



Guidance on the development, assessment and maintenance of long-life flexible pavements

**Prepared for Highways Agency, Quarry Products Association,
and Refined Bitumen Association**

D Merrill

First Published 2005
ISSN 0968-4107
ISBN 1-84608-638-8
Copyright TRL Limited 2005.

This report has been produced by TRL Limited, under/as part of a contract placed by the Highways Agency, Quarry Products Association and Refined Bitumen Association. Any views expressed in it are not necessarily those of the Highways Agency, Quarry Products Association and Refined Bitumen Association.

TRL is committed to optimising energy efficiency, reducing waste and promoting recycling and re-use. In support of these environmental goals, this report has been printed on recycled paper, comprising 100% post-consumer waste, manufactured using a TCF (totally chlorine free) process.

CONTENTS

	Page
Executive Summary	1
1 Introduction	3
2 Background	3
2.1 Long-life fully-flexible pavement concept	3
2.2 The benefits of long-life pavements	4
2.3 The design of new long-life pavements	4
2.4 Evolved long-life pavements	5
2.5 Assessment and upgrading within an assessment framework	6
2.6 Long-life pavements and robust pavements	6
3 Existing methods of structural assessment and upgrading	7
3.1 Structural assessment	7
3.2 Upgrading	8
4 Enhancements to the existing assessment and upgrading methods	9
4.1 General approach	9
4.2 Upgrading	11
4.2.1 <i>Upgrading method for pavements up to 400 mm TTBM using the existing assessment criteria</i>	12
5 Condition assessment of long-life and robust pavements	13
5.1 Condition assessment advice from the Design Manual for Roads and Bridges	13
5.2 Additional condition assessment advice for cracking and rutting	14
5.2.1 <i>Depth of cracking</i>	14
5.2.2 <i>Rutting</i>	14
6 Maintenance techniques for long-life or robust pavements	15
6.1 Existing treatments covered in the design manual for roads and bridges	15
6.2 Proposed alternative treatments	16
6.3 Treatment selection for long-life and robust pavements	18
7 Potential benefits of long-life and robust pavements	18
8 Summary	19
9 Acknowledgements	19
10 References	19

	Page
Appendix A: Supporting case studies	21
Appendix B: A statistical method for the objective assessment of trends	25
Abstract	26
Related publications	26

Executive Summary

This guidance originates from research that was jointly sponsored by the Highways Agency, the Quarry Products Association and the Refined Bitumen Association. The aim of the research was to enhance the long-life pavement assessment and upgrading methodologies so that they may be applied more widely than is currently permitted; it also aimed to present clearly the current advice on the maintenance options for long-life flexible pavements, and to introduce some additional techniques that could be successfully applied.

The guidance is a single resource dedicated to providing advice on the construction, assessment and maintenance of pavements that are not expected to experience structural deterioration, commonly referred to as long-life pavements. In addition to the findings of the research, the guidance uses extracts from the Design Manual for Roads and Bridges (DMRB) and also the information collected in the long-life flexible pavement design document TRL Report TRL250.

The concept of robust pavements has been introduced. Robust pavements are expected to deteriorate in a similar fashion to long-life pavements; however, provided that these pavements demonstrate similar characteristics to long-life pavements, these pavements can be thinner than long-life pavements. The main difference between long-life pavements and robust pavements is the level of risk associated with structural deterioration; robust pavements have a higher risk of structural deterioration than long-life pavements although this additional risk can be mitigated by the appropriate adjustment of maintenance assessment strategies.

Enhanced advice for the assessment and upgrading of robust and long-life pavements has been proposed. This advice has been designed to complement, but not replace, the existing Highways Agency practices and it extends the applicability of the concept beyond the trunk road network.

A number of maintenance treatments that are suitable for robust and long-life pavements are listed. In addition to these treatments that are contained in the existing versions of the DMRB, two novel treatments are presented that offer the opportunity to maintain long-life pavement in a more efficient and sustainable manner: trench inlay and partial depth inlay.

The benefits of the long-life pavement concept and the likely benefits arising from this guidance have been considered. In summary, the guidance:

- Enables more accurate future budgeting of maintenance funds.
- Prevents unnecessary strengthening.
- Enables some robust pavements with a medium risk of structural deterioration to be developed to a long-life pavement with a lower risk of structural deterioration.
- Assists maintenance engineers better define the evidence for maintenance decision processes.

As well as describing the economic and environmental benefits of the long-life pavement concept, this guidance introduces:

- The concept of robust pavements which enables many of the benefits of the long-life pavement to be obtained for a wider range of pavements.
- Enhanced assessment advice that provides more confidence in the assessment of robust and long-life pavements.
- For robust pavements, enhanced upgrading methods that can be used to reduce the risk of future structural deterioration.
- More economic maintenance treatments for long-life pavements.

The scope of this guidance covers only fully-flexible pavements that are not expected to deteriorate structurally. The guidance does not cover totally new pavement constructions, which have been covered in TRL Report TRL250; however, aspects of the design of new long-life pavements are included for completeness. The guidance includes:

- The assessment of existing pavements to gauge the likelihood of structural deterioration occurring in the future.
- The creation of long-life, or robust pavements that are unlikely to experience structural deterioration, by the appropriate maintenance of existing flexible pavements.
- Maintenance techniques that are appropriate to long-life or robust pavements.

1 Introduction

This guidance originates from research that was jointly sponsored by the Highways Agency, the Quarry Products Association and the Refined Bitumen Association. The aim of the research was to enhance the long-life pavement assessment and upgrading methodologies so that they may be applied more widely than is currently permitted. It also aimed to present clearly the current advice on the maintenance options for long-life flexible pavements, and to introduce some additional techniques that could be successfully applied.

The guidance is a single resource dedicated to providing advice on the creation, assessment and maintenance of pavements that are not expected to experience structural deterioration, commonly referred to as long-life pavements. The guidance uses extracts from the Design Manual for Roads and Bridges (DMRB) and also the information collected in the long-life flexible pavement design document TRL Report TRL250; the extracts from the DMRB are highlighted throughout this guidance in *italics*.

In order to apply the long-life pavement concept to a wider range of pavements, the concept of robust pavements has been introduced in this report. Robust pavements are expected to deteriorate in a similar fashion to long-life pavements; however, provided that these pavements demonstrate similar characteristics to long-life pavements, these pavements can be thinner than long-life pavements. The main difference between long-life pavements and robust pavements is the level of risk associated with structural deterioration; robust pavements have a higher risk of structural deterioration than long-life pavements although this additional risk can be mitigated by the appropriate adjustment of maintenance assessment strategies.

Enhanced advice for the assessment and upgrading of robust and long-life pavements has been proposed. This advice has been designed to complement, but not replace, the existing Highways Agency practices and it extends the applicability of the concept beyond the trunk road network.

A number of maintenance treatments that are suitable for robust and long-life pavements are listed. In addition to these treatments, that are contained in the existing versions of the DMRB, two novel treatments are presented that offer the opportunity to maintain long-life pavement in a more efficient and sustainable manner: trench inlay and partial depth inlay.

The scope of this guidance covers only fully-flexible pavements that are not expected to structurally deteriorate. The guidance does not cover completely new constructions; however, aspects of the design of new long-life pavements are included for completeness. As such, the guidance includes the assessment of existing pavements to gauge the likelihood of structural deterioration occurring in the future; the creation of long-life or robust pavements that are unlikely to experience deterioration structurally by the appropriate maintenance of existing flexible pavements; and maintenance techniques that are appropriate to long-life or robust pavements.

2 Background

Long-life pavements are a particular type of pavement. Although it is attractive to define such pavements in terms of physical attributes such as thickness, material type or stiffness; the long-life pavement concept is more adequately described by the functional aspects of the system.

The European Long-Life Pavement Group (ELLPAG) has developed a generic definition for long-life pavements that is independent of the type of construction or national technical standards.

‘A Long-life Pavement is a type of pavement that can be identified as one lacking any deterioration in either the foundation or the structural pavement layers. Any distresses that might occur are confined to the surfacing layers only.’

In this definition (FEHRL, 2004), deterioration is whatever type or degree of deterioration that a network manager considers significant and that may result in structural maintenance being required. However, in this document only flexible pavements are considered and the behaviour is described in more detail.

2.1 Long-life fully-flexible pavement concept

For a detailed description of the concept of a long-life flexible pavement, precise and consistent terminology for the layers of the pavement system is essential. Figure 2.1 shows the terminology used to describe the layers of a flexible pavement.

Earlier research has identified general behavioural characteristics for heavily trafficked flexible pavements, these were:

- Stiffening or curing of base materials caused by hardening of the bitumen leading to an increase in pavement strength with time.
- Fatigue cracking that initiates at the bottom of the base layer has rarely, if ever, been encountered.
- Cracking of the asphalt pavement can occur in the surfacing and is due, in part, to embrittlement of the binder in the surface course. If cracking in the surfacing is allowed to progress unchecked, the propagation of cracking through the main pavement layers may occur.
- Pavement deformation is often due to internal deformation of the surfacing rather than deformation throughout the entire structure (including the subgrade).
- Pavements are most vulnerable in the first few years of their life, because curing of the asphalt is yet to occur. Therefore potential long-life pavements may suffer irreversible structural damage in their early life.

These characteristics were collated in a statement provided in TRL Report TRL250: ‘A well constructed, flexible pavement that is built above a defined threshold strength will have a very long structural service life provided that distress, in the form of cracks and ruts appearing at the surface, is detected and remedied before it begins to affect the structural integrity of the road’. This conclusion was used as the basis for the design of long-life flexible pavements.

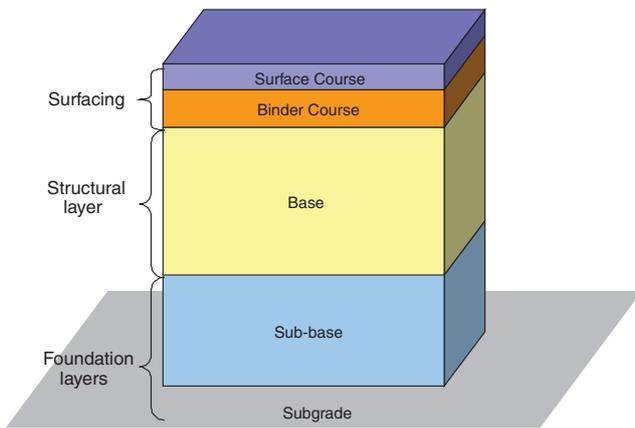


Figure 2.1 The layers of a long-life flexible pavement

The concept of long-life pavements was naturally extended to the assessment and maintenance of existing flexible pavements. This change to the approach to the assessment and maintenance of these pavements was required in order to take full advantage of these characteristics. These changes have been incorporated into the current version of the Design Manual for Roads and Bridges.

2.2 The benefits of long-life pavements

The adoption of the concept of long-life flexible pavements produces obvious economic and social benefits.

In terms of the construction of a new road, the concept of threshold strength allows for adjustments to be made so that design thicknesses for increasing levels of traffic are capped. These capped thicknesses limit the amount of material that is required to construct a road and therefore can result in more efficient road construction. In addition, the consumption of non-renewable resources can be reduced in terms of road construction materials as well as the energy required for production and transportation.

In terms of maintenance of an existing road, the long-life concept allows road managers to take advantage of pavement structures that are not expected to deteriorate structurally. Excavation and replacement of structural layers of the pavement are unlikely to be required. Maintenance is then restricted to the surfacing layers that can be replaced quickly. The costs of maintenance in terms of direct costs and costs arising from delays to users are reduced. There are similar environmental benefits to that for new construction.

The speed of maintenance is a particular benefit of long-life pavements. The pavement can be maintained by performing maintenance operations during night working with little or no impact on the users. Such a facility allows the impact of maintenance to be minimised and, given that works can be completed within a matter of hours, the maintenance works can be more closely managed.

2.3 The design of new long-life pavements

The pavement structure is a system of layers whose individual performance is reliant upon the successful performance of the other layers. In order to produce a

long-life pavement, it is essential that each of the pavement layers is fulfilling its role to a high standard thereby ensuring the integrity of the structure for long-life.

TRL Report TRL250 comprehensively covered the design of long-life flexible roads which included design and construction considerations for each layer in the pavement from the foundation to the surfacing. This report should be carefully considered prior to designing a flexible long-life pavement, however a summary of the main elements of the report is provided in this guidance.

Foundation layers

The primary role of the foundation is to provide a platform on which to construct the structural layers and the surfacing. In order to carry out this role, it shall be designed so that it protects the subgrade layer during construction in adverse weather conditions. The foundation should also be constructed so that it can carry the construction traffic without significant damage.

In order to design the thickness of the foundation, the subgrade is assessed in terms of either equilibrium CBR (California Bearing Ratio) or a CBR measured at the time of construction. The thickness of foundation is then chosen according to established design charts provided in HD25 (Highways Agency, 2005) and reproduced in Figure 2.2.

