VOLUME 7 PAVEMENT DESIGN AND MAINTENANCE

SECTION 2 PAVEMENT DESIGN AND CONSTRUCTION

PART 3

HD 26/01

PAVEMENT DESIGN

SUMMARY

This revision to HD 26 provides updated information on the materials and thicknesses for new pavement construction. The revision includes a design chart for performance-related fully flexible design.

INSTRUCTIONS FOR USE

This is a revised Standard to be incorporated in the Manual.

1. This document supersedes HD 26/94, which is now withdrawn.

2. Remove HD 26/94, which is superseded by HD 26/01, and archive as appropriate.

3. Insert HD 26/01 into Volume 7, Section 2, Part 3.

4. Archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

SCOTTISH EXECUTIVE DEVELOPMENT DEPARTMENT

THE NATIONAL ASSEMBLY FOR WALES
CYNULLIAD CENEDLAETHOL CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

Pavement Design

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SECTION 2 PAVEMENT DESIGN AND CONSTRUCTION

PART 3

HD 26/01

PAVEMENT DESIGN

Contents

1. INTRODUCTION

General

1.1 This part details various combinations of materials and thicknesses which may be considered for pavement construction, whether new build or full reconstruction. The design guidance is also useful when developing recommendations for partial reconstruction or strengthening overlays, if used in connection with the investigation techniques described in HD 30 (DMRB 7.3.3). It does not include the estimation of design traffic (see HD 24, DMRB 7.2.1), nor does it cover the design of pavement foundations (see HD 25, DMRB 7.2.2). Additional information on surfacing and surfacing materials is given in HD36 (DMRB 7.5.1).

1.2 The naming of the various pavement layers will be subject to change over the next few years to reflect European harmonisation:

Wearing Course	will become Surface Course
Basecourse	will become Binder Course
Roadbase	will become Base

The naming used in this Part has been amended to reflect this change although changes to the Specification and to British Standards will take longer to implement. In addition, all bituminous materials are now covered by the generic description ‘asphalt’.

1.3 Chapter 2 sets down the philosophy behind the Standard Designs and summarises the alternatives in the form of charts. Chapter 3 provides additional information on material behaviour to assist the designer, and Chapter 4 introduces analytical procedures which may be used by the designer to produce Alternative Designs.

Implementation

1.4 This Part shall be used forthwith on all schemes for the construction, improvement and maintenance of trunk roads including motorways currently being prepared, provided that, in the opinion of the Overseeing Organisation this would not result in significant additional expense or delay. Design organisations should confirm its application to particular schemes with the Overseeing Organisation.

Mutual Recognition

1.5 The construction and maintenance of highway pavements will normally be carried out under contracts incorporating the Overseeing Organisation’s Specification for Highway Works (MCHW1). In such cases products conforming to equivalent standards and specifications of other States of the European Economic Area and tests undertaken in the other States will be acceptable in accordance with the terms of the 104 and 105 Series of Clauses of that Specification. Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect regarding which advice should be sought.

2. STANDARD DESIGNS

DESIGN PHILISOPHY

2.1 The designs given in this Part are based on LR1132 (1984), for flexible and flexible composite construction, and RR87 (1987), for rigid and rigid composite construction, but amended and updated to take account of later research on new pavement materials and observed performance.

Flexible Pavements

2.2 LR1132 was based on observations and measurements of full-scale road experiments over a 20 year period, supplemented by structural analysis to rationalise and extend the data. The analysis used the elastic stiffness modulus of the various pavement and foundation layers, to calculate the strains developed within the structure. The strains could be related to life for the type of 'determinate' pavement structures which then existed.

2.3 Monitoring the performance of heavily trafficked roads has indicated that deterioration, in the form of cracking or deformation, is far more likely to be found in the surfacing rather than deeper in the structure for the thicker pavements which are more typical today. Therefore a well constructed flexible pavement, built above a threshold strength, will have a very long structural life - provided that distress, seen as cracks and ruts at the surface, is treated before it begins to affect the structural integrity of the road. Further background information is available in TRL Report 250 (1997).

2.4 Full scale road trials have also been carried out using high stiffness macadams - High Modulus Base (HMB) - manufactured to a standard composition for dense bitumen macadam (DBM) but using a binder of 35pen (HMB35). The trials demonstrated that the material behaved in a similar way to conventional base macadams, provided that the appropriate mixing, laying, and compaction temperatures were maintained. HMB35 has a high stiffness, and therefore offers better load spreading capabilities than either DBM, or Heavy Duty Macadam (HDM), so it is possible to achieve the same life with a thinner base. After allowance has been made for increases in production costs, savings can be achieved compared to conventional DBM.

2.5 Generally for "long life" indeterminate flexible pavements designed to carry traffic for at least 40 years, it is not necessary to increase the pavement thickness beyond that required for 80msa. Nevertheless, "long life" designs are not recommended to be thinner than 200mm, in order to help avoid structural rutting and to retard the progression of cracks from the surface down through the asphalt layers.

Flexible Composite Pavements

2.6 "Long life" indeterminate designs are also presented for flexible composite pavements, for traffic from 20 to 200msa. The thickness of the cemented lower base is reduced as the CBM strength increases, but all CBMs of strength equal to or greater than CBM1A, 2A and 3 must have induced cracks. As a consequence, the thickness of the asphalt overlay for indeterminate designs has been reduced to 190mm.

Rigid and Rigid Composite Pavements

2.7 RR87 was largely empirical, based on the performance of full scale experimental roads. There was less performance data for Continuously Reinforced Concrete Pavements (CRCP) and designs were developed from jointed reinforced concrete (JRC). For rigid composite structures, an allowance was made for the structural contribution and thermal insulation affected by the asphalt surfacing.

2.8 Use of CRCP with a Thin Wearing Course System (TWCS) can provide a "long life" with all the advantages offered by the noise reducing properties of the surfacing. Such pavements are ideally suited to the application of further asphalt overlays at stages during the future pavement life.

2.9 Developments in maintenance techniques, such as "crack and seat", have shown that some types of rigid pavement can now be effectively incorporated into a pavement strengthened with an overlay. Future developments, such as concrete inlays (currently under trial) may require consideration of lower design lives than the traditional 40 years as part of an overall planned maintenance strategy for a section of highway.

Pavement Deterioration

2.10 There are four main phases of structural deterioration for a flexible pavement that is not defined as indeterminate (See Annex 3 of HD 29 DMRB 7.3.2).

1) When a new or strengthened pavement is reaching equilibrium with a steady improvement in load spreading ability.

2) When load spreading ability is fairly stable, and the rate of structural deterioration may be predicted with some confidence.

3) When structural deterioration becomes less predictable. Pavements entering this phase should be monitored and investigated to determine what, if any, maintenance is appropriate to ensure that the next phase is not reached; hence this phase is termed the "investigatory" phase. (The term "critical" is no longer used). Residual life is the time period before a pavement is expected to enter its investigatory phase.

