VOLUME 7 PAVEMENT DESIGN AND MAINTENANCE

SECTION 2 PAVEMENT DESIGN AND CONSTRUCTION

PART 3

HD 26/06

PAVEMENT DESIGN

SUMMARY

This Standard provides the details of permitted materials and of thickness for the construction of pavements for new trunk roads. This revision updates the previous Standard and also introduces different permitted designs that relate to the strength of the available foundation.

INSTRUCTIONS FOR USE

1. Remove Contents pages from Volume 7 and insert new Contents pages for Volume 7 dated February 2006.

2. Remove HD 26/01 from Volume 7, Section 2 which is superseded by this Standard and archive as appropriate.

3. Insert HD 26/06 into Volume 7, Section 2.

4. Please archive this sheet as appropriate.

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Pavement Design

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Contents

Chapter

1. INTRODUCTION

Mandatory Sections

1.1 Sections of this document which form part of the Standards of the Overseeing Organisations are highlighted by being contained in boxes. These are the sections with which the Design Organisations must comply, or must have agreed a suitable departure from Standard with the relevant Overseeing Organisation. The remainder of the document contains advice and enlargement which is commended to Design Organisations for their consideration.

General

1.2 This part details various combinations of materials and thicknesses that may be considered for pavement construction, whether for new build, widening of an existing carriageway, or full reconstruction. The design guidance is also useful when developing recommendations for partial reconstruction or strengthening overlays when used together 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 pavement materials is given in HD 36 and HD 37 (DMRB 7.5.1).

1.3 Chapter 2 sets down the philosophy behind the Standard Designs and summarises the alternatives in the form of nomographs or equations. Chapter 3 provides additional information on material behaviour to assist the designer. Chapter 4 discusses analytical procedures and material properties, which may be used by the designer to produce Alternative Designs or develop partial reconstruction and strengthening overlay options.

Implementation

1.4 This Part must 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 must confirm its application to particular schemes with the Overseeing Organisation.

Use in Northern Ireland

1.5 For use in Northern Ireland, this Standard will apply to those roads designated by the Overseeing Organisation.

Mutual Recognition

1.6 The construction and maintenance of highway pavements will normally be carried out under contracts incorporating the Overseeing Organisations' Specification for Highway Works (SHW) which are contained in the Manual of Contract Documents for Highway Works Volume 1 (MCHW 1). In such cases products conforming to equivalent standards and specification of other Member States (MS) of the European Economic Area (EEA) or a State which is party to a relevant agreement with the European Union and tests undertaken in other MS of the EEA or a State which is party to a relevant agreement with the European Union will be acceptable in accordance with the terms of Clauses 104 and 105 (MCHW 1.100). 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 TRL Report 615 (2004) for flexible construction (including pavements previously known as flexible composite); TRL Report 630 (2005) for rigid (continuous) construction; and TRL Report RR87 (1987) for rigid (jointed) construction.

2.2 The adoption of the material specific calibration adjustment factors recommended in TRL Report 615 (2004) will give pavement designs using traditional materials that are in close agreement with the previous flexible and flexible composite designs, which were based on TRL Report LR1132 (1984).

2.3 The standard designs for HMB35 have been removed, but designs for an Enrobe a Module Eleve (EME2) material based on French practice has been added. The design thickness lines for DBM50 and HDM50 have been combined, based on past performance of these two almost identical materials. In Scotland, HMB 35 is also permitted using the same design thickness as shown for DBM50/HDM50 base materials.

2.4 The CRC designs now include a wider choice of concrete strength and foundation classes than previously. The design philosophy continues to be based on TRL Report RR87 (1987).

2.5 Design thicknesses are based on four foundation stiffness classes, defined as the equivalent half-space long-term stiffness of the composite foundation under the completed pavement, as follows:

- Foundation Class 1 ≥ 50 MPa;
- Foundation Class 2 ≥ 100 MPa;
- Foundation Class 3 ≥ 200 MPa;
- Foundation Class 4 ≥ 400 MPa.

2.6 It should be noted that the stiffness values given in any performance related Specification will differ from the above, since any in situ tests measure the early age and with the materials in different confinement conditions.