The performance of a foundation layer is controlled by the design of the layer and the quality of its construction. The foundation of a long-life pavement shall be constructed to a high quality to ensure that it provides adequate stiffness in order to ensure complete compaction of the overlying layers. The foundation should be made durable so that it maintains, or develops, support to the pavement layers throughout the life of the pavement. Durability and support should be checked, albeit by proxy, by some form of end-performance specification system during construction.

Structural layers

The designs for the structural layers of a long-life flexible pavement have been formed using strong evidence regarding the behaviour of pavements comprising thick asphalt layers. This evidence demonstrates that:

- The deterioration of thick, well-constructed, flexible pavements is hardly ever structural and generally occurs at the pavement surface.
- The properties of asphalt change with time. For the structural layers, these changes have been termed ‘curing’ which is where the asphalt layers are seen to increase in stiffness, and hence strength, with age. Curing was proposed as a primary reason for the lack of structural damage in thick, well-constructed pavements.

A threshold thickness, determined using analytical methods, for avoiding structural deterioration in new pavement constructions was determined as 270 mm for a flexible pavement containing DBM100 material; this was deduced from the observed performance of mature pavements and some conservatism for ensuring that deterioration would not occur in early life. Since surface cracking in thick pavements was also observed to penetrate

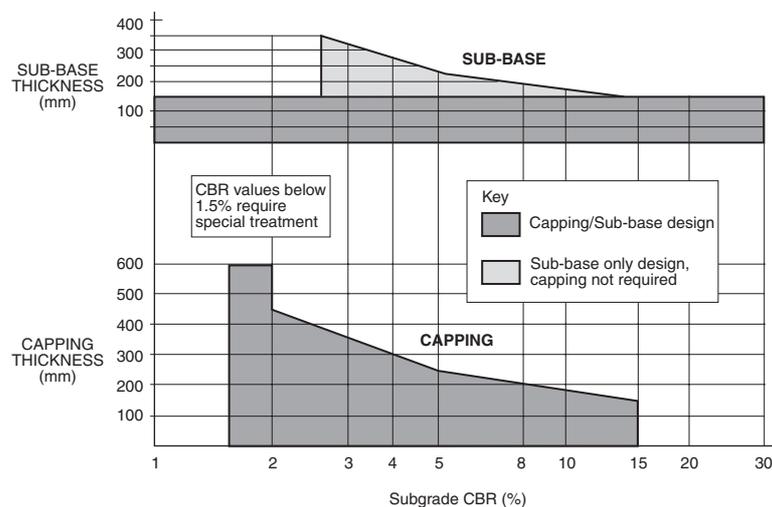


Figure 2.2 Foundation design charts in TRL Report TRL250

up to 100 mm, this thickness was added to the threshold together with a further 20 mm for the anticipated increase in maximum legal axle load from 10.5 to 11.5 tonnes. This gave a threshold thickness for the asphalt layers in a long-life flexible pavement as 390 mm, which was equivalent to designs for a total traffic loading of 80 msa.

It was therefore proposed that designs for traffic in excess of 80 msa should be capped at the threshold thickness. Additional thickness above the threshold thickness would serve no structural purpose. Equivalent design thresholds have been determined for other asphalt materials and these have been tabulated in Table 2.1.

Table 2.1 Design thicknesses for long-life roads using standard asphalt base materials

Base material	Threshold thickness for long-life design
DBM125	420 mm
DBM100	390 mm
DBM50	350 mm
HDM	320 mm
HMB35	310 mm

Surfacing

The surfacing of a long-life, flexible pavement has to serve many functions. In TRL Report TRL250, the attributes of an ideal surfacing are listed as:

- offering good skid resistance;
- allowing for rapid drainage of surface water;
- minimising traffic noise;
- resisting cracking and rutting;
- withstanding traffic turning and braking forces;
- protecting the underlying road structure;
- requiring minimal maintenance;
- being capable of being re-cycled or overlaid;
- being durable;
- giving value for money.

Nunn *et al.* (1997) acknowledged that while many surfacing treatments have some of the attributes listed above, no treatments have them all. The advice offered in TRL Report TRL250 concerns the appropriate selection of materials for long-life pavements from traditional hot rolled asphalts to thin surfacings. Indeed, the critical performance parameter may be the maintenance of surface characteristics such as texture and frictional properties for long-life pavements.

2.4 Evolved long-life pavements

The long-life pavement concept is based around the idea of a threshold strength above which structural deterioration is unlikely to occur. It is acknowledged that the properties of asphalt pavements change with time due to temperature effects but also due to long-term changes in the chemical composition of the bitumen known as ‘ageing’.

The ageing of the asphalt in the structural layers of the flexible pavement is often termed ‘curing’. As the material ages the effective stiffness of the material increases and improves the load spreading ability of the structure. In contrast, curing also reduces the resistance of the material to cracking for a given level of strain. TRL Report TRL250 assesses the risk of cracking due to the action of curing. It was deduced that the overall risk of cracking is likely to be reduced since the strains in the structure will also reduce as a result of increased load spreading ability. Pavements that contain materials which cure significantly develop strength with age, at some time exceeding the threshold strength required so that structural deterioration is no longer anticipated, resulting in a long-life pavement.

Prior to the creation of the concept, pavements were constructed and maintained according to conventional methodologies that guarded against anticipated deterioration in the structure of the pavement. Conventional methodologies resulted in pre-emptive strengthening maintenance that appear in some cases to have increased the pavement strength beyond the threshold strength, thereby forming a long-life pavement.

2.5 Assessment and upgrading within an assessment framework

Figure 2.3 illustrates a general framework for pavement maintenance assessment in the form that is currently used by the Highways Agency; this framework applies to all pavement types, including long-life pavements. The framework includes two levels of assessment: a network level and a scheme level. The two levels are defined so that the requirements for the network as a whole or an individual pavement can be determined.

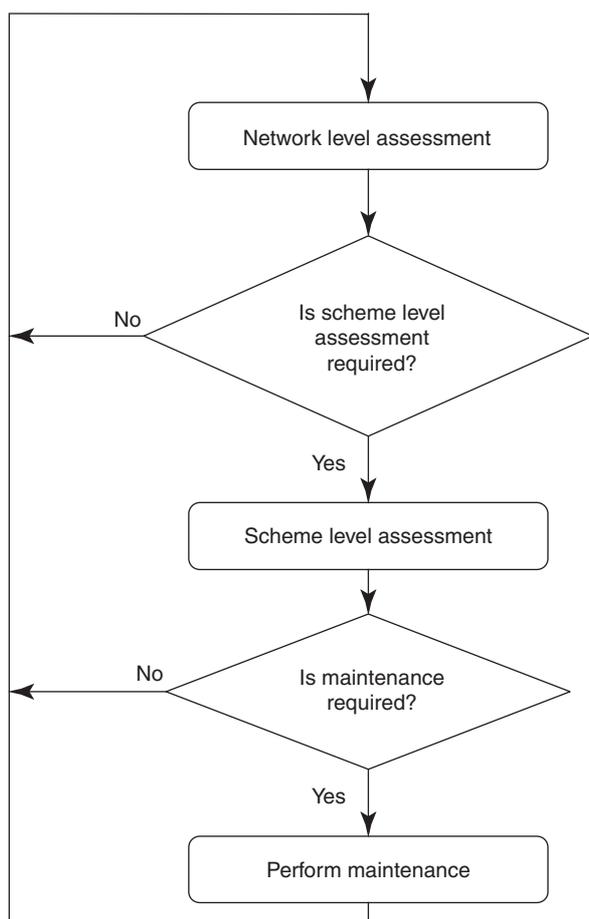


Figure 2.3 The general framework for pavement maintenance assessment

Network level assessments are performed to quantify the maintenance needs of the network as a whole. Network level assessment includes the routine network level condition surveys that are performed on an annual basis. These routine surveys provide a measure of condition that is used to calculate performance indicators, identify potential maintenance schemes and set the global maintenance budget. As part of the network level assessment, schemes can be selected for scheme level assessment.

Scheme level assessments are performed to define the actual maintenance requirements of a particular scheme. The routine condition data, collected at network level, can be included in a scheme level assessment but should be supplemented with specific surveys to assist in defining more closely the actual condition of the pavements and the

appropriate maintenance requirements. The scheme level assessment also includes an economic appraisal. For a particular scheme there may be a range of maintenance options available; the option offering the most economic long-term value would normally be favoured.

One of the maintenance options under consideration at scheme level may indeed be to upgrade the pavement to 'long-life'. Upgrading of the pavement will only be performed as part of this maintenance assessment framework, where the need for maintenance has been identified and the upgrading operation justified as the most economic maintenance option.

The assessment techniques discussed in this report are more likely to be performed at scheme level than at a network level; this is because the data required for the assessment are unlikely to be provided by current routine survey data.

The main purpose of assessing the condition of pavements is to estimate their future maintenance requirements. Potential robust and long-life pavements are a concept rather than being absolutely definable in terms of some geometric or structural property; this concept covers the anticipated modes of deterioration and associated maintenance requirements. It is therefore impossible to rigorously determine whether a pavement is currently long-life or robust from its measured condition. Thus, the scheme level structural assessment procedures in this guidance are performed to class the pavement based on whether the likely future maintenance needs are consistent with those associated with the long-life pavement or robust pavement concept. However:

The structural pavement assessment procedures cannot determine what is, or is not, a long-life or robust pavement; but they can indicate the likely future maintenance needs and monitoring strategy.

Upgrading a pavement to form a long-life or robust pavement implies that by consciously carrying out some appropriate maintenance operations, the structural properties of the pavement are developed in such a fashion that the structural layers of the road are not expected to deteriorate. In the case of robust pavements, this expectation may be dependent on the expected traffic loading.

2.6 Long-life pavements and robust pavements

A pavement that does not structurally deteriorate will require only its surface layers to be maintained. In the UK, long-life pavements have been considered as the only type of pavement to fulfil this role. According to the assessment methods described in HD29 (Highways Agency, 2005), potentially long-life pavements can be identified in the UK as having low deflections and an asphalt layer thickness in excess of 300 mm; the thickness threshold for new constructions can be higher than for the assessment of existing pavements to take into account natural deviations in material properties and thickness that occur during construction as well as protecting against damage in early life. The identification criteria have been set in a relatively conservative approach in order to provide confidence in the detection of potentially long-life pavements. Therefore it is likely that some pavements which are constructed thinner

and have higher deflections than long-life pavements will also require that only the surface layers are maintained.

The information on pavement performance contained in TRL Report TRL250 suggests that there may be a significant number of flexible pavements with asphalt layers that are greater than 200 mm but less than 300 mm thick, which do not require structural maintenance. At this stage, it is unwise to suggest that these pavements are also long-life pavements since it is possible that the structure is just strong enough to carry the daily traffic without any detriment to the structure; an increase in daily traffic could bring about structural deterioration in the future.

Surface initiated deterioration such as surface cracking will, in theory, have less effect on a thick flexible pavement than a thinner pavement. Furthermore, the current threshold thickness for long-life pavements of 300 mm includes a buffer zone for surface initiated deterioration. The buffer zone ensures that there is a minimal risk that surface initiated deterioration develops into structural deterioration. Reducing the overall thickness of the pavement reduces this buffer zone and consequently increases the theoretical risk of deterioration requiring major maintenance.

Nonetheless there is a case for the identification of pavements that are not expected to deteriorate structurally but may require regular monitoring and maintenance to reduce the additional risks that structural deterioration occurs in the future. These pavements have been defined as 'robust' pavements.

A robust flexible pavement will:

- have an asphalt thickness of at least 200 mm;
- not experience structural deterioration in the form of fatigue cracking or structural deformation provided that the traffic levels do not exceed a certain level;
- be supported by a good quality foundation;
- require regular structural assessment;
- be maintained in a similar fashion to long-life pavements.

Robust pavements are unlikely to offer the same value for money as long-life pavements in heavily trafficked locations; this is due to the increased risk of structural deterioration. However, for locations where the traffic levels are moderate, robust pavements could provide significant economic benefits through the adoption of long-life maintenance principles with the appropriate monitoring and timely maintenance to mitigate the risk of structural deterioration.

Robust pavements may have a greater risk of deteriorating structurally than long-life pavements. If this risk is considered to be unacceptable it may be more desirable to upgrade the pavement by structural strengthening in order to become potentially long-life pavements.

3 Existing methods of structural assessment and upgrading

This section details the methods for the structural assessment of pavements that are potentially long-life pavements and the upgrading of existing pavements to form potentially long-life pavements. These methods are currently included in HD29 (Highways Agency, 2005).