4) When the pavement deteriorates to a "failure" condition from which it can be strengthened only by total reconstruction. It is important to realise however that such pavements may not need reconstruction immediately, but will probably have several years of useful life, before increasing routine maintenance costs trigger the need for reconstruction.

2.11 More detailed information on pavement deterioration mechanisms for all pavement types is given in HD 30/99 (DMRB 7.3.3.2), and the "failure" criteria for rigid pavements are described in RR87.

Whole Life Cost

2.12 A Whole Life Cost assessment of a pavement considers both Works Costs (New construction; Maintenance; Residual Value) and User Costs (Traffic delay; Accidents at Roadworks; Skidding Accidents; Fuel Consumption/Tyre Wear; Residual Allowance).

2.13 A minimum whole life cost for a new pavement is generally achieved when a design life of approximately 40 years is assumed. For this reason, the standard design life for all types of pavement, with appropriate maintenance, is 40 years. An important factor is the degree to which future maintenance is likely to cause disruption.

2.14 For roads surfaced with asphalt, surface treatment would be expected to be required at about 10 year intervals. The period until surface treatment is required will also vary depending on the site's requirement for skidding resistance.

2.15 CRCP can be considered as part of a staged construction, because it can be strengthened with an overlay of asphalt or concrete (with asphalt surfacing in England) at a later date. The implications for additional loading on underbridges, clearance at overbridges, and problems at wide-flange steel beams should be considered.

2.16 It is often more economical to continue CRCP construction over buried structures rather than to end the pavement on each side of the structure which would necessitate the use of anchorages or movement joints.

DESIGN IMPLEMENTATION

Pavement Type

2.17 Options for permitted surfacings are set out in HD 36 (DMRB 7.5.1) and further details given in HD 37 and HD 38 (DMRB 7.5). Four types of pavement are generally considered as follows:

a) **Flexible;** where the surface course, binder course and base materials are bound with bitumen. Permitted binder course and base materials are as follows:

- Dense Bitumen Macadam (DBM)
- DBM with 50 penetration bitumen (DBM50)
- Heavy Duty Macadam (HDM)
- High Modulus Base with 35pen bitumen (HMB35), **except in Scotland where a Departure from Standard shall be obtained from the Overseeing Organisation.**
- Stone Mastic Asphalt (SMA), for use as binder course only, **except in Scotland where a Departure from Standard shall be obtained from the Overseeing Organisation.**
- Hot Rolled Asphalt (HRA), **which shall only be used in England and Wales with the approval of the Overseeing Organisation.**

Details of composition, manufacture and laying are given in the Specification (MCHW1) Series 900 and in British Standards.

b) **Flexible Composite;** where the surface course and upper base materials are bound with bitumen on a lower base of cement bound material (CBM). Various strength CBMs are permitted (see Figure 2.3 and MCHW1 Series 1000). For all designs the CBM layers (of strength equal or greater than CBM1A, 2A and 3) have transverse cracks induced.

Lower base materials comprising other hydraulic/ pozzolanic binders which achieve adequate flexural strength and stiffness modulus, may also be considered by the Overseeing Organisation. These materials typically have lower early age strength than CBMs but may provide a more cost effective pavement structure, especially if used as a combined sub-base/lower base layer. The potentially large range of material combinations, and difficulty in predicting future performance, means that no standard design charts can be prepared at present.

c) **Rigid;** comprising concrete slabs in the following categories:

- Unreinforced Concrete (URC)
- Jointed Reinforced Concrete (JRC)
- Continuously Reinforced Concrete Pavement (CRCP)

In England, rigid concrete construction of any type is not a permitted option for trunk roads unless it has an asphalt surfacing, see HD 36 (DMRB 7.5.1).

d) **Rigid Composite;** CRCR with an asphalt overlay or surfacing of at least 100mm. A ground beam anchorage is required at terminations of every CRCR.

For all rigid and rigid composite pavement alternatives the concrete slab shall be Pavement Quality Concrete (PQC), manufactured, laid and cured in accordance with the Specification (MCHW1) Series 1000.

2.18 Except where the pavement design is the responsibility of the contractor, designs shall be carried out for several options. These shall cover the range of base types (flexible/rigid/composite) permitted by the Overseeing Organisation, except where there are technical or environmental reasons why only one pavement type is suitable. Advice on surfacing types permitted by each Overseeing Organisation is available in HD 36 (DMRB 7.5.1).

Design Life

2.19 A pavement should preferably be designed for the predicted traffic over 40 years. For most trunk roads where design traffic is heavy in relation to the capacity of the layout, and in all cases where whole life costing is taken into account, 40 year designs shall be included as permitted options. 20 year designs may be appropriate for less heavily trafficked schemes or for major maintenance where other site constraints apply. The design traffic in msa shall be obtained from HD 24 (DMRB 7.2.1), Figs 2.1 and 2.2 for the 20 year designs and Figs 2.3 and 2.4 for the 40 year designs.

Design Charts

2.20 Figures 2.1 - 2.5 give the pavement material thicknesses appropriate to the various base types for a Standard Foundation. The total bound thickness shall be rounded up to the nearest 10mm in each case. They assume a granular Type 1 sub-base for flexible and flexible composite pavements, but CBMs or stabilised materials may be substituted provided it can be demonstrated that their performance is not inferior to Type 1. Where it can be demonstrated that the performance of the foundation is better than the Standard (refer to HD 25, DMRB 7.2.2) and can be expected to remain so for the design life of the pavement, then the Overseeing Organisation may consider reduced pavement thicknesses. Advice on procedures for assessing revised thicknesses can be found in Chapter 4 of this Part and HD 30 (DMRB 7.3.3). These procedures can also be applied in the assessment of the additional thickness of bound materials which is necessary where the foundation is below the Standard.

Flexible Construction

2.21 For fully flexible pavements two design charts are given (Figures 2.1 and 2.2). The preferred chart is Figure 2.1, which provides thicknesses based on Grades of Base ranked in terms of their characteristic stiffness. (The requirements for these Performance-specified Grades are given in the Specification (MCHW 1) Series 900, Clauses 929 and 944; also the Notes for Guidance (MCHW 2) Clause NG 944). For schemes where the additional materials testing required for the Performance-specified Grades is not justified, Figure 2.2 may be used in conjunction with the Specification (MCHW 1), Clause 929 and the appropriate recipe-based material specifications.

2.22 A number of surface course, binder course and base materials are now available. The total thickness for a fully flexible pavement depends on the base type. A DBM base is the least stiff material, and so requires the thickest construction. The stiffness of asphalt material then increases from DBM50, through HDM, to HMB35. As the stiffness increases, a reduced thickness of material will provide the same structural equivalence.

Flexible Composite Construction

2.23 Similarly, for flexible composite pavements, a range of strengths for CBM materials are permitted with thinner construction resulting from stronger material. For a given strength, better performance is expected for those CBM's made with coarse aggregate that has a lower coefficient of thermal expansion. For indeterminate designs in the range 20-200msa the design thicknesses are uniform for a given material combination.