2.7 Foundation Class 1 is a capping only design, in accordance with HD 25 (DMRB 7.2.2) without a subbase layer. This foundation must not be used for design traffic in excess of 20 million standard axles (msa) without a 'Departure from Standard' from the Overseeing Organisation.

2.8 Foundation Class 2 is either a subbase and capping design, or a subbase only design, in accordance with HD 25 (DMRB 7.2.2). This foundation must not be used for design traffic in excess of 80 msa, unless 150mm or more of a bound subbase is used, without a 'Departure from Standard' from the Overseeing Organisation.

2.9 Foundation Classes 3 and 4 are designs typically incorporating Cement or other Hydraulically Bound Mixtures (collectively referred to as HBM in this Part). Refer to Chapter 3 for further details on HBM.

2.10 For new road design, all lanes, including the hardshoulder, must be constructed to carry the design traffic in the heaviest loaded lane, commonly the left hand lane, as calculated in HD 24 (DMRB 7.2.1).

2.11 For maintenance design, each lane would, as a minimum, be strengthened/reconstructed to carry the design traffic for that particular lane. However, the design must ensure continuity of drainage, both in and below the pavement layers and across the carriageway width.

2.12 For motorway widening the requirements of the Overseeing Organisation will depend on the specific project, and will take account of a range of constraints, including technical, operational and financial. Also see HD 27 (DMRB 7.2.4).

2.13 The minimum design traffic for lightly trafficked trunk roads should be 1msa as set out in HD 24 (DMRB 7.2.1).

Flexible Pavements

2.14. For trunk roads up to 30 msa, it may be advantageous to use cold recycled materials and a design guide is available as part of TRL Report 611 (2004). These designs may also be suitable for non-trunk roads including those with design traffic less than

1 msa. For roads carrying less than 2.5 msa, using cement as the primary binder, the adjustments contained in Table 7.5 of TRL Report 611 (2004) have been reviewed. Experience indicates that such adjustment is unnecessary and that HBM based on the use of cement with strength classification H2 can be safely used for Type 4 roads and H3 for Type 3 roads. Further information is available from the Overseeing Organisation.

2.15 Monitoring the performance of all types of flexible pavements that are heavily trafficked 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. Generally for 'long life' it is not necessary to increase the pavement thickness beyond that required for 80 msa, provided that surface deterioration is treated before it begins to affect the structural integrity of the road.

2.16 For 'long-life' flexible pavements with an HBM base, a total 180mm thickness of asphalt overlay to HBM base is required to sufficiently delay the onset of reflection cracking, provided transverse cracks have been induced in the HBM base at 3m intervals, where required by the Specification (MCHW1) Series 800.

Rigid Pavements

2.17 Rigid concrete construction is a permitted option for trunk roads including motorways but generally if it has an asphalt surfacing, see HD 36 (DMRB 7.5.1) for permitted surfacing options in each UK country. The requirement for asphalt surfacing does not apply to lay-bys and hardstanding locations, which may have a concrete surface, see Paragraph 2.46. This requirement generally makes jointed construction unsuitable for consideration, as a result of reflection cracking of the surfacing and the potential for future increased maintenance.

2.18 However, when widening to an existing jointed concrete pavement, there may be advantages in using the same form of construction as a base layer to receive an asphalt surfacing and provide continuity across the carriageway width. Such construction must only be used in England with the approval of the Overseeing Organisation.

2.19 Use of continuously reinforced concrete pavements with a Thin Surface Course System (TSCS) 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.

Pavement Deterioration

2.20 Detailed information on pavement deterioration mechanisms for all pavement types is given in HD 30 (DMRB 7.3.3), and the 'failure' criteria for rigid pavements are described in TRL Report RR87 (1987).

Whole Life Value

2.21 Whole life costing examines the costs of a project from inception to disposal, including the direct costs of constructing and maintaining a highway and the indirect costs imposed on society and the environment by its use and operation (e.g. traffic delay, accidents at roadworks, skidding accidents, fuel consumption and tyre wear).

2.22 The sustainability of a scheme shall be considered when considering different design options. The five principles of sustainable development set out in the UK Government's strategy "Securing the Future" (2005) are:

- Living within Environmental Limits;
- Ensuring a Strong, Healthy and Just Society;
- Achieving a Sustainable Economy;
- Promoting Good Governance;
- Using Sound Science Responsibly.