3.1 Structural assessment

The deflectograph (Figure 3.1) is a long established tool for measuring the structural capacity of a pavement. This device has been used by a wide range of authorities both in the UK and abroad. A deflectograph survey is carried out at slow speed and a measurement of the peak deflection under both the nearside and offside wheel is taken. A deflection measurement is taken approximately every 4 m. The load on the pavement is applied by two dual wheel assemblies, each applying a wheel load of 3.75 tonnes. It is advised that only data from deflectograph surveys less than four years old can be considered as an adequate representation of the current condition of the pavement.



Figure 3.1 A defelectograph

Nunn and Ferne (1997) presented criteria for the assessment of long-life pavements using the deflectograph. The method identifies potentially long-life pavements as those with a significant thickness of asphalt and with low deflections; the criteria reside as part of the current advice in HD29 (Highways Agency, 2005) and have been reproduced in Figure 3.2.

The criteria are applied using a value of standard deflection and the Total Thickness of Bituminous Material (TTBM) in the following manner:

Determination of standard deflection

The standard deflection is typically presented as the 85th percentile of the deflectograph deflections over a 100 m length corrected to a standard temperature of 20°C.

Determination of TTBM

The *Design Manual for Roads and Bridges* gives specific advice for the determination of TTBM. A diagrammatical representation of this advice is provided in Figure 3.3.

Pavements classified as Determinate Life Pavements

These pavements are likely to have a determinate life and are therefore unlikely to be covered in this guidance. Advice on the likely deterioration modes and maintenance requirements of these pavements is available in the *Design Manual for Roads and Bridges*.

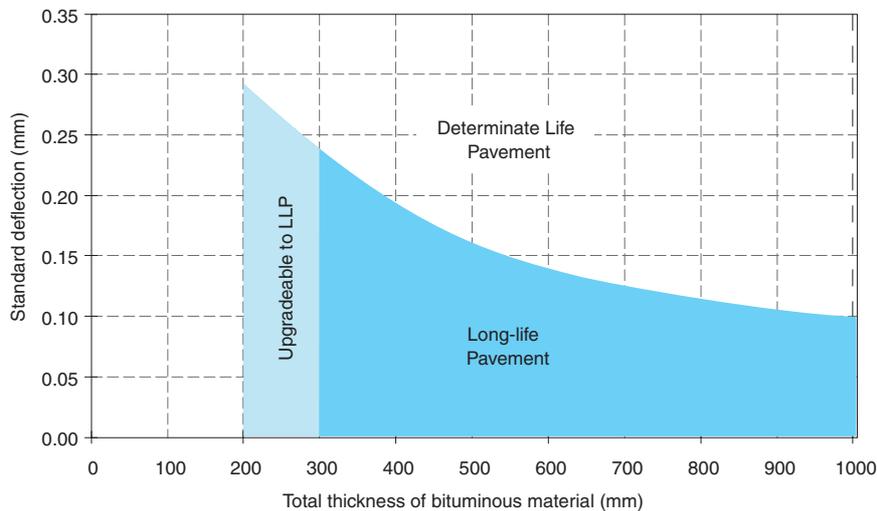


Figure 3.2 Pavement categories in HD29 (Highway Agency, 2005)

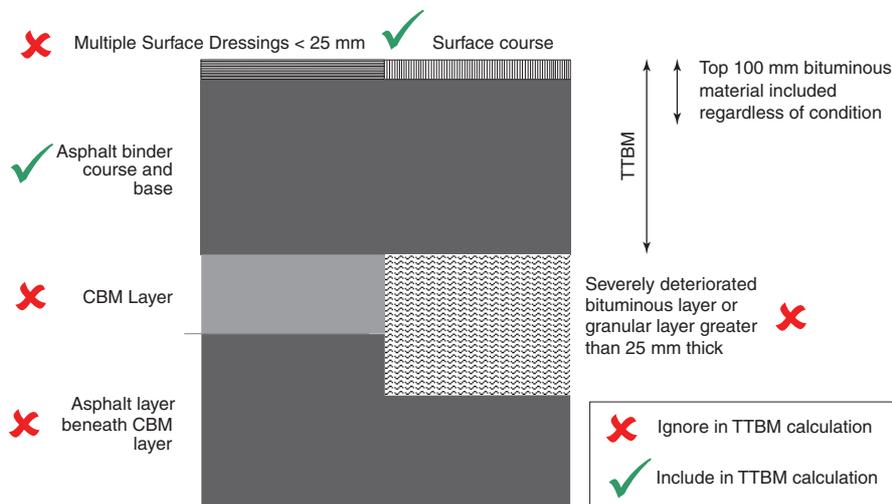


Figure 3.3 Calculation of TTBM

Pavements classified as Long-Life Pavements

The *Design Manual for Roads and Bridges* advises that ‘pavements in this category can be expected to last for an indefinite period provided that deterioration at the surface is not allowed to compromise the pavement structure’.

It follows that these pavements are not expected to receive any structural improvement by the application of an overlay if there is no structural deterioration. The maintenance requirements of pavements in this category should then be limited to treatment of the surfacing only.

Pavements classified as Upgradeable to Long-Life Pavements

Not all pavements in this category will be suitable for classification as ‘Upgradeable to Long-Life Pavement’ (ULLP) status; these assignments should only be adopted if there is other evidence to suggest that the pavement is not experiencing structural deterioration.

For pavements that are suitable for upgrading to long-life pavements, the road owner should expect that long-life pavement status could be achieved by the application of no

more than 100 mm of overlay. The actual overlay thickness is that required to bring the TTBM up to 300 mm, providing this is at least 40 mm. Note that the *Design Manual for Roads and Bridges* advises that the actual overlay requirements should not be based upon the results of deflection analyses alone and should be confirmed using evidence of the existing material condition.

A ULLP must, by definition, also be considered as a robust pavement provided that the associated increased risk of structural deterioration was accepted. An LLP should not contain layers that have structural deterioration; therefore a ULLP must also be free from structural deterioration.

3.2 Upgrading

The *Design Manual for Roads and Bridges* contains advice for the upgrading of an existing pavement to one having long-life properties. Using the techniques described in Section 3.1, a pavement can be classified as ULLP. A ULLP has an asphalt layer between 200 mm and 300 mm thick and has low deflections that would be expected to fall within the

long-life pavement category according to the criteria shown in Figure 3.2 when overlaid to a TTBM of 300 mm. This particular definition should be remembered when applying the deflectograph-based assessment techniques.

By definition, any existing pavement structure can be upgraded to form a long-life structure and the methods for upgrading the structure could range from a moderate overlay to a full reconstruction of the entire pavement. However, economics will dictate when the upgrading of a structure to be a long-life flexible pavement is feasible. Long-life pavements are most advantageous in heavy traffic situations and therefore it is in these situations where the economics are likely to advocate long-life pavements; therefore, it would be expected that in most cases an existing structure on a medium to heavily trafficked route will be of reasonable thickness and therefore require a limited overlay if upgrading to long-life is desirable. The definition of ULLP provided in the DMRB should therefore cover most upgrading situations.

HAPMS Confirm is the Highways Agency's Pavement Management System. HAPMS Confirm has the facility for calculating the overlay required for pavements classified as ULLP so that they may be considered to be 'long-life'. This calculation is simply the difference between the TTBM and 300 mm, subject to the minimum overlay thicknesses defined in the software.

4 Enhancements to the existing assessment and upgrading methods

The following section details a number of proposed enhancements for the structural assessment of pavements that are potentially long-life pavements and the upgrading of existing pavements to potentially 'long-life'. These methods may be used in addition to the existing methods to assess whether a pavement is likely to be either a robust or a long-life pavement. Conflicts should be resolved at a scheme level on the basis of the balance of evidence supporting the long-life characteristics. Many of the methods contained in this section are indeed carried out as part of a scheme level assessment. However, the methods have been highlighted in this document for their direct value in determining the likelihood that the future structural maintenance needs for robust or long-life pavements.

Part of the research work carried out in this project looked at the possibility of producing an assessment and upgrading method based upon the structural properties of individual pavement layers obtained from a combination of in-situ and laboratory testing. At the time of writing, it was considered that the current state of knowledge regarding the elements required was not sufficiently robust to achieve a satisfactory method. As a consequence, a central deflection-based approach has been used for the proposed methods rather than attempting to obtain the properties of individual layers.

4.1 General approach

In addition to the deflection and thickness approach for the assessment of pavement detailed in Section 3, the

enhanced advice considers the condition of the pavement in conjunction with the design assumptions for a long-life pavement given in TRL Report TRL250. The characteristics of a long-life pavement are such that:

- 1 It demonstrates resistance to structural damage by the level of traffic it carries.
- 2 All the asphalt layers are sound.
- 3 It has a strong foundation.
- 4 The asphalt layers are suitably thick.

The existing methodology covers, in part, a number of these criteria. Thickness is covered by the use of TTBM in the existing methodology. Low deflections are a consequence of strong foundations and sound asphalt materials. However, greater confidence can be gained from the existing assessment techniques provided these criteria are also met individually. An individual criterion can also assist in providing an additional reason for demonstrating that the pavement is not expected to deteriorate structurally, even though the existing classification method has defined them as either long-life or robust pavements.

The enhanced assessment method uses a combination of tests and observations to show how strongly a pavement exhibits the four characteristics of a long-life pavement.

The methods of showing that the pavement has not been damaged by traffic (1) and that it has a strong foundation (3) can utilise falling weight deflectometer (FWD) measurements. The FWD is a widely used tool as part of the assessment of pavement condition at scheme level. The Highways Agency currently advocates the use of deflectograph testing as the primary measure of pavement strength (Highways Agency, 2005), however the FWD can be used to provide additional detailed information on the condition of the pavement layers.

The Highways Agency employs a system of annual calibrations for FWD devices that are used on its network. A FWD device (Figure 4.1) should have satisfied the annual calibration trial criteria before it can be used for this method, in addition to the check for consistency between these devices that is described in HD29



Figure 4.1 The falling weight deflectometer (FWD)

(Highways Agency, 2005). Care must be taken with the interpretation of deflection measurements; a thorough knowledge of the pavement construction and its foundation is essential, as is the use of appropriate temperature correction techniques.

For synergy with any network level structural assessment, the enhanced techniques should ideally be made on 100 m sections of the pavement under evaluation.

Demonstration of each of the four characteristics of long-life and robust pavements are used to build confidence for the likely future maintenance needs and may be used to support the original classification described in Section 3.2. Pavements that can easily demonstrate every one of these characteristics provide the most confidence. However, where few of these characteristics can be clearly demonstrated there is a reduced likelihood that the pavement is potentially long-life. Similarly, a robust pavement could also be classified as a determinate life pavement using the initial assessment criteria, but its justification as a robust pavement can be demonstrated if the characteristics can be demonstrated.

Resistance to structural damage by traffic

A pavement that is resistant to damage by the traffic it carries will have desirable structural properties. The response of a pavement to traffic loading is controlled by the combination of its structural and material properties. TRL Report TRL250 demonstrated that provided that the responses of a pavement under traffic loading are restricted to below a certain threshold, the risk of structural deterioration may be negligible. Although the material properties and traffic may change with time, the three stated elements (structure, materials and traffic) can conspire to maintain the response below the threshold. A measurable pavement response is deflection at the surface of the pavement; confidence in the assessment with deflection increases with the frequency of deflection measurements. Increasing the frequency of measurement improves the analysis, however a deflection measurement every 10 m in the most heavily trafficked lane should be sufficient. A resistance to damage by traffic may be demonstrated by a property of the pavement that can be correlated with a resistance to damage by traffic; this can be achieved in a variety of ways:

- For a given thickness of pavement, a threshold deflection can be used to indicate a strong pavement. This deflection should ensure that the responses within the structure are low so that robustness is being achieved regardless of the traffic level. The current approach described in Section 3.1 of this document would be suitable.
- The use of back-analysis techniques to determine the structural properties of pavement layers is described in HD29 (Highways Agency, 2005). A pavement that is resistant to structural damage by traffic will have retained its desirable structural properties and therefore will be exhibiting good stiffness in each of the pavement layers. It is expected that long-life or robust pavements will have pavement layers judged to be of good integrity according to the criteria.

- The evolution with time and traffic of the deflection response of a pavement under a known load can be monitored. If this deflection level is not increasing significantly over a number of years then this is an indication that there is likely to be a resistance to damage in the pavement structure. However, the comparison of surveys taken over a period of time requires that each survey is either carried out under identical conditions, e.g. for loading, temperature and moisture, or that the measurements are robustly and accurately corrected back to standard conditions. This is relatively straightforward for load correction and procedures for temperature correction are available although care is needed if the necessary precision is to be achieved. At present there is no standard approach for correcting for variations in the moisture content of the foundation; however, these should not vary significantly provided the pavement drainage works correctly.

The determination of trends in data containing random errors is often based on a subjective assessment. An objective statistical approach is available using the Mann-Kendall technique (Kendall, 1938), illustrated in Appendix B. With all trend analyses, care should be taken to ensure that sufficient information has been collected to make reliable judgements on the trend.