2.24 Individual construction widths of CBM roadbase shall not exceed 4.75m. This minimises the risk of longitudinal cracking induced by combined stresses in a flexible composite pavement designed with indeterminate life (ie design life exceeds 20msa). Highway Construction Details (MCHW3) gives typical joint layouts. Flexible composite roads with determinate life (ie thinner construction) are more likely to deteriorate by general cracking; consequently restricting the individual laid width will not necessarily lead to improved performance.

Rigid and Rigid Composite Construction

2.25 For jointed concrete pavements, load induced stresses at slab corners and edges are greater than in the slab centre, necessitating dowel bars to distribute loads between slabs. Joint associated distress occurs principally when dowels do not function properly. The use of a tied shoulder or 1m edge strip ensures that the untied edge is remote from the wheelpaths, with a consequent reduction in stress. This load distribution occurs whether or not a longitudinal construction joint or wet-formed joint is included adjacent to the edge line as permitted by Highway Construction Details (MCHW3).

2.26 Figures 2.4 and 2.5 assume the presence of a minimum 1m edge strip or tied hardshoulder adjacent to the most heavily trafficked lane. Urban roads, and any other roads that do not have a 1m edge strip or a tied hardshoulder adjacent to the left hand lane will require thicker slabs. The additional thickness required is given in Figure 2.6. Heavy trafficking of right hand lanes and hardshoulders during future maintenance will be of relatively short duration and need not be considered in design.

2.27 Edge treatments and other construction drawings are given in the Highway Construction Details (MCHW3). For further advice on edge of pavement drainage, refer to HA 39 (DMRB 4.2.1).

2.28 For CRCP and CRCR the depth of reinforcement in the slab has been chosen to reduce the risk of corrosion caused by salts penetrating the cracks. Transverse reinforcement is required for ease and consistency of construction. Transverse bars may be incorporated into the support arrangement for the reinforcement, so long as the required quantities and position of steel is maintained. (See Notes to Figure 2.5).

2.29 Longitudinal steel in CRCP or CRCR may be welded or spliced on site and positioned so that front loading of concrete to a slipform paver is possible, provided the bars are guided into the correct position in the slab through gates in the paver.

2.30 To ensure that forces are not transmitted to structures and adjacent forms of pavement construction by the expansion of the slab, either the ends of the CRCP and CRCR shall be restrained by a ground beam anchorage, or (for CRCP only) movement shall be accommodated within a wide flange steel beam. Both types use transition slabs, as shown in the Highway Construction Details (MCHW3).

2.31 Ground beam anchors shall not be used for CRCP where the subgrade strength is poor, especially on high embankments where consolidation may be insufficient to restrain movement of the beam downstands.

2.32 CRCP or CRCR options shall be considered where the design traffic loading exceeds 30msa. It is recommended that they should also be included for less heavily trafficked schemes where the advantages of lower maintenance throughout the design life may be worthwhile. Proposals for designs above 400msa will be considered by the Overseeing Organisations under the normal Departures procedure.

Ground Subject to Movement

2.33 Flexible composite and URC construction are suitable in normal applications except where differential movement, subsidence or appreciable settlement is expected. This includes areas where mines are currently worked, or may be worked in the future. Flexible and JRC construction are suitable in all applications, except where large differential movements or large settlements caused by compressible ground, or considerable subsidence caused by mining are expected. CRCP and CRCR constructions are suitable in all applications. They may be particularly suitable where large differential movements are expected because they can withstand significant strains while remaining substantially intact.

Laybys and Hardstandings

2.34 To resist the problems caused by oil and diesel spillage, laybys and hardstandings shall be surfaced with either:

i) Concrete, see Specification (MCHW1) Series 1000;

ii) Block paving, see Specification (MCHW1) Series 1100;

iii) A deformation resistant surfacing made with a proprietary fuel resistant binder.

Alternative Designs

2.35 If any pavement design other than those given in this section is to be considered, approval to proceed is required from the Overseeing Organisation at the preliminary design stage. Submissions seeking approval for alternative designs shall include a justification for the choice of non-standard materials and/or thicknesses, supporting calculations and an indication of any additional specification requirements or testing regime which may be necessary for their validation. Analytical pavement design procedures (see Chapter 4) may be used in support of any such alternative proposal.

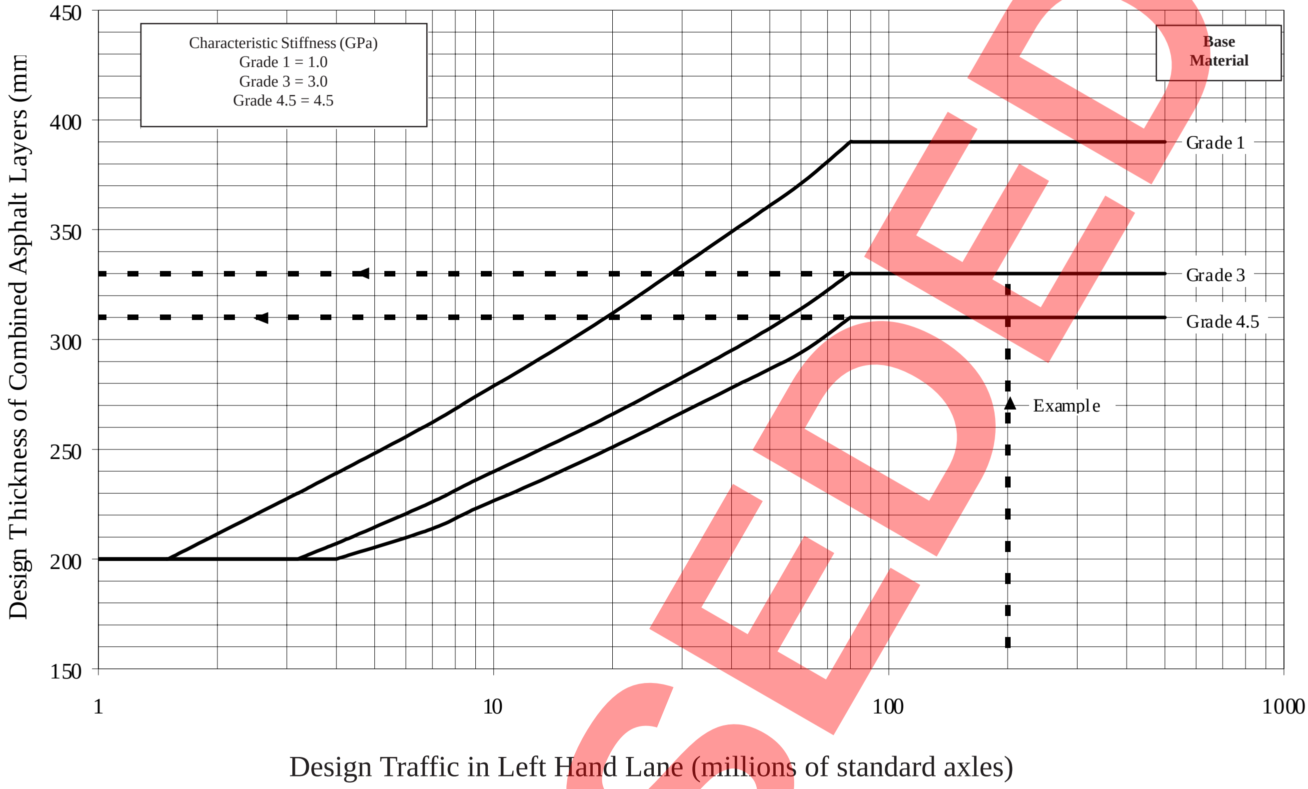


Figure 2.1: Design Thickness for Flexible Pavements: Performance-specified Grades of Base

Figure 2.2: Design Thickness for Flexible Pavements: Recipe-based Specifications of Base

Notes on Figures 2.1 and 2.2:

1. Surface course shall consist of one of the permitted materials presented in Tables 2.2E, 2.2S, 2.2NI or 2.2W (as appropriate) in HD 36 (DMRB 7.5.1). For further details refer to HD 37 and HD 38 (DMRB 7.5).