Strategies applicable to the UK devolved administrations are also being produced.

2.23 Integrating these principles in highway design can include:

- reusing in situ materials to minimise resource consumption, waste disposal and emissions resulting from material haulage;
- using pavement designs that give good value in whole life cost terms;
- using pre-formed components to maximise quality, minimise health and safety risks associated with site works and minimise the delays to road users;
- providing maintenance designs which maximise the residual life of existing components;
- designing highways that allow recycling of end-of-life materials to their maximum utility;

- using alternative designs based on innovation and best practice to minimise construction times and traffic disruption.

2.24 The Highways Agency's "Building Better Roads: Towards Sustainable Construction" explains how the Highways Agency is promoting sustainability throughout its business and sets out its expectations for suppliers.

DESIGN IMPLEMENTATION

Pavement Type

2.25 The options for types of pavement structure have been reviewed and are described below under two main types. Options for permitted surfacing systems are set out separately in HD 36 (DMRB 7.5.1) and further details given in HD 37 and HD 38 (DMRB 7.5.2 and 7.5.3).

a. Flexible Pavements

Where the upper layers of the pavement are bound in bitumen and the lower (base) layers are either bound in bitumen or with a hydraulic binder. Permitted binder and base layers are as follows:

- Dense Bitumen Macadam (DBM50 or DBM 125) or Heavy Duty Macadam (HDM50);
- Stone Mastic Asphalt (SMA), for use as a binder course only, not as a base, except in Scotland where a 'Departure from Standard' must be obtained from the Overseeing Organisation;
- Hot Rolled Asphalt (HRA50), which (if it does not comply with Clause 943) must only be used in England, Wales and Northern Ireland with the approval of the Overseeing Organisation;
- EME2, but only on a Class 3 or 4 Foundation, subject to a Departure from Standard being granted by the Overseeing Organisation. (Also see Fig 2.1, Note 15);
- Permitted hydraulically bound materials (HBM) for use in the base layers. These may include:
  - CBGM, Cement Bound Granular Material;
  - FABM, Fly Ash Bound Material;
  - SBM, Slag Bound Material.

  Materials are further categorised in the Specification (MCHW 1) Series 800. Some standard materials are shown in the Table as part of Fig 2.1.

Details of composition, manufacture and laying are given in the Series 800 and 900 (MCHW1) and in material Standards.

b. Rigid Pavements

Preferred rigid pavement construction is either:

- Continuously Reinforced Concrete Pavement (CRCP), (normally with an asphalt overlay of minimum thickness 30mm); or
- Continuously Reinforced Concrete Base (CRCB) with an asphalt overlay of 100mm.

See HD 36 (DMRB 7.5.1) for details of permitted surfacing in each UK Country.

Other forms of rigid construction, permitted for limited use and in special circumstances but only with approval from the Overseeing Organisation, include:

- Unreinforced Jointed Concrete (URC);
- Jointed Reinforced Concrete (JRC).

2.26 Except where the pavement design is the responsibility of the contractor, designs must be carried out for several options. These must cover the range of base types 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

2.27 For trunk roads including motorways where design traffic is heavy in relation to the capacity of the layout, and in all cases where Whole Life Value is taken into account, 40 year designs must 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. In England, a 'Departure from Standard' must be obtained from the Overseeing Organisation for use of 20 year designs. The design traffic in msa should be obtained from HD 24 (DMRB 7.2.1).

2.28 In addition to major maintenance, a surface treatment may be expected to be required at about 10 and 20 year intervals dependent on the nature of the traffic. The period until surface treatment is required will also vary depending on the site's requirement for skidding resistance.

Design Nomographs

2.29 The design thicknesses of the layers, for different materials for Standard Designs, on Foundation Classes 1 to 4, can be derived using:

- Figure 2.1 Flexible Pavements;
- Figure 2.2 Rigid (Continuous) Pavements;
- Figure 2.3 Rigid (Jointed) Pavements.