In addition to the recent structural properties of the pavement, the assessment and maintenance history of a mature pavement can be consulted if the pavement has significantly exceeded its original design life. Such mature pavements that have been assessed for maintenance and have only been treated using non-structural treatments where required, have already demonstrated a behaviour similar to that expected for a long-life or robust pavement. Provided that operating conditions of these pavements in the future are not significantly different to the past and the pavements have exceeded their original design life, these pavements are demonstrating a resistance to damage by traffic.

Soundness in the asphalt layer

A well-constructed asphalt layer should be compacted to a high degree in all layers. It should exhibit good bond between the layers and the aggregate skeleton should provide the appropriate degree of interlock. A sound asphalt layer should not show any signs of structural deterioration.

Soundness implies that the condition of the asphalt layer reflects that of a recently placed layer that has been properly constructed. In most cases this property will be checked using a visual assessment and it is likely to rely upon a subjective assessment. Visual assessment means that the asphalt layers should be exposed, which can be achieved using a trial pit or by cutting cores. Cutting cores is preferable since this requires less intrusion into the structure of the layer and can be performed more swiftly than excavating a trial pit. Sufficient cores should be extracted from each assessment length in order to provide sufficient confidence in the assessment. The frequency of coring should reflect the variability of the construction and the required confidence in the assessment. An increased frequency of extraction will add to the overall cost of the assessment.

Any core sample extracted from the pavement should be free from significantly voided layers. It should not be debonded; however, it should be noted that asphalt layers could be separated during the core cutting operations. The interfaces between layers should be inspected to see if they are freshly exposed or otherwise (the colour of the bitumen on the interface between the layers should be similar to the walls of the core if freshly exposed otherwise it may be lighter) and the aggregate should be evenly distributed within the layer (no segregation). Deterioration of the bituminous material such as cracking or disintegration of the material itself should not be evident.

Foundation stiffness

TRL Report TRL250 associates long-life pavements with those that are constructed on a good foundation. HD29 (Highways Agency, 2005) defines a threshold stiffness (using back-analysis procedures) of 100 MPa or greater for the foundation of a pavement expected to be associated with good performance.

Demonstration of the stiffness of a foundation can be shown using two types of measurements:

Type 1:

Using an FWD, the deflections furthest from the loading plate (normally 1200 to 1800 mm depending on the pavement construction) are considered to be controlled by the properties of the foundation. Therefore, low values of these deflections will be attributed to a strong foundation.

It is possible to use the Surface Modulus concept (FEHRL, 1996) to produce modulus or stiffness values directly from each of the deflections measured at each geophone location. The surface modulus values calculated at each geophone relate to the stiffness in the pavement at different equivalent depths. Moving further from the load plate indicates a stiffness deeper in the pavement structure. In order to demonstrate adequate foundation stiffness, the surface modulus at all equivalent depths (i.e. all geophone locations) should exceed 100 MPa.

Back-analysis procedures can also be used to estimate the stiffness of the foundation. HD29 (Highways Agency, 2005) describes these in detail.

Type 2:

Using a non-destructive, lightweight, portable deflection testing equipment, measurements can be made directly on the top of the foundation provided that the foundation is exposed by opening a trial pit or by cutting a large core hole without disturbing the foundation material.

However, there is no universally accepted measuring device suitable for use in a small excavation. The process of excavation, either by pneumatic drill or core cutting bit, is likely to disturb the material directly underneath which could affect the results. This is not an attractive method due to the time required to make the excavations and the fact that the necessary large intrusion into the structure of the pavement will require some form of reinstatement treatment.

Asphalt thickness

Asphalt thickness is a key determinant of pavement performance; this is emphasised by the fact that the pavement design method (Highways Agency, 2005) is primarily concerned with the appropriate selection of asphalt thickness for a given material choice. Furthermore, many of the observations about the performance of a pavement that may behave as a long-life pavement were related to the total thickness of the asphalt layers.

The thickness of an asphalt layer should be one property that is at least measurable. If construction records were perfect, it would be a simple property to determine. Unfortunately it is unlikely that such records will have the required reliability. Measurement techniques range from sampling techniques such as coring or pseudo-continuous measures such as the use of ground penetrating radar. Guidance on determining layer thickness can be found in HD29 (Highways Agency, 2005). Checks should be made to confirm that the thickness derived from either of these methods is consistent with the approach to determine the TTBM shown in Figure 3.2.

For the length of pavement under assessment (typically 100 m), the median asphalt thickness should be declared.

4.2 Upgrading

The concept of upgrading is that by performing some maintenance operation, the state of the pavement is changed to one which satisfies each and every characteristic described in Section 4.1; satisfaction of the characteristics then enables the pavement to be considered as either a potentially robust pavement or a potentially long-life pavement. An underlying concept of this method is that any pavement can be upgraded in this manner.

Pavements are not automatically upgraded within the current Highways Agency maintenance approach. However, there are occasions where a method for all types of flexible pavement is required for determining an appropriate treatment after which structural deterioration is not expected for a very long time. For these occasions, the existing pavement may require upgrading to further increase the assurance that a robust pavement will not experience structural damage. These operations could reduce the risk of structural deterioration to an extent where the pavement can be considered as a long-life pavement.

Upgrading of a structure can be achieved by an overlay or the reconstruction of the entire pavement layer. If the scheme assessment has detected that the stiffness of the foundation is insufficient, reconstruction is likely to be the most appropriate route to the creation of a potentially long-life pavement. Similarly, when the overlay design results in a thickness that cannot be economically justified or accommodated within the existing constraints of the road (e.g. headroom restrictions) reconstruction may be necessary.

The design of this overlay would ideally ensure that the critical responses in the pavement structure are modified to be within a certain threshold. However, computed responses are highly sensitive to the derived structural properties of the pavement. Therefore, until a conclusive method can be developed to determine the structural properties of the pavement, an upgrading methodology based upon deflection measures is proposed.

As this upgrading method is based upon the existing criteria, the upgrade should be currently determined using the deflectograph to provide deflection measures. In the future, this method could be revised in order to accommodate the use of falling weight deflectometer measurements.

4.2.1 Upgrading method for pavements up to 400 mm TTBM using the existing assessment criteria

The thickness of an asphalt pavement that has a measured deflection higher than the existing criteria, can be compared to an asphalt ‘threshold’ thickness of a pavement with the same deflection that just meets the criteria.

The difference between the actual thickness and the ‘threshold’ thickness is an ‘excess’ thickness as illustrated in Figure 4.2. This ‘excess’ thickness is required to compensate for deficiencies in the stiffness of one or more layers of the pavement so could also be termed a ‘deficiency’ thickness. In terms of the classification of long-life and robust pavements, this deficiency thickness can be used to determine the upgrade treatment.

The proposed upgrading methodology utilises the existing assessment criteria from which two quantities can be identified:

- The ‘excess’ thickness that is the difference between the actual thickness and the thickness that would satisfy the existing criteria for the same level of deflection, H_s . In terms of robust and long-life pavements, this difference reflects the thickness deficiency to be reinstated.
- The difference between the current thickness and the thickness required for either a robust pavement or a long-life pavement, H_T . When the existing asphalt layer thickness exceeds 300 mm for upgrading a pavement, this thickness is zero. This thickness is also zero when the existing asphalt layer exceeds 200 mm for upgrading to a robust pavement.

The resulting upgrade thickness would be given by the thickness $H_s + H_T$. This method is a conservative approach to overlay design to increase assurance that the pavement will not require structural maintenance in the foreseeable

future. When thick overlay thicknesses are produced by this methodology, these should be considered with regard to the likely risk and impacts of future structural deterioration at the site considering the evidence collected against each of the long-life pavement characteristics. Thick overlay treatments that increase the TTBM beyond 500 mm are worthy of particular careful review.

After upgrading, it is unlikely that the resulting pavement structure will satisfy the existing deflection-thickness criteria. Unless a high modulus material is used, the upgrade treatment will have the effect of reducing deflection for a given additional thickness at a similar rate to the criteria and therefore will remain above the deflection criterion, however the pavement should demonstrate more strongly the long-life pavement characteristics. In addition, upgrading by the application of an overlay will not change the properties of the foundation; however it could mitigate the effect of deficiencies in this part of the structure. The upgrading criteria have been developed by the extrapolation of the existing deflection-thickness criteria for TTBM lower than 200 mm, Figure 4.3.

Figure 4.4 provides an example of the upgrading approach for a pavement with 250 mm TTBM and a measured standard deflection of 0.32 mm. In this example, an ‘excess’ thickness (H_s) of 105 mm was determined and a thickness of 50 mm (H_T) is required to reach the long-life pavement thickness criteria of 300 mm; this results in a calculated overlay requirement of 155 mm which would increase the total thickness of the asphalt layer to 405 mm.

A method of designing an upgrade for pavements that do not satisfy the existing deflection criteria has been formed. A threshold thickness for the long-life design of new pavements using conventional DBM125 materials is 420 mm as shown in Table 2.1. The value of applying a strengthening overlay to produce pavements that are much thicker than the current standard designs and are already exhibiting the long-life pavement characteristics is questionable; therefore, it is proposed that this upgrading method should be limited to pavements that, after upgrading, have a TTBM of less than 500 mm.

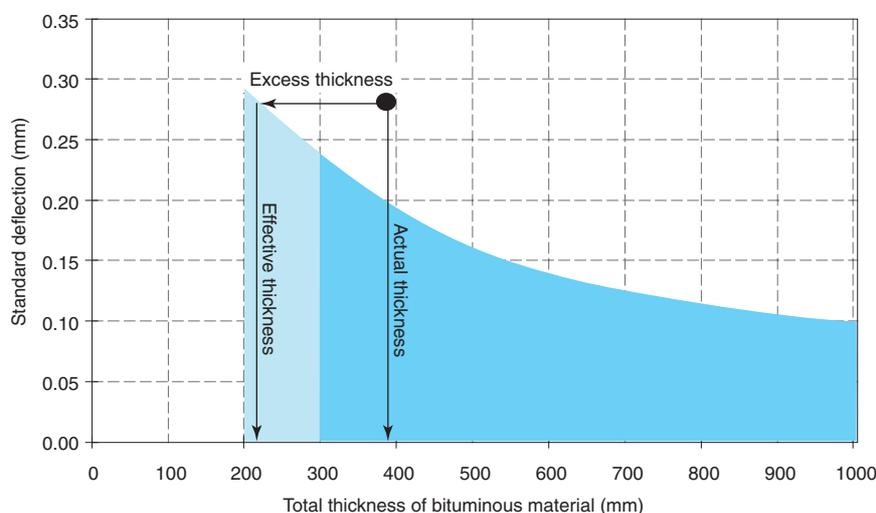


Figure 4.2 Illustration of ‘excess’ thickness

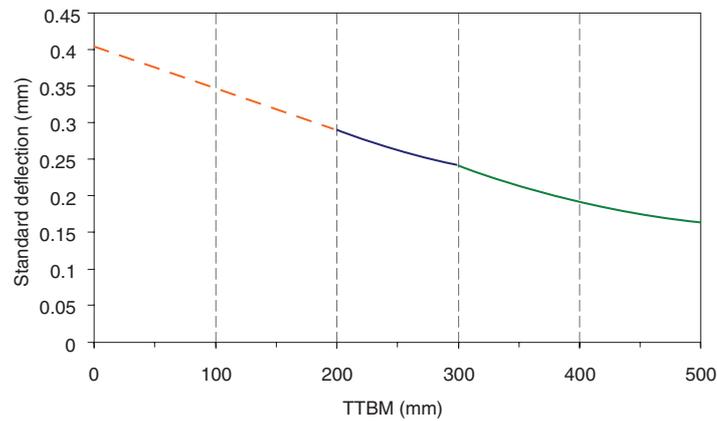


Figure 4.3 Extrapolated deflection-thickness criteria for determining ‘excess’ thickness

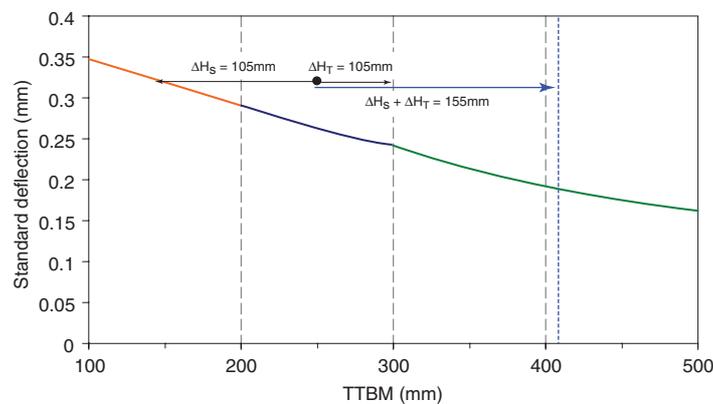


Figure 4.4 an example of the proposed upgrading methodology

5 Condition assessment of long-life and robust pavements

The DMRB offers comprehensive advice on the assessment of all pavements. This advice has been distilled in this section for the particular case of long-life pavements; robust pavements can also be covered by the majority of the advice for long-life pavements in the DMRB. Extracts of advice that have been reproduced from the DMRB are indicated by italics together with the appropriate sub-clause. In addition to the advice given in the DMRB, advice on the determination of crack depth and rutting is also offered.