2. For HRA surfacing where permitted, refer to either:

Clause 943 of the Specification (MCHW1), or to:

Clause 911, with reference to BS594: Part 1: Annex B: Table B1 for stability and flow values related to traffic loading.

For Scotland, design values are given in the Overseeing Organisation's special requirements in Clause NG911S.SO (MCHW2).

In Northern Ireland recipe mixes to BS594: Part 1 may be used where considered appropriate by the Overseeing Organisation.

3. If 50mm of Porous Asphalt (PA) surfacing is to be used, it shall be modified with a polymer or fibre additive. Its contribution to the material design thickness is only 20mm. A 60mm dense binder course, compacted to meet the maximum air voids requirement in the Specification (MCHW1) Series 900, is required beneath PA surfacing.

4. A binder course, or upper base layer, compacted to meet the maximum air voids requirements in the Specification (MCHW1) Series 900 is required beneath the surface course. It shall be of any permitted material (subject to Note 6) and be at least 50mm thick, except for SMA binder course which should be a minimum of 30mm thick.

5. Figures 2.1 and 2.2 assume a maximum thickness of 50mm for HRA. Although other permitted materials may have lower stiffness than HRA it is assumed that the additional roadbase required to make up for the thinner surfacing adequately compensates in overall load spreading ability.

6. Figure 2.1 assumes that the binder course achieves the same minimum stiffness characteristics as the base; Figure 2.2 assumes that the binder course is the same material as the base. However any permitted material may be used as long as the overall pavement thickness is adjusted to give equivalent load spreading ability. (Refer to Chapter 4 of this Part for guidance).

7. DBM and HMB 35 base (and binder course) shall contain 100 and 35 penetration grade binder respectively. HRA, DBM50 and HDM base (and binder course) shall contain 50 penetration grade binder.

8. Where traffic exceeds 80msa, binder course and base materials shall contain crushed rock, or slag coarse aggregate, unless local experience exists of the successful use of gravel.

Examples

1. Using Performance-specified Grades of Base (Figure 2.1)

   Design Traffic 200msa

   Binder course/Base options, assuming 30mm of Thin Wearing Course System (TWCS):

   a) 30mm TWCS
   50mm Grade 4.5 binder course
   230mm Grade 4.5 base

   b) 30mm TWCS
   50mm Grade 3 binder course
   250mm Grade 3 base

2. Using Recipe-based Specifications for Base (Figure 2.2)

   Design Traffic 30msa
   Assuming **HDM** base as an example:-

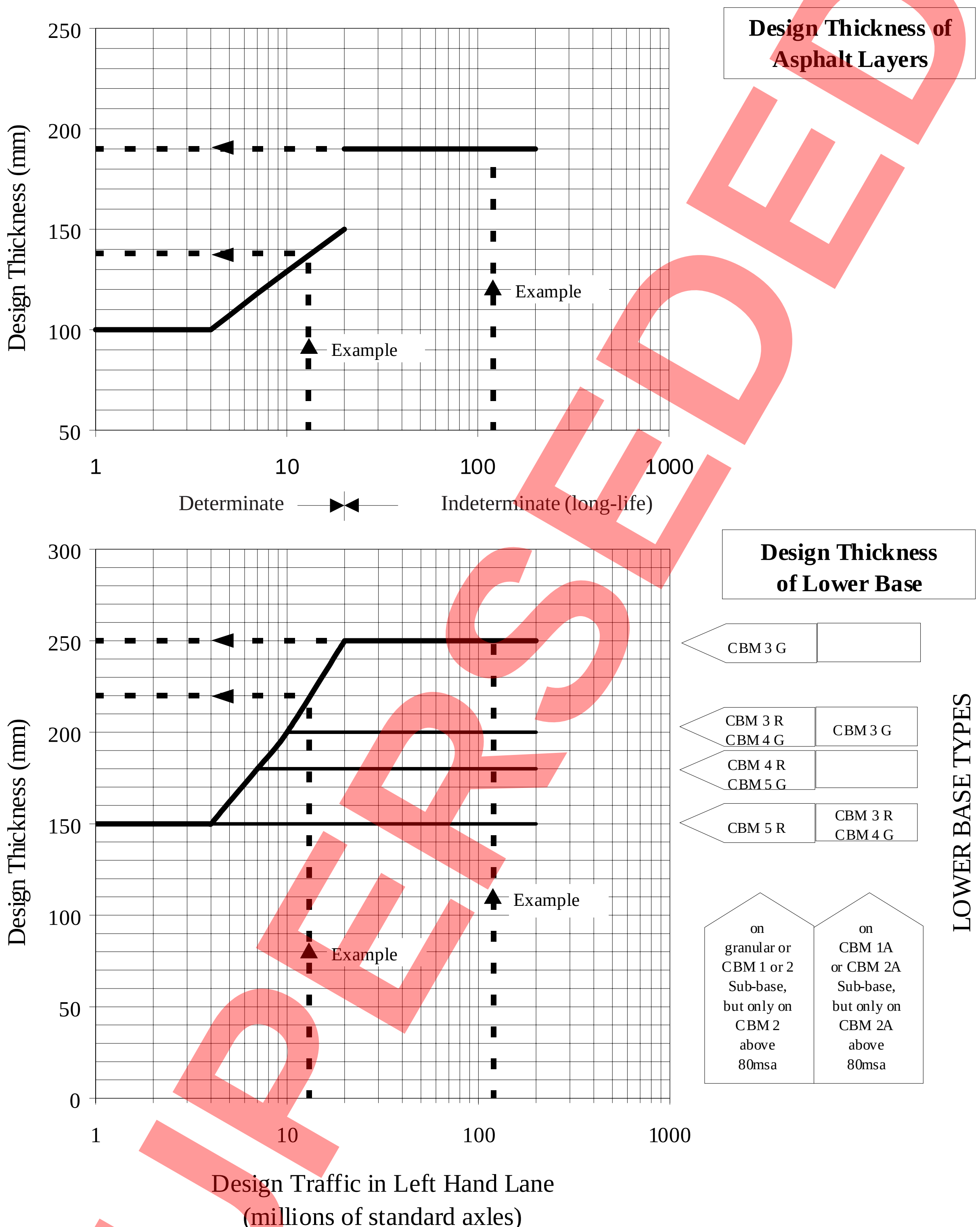
   Design Thickness 280mm
   (275mm rounded up to nearest 10mm)

   Surfacing options permitted for each scheme will vary but some examples are given below:

a) 30mm TWCS + 60mm HDM binder course + 190mm HDM base

b) 45mm HRA surface course (where permitted)* 235mm HDM base

* or 50mm HRA surface course can be used



R = Roadbase having a coefficient of thermal expansion less than 10 x 10^{-6} per °C, containing crushed rock aggregate.