Flexible Construction

2.30 For flexible pavements on an asphalt base, the total thickness of asphalt (comprising the surface course, binder course and base) is obtained from the right hand portion of the Nomograph (Fig 2.1) and depends on the base material type. A DBM125 base is the least stiff material, and so requires the thickest construction. The stiffness of asphalt material then increases from HRA50, through DBM50/HDM50, to EME2. A reduced thickness of material will provide the same structural equivalence, provided the stiffness is adequately increased.

2.31 For a flexible composite pavement, the left hand portion of the Nomograph gives the thickness of HBM for a given strength, with the thickness of overlying asphalt in the central portion of the Nomograph. Better performance is expected for those mixtures made with a crushed rock coarse aggregate that has a coefficient of thermal expansion less than 10×10^{-6} per °C (typically limestone).

2.32 Previous UK HBM base designations, are not directly comparable with the new HBM base designations now detailed in the Specification (MCHW1) Series 800. This is due to differences in aggregate grading; compressive strength measured at different ages; and a wider range of HBM designations with different strength properties. For standard design purposes some of the materials with nominally similar equivalence are identified in the supporting Table in Figure 2.1. Other materials are listed in the Specification (MCHW 1) Series 800.

2.33 Individual construction widths of HBM base must not exceed 4.75m. This minimises the risk of longitudinal cracking induced by combined stresses in a 'long life' HBM base pavement. The Highway Construction Details (MCHW3) give typical joint layouts. Flexible roads with an HBM base with thinner construction are expected to deteriorate by general cracking of the HBM such that restricting the individual construction width will not necessarily lead to improved performance.

Rigid Construction

2.34 For a rigid pavement, the total thickness (excluding any asphalt surfacing) is obtained from the right hand portion of the Nomograph (Fig 2.2) for CRCP; and the left hand portion for a CRCB. Thickness for a given design traffic depends on the flexural strength of concrete and the Foundation Class.

2.35 CRCP or CRCB options must be considered where the design traffic loading exceeds 30 msa, especially where the advantages of lower maintenance throughout the design life may be worthwhile.

2.36 To ensure that forces are not transmitted to structures and adjacent forms of pavement construction by thermally induced movements of the slab, the ends of the CRCP and CRCB must be addressed in the design. A site-specific/designed termination will be considered by the Overseeing Organisation. Transition slabs, are required where shown in the Highway Construction Details (MCHW3).

2.37 Ground beam anchors must not be used where the subgrade strength is poor, or on high embankments where consolidation may be insufficient to restrain movement of the beam downstands.

2.38 As concrete strength increases, the spacing of transverse shrinkage cracks in CRCP and CRCB would naturally tend to increase. Therefore, the percentage of longitudinal crack control steel is increased with strength to maintain the appropriate crack spacing. Wider cracks increase the likelihood of corrosion in the steel and should be avoided. The depth of steel in the concrete slab has also been chosen to reduce the risk of corrosion caused by salts penetrating through the expected fine cracks.

2.39 Transverse steel is required for ease and consistency of construction, and to prevent longitudinal cracking and local deterioration. Transverse bars may be incorporated into the support arrangement for the steel, so long as the required quantities and position of the steel is maintained.

2.40 Figure 2.2 assumes the presence of an integral minimum 1m edge strip or tied hardshoulder adjacent to the most heavily trafficked lane. Urban roads, and any other roads that do not have either of these adjacent to the left hand lane, will require 30mm thicker slabs. Heavy trafficking of right hand lanes and hardshoulders during future maintenance will be of relatively short duration and need not be considered in the design.

2.41 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 at slab corners and edges. This load distribution occurs whether or not a longitudinal construction joint or wet-formed joint is included adjacent to the edge line. 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).

2.42 The design equations for jointed concrete pavements are given in Figure 2.3. 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.

Ground Subject to Movement

2.43 CRCP and CRCB pavements are the only types suitable where large or significant differential movement or settlement is expected, because they can withstand large strains while remaining substantially intact.

2.44 Flexible with asphalt base and JRC pavements are suitable where slight differential movements, or settlement caused by compressible ground, or subsidence are expected.

2.45 Flexible with HBM base and URC pavements are not suitable where differential movement, subsidence or appreciable settlement are expected. This includes areas where mines are currently worked or may be worked in the future.