5.1 Condition assessment advice from the Design Manual for Roads and Bridges

Implicit in the definition of long-life pavements is a structure of adequate strength manifested by a substantial thickness of bituminous material and low deflections. The low deflections are indicative of a generally sound pavement with good foundation support. The comparison of information gathered on the test areas should concentrate on depth of cracking, rutting and other material deterioration. The findings will give an indication of the rate of progress of the damage and will assist in

deciding on the timing and extent of remedial treatment [sub-clause 6.5 of DMRB 7.3.3].

Construction information is a vital component in the understanding of pavement condition data. If little core data is available on the road then consideration should be given to additional occasional coring (e.g. 1 per 100 m) outside test areas or a Ground Radar survey as described in HD 29 (DMRB 7.3.2); full details of the procedures for taking cores, opening test pits and logging the findings are given in the DMRB [sub-clause 5.8 of DMRB 7.3.3].

Where required, detailed investigations on flexible pavements should be carried out for 40 m section lengths.

A further detailed visual survey should be carried out at all investigation sections. The location of surface cracks should be noted and on flexible pavements rut depths measured at 10 m intervals in both wheelpaths. Some of the key areas of distress should be photographed including a recognisable object or ruler to give scale. The use of video film may be considered. Drainage features, the crossfall, gradient and depth of cutting or fill should be observed in respective test areas and any differences noted [sub-clause 5.12 of DMRB 7.3.3].

Investigations on sites containing long-life pavements should concentrate in the first instance on determining the extent (area and depth) of damage to the surfacing, which normally consists of a basecourse and wearing

course. The damage usually takes the form of polishing, wheelpath rutting, cracking and crazing [sub-clause 5.13 of DMRB 7.3.3].

If the surface is polished, the skidding resistance is likely to be below the investigatory level for the site. A check should be made to establish whether the procedures set out in HD 28 (DMRB 7.3.1) have been carried out and whether surface treatment is required for this reason alone [sub-clause 5.14 of DMRB 7.3.3].

Further tests in areas of distress should follow the pattern shown in Figure 5.1 (DMRB 7.3.3). Cores should be taken on the cracks and at crack ends to determine their depth, direction and manner of propagation. Any ruts or deformation should also be straddled by cores. Where extensive rutting is present, it may be necessary to open a test pit to determine which layers are deformed. All cores should be of sufficient depth to ensure that the full depth of cracking is recorded and provide some evidence of the layers affected by rutting and any loss of integrity of materials, such as stripping of the binder. If, as is likely from the pavement categorisation, it is found that the distress is confined to the surfacing layers no further site investigations are required [sub-clause 5.15 of DMRB 7.3.3].

However, if it is found that the cracks, rutting or other deterioration extends downwards into the roadbase, the more extensive investigations required for determinate-life pavements with <5 years life will be required [sub-clause 5.16 of DMRB 7.3.3].

5.2 Additional condition assessment advice for cracking and rutting

5.2.1 Depth of cracking

The appreciation of the depth of surface initiated cracking is a key factor in the assessment of long-life pavements. The depth of cracking will control the depth of maintenance required; therefore accurate determination of crack depth is a pre-requisite for efficient maintenance. Furthermore, the monitoring of crack depth is essential in order to intervene before the depth of cracking jeopardises the structural layers of the pavement; a fundamental requirement for long-life pavements.

Ideally, the assessment and monitoring of crack depth will be carried out using a non-destructive test; however, the non-destructive assessment of such cracks has historically been a challenge. Recent research has indicated that there are some radar-based techniques which could provide a suitable solution; these techniques are currently being evaluated on the HA network¹. When validated, these techniques could provide a cheaper and faster alternative to coring. Until the performance of these

non-destructive tests has been validated, limited coring of the existing cracks is perhaps the most appropriate means of determining crack depth currently available.

Coring of every crack that is visible may not be feasible and, if concentrated in a localised area, may affect the integrity of the pavement structure. The frequency of coring should be decided according to the degree of deterioration and resources available; however, coring should aim to provide an adequate sample in order to make a reasonable judgement on the state of the deterioration. Coring should therefore be directed to the most visible cracks, the core should be extracted from directly over the crack and the depth of cracking recorded as the maximum visible penetration. Where the bottom of the crack is not clearly visible in the core, such as illustrated in Case B of Figure 5.1, the recorded depth of cracking should indicate that this might not be the maximum depth of penetration; for this type of crack, other locally sampled crack depths may assist in assessing the maximum depth of penetration.

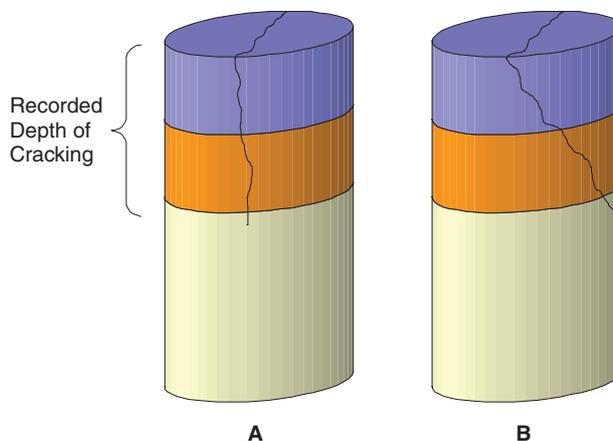


Figure 5.1 Illustration of cores showing different paths of crack propagation

5.2.2 Rutting

Rutting in long-life pavements is expected to occur in the surface layers only and is often referred to as non-structural rutting. Non-structural rutting may be indicated on the surface by the occurrence of shoulders beside the wheel path as shown in Figure 5.2; however, the lack of shoulders does not imply that the rutting is structural. These shoulders occur due to a viscous, lateral displacement of material under the action of the wheel load. Where shoulders are not detectable on the pavement surface, a test pit may need to be opened in order to view where the deformation has occurred.

Although not affecting the structural layers of the pavement, non-structural rutting may develop quickly in extreme conditions such as a prolonged period of high temperatures and sunshine. Non-structural rutting that is not corrected in a timely fashion may progress to a stage that begins to affect the structural layers.

Surface rutting can be detected by a detailed visual survey or a machine based approach. The machinebased approach will provide a more detailed view of the rutting that is

¹ A preliminary investigation of a GPR-based non-destructive crack depth measurement device was undertaken by TRL in 2002; the results of this investigation were very promising. As a result of these, controlled trials of the device are being undertaken on the Highways Agency network. Agents are able to hire the equipment or to commission specialist survey contractors to survey surface cracks along with coring; results of the trial are being monitored by TRL.

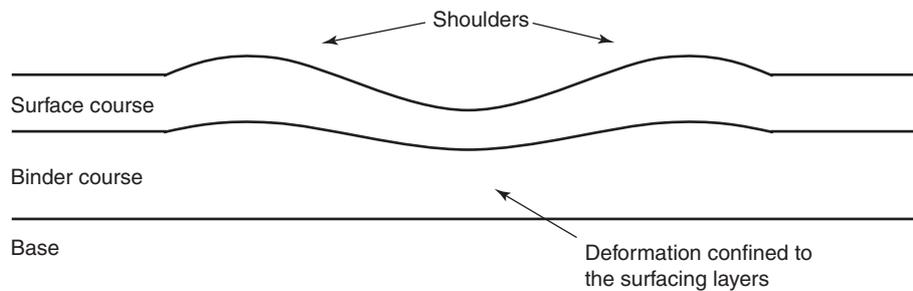


Figure 5.2 Illustration of the cross-section of a typical non-structural rut

evident along the length of the pavement; ruts that are measured during a visual condition survey will be only a small sample that records the peak deformation at specific intervals. Machinebased methods can more easily provide detailed transverse profiles than are possible with manual methods, enabling the shape of the rut profile to be assessed. The shape of the rutting profile could be important in the detection of non-structural rutting, Figure 5.2.

Where significant deformation of the surface has occurred, confirmation of non-structural rutting should be made by the excavation of a trial pit with clear cut faces; similar information can be collected by taking several cores distributed in a straight line transversely across the lane. Even though the surface profile may be indicating the presence of deformation within the surfacing, visual evidence that the structural layers are free from deformation should be sought.

Significant structural deformation may be detected by the use of ground penetrating radar operated transversely across the traffic lane.

6 Maintenance techniques for long-life or robust pavements

Long-life or robust flexible pavements are particular types of pavement; the maintenance of these types of pavement is implicitly covered by the existing maintenance advice contained in the Design Manual for Roads and Bridges. This section highlights the range of treatments that could be considered for the particular case of either long-life or robust flexible pavements as well as proposing two novel alternative treatments.

The maintenance treatments for long-life roads should, by definition, consist of non-structural treatments only. Maintenance of long-life roads will be performed to either restore the surface characteristics of the pavement or to prevent deterioration in the surfacing layers affecting the structural layers.

6.1 Existing treatments covered in the design manual for roads and bridges

HD31 (Highways Agency, 2005) classifies maintenance treatments into one of three classes:

- Surface treatments.
- Minor maintenance.
- Major maintenance.

Surface treatments are applicable to all types of pavement including long-life or robust pavements; therefore no special attention will be given to these treatments in this document. HD31 (Highways Agency, 2005) also details a range of treatments for the surfacing layer including: crack sealing, surface dressing, thin surfacing and retexturing; detailed advice on the use of these treatments is given in HD37 (Highways Agency, 2005).

Treatments grouped under ‘Minor Maintenance’ include Carriageway Patching and Trench Reinstatement. Trench reinstatement is not a suitable maintenance treatment for long-life pavements as this treatment is often carried out after access has been gained to underground services; the structural layers of a long-life or robust pavement should not need replacing, therefore it is unwise to place underground services beneath such a pavement. Carriageway patching is a suitable treatment provided that the patch extends only to the depth of the surfacing layers.

The major maintenance treatments for long-life pavements that are included in the *Design Manual for Roads and Bridges* are essentially restricted to overlay, inlay and resurfacing operations. This guidance concentrates on those minor and major maintenance treatments that are applicable to long-life pavements.

Figure 6.1 illustrates the different options for major maintenance treatments for long-life or robust pavements in the Design Manual for Roads and Bridges. The striped areas indicate new or replacement layers where a treatment has been performed.

Overlays

An *overlay* is a traditional treatment that is generally applied for the purposes of increasing the structural capacity of a pavement (except for thin overlay) as well as restoring the functional characteristics of the pavement such as surface profile. However, in the context of long-life or robust pavements, its inclusion into this guidance is justified on the basis of the change in level that it produces. It is envisaged that an overlay of a long-life flexible pavement will be performed to maintain the surface level in the following situations:

- When adjacent pavement sections are overlaid to increase the structural capacity of the adjacent pavement and/or to upgrade the adjacent pavement to long-life status.
- When a road is widened and the choice of pavement design for the new construction necessitates an increase in overall surface level.

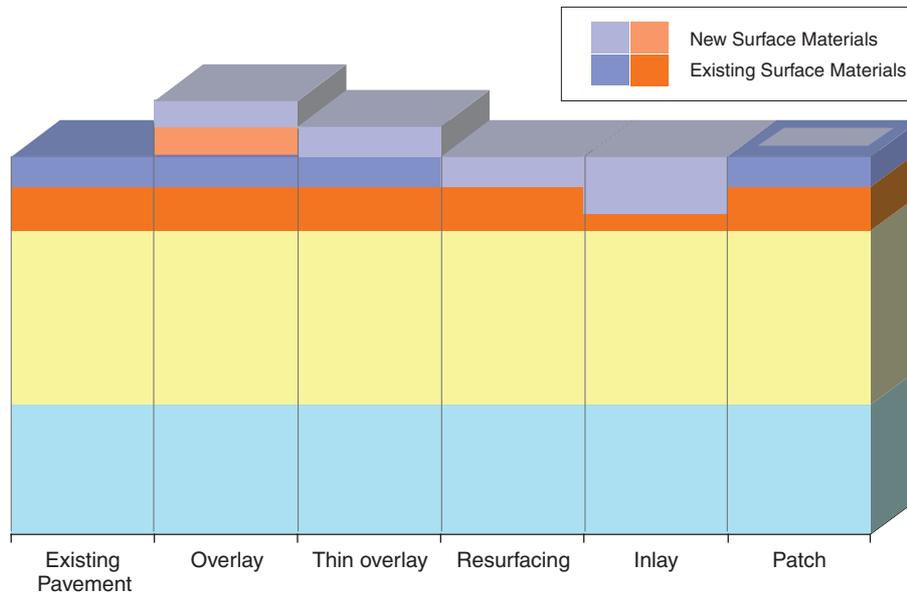


Figure 6.1 Types of treatment permitted for long-life pavements

There are instances when the application of an overlay is not feasible. The Design Manual for Roads and Bridges provides explicit advice on the feasibility of overlays.