G = Roadbase containing gravel aggregate or Roadbase that has a coefficient of thermal expansion more than 10 x 10^{-6} per °C, containing crushed rock aggregate.

Figure 2.3: Design Thicknesses for Flexible Composite Pavements

Notes on Figure 2.3

1. Notes 1-4 and 7-8 for Figures 2.1 and 2.2 shall apply to Figure 2.3.

2. The thickness of asphalt layers in Figure 2.3 is applicable to all permitted binder course base materials.

3. In Scotland, the minimum thickness of CBM 3 or 4 shall be 175mm.

4. Where a cement bound sub-base is used, it must be checked to ensure that no longitudinal cracks are present before the lower base is laid.

5. All CBM 1A, 2A, 3 or stronger sub-bases and bases shall have cracks induced, normally at 3m centres, in accordance with the Specification (MCHW1) Clause 1047. Cracks induced in the base shall be approximately aligned with the induced cracks in the sub-base (±100mm).

Examples

1. Design Traffic 13msa
Asphalt Layers: Total = 140mm

Some **surfacing** options:

a) 45mm HRA surface course (where permitted)
95mm DBM base

b) 15mm TWCS
30mm SMA binder course
95mm HDM base

c) 30mm TWCS
110mm DBM 50 binder course/base

Some **lower base** options:

a) 220mm CBM 3G on granular, CBM 1 or CBM 2 sub-base
b) 200mm CBM 3R on granular, CBM 1 or CBM 2 sub-base
c) 200mm CBM 3G on CBM 1A or CBM 2A sub-base
d) 200mm CBM 4G on granular, CBM 1 or CBM 2 sub-base
e) 150mm CBM 5R on granular, CBM 1 or CBM 2 sub-base

2. Design Traffic 120msa.

Some options:

a) 15mm TWCS
50mm DBM binder course
125mm HDM base
200mm CBM 3G (pre-cracked)
on CBM2A sub-base (pre-cracked)

b) 30mm TWCS
30mm SMA binder course
130mm HDM base
150mm CBM 5R (pre-cracked)
on CBM 2 sub-base