Laybys and Hardstandings

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

i) concrete, see Series 1000 (MCHW1);

ii) block paving, see Series 1100 (MCHW1);

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

Central Reserves

2.47 Where there is a requirement for hardened central reserves, the minimum standard for construction must be based on Paragraph 3.11 and Fig 3.3 in HD 39 (DMRB 7.2.5). Other forms of construction will be subject to approval by the Overseeing Organisation and must be based on a minimum of 70mm thickness of bound material to inhibit weed penetration and minimise future maintenance.

Alternative Designs

2.48 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 must 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 that may be necessary for their validation. Guidance is given in Chapter 4 of this Part.

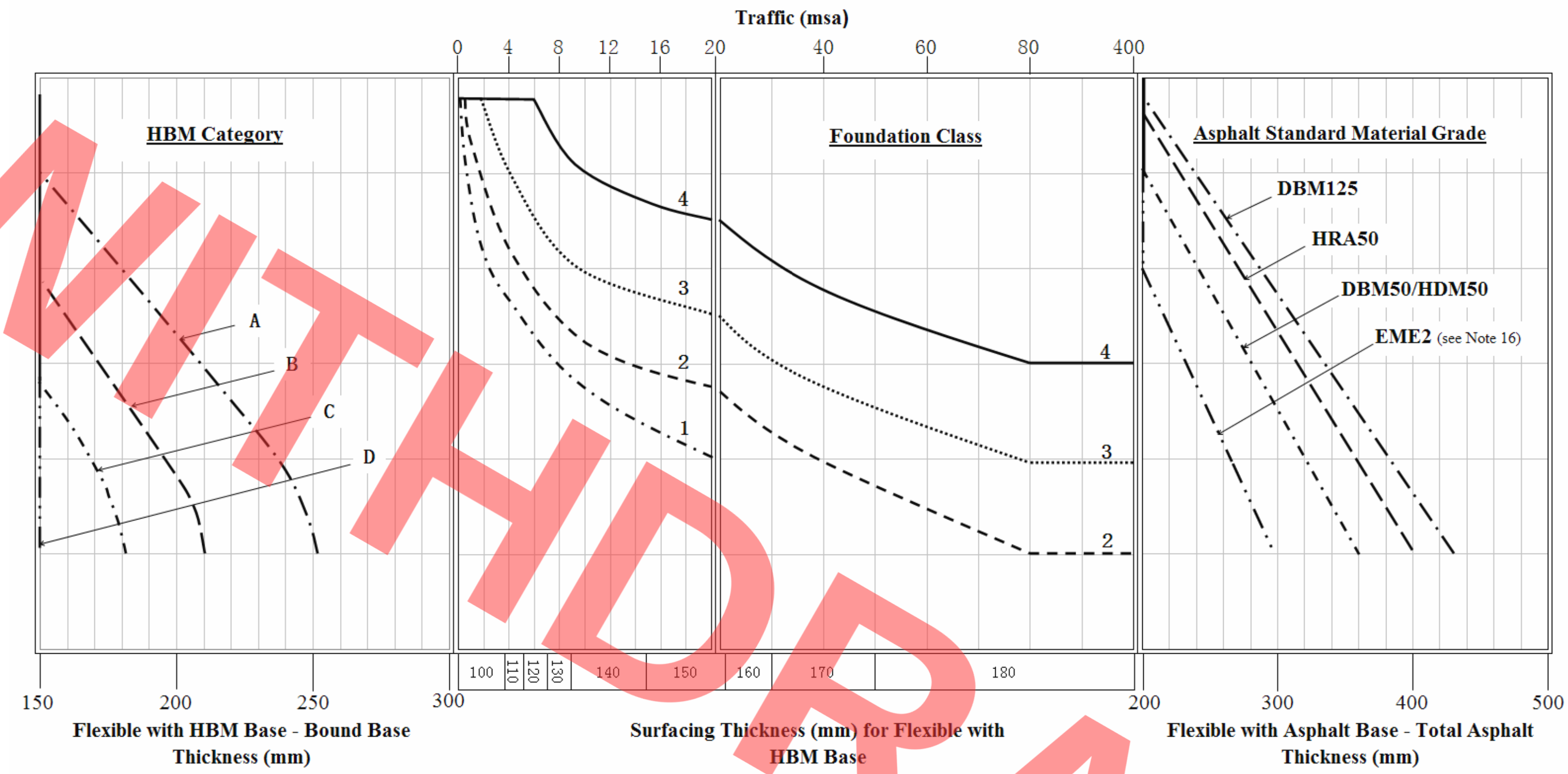

Figure 2.1 Design Thickness for Flexible Pavements

Examples of Hydraulic Bound Base Materials

HBM Category	A	B	C	D
Crushed Rock Coarse Aggregate: (with coefficient of thermal expansion <10 × 10 $^{-6}$ per ^{0}C)	-	CBGM B – C8/10 (or T3) SBM B1 – C9/12 (or T3) FABM1 – C9/12 (or T3)	CBGM B – C12/15 (or T4) SBM B1 – C12/16 (or T4) FABM1 – C12/16 (or T4)	CBGM B – C16/20 (or T5) SBM B1 – C15/20 (or T5) FABM1 – C15/20 (or T5)
Gravel Coarse Aggregate: (with coefficient of thermal expansion ≥10 × 10 $^{-6}$ per ^{0}C)	CBGM B – C8/10 (or T3) SBM B1 – C9/12 (or T3) FABM1 – C9/12 (or T3)	CBGM B – C12/15 (or T4) SBM B1 – C12/16 (or T4) FABM1 – C12/16 (or T4)	CBGM B – C16/20 (or T5) SBM B1 – C15/20 (or T5) FABM1 – C15/20 (or T5)	-

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Notes on Figure 2.1:

Flexible Pavement Construction

1. Thickness to be rounded up to the next 10mm.

2. Minimum allowable total asphalt material thickness is 200mm for flexible construction with asphalt base. Minimum allowable HBM base thickness is 150mm for flexible construction with HBM base, except in Scotland where the minimum thickness of HBM is 175mm.

3. Asphalt surfacing thickness in mm (H) over HBM base is given by:

$$H = -16.05\times(Log(N))^2 + 101\times Log(N) + 45.8$$

where:

N = Design traffic (msa), up to 400msa.

Calculated thickness (mm) to be rounded up to the next 10mm; with a minimum thickness of 100mm for <4msa, and a thickness of 180mm for >80msa.