Where one lane of a dual carriageway requires treatment but other lanes still have substantial remaining life, the additional cost of a structurally unnecessary overlay over satisfactory lanes will have to be considered. It may be cheaper to fully or partially reconstruct the nearside lane [sub-clause 7.12 of DMRB 7.3.3].

A thin overlay treatment is a possible treatment for long-life and robust pavements. It is unlikely that this type of treatment is performed for structural reasons. It is most likely to be used as an economical method for restoring the functional characteristics of the pavements where the existing surfacing is intact and the additional thickness of the thin overlay can be accommodated within the existing geometry of the road.

Resurfacing

Resurfacing is effectively an inlay treatment where the existing surface course only is replaced to a similar thickness. Resurfacing is not undertaken for structural improvement and is performed to renew the functions of the surfacing whilst maintaining the existing level of the pavement. It is preferred to a thin overlay treatment in situations where there are headroom restrictions.

Timely surface treatment can be effective in halting deterioration before serious damage to the remaining structure takes place. If it is timed to coincide with a need for improvement to surface texture or skidding resistance, then it is economically even more attractive [sub-clause 7.15 of DMRB 7.3.3]

Inlay

Inlay treatments are not explicitly described in the DMRB; however, they are covered by the advice in the DMRB as it can be seen as a form of overlay after the existing surfacing of the pavement has been removed. An inlay treatment

involves the removal of the surface course and a proportion of the binder course and possibly the base materials. Replacement asphalt layers are then laid on to the remaining pavement structure to restore the original thickness.

It is envisaged that an inlay of a long-life or robust flexible pavement will be performed to prevent any deterioration that has been identified in the binder course (and possibly in the uppermost part of the base) from affecting the structural layers of the pavement.

Patching

Patching treatments are applied to long-life and robust pavements to replace surfacing materials that have aged and have begun to break up and form crazed areas. The entire depth of defective material should be removed in the patch; therefore the treatment could involve either the replacement of the surface course only or both the surface course and binder course layers

Patching may be employed as a holding treatment until a longer length of maintenance treatment can be justified; although site specific economic analysis will dictate the minimum treatment length for inlay, resurfacing and thin overlay treatments.

6.2 Proposed alternative treatments

In addition to the advice contained in the DMRB, two other major treatments for use on long-life flexible pavements have been selected for inclusion in this guidance: Trench Inlay and Partial Depth Inlay. Whereas there is a considerable body of information on conventional maintenance treatments, it has not been possible to demonstrate the performance of these alternative treatments in a limited fashion at the time of the production of this guidance. The trials that have been undertaken to demonstrate the performance of these treatments are briefly described in Appendix A. The application of these treatments should be considered by balancing the risks of early failure with the potential benefits.

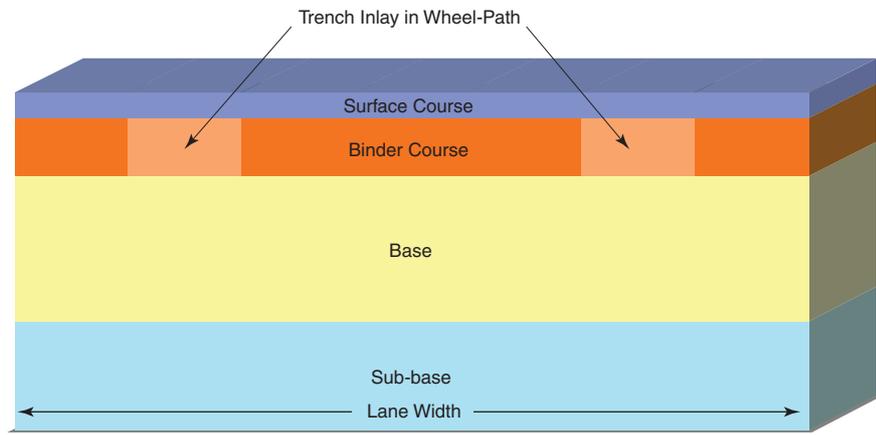


Figure 6.2 Illustration of trench inlay treatment

Trench inlay

A trench inlay is performed to correct deterioration that is confined to the wheel-paths and could be chosen in preference to a conventional inlay treatment.

The benefit of a trench inlay over a conventional inlay is that only material in the vicinity of the observed deterioration is replaced, relatively untrafficked parts of the existing surfacing remain. A trench inlay has obvious economic and sustainability advantages in terms of materials consumption; it could potentially have advantages in terms of a more rapid maintenance operation with consequently less disruption to traffic, but these advantages have yet to be confirmed in a full-scale trial. However there are two operational issues that should be considered before commencing such a treatment:

- Steps should be made to ensure that the new material makes an excellent bond with the existing material surrounding the trench.

- Care should be taken, during compaction of the new material, so that the satisfactory compaction of all the new material is achieved, in particular that in the lower corners of the trench. In a pilot-scale trial of these techniques, Sanders and Nunn (2004) achieved good compaction throughout the trench.

Partial depth inlay

Traditional full-depth inlay treatments are designed to remove and replace the full-depth of cracked material; however, a partial depth inlay treatment does not necessarily require the removal of the existing pavement materials to the maximum depth at which cracking has occurred. Figure 6.3 illustrates that there are potential savings in terms of the amount of material required to carry out this treatment over a conventional inlay treatment.

For long-life and robust pavements, cracking evident at the surface of the pavement originates from the surface

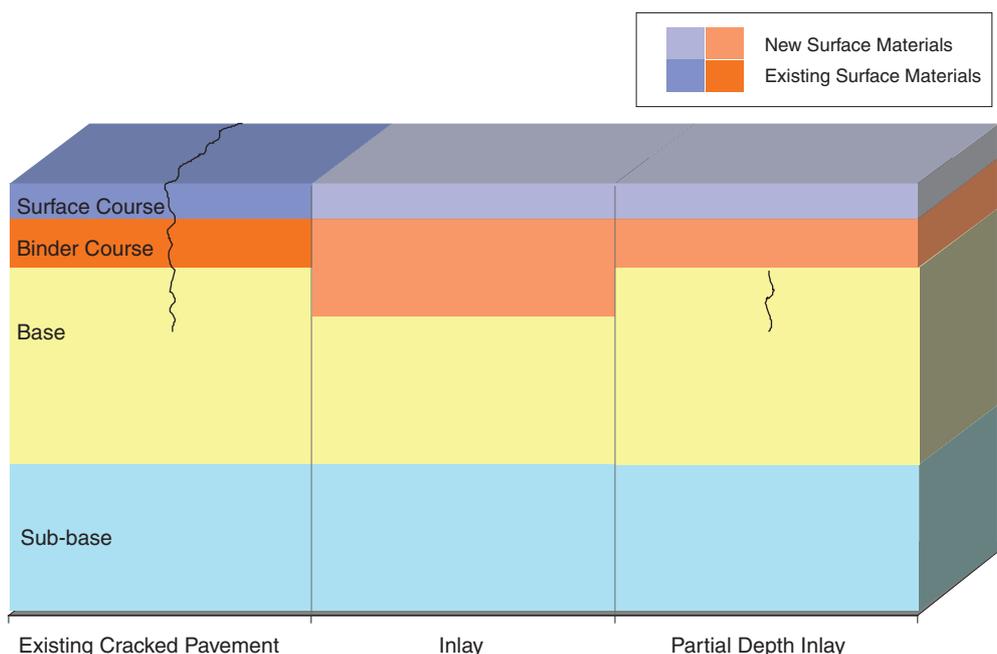


Figure 6.3 Illustration of partial depth inlay treatment

and propagates downwards. The application of a partial depth inlay will restore a crack-free surface and seal the remaining crack from water and air ingress. The crack would then be sealed in a relatively inert part of the pavement (neither directly in contact with the traffic and the environment nor in a location where high tensile stresses are expected) thus arresting the growth of the crack. Furthermore, it is likely that the high temperature of the inlay material at the time of construction will have a beneficial effect on the remaining cracks and may provide some form of healing. It is advised that this treatment is not performed if the surface crack penetrates a significant proportion of the total thickness of the asphalt layer, i.e. greater than 40%.

There is a small risk that this treatment will not arrest the progression of the incumbent crack; regular monitoring of the pavement could reduce such a risk. For robust pavements, the risk is much higher because the thickness of the asphalt can be less than required for long-life pavements; partial depth inlay is not recommended for robust pavements with less than 300 mm asphalt thickness.

When designing an inlay treatment, consideration must be given to the quality of the assessment and types of cracking observed. Crack depth may vary widely along the pavement and a decision will be required as to whether to design the treatment for the deepest crack or for a more representative depth of cracking along the whole site. Such a decision will need to consider the frequency of crack depths and the risk that future maintenance could arise from a failure to treat the deterioration adequately.

6.3 Treatment selection for long-life and robust pavements

Long-life and robust pavements should not require structural maintenance treatments; therefore the maintenance operations that can be performed on a long-life pavement are confined to those treatments that remedy the functional aspects of the pavement. Such treatments will restore the characteristics of the surfacing layers and include thin overlay, inlay, resurfacing.

Table 6.1 provides advice on which treatments are likely to be used when distress in the pavement reaches some level when maintenance is required. An '✘' indicates that this type of treatment is unlikely to be performed in order to remedy that single type of defect; whereas a '✓' indicates that this type of treatment could be used to remedy a single type of defect. The overall selection of treatments should aim to remedy each of the significant defects.

The selection of the appropriate treatment is a complicated operation that is performed considering a number of factors including:

- the degree and distribution of distress;
- the levels of traffic at the site;
- the planned future maintenance;
- the whole life costs of the treatment;
- the treatments proposed for adjacent parts of the pavement.

Table 6.1 Treatments for long-life pavement appropriate to types of defect

<i>Defect</i>	<i>Thin overlay</i>	<i>Resurfacing¹</i>	<i>Inlay²</i>
Low friction	✓	✓	✘
Poor texture	✓	✓	✘
Profile	✓	✓	✓
Rutting	✓	✓	✓
Transverse cracking	✘	✓	✓
Longitudinal cracking	✘	✓	✓
Crazing	✘	✓	✓

¹ *Thin overlay may be a more economic option than resurfacing where the existing surface course of the pavement is free from cracking and significant deformation and where there are no constraints imposed by headroom and other street furniture.*

² *Consider patching if less than 10 m requires treatment.*

7 Potential benefits of long-life and robust pavements

The information contained in this guidance extends the advice contained on long-life pavements within the DMRB and extends the concept of long-life pavements to a class of pavements called 'robust' pavements; it therefore creates additional benefits and associated risks.

Adoption of the long-life pavement concept

The whole life cost benefits of long-life pavements were assessed in TRL Report TRL250. The chief benefits identified were the lower initial construction costs for heavily trafficked situations. User costs were also reduced, particularly if maintenance operations could be performed at night. The requirement to complete a maintenance treatment at night can preclude the use of an overlay, therefore long-life pavement treatments that require only inlay or resurfacing can take advantage of these savings.

Environmental benefits arise from the use of long-life and robust pavements and come from a number of different sources. For heavily trafficked situations, they reduce the consumption of non-renewable resources during construction and maintenance operations such as bitumen and virgin aggregate. In addition the reduced user costs, through reduced congestion as a result of minor or night-time maintenance, will assist in the control of air pollution from road vehicles; congestion also reduces fuel efficiency.

Introduction of the robust pavement concept

The concept of a robust pavement has been introduced in this guidance. These pavements offer similar benefits to long-life pavement although they have a higher risk of structural deterioration. Such pavements will enable many of the advantages of long-life pavements to be adopted more widely than is currently possible. The network level assessment criteria is designed for use on the UK trunk road network, the concept of a robust pavement could, for the first time, bring about a long-life approach to the maintenance of a significant proportion of the principal and secondary road network.

Enhanced assessment techniques

The proposed enhancements to the assessment criteria provide methods of increasing the confidence of the classification as potentially robust, long-life or otherwise. Indeed many of these methods are routinely operated. However, particular methods for the investigation of the behaviour of the pavement with respect to the characteristics expected of a long-life pavement allow for more confidence in the assessment and for the assessment to be applied to a wider range of pavements.

Enhanced upgrading techniques

The existing upgrading and assessment techniques provide an adequate first indicator of the likely future structural maintenance requirements for pavements provided that other adequate supporting information can be collected. This method offers a simple means of upgrading the pavement provided that the deflections in the pavement are suitably low.