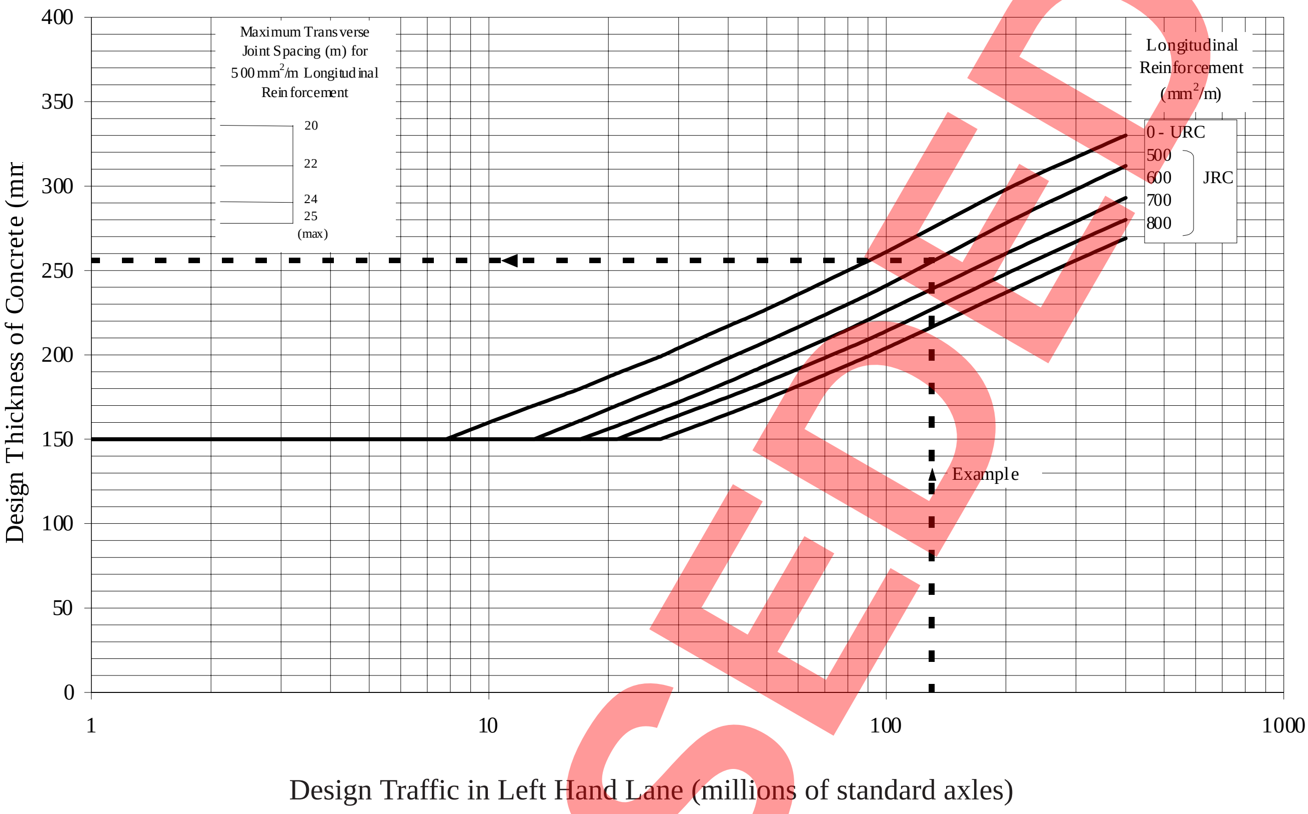


Figure 2.4: Design Thickness for Rigid Jointed Pavements

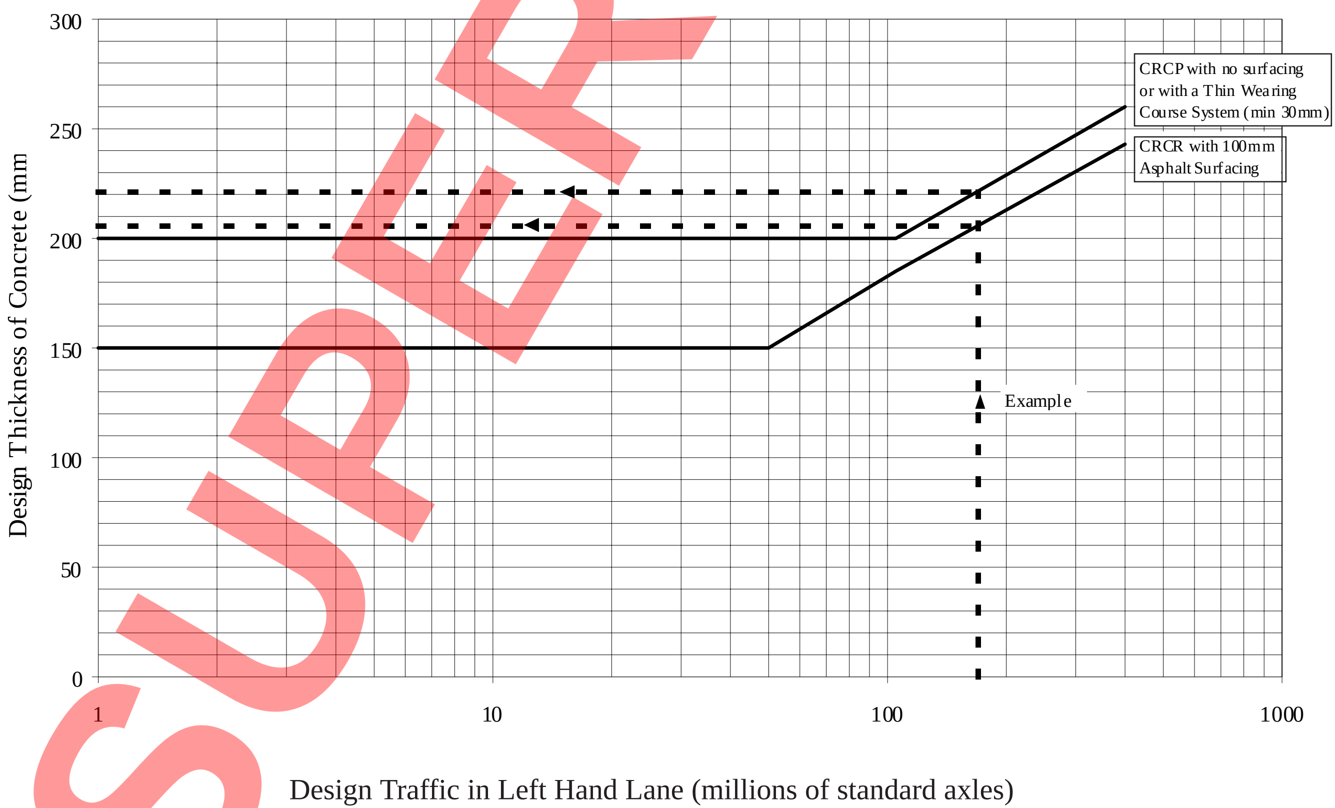


Figure 2.4: Design Thickness for Continuously Reinforced Concrete Pavements (CRCP) and Continuously Reinforced Concrete Roadbase (CRCR)

Notes on Figure 2.4

1. Maximum transverse joint spacings for URC pavements:

   a) For slab thickness up to 230mm
   - 4m for contraction joints

   b) For slab thickness 230mm and over
   - 5m for contraction joints

2. The maximum transverse joint spacings for JRC pavements shall be 25m except for slabs having 500mm²/m reinforcement, where the maximum joint spacing shall be read from the insert to Figure 2.4.

3. For JRC pavements, intermediate values of slab thickness, longitudinal reinforcement area, and maximum transverse joint spacing, may be interpolated. The minimum longitudinal reinforcement permitted is 500mm²/m.

4. If limestone coarse aggregate is used throughout the depth of the slab, transverse joint spacings may be increased by 20%.

5. For details of permissible concrete surfacing refer to HD 36 and HD 38 (DMRB 7.5.1 and 7.5.3).

Example

Design Traffic 130msa
Pavement Type JRC
Reinforcement 500mm²/m

Design Thickness 260mm
Transverse Joint Spacing
25m (non limestone coarse aggregate)
or 30m (limestone coarse aggregate)

(Note: Unsuitable in England since JRC would require an asphalt surface, which would lead to reflection cracking and subsequent maintenance of surfacing).

Notes on Figure 2.5:

1. Notes 1, 2, 4, 7-8 for Figures 2.1 and 2.2 shall apply to Figure 2.5.

2. Two options for CRCP are available:

a) CRCP with no surfacing - not a permitted option in England

b) CRCP with minimum 30mm of Thin Wearing Course System.

3. If PA surface course is used over CRCR, it shall be over a dense binder course in accordance with Clause 929 of the Specification (MCHW1) and either:

   i) 50mm thick over 90mm of binder course, or:
   ii) 50mm thick over 60mm of binder course but with the CRCR slab thickness increased by 10mm.

4. PA surface course shall be modified with a polymer or fibre additive.

5. Longitudinal reinforcement in CRCP without surfacing, or with a minimum of 30mm Thin Wearing Course System, shall be 0.6% of the concrete slab cross-sectional area, comprising 16mm diameter deformed steel bars. Transverse reinforcement shall be 12mm diameter deformed bars at 600mm spacings.

6. Longitudinal reinforcement in CRCR with a minimum of 100mm asphalt surface course and binder course shall be 0.4% of the concrete slab cross-sectional area, comprising 12mm diameter deformed bars.

7. For CRCP, a ground beam anchorage or wide-flange steel beam shall be provided at the ends of all pavements and any discontinuities.

8. A ground beam anchorage is required at the termination or at any discontinuity of a CRCR.

9.	Exposed Aggregate Concrete Surfacing (EACS) shall only be used with the approval of the Overseeing Organisation. For options and details refer to HD 36 and HD 38 (DMRB 7.5.3.1 and 3).

Example

Tied hardshoulder or 1m edge strip.
Design Traffic 170msa

Some options:

a) 30mm TWCS
220mm CRCP

b) 45mm HRA surface course (where permitted)
55mm DBM binder course
210mm CRCR

c) 15mm TWCS
85mm DBM binder course
210mm CRCR

Note: For b) above, use of a Performance based surfacing to Clause 943 is recommended.