4. Where the asphalt design thickness is 300mm or less, the material is to be laid with no negative tolerance.

5. Surface course and binder course must be one of the permitted materials presented in HD 36 (DMRB 7.5.1). For further details refer to HD 37 and HD 38 (DMRB 7.5).

6. For HRA surfacing, where permitted, refer to either Clause 943 of the Specification (MCHW1), or Clause 911 of the Specification (MCHW1), with reference to BS 594-1: 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 BS 594-1 may be used where considered appropriate by the Overseeing Organisation.

7. If 50mm of Porous Asphalt (PA) surfacing is to be used, it must be modified with a polymer or fibre additive. Its contribution to the material design thickness is only 20mm. A 60mm dense binder course is required beneath PA surfacing, compacted so that the air voids are less than the maximum in the Series 900 (MCHW1).

8. A binder course, see the Series 900 (MCHW1), must be provided beneath a TSCS, but is optional beneath other materials such as HRA where this is permitted. If used, the binder course can be of any permitted material (subject to Note 7), and be at least 50mm thick (except for SMA binder courses, which should be at least 30mm thick), and compacted so that the air voids are less than the maximum in the Specification (MCHW1) Series 900.

9. This Figure 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.

10. DBM125 base and binder course must contain 100/150 penetration grade binder. HRA50, DBM50 and HDM50 base and binder course must contain 40/60 penetration grade binder. EME2 base and binder course must target a penetration of 15-20, which can be achieved using 10/20 or 15/25 penetration grade binder. In Scotland, where HMB35 might be used, the material must target a penetration of 30/45.

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

12. The thickness of asphalt layers for flexible construction with HBM base is applicable to all permitted base materials.

13. HBM designations shown in the table insert to Figure 2.1 are consistent with those detailed in the Specification (MCHW1) Table NG 8/1.

14. All HBM layers that are expected to reach a compressive strength of 10MPa at 7 days must have cracks induced in accordance with the Specification (MCHW 1) Clause 818.