An enhancement of this technique has been proposed for pavements whose deflections are not suitably low, but whose behaviour reflects the characteristics of long-life and robust pavements, and where there is a requirement to reduce the risk that the pavement will require structural maintenance in the foreseeable future.

These changes permit the long-life pavement maintenance approach to be applied to much wider proportion of the trunk road network, if economically desirable. Although the current method can be applied to a significant proportion of the trunk road network, there will be a small but significant proportion of the trunk road network that could benefit from the increased flexibility of upgrading.

Additional maintenance options

Two additional maintenance options have been presented for long-life pavements: trench inlay and partial depth inlay. Both options are considered to be alternatives to a conventional inlay treatment and are designed to minimise the amount of material that is removed and placed during maintenance.

The successful implementation of either of these treatments will bring about economic and environmental benefits. The economic benefits of such treatments will be tempered by the additional operations that are required. This is particularly an issue for the trench inlay, where the success of the system will be governed by the quality of the preparation of the trench and the careful compaction of replacement asphalt. The environmental benefits of these two systems can be measured by the reduction of material that is both taken away from and brought to site: not only on the reduction in fuel required to carry out these operations but if neither process is linked to recycling, the amount of material that is extracted from finite resources and taken to land-fill.

8 Summary

A summary of the research presented in this report is provided:

- This research has extended the applicability of the long-life pavement concept to a wider range of pavements

and thus brings the financial and environmental benefits to a larger proportion of the network.

- The enhanced methods of assessment proposed builds upon the existing techniques described in the current version of the Design Manual for Roads and Bridges through the extended use of deflectograph and falling weight deflectometer measurements.
- This research has introduced the concept of robust pavements which enable the benefits of a long-life pavement and its associated simplified maintenance treatments to be obtained if the associated added risk of incorrect identification is accepted.
- Four conventional major maintenance treatments have been highlighted for use on long-life and robust pavements: thin overlay, inlay, resurfacing and patching. Overlay treatment is also included but only for instances where a change in surface level is required.
- Novel maintenance treatments are also included in this guidance that could lead to more efficient maintenance of robust and long-life pavements. The potential performance of the trench inlay treatments has been demonstrated through experience on the local authority roads and pilot-scale testing. A long-term, full-scale trial of a partial depth inlay treatment has been constructed for future monitoring.

9 Acknowledgements

The research was jointly sponsored by the Highways Agency, the Quarry Products Association and the Refined Bitumen Association. The work described in this report was carried out in the Infrastructure Division of TRL Limited. The author is grateful to Mr B Ferne who carried out the quality review and auditing of this report.

10 References

British Standards Institution (1993). *Method for determination of the indirect tensile stiffness modulus of bituminous mixtures.* BS DD 213. London: British Standards Institution.

Dommelen A van (2002). *The use of FWD in DBM contracts.* 2nd European FWD User's Group Meeting, Cascais, Portugal.

Highways Agency (2005). *Design Manual for Roads and Bridges.* Highways Agency, The Scottish Office Development Department, The Welsh Office, The Department of the Environment for Northern Ireland. London: The Stationery Office.

HD 25/94: Foundations (DMRB 7.2.2)

HD 26/01: Pavement Design (DMRB 7.2.3)

HD 29/94: Structural Assessment Methods (DMRB 7.3.2)

HD 30/99: Maintenance Assessment Procedure (DMRB 7.3.3)

HD 31/94: Maintenance of Bituminous Roads
(DMRB 7.4.1)

HD 37/99: Bituminous Surfacing Treatments and
Techniques (DMRB 7.5.2)

Forum of European National Highway Research Laboratories (FEHRL) (2004). *Making best use of long-life pavements in Europe: A guide to the use of long-life fully-flexible pavements.* FEHRL Technical Report 2004/1. Brussels: Forum of European National Highway Research Laboratories.

Forum of European National Highway Research Laboratories (FEHRL) (1996). *Harmonisation of the use of the falling weight deflectometer on pavements, Part 1: Harmonisation of FWD measurements and data processing for flexible road pavement evaluation.* FEHRL Report No. 1996/1. Brussels: Forum of European National Highway Research Laboratories.

Kendall M G (1938). A new measure of rank correlation. *Biometrika*, **30**, p. 81-93.

Nunn M E, Brown A, Weston D and Nicholls J C (1997). *Design of long-life flexible pavements for heavy traffic.* TRL Report TRL250. Wokingham: TRL Limited.

Nunn M E and Ferne B W (1997). *Design and assessment of long-life flexible pavements.* Transportation Research Circular. Washington DC: Transportation Research Board. 2001-12 **503**, pp. 3949.

Sanders P and Nunn M E (2004). *Investigation into the properties of a 20 mm EME binder course for use on heavily trafficked roads.* Project Report. Wokingham: TRL Limited. (Unpublished project report available on direct personal application only)

Appendix A: Supporting case studies

A.1 Examples of the use of the enhanced assessment and upgrading approach

Two sites from the Highways Agency's validation monitoring programme (Highways Agency, 2005) were selected. These sites are: the M25 at Brentwood and the A414 at Cole Green. The sites were chosen to illustrate the advantages of the enhanced assessment and upgrading techniques across a range of conditions. An illustration of how the enhanced upgrade technique could be used at Brentwood is given, although it is accepted that such an upgrade treatment will only be required in a particular scenario.

A.1.1 M25 Brentwood

The M25 at Brentwood opened in 1982 and is a heavily trafficked site that has been monitored since 1995. It is an example of a pavement with deflections that are higher than the existing criteria but is behaving as a long-life pavement. The 85th percentile of the deflectograph measurements places it in the DLP category according to the conventional assessment criteria; the average of the 85th percentile values over the survey years is shown in Figure A1.

Under the enhanced assessment advice, the characteristics of the pavement have been compared to the characteristics of a long-life pavement.

Evidence of resistance to damage by traffic:

Figure A2 shows the evolution with time of the average central deflection value from the FWD; these measurements have been corrected for temperature. Although this is a heavily trafficked site, there was no significant trend detected in the evolution of deflection (according to the method shown in Appendix B) suggesting that there is no significant evidence of damage by traffic. In addition, the maintenance history of this site was consulted; this site had received no structural maintenance and it had carried almost all of the original design life by 1998; the pavement received an inlay treatment in 1996. Since 1996, this site has been regularly monitored, no structural maintenance has been required and the deflection behaviour has remained stable.

Asphalt soundness:

During 1998, cores were extracted from the pavement; no evidence of poor material was recorded.

Foundation stiffness: Using the recorded FWD deflections at the outer geophones in each survey, the minimum surface modulus at the equivalent depth of the foundation was estimated to be 119 MPa, therefore satisfactory support from the foundation is indicated.

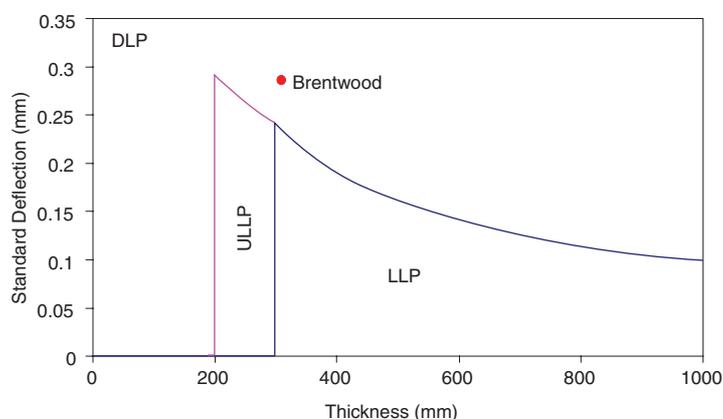


Figure A.1 The 85th percentile of deflectograph results at Brentwood compared to the criteria given in Figure 3.2

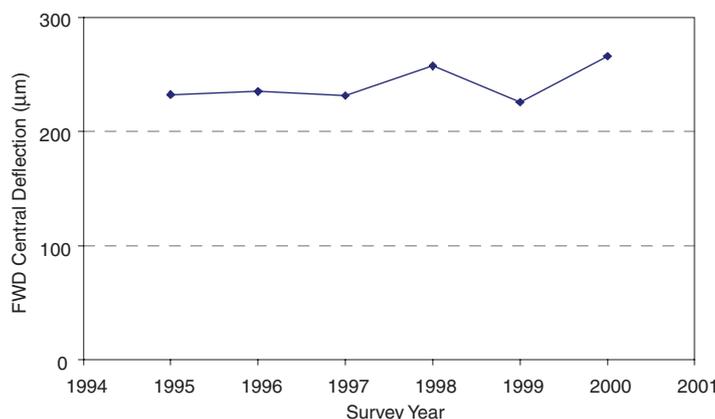


Figure A.2 Evolution of deflection at the M25 Brentwood

Asphalt thickness:

The cores extracted during 1998 confirmed that the asphalt layer was approximately 310 mm thick.

The pavement at this site appears to satisfy each of the characteristics associated with long-life pavements; therefore this indicates that this pavement could be considered as a potentially long-life or in the new terminology, a robust pavement.

A.1.2 A414 Cole Green

The A414 at Cole Green is a site that has been monitored for many years. It is an example of a pavement with low deflections; the 85th percentile of the deflectograph readings places it in the LLP category according to the conventional assessment criteria, the average value over the survey years is shown in Figure A3.

Under the enhanced assessment advice, the characteristics of the pavement have been compared to the characteristics of a long-life pavement.

Evidence of resistance to damage by traffic:

Figure A4 shows the evolution with time of the average central deflection value from the FWD; these measurements have been corrected for temperature. The evolution of deflection at this site exhibits a negligible increase and these deflections are low. There was no significant trend detected in the evolution of deflection

(according to the method shown in Appendix B) suggesting that there is no significant evidence of damage by traffic.

Asphalt soundness:

During 1998, cores were extracted from the pavement; no evidence of poor material was recorded.

Foundation stiffness:

Using the recorded FWD deflections at the outer geophones in each survey, the minimum surface modulus at the equivalent depth of the foundation was estimated to be 175 MPa, therefore satisfactory support from the foundation is indicated.

Asphalt thickness:

The cores extracted during 1998 confirmed that the asphalt layer was approximately 305 mm thick.

The pavement at this site appears to satisfy each of the characteristics associated with long-life pavements, this confirms the initial classification of the pavement as a LLP according to the deflection-thickness criteria.

A.1.3 A228 Snodland By-pass

The Snodland by-pass was constructed in the early eighties and is of fully-flexible construction. In 2001 a structural

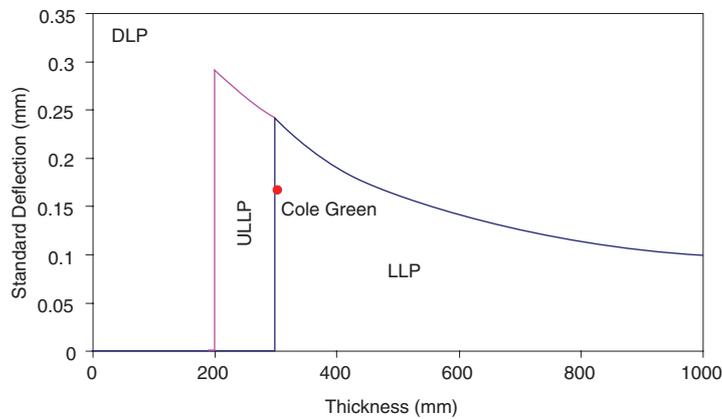


Figure A.3 The 85th percentile of deflectograph results at Cole Green compared to the criteria given in Figure 3.1

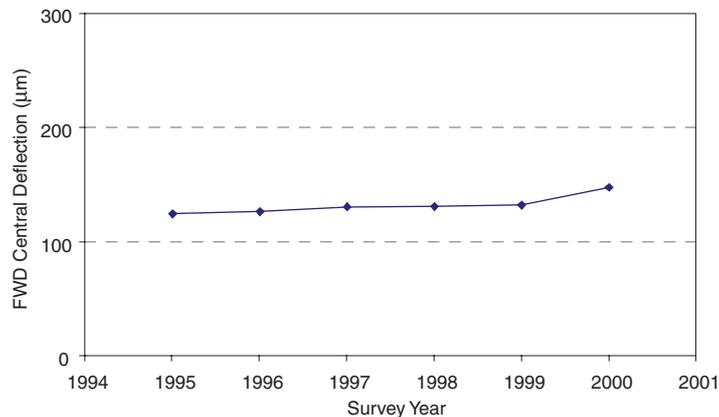


Figure A.4 Evolution of deflection at the A414 at Cole Green

strengthening treatment was carried out by Kent County Council due to increasing traffic levels caused by local increases in traffic on the M2 and M20 motorways and the presence of a longitudinal cracking and ruts in the nearside wheel-path. Kent County Council made the survey data available to the research in order to construct the following case study.

