties

1Q 14. What materials are used in long life pavements in Europe? In Australia, some areas have effective long life pavements with slag road base layers, with 100-150mm AC on top. Our study focused on fully flexible, i.e. asphalt surfacing, binder and base layers. A variety of materials are used below that - crushed stone, hydraulic (the UK), recycled building rubble (the Netherlands).

1Q 15. How are different asphalt mixtures accounted for in pavement designs (e.g. high modulus / EME / modified asphalt / RAP / WMA etc.)? It varies, but all available materials are not covered in the design. The UK design procedure prescribes different thicknesses for different types of materials (RAP and WMA not yet included), while the Dutch uses a standard mix (and therefore thickness).

1Q 16. What testing is carried out on sub-bases prior to paving of asphalt layers? No detailed information provided, but density (the Netherlands) and light falling weight deflectometer tests (the UK) mentioned [subgrade only?].

1Q 17. How have the material properties used in the design procedure been validated? No formal validation procedure mentioned. Mix laboratory properties defined on projects. Not clear how they relate to the structural design properties.

1Q 18. Are the apparent laboratory performance gains in PMB materials implemented in thickness design? Demonstrated in laboratory (research) tests, but not included in the standard UK and Dutch designs.
1Q 19. How is the modulus of asphalt mixtures measured? *Frequency sweep.*

1Q 20. Has work been done in Europe correlating dynamic modulus with indirect tensile modulus, and the relationship to insitu modulus? *Not addressed in the discussions. Some work could have been done at Delft University.*

1Q 21. The lack of good data and modeling somewhat precludes the opportunity to introduce exotic binders. For instance, do we know enough about the lab/field fatigue relationship, fatigue endurance and healing and long-term performance of PMB mixes, to determine if we can offset the added cost of the PMB by thickness reduction and still offer overall savings? *A large amount of information is available (e.g. at Delft University and BP in Germany), but none of the road agencies (except perhaps in France) incorporated into their design procedures. Mainly due to the complexities of testing and conversion from laboratory test results to field performance.*

1Q 22. Is there any on-going monitoring of material properties? *Nothing formal presented.*

1Q 23. How is curing taken into account in terms of design moduli? *The Dutch increases the fatigues relationship by a factor of 2.5.*

1Q 24. Can RAP and other construction waste or crushed concrete be included in the design and construction of long life asphalt pavements? *None of the road authorities visited had done that (except perhaps in laboratory studies).*

**Fatigue & healing**

1Q 25. How can fatigue testing be used to determine the endurance limit for asphalt mixes? What are the influences of test method and specimen size? Should the standard test method be modified? *Fatigue testing had not been used to develop endurance limits for structural design, but fatigue limits are defined for base materials on high trafficked roads. The test method and specimen size have a significant influence on the results. Different test equipment and protocols are used in Europe and the UK, which makes a comparison of results impossible [difficult/cumbersome?].*

1Q 26. Fatigue testing – what is the definition of failure and how is it related to field performance? *Failure is defined as a sample reaching 50% of its original stiffness. The only formal conversion from laboratory to field performance presented was in the Netherlands, i.e. a factor of 10.*

1Q 27. Do the specific binders used have an impact on reducing the fatigue strain and hence increase the life of the long life pavement? *Yes, demonstrated in many laboratory studies.*

1Q 28. Healing of asphalt mixes, what is the influence on very long life flexible pavements and how would you incorporate it into a design procedure? *The effect of healing was recognized, but the influence neither quantified nor incorporated in designs.*

1Q 29. Has the endurance limit and healing of PMB mixes been evaluated? *In laboratory studies, e.g. at Delft university.*
1Q 30. Will the axle loading, triaxle vs. single axle and frequency of loading affect the healing of asphalt? Prof Molenaar found that temperature is the main contributor, i.e. more than loading frequency. That means the effects of the axle loading configuration may be small.

1Q 31. Australia usually employs a ‘fatigue layer’ at the underside of the bound materials. Is there any equivalent in Europe? High modulus layers used in France, the UK and Germany which could achieve the same results, but the term “fatigue layer” not mentioned.

**Contract and construction**

1Q 32. At the tender stage of a project, how are flexible pavements compared with rigid pavements? Not discussed, but presumably on whole-of-life costs and environmental effects.

1Q 33. In Design and Construct contracts, is there experience in Europe of specifying perpetual pavement characteristics? What are the specified requirements? This was only raised in the discussions with Rijkswaterstaat officials.

1Q 34. For roads designed and constructed according to this design procedure are all roads still structurally sound? Has there been any monitoring of the network in the succeeding years post construction? Not formally to document performance.