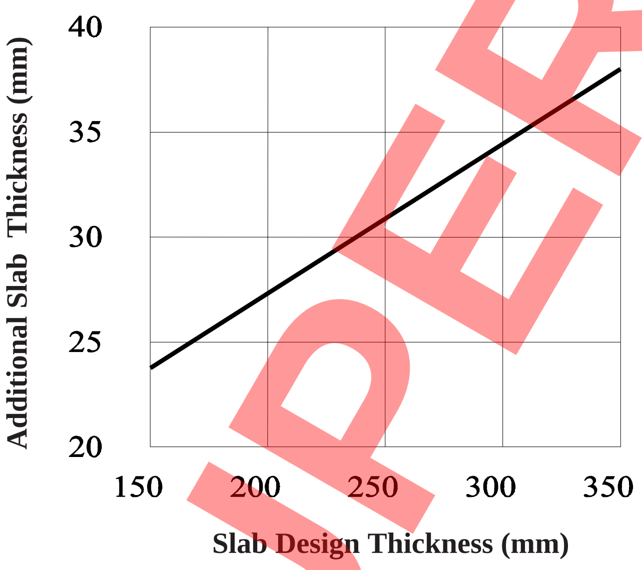


Figure 2.6: Additional Concrete Slab Thickness for Pavements without 1m Edge Strip or Tied Hardshoulder

3. MATERIALS

BITUMEN BOUND MATERIALS

3.1 Most asphalt binder course and base materials are characterised by an aggregate skeleton, where the individual particles are mechanically interlocked, bound with penetration grade bitumen in the range 35-100pen. The aggregate skeleton provides deformation resistance (provided that in-situ air voids are typically in the range 2-6%), as well as contributing to stiffness. Clause 929 of the Specification (MCHW1) provides guidance. The binder content should be sufficient to provide thick enough binder films on the aggregate to create fatigue resistance and achieve durability. Generally the lower penetration binders are used to obtain increased stiffness.

Premature Rutting

3.2 Early age deformation (rutting) in surface and binder course layers may be initiated by slow moving commercial vehicles (eg in a contraflow), especially on uphill lengths and when pavement temperatures are high, relatively soon after the materials have been laid (eg during major maintenance). Such situations should therefore be avoided. Where HRA (if permitted) is used, Clause 943 of the Specification (MCHW1) and Notes for Guidance (MCHW 2) provide guidance on performance requirements. For SMA binder course performance requirements, see Clause 937 and NG 937 (MCHW 1 & 2).

Bond

3.3 The designs given in this Part are based on the structural requirements for the pavement layers. They implicitly assume that full bond is achieved between layers (unless specifically required otherwise, such as between a jointed concrete slab and underlying sub-base). This bond may take some time to develop, and is one of the reasons why deflection measurements taken at early age can be higher than expected. For 'lean' base materials, particularly where low penetration binder is used, it may be prudent to specify use of a bond coat to ensure satisfactory whole life performance.

3.4 Particular attention should be paid to specifying and achieving good bond between a Thin Wearing Course System and the underlying flexible or rigid construction. This is because, under certain circumstances (eg braking vehicles), high shear stresses can be developed at these shallow interfaces.

3.5 Since Thin Wearing Course Systems may have a higher void content (with larger individual air voids) than the more traditional Hot Rolled Asphalt, it is important to ensure that the chosen binder course or upper base layer can provide an effective barrier to water entering the lower pavement layers. Such durability issues are particularly important where the base may be manufactured quite 'lean' in binder, perhaps in an attempt to provide high stiffness and rut resistance. For SMA binder course an air void content of 2-6% is required for durability, and wheeltracking limits are imposed, see the Specification (MCHW1) Series 900.

3.6 When considering the costs and benefits of using Porous Asphalt (PA), it should be remembered that:

- PA can be significantly more expensive;
- PA has shorter life than other surfacings;
- PA will cost more to repair;
- Other sound reduction measures or surfacings may be more worthwhile in whole life cost terms;
- Although spray may be reduced, evidence suggests that there is no reduction in accidents.

3.7 A decision on whether to use PA should be taken only after consideration of all relevant factors. The Overseeing Organisation may be consulted for advice on the suitability of using PA in particular circumstances. Further details on PA are contained in HD 37 (DMRB 7.5.2).

PAVEMENT QUALITY CONCRETE

3.8 The stress generated in a concrete slab partly depends on the stiffness ratio between the slab and its underlying support. To maximise the pavement life, all rigid pavements are specified with a relatively stiff cemented sub-base. This type of sub-base erodes less than an unbound material and is less water susceptible should joint sealants fail.

3.9 Concrete is inherently strong in compression, but weak in tension. Repeated stressing will eventually lead to crack initiation unless the stress is very low. Thicker slabs result in lower stresses being generated under the combined influence of vehicular and temperature loading.

Jointed Pavements

3.10 Temperature and, to a lesser extent, moisture changes cause shrinkage/expansion of the slab which, if restrained, induce stresses in the concrete. A separation membrane is required between slab and sub-base for both URC and JRC pavements, in order to reduce this restraint and thus inhibit the formation of mid bay cracks. It also helps reduce loss of water from the fresh concrete.

3.11 Three different types of joints are used in concrete pavements. They are contraction, expansion and warping joints, typical details of which are illustrated in Highway Construction Details (MCHW3). All three types permit warping movement.

3.12 **Contraction** joints enable the slab to shorten when its temperature falls and allow the slab to expand subsequently by approximately the same amount. **Expansion** joints allow the slab to shorten and also cater for the expansion movement that would naturally occur at temperatures higher than that of the concrete at the time the slab was constructed. Transverse joints are either expansion or contraction types. However, longitudinal joints are of the **warping** type only. These tie the slabs together, and can be thought of as acting as 'hinges' in the slab.

3.13 The permitted spacing of transverse joints is a function of slab thickness, aggregate type, and, for JRC, the quantity of reinforcement. Joint spacing reflects the capacity of the slab to distribute strain rather than allow damaging strain concentrations.

3.14 Limestone aggregate has a lower coefficient of thermal expansion than other aggregate types, resulting in less expansion/contraction of the slab. Therefore greater joint spacings can be used. The effectiveness of reinforcement, as a distributor of strain, increases with the amount used. Greater joint spacings can be used with larger areas of reinforcement, although this results in greater movement at each joint, necessitating appropriate selection of sealants.

Continuously Reinforced Concrete (CRCP and CRCR)

3.15 CRCP/CRCR pavements develop a fine transverse crack pattern soon after the concrete is laid. Initially the crack spacing is about 3 or 4m. Further cracking is usual after the road has been in service for a time. The continuous longitudinal reinforcement holds the cracks tightly closed, ensuring load transfer by aggregate interlock and minimising corrosion of the reinforcement. The crack propagation in CRCP/CRCR pavements is closely related to the proportion of steel, the strength of the concrete and the aggregate used.

3.16 The separation membrane is omitted from CRCP/CRCR construction in order to give a higher level of friction between the concrete slab and the sub-base than for jointed slabs. The restraint provided by the sub-base reduces the amount of movement at the ends of the pavement and encourages the desired crack pattern. The use of a layer of material under the CRCP/CRCR with uniform surface properties, such as may be provided by paver-laid wet-lean concrete or an asphalt material, is recommended. The thickness of any dense asphalt material may be considered as part of the bound sub-base.

3.17 Discontinuities in the slab should be avoided wherever possible as they encourage the formation of closely spaced cracks, with increased risk of spalling. Gullies and manholes should be located outside the main CRCP/CRCR slab for this reason. If this is not possible, the slab around the gullies and manholes should be heavily reinforced as shown in the Highway Construction Details (MCHW3).