Evidence of resistance to damage by traffic:

Figure A4 shows the 85th percentile of deflectograph readings on the Northbound and Southbound carriageways. Figure A5 shows the criteria for a potentially ULLP according to Figure 3.2 for the TTBM determined on the northbound and southbound carriageways. The 85th percentile values have been plotted for both carriageways with the distance along road, Figure A5.

On the northbound carriageway, the deflection measurements are low, many below the ULLP criteria, suggesting that the pavement is structurally adequate. On the southbound carriageway, the deflections are higher and in some locations greater than the ULLP criteria.

Asphalt soundness:

Prior to commencing the maintenance treatment a large number of cores were extracted. The core records do not show any significant deterioration although it was suspected that the coring was not directed to the investigation of the observed visual deterioration.

Foundation stiffness:

Suitable records on the condition of the foundation were unavailable.

Asphalt thickness:

The cores extracted confirmed that the asphalt layer was approximately 245 mm thick on the northbound carriageway and 240 mm thick on the southbound carriageway.

In order to produce a potentially long-life pavement, the deflection measurements on the northbound carriageway suggest that the application of just 55 mm overlay would be sufficient at all sections; according to the current criteria, as shown in Figure 3.2 such an upgrade treatment would not be possible at all locations on the southbound carriageway. Otherwise, provided that the visual deterioration was initiated at the surface and the appropriate maintenance treatment carried out for this, it is likely that this pavement could have been operated as a robust pavement without increasing the overall pavement thickness by overlay. The benefits of this approach considering the costs associated with additional monitoring and risk would need to be confirmed.

A.1.4 Example of the use of the proposed upgrading procedures

The following example is a simulated use of the proposed upgrading procedures for the assessment example given for the M25 Brentwood. The site is not classed as a long-life pavement according to the current criteria. There may be a desire to take action to ensure that this pavement will not receive structural maintenance for the foreseeable future; therefore the enhanced assessment and upgrading advice will provide further information and the possibility of designing an appropriate upgrade treatment. The assessment provided in section A.1.1 confirmed that this pavement was robust according to the proposed criteria for long-life pavements and therefore the additional upgrading approach could be used.

The pavement cannot be considered as an upgradeable to long-life pavement as it does not satisfy the existing assessment criteria as shown in Figure 3.1 whereas the enhanced upgrade methodology is suitable for application to this pavement.

Using the enhanced upgrading methodology, the overlay design procedure is as follows:

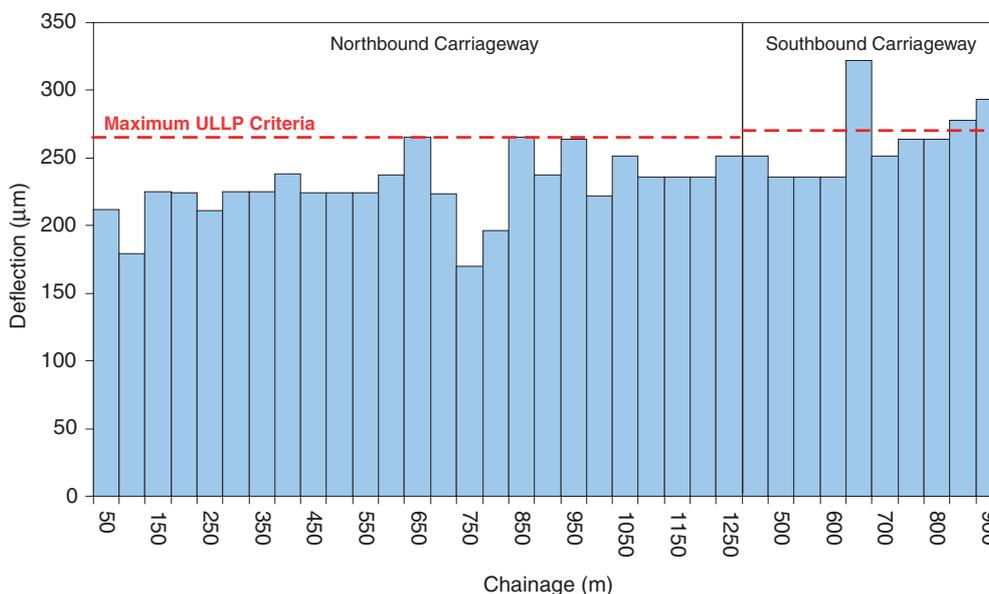


Figure A.5 85th percentiles of deflectograph measurements at Snodland

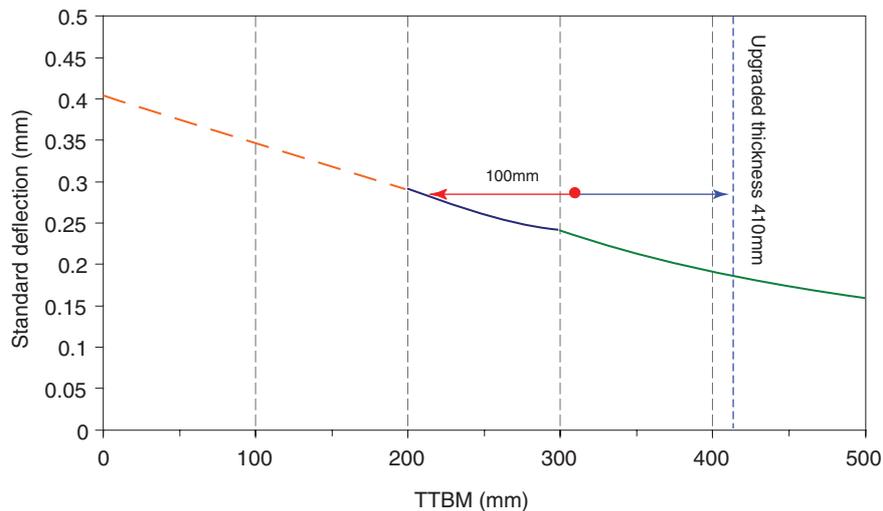


Figure A.6 Example upgrade using the data from Brentwood (Figure A.1)

• TTBM of existing pavement [A]	Thickness	310 mm
• Long-Life Pavement thickness criterion		300 mm
• TTBM > 300 mm $\therefore H_T = 0$ mm		0 mm
• Estimated TTBM for a pavement satisfying the extrapolated criteria with a deflection of 285 μ m [B]		210 mm
• $H_S = [A] - [B] = 310 \text{ mm} - 210 \text{ mm}$		100 mm
• Overlay design estimate $H_S + H_T$ [C]		100 mm
• TTBM of upgraded structure: [A] + [C]		410 mm

The proposed upgrading method resulted in a substantial increase in thickness because the deflection measurements on the existing pavement were well outside the existing criteria for potentially long-life pavements. Before the upgrading treatment is applied, an appraisal of the design should be made in comparison with the other options for upgrading (i.e. full reconstruction of the pavement).

A.2 Novel maintenance techniques for long-life pavements

A.2.1 Trench inlay

TRL have undertaken a pilot-scale trial of the trench inlay system (Section 6.2) using the TRL Pavement Test Facility within this programme of work. The experiment was formed within a pavement comprising high-modulus material and trafficked at a pavement temperature of 40°C; the results of this trial were reported by Sanders and Nunn (2004).

Trench inlay treatments have also been frequently applied on local authority roads. Sites where this type of treatment has been used were visited and the condition of the pavement assessed using a digital video survey; in total 28km of treatment were surveyed at 15 sites. The study found that the performance of the treatment at sites where a detailed structural assessment had been carried out was far superior to the other sites where only deflectograph or visual condition surveys had been undertaken. There were also instances of problems with the condition of the treatment that were attributable to poor compaction.

The study highlights the need for following the existing structural assessment procedures in order to enable appropriate trench inlay treatment to be designed and placed. In several cases, problems have arisen due to poor workmanship and a failure to address adequately the original cause of deterioration.

A.2.2 Partial depth crack treatment

In May 2003, a partial depth crack treatment (as illustrated in Figure 6.3) was undertaken on a bituminous pavement exhibiting surface cracking located on a major trunk road. The cracks in the existing structure originated at the surface and penetrated into the structure to a maximum recorded depth of 170 mm. For maintenance an 80 mm depth was inlaid with HDM and a further 30 mm Thin Surfacing System added.

The performance of this treatment could not be judged within the time-scale of this project and longer term monitoring of the pavement condition will be required.

A.3 References

Highways Agency (2005). *Validation monitoring of design and assessment methods.* Highways Agency Research Compendium. Retrieved: 2005, from www.ha-research.co.uk.

Sanders P and Nunn M E (2004). *Investigation into the properties of a 20 mm EME binder course for use on heavily trafficked roads.* Project Report. Wokingham: TRL Limited. (Unpublished project report available on direct personal application only)

Appendix B: A statistical method for the objective assessment of trends

It is possible to observe a trend in random data using linear regression techniques. Regression analysis will almost always result in positive or negative gradient; therefore it is impossible for this to be used as a tool for detecting no trend in the data.

The Mann-Kendall test assumes that where no significant trend exists, random error will produce positive and negative relationships between all the points. The random error is assumed to be normally distributed resulting in a normal distribution of relationships. Through the assignment of positive relationships of 1, and negative relationship of -1 , an overall view on the direction of these relationships can be made through the summation of assigned values.

The statistical test of these relationships is performed as follows:

The variance, s^2 , is given as:

$$s^2 = \frac{n(n-1)(2n+5)}{18}$$

For each set of two points $\{F(i); F(j)\}$ in the set, the relationship (R) is assigned:

$$R_{i,j} = \begin{cases} -1 : F(i) < F(j) \\ 0 : F(i) = F(j), i < j \\ 1 : F(i) > F(j) \end{cases}$$

The summation of relationships (C) is:

$$C = \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} R_{i,j}$$

The test statistic (T) is computed as:

$$T = \begin{cases} \frac{C-1}{5} : C > 0 \\ 0 : C = 0 \\ \frac{C+1}{5} : C < 0 \end{cases}$$

The test statistic is compared to a critical value from tables, Z_{α} , (where α is the test level) and the following conclusions can be stated:

$T > Z_{\alpha}$: There is a significant increasing trend

$T < -Z_{\alpha}$: There is a significant decreasing trend

$|T| < Z_{\alpha}$: There is no trend

Abstract

This report has been produced by TRL as a result of collaboration between the Quarry Products Association, Refined Bitumen Association and Highways Agency. The report provides guidance on the construction, assessment and maintenance of pavements that are not expected to experience structural deterioration, commonly referred to as long-life pavements. In order to apply the long-life pavement concept to a wider range of pavements, the concept of robust pavements has been introduced. Robust pavements are expected to deteriorate in a similar fashion and demonstrate similar characteristics to long-life pavements, with the exception that they can be thinner and carry a higher risk of structural deterioration than long-life pavements. This additional risk can be mitigated by the appropriate adjustment of maintenance assessment strategies.

Enhanced advice for the assessment and upgrading of robust and long-life pavements is proposed. This advice complements the existing Highways Agency practices and it extends the applicability of the concept beyond the trunk road network.

Maintenance treatments that are suitable for robust and long-life pavements are listed and novel treatments are presented that offer the opportunity to maintain long-life pavements in a more efficient and sustainable manner. This guidance will enable more accurate future budgeting of maintenance funds and assist highway engineers in the maintenance decision process.

Related publications

- TRL638 *A model set of asphalt sustainability indicators* by A R Parry. 2005 (price £30, code EX)
- TRL636 *The application of Enrobé à Module Élevé in flexible pavements* by P J Sanders and M Nunn. 2005 (price £40, Code HX)
- TRL456 *Development of a performance-based surfacing specification for high performance asphalt pavements* by D J Weston, M E Nunn, A J Brown and D Lawrence. 2001 (price £50, code L)
- TRL250 *Design of long-life flexible pavements for heavy traffic* by M E Nunn, A Brown, D Weston and J C Nicholls. 1997 (price £50, code L)
- TRL231 *Road trials of high modulus base (HMB)* by M E Nunn and T M Smith. 1997 (price £25, code E)
- PR66 *Evaluation of Enrobe a Module Eleve (EME: a French high modulus roadbase material* by M E Nunn and T M Smith. 1994 (price £25, code E)
- RR189 *Structural investigation of the road for the design of strengthening* by R T N Goddard. 1990 (price £20, code B)
- LR1132 *Design of bituminous pavements* by W D Powell, H C Mayhew, J F Potter and M E Nunn. 1984 (price £20, code A)
- CT119.1 *Bituminous binders and mix design update (2001-2003) Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)
- CT40.4 *Bituminous road design and construction update (2003-2004) Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

Prices current at June 2005

For further details of these and all other TRL publications, telephone Publication Sales on 01344 770783, email: publications@trl.co.uk, or visit TRL on the Internet at www.trl.co.uk.