3.18 Where a CRCP has an asphalt surface course, surface noise generation is reduced and water penetration (and the potential for reinforcement corrosion) is likely to be reduced. If the surfacing is 100mm thick (or more) it also provides a degree of thermal protection from rapid temperature changes for the concrete base. If the 30mm minimum TWCS is used, the bond coat required to ensure good adhesion between the CRCP and the TWCS shall comply with the requirements of the Specification (MCHW1) Clause 942 and any additional BBA HAPAS requirements for the TWCS being used.

Crack and Seat

3.19 Cracking and seating of URC pavements, prior to application of an asphalt overlay, can be a cost effective strengthening alternative to reconstruction, for concrete pavements near the end of their design life. Procedures for determining the thickness of the overlay can be based on an analytical procedure as described in Chapter 4 of this Part.

CEMENT AND OTHER HYDRAULIC/ POZZOLANIC BOUND MATERIALS

Crack Inducement/Pre-cracking of CBM's

3.20 Transverse cracks may occur in the surface of flexible composite pavements as a "reflection" of the naturally occurring thermal stress cracks in the CBM base, which typically occur at a natural spacing of 10-30m. The introduction of cracks in the CBM base at a closer spacing will reduce the magnitude of the thermal movements at individual cracks, and hence the tensile stresses in the asphalt overlay. This minimises the size and severity of the surface crack, which reduces future maintenance costs and allows the pavement life to be extended.

Hydraulic/Pozzolanic Binders

3.21 Use of secondary aggregates, combined with hydraulic or pozzolanic binders, for sub-base and lower base layers has become increasingly common, and can result in environmental benefits. Due to the relatively slow strength gain of such materials (compared to a CBM for example) they should be considered more like unbound granular layers in the short term (construction phase). Strength gain in the medium to long term (given appropriate environmental conditions) results in a stronger foundation for the upper pavement layers. The slower strength gain (and reduced heat of hydration) may have additional benefits in reducing the magnitude of initial thermal movements. This helps to increase the pavement life, or alternatively, in some circumstances a reduced thickness for the upper pavement layers may be justified. Chapter 5 lists a number of publications that provide guidance on suitable materials.

4. ALTERNATIVE DESIGN PROCEDURES

Analytical Pavement Design

4.1 The philosophy of analytical design is that the pavement should be treated in the same way as other civil engineering structures, the procedure for which may be summarised as follows:

a) Specify the loading.

b) Estimate the size of components.

c) Consider the materials available.

d) Carry out a structural analysis using theoretical principles.

e) Compare critical stresses, strains or deflections with allowable values.

f) Make adjustments to materials or geometry until a satisfactory design is achieved.

g) Consider the economic feasibility of the result.

4.2 Classical pavement design relies upon the use of a simplified multi-layer linear elastic model of the pavement structure. Appropriate stiffness moduli are chosen for the various pavement layers, either on the basis of known mixture properties or from laboratory or field tests. A standard axle load (40kN wheel load) is then applied, and the relevant critical strains or stresses are calculated.

4.3 The classical approach assumes two primary modes of failure caused by trafficking of a pavement:

- Fatigue cracking at bottom of the base.

- Overstressing of the subgrade, resulting in deformation.

However, the designer should always use judgement and consider other modes of failure which might be more critical for the particular pavement under construction. For example:

- Permanent deformation within the asphalt materials.

- Reflection cracking, for composite pavements.

- Surface initiated cracking and other durability related issues.

4.4 The design task is to proportion the pavement structure so that the critical levels of stress or strain will not be exceeded in the design life. To achieve this, the designer needs information on the engineering properties of the materials, particularly:

- Effective stiffness modulus, which governs load spreading behaviour.

- Deformation resistance, which governs rutting behaviour. (Asphalt materials only.)

- Fatigue resistance, which governs cracking behaviour.

4.5 Relationships between pavement life and these critical strains or stresses have been derived from a combination of laboratory testing and pavement performance monitoring. The references given in Chapter 5 of this Part give further background.

4.6 However it is still necessary for the designer to make appropriate judgements. For example two very different asphalt mixes, even if both nominally of the same type (eg HDM) could yield different lives, depending on the aggregate structure and binder content. Similarly, the permanent deformation behaviour of a sandy subgrade will differ from a clay, even if they have the same stiffness.

4.7 It should be noted that a specific analytical design method has not been defined. The available methods differ in their mathematical formulation and each method is generally internally consistent. It should be appreciated that inadequate designs can result if elements from different methods are combined inappropriately.

Alternative Pavement Designs

4.8 The analytical approach provides a means of customising a pavement design to locally available materials, or construction methods (eg stabilisation). However, it is essential that the material properties assumed are actually achieved on site if the whole life performance of the pavement structure is to be achieved. It is also essential that due consideration is given to the overall durability of the pavement structure (ie the resistance of the materials to the deleterious effects of water, air, and other environmental factors).

4.9 Where used appropriately, the Overseeing Organisations will accept the use of analytical pavement design to justify alternatives. However, full supporting details must be submitted in order for a Departure from Standard to be authorised.

4.10 Where Alternative Pavement Designs can be readily compared with the Standard Design charts in this Part, it should be shown that the overall load spreading ability of the alternative pavement (in terms of critical strains, stresses and stiffness moduli) is equal to or greater than the standard obtained from HD 25 and Chapter 2 of this Part. In addition the expected serviceability (eg skidding resistance) and maintainability should not be inferior to the Standard Design. Values for the engineering properties of all materials proposed should be provided. Proposals should show a realistic balance between the strength of the foundation and that of the pavement. Design thickness proposals shall make allowance for construction tolerances.

4.11 Values of elastic stiffness modulus for use in analytical design shall be:

DBM	3,100 MPa
DBM50 & HDM	5,600 MPa
HMB 35	7,000 MPa

Design stiffness moduli used for pavement design are at the reference condition of 20°C and 5 Hz and shall not be confused with ITSM stiffness, which is measured for compliance testing at the lower frequency of 2.5 Hz. Design stiffness moduli for foundation layers shall not be confused with foundation surface stiffness measured using the FWD or plate bearing tests.

4.12 In other cases, in order to assist with the evaluation of the alternative, the following should also be supplied:

- Information on the analytical pavement design model adopted;
- Definition of pavement requirements in terms of design traffic normally given in million standard axles (msa);
- Material properties assumed and how obtained (eg from site or laboratory testing or published data);
- Information on the failure mechanisms considered by the designers;
- Test procedures to be adopted on site to ensure that the mean and minimum parameter values assumed in the design are achieved on site;
- Sensitivity analysis to identify the parameters that have most influence on life;
- Procedures to be adopted on site to reduce the variability of pavement construction, in particular the most influential parameters identified from the sensitivity analysis;
- Experience of long term performance of similar pavements, both in the UK and overseas;
- Comparisons with other published designs, especially from countries with similar trafficking levels, climatic conditions and material properties to the UK.

4.13 It should be noted that the procedures laid out in Annex B of HD 30/99 (DMRB 7.3.3) for determining the thickness of a continuously reinforced concrete overlay (based on RR87) can also be used to design a CRCP on a foundation stronger than the standard assumed in HD 25 (DMRB 7.2.2).

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