15. Where induced cracks are required in an HBM, these must be aligned (maximum 100mm tolerance) with any induced cracks in the underlying construction.

16. EME2 must only be laid over a Class 3 or 4 foundations or a Class 2 foundation that has a surface stiffness modulus of at least 120MPa at time of construction. Further details of EME2 are given in TRL Report 636 (2005).

Examples for Figure 2.1

1. Design traffic of 60 msa and Foundation Class 2:

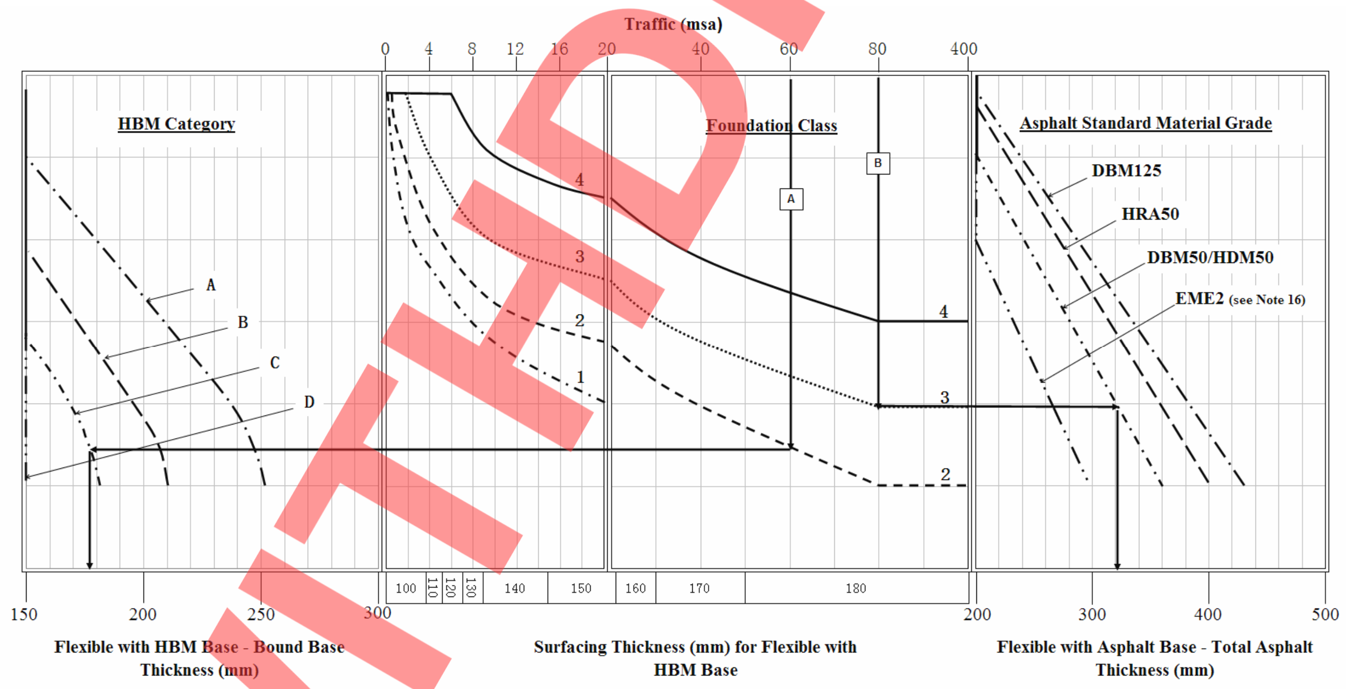
   Flexible Composite Option [A]:
   180mm Asphalt**, over
   180mm HBM Category C*

   Note *: Refer to the table insert to Figure 2.1 for HBM Category C options, e.g. a CBGM B with laboratory performance category C12/15 (or T4). Laboratory performance categories are detailed in the Specification (MCHW1 Series 800).

2. Design traffic of >80 msa ('long life' pavement) and Foundation Class 3:

   Flexible Option [B]:
   320mm Asphalt**, comprising DBM50 binder course and DBM50 base

   Note **: The total asphalt thickness from Figure 2.1 comprises the surface course, binder course and base.



For clarification, Tables 2.1 and 2.2 provide details for designs for low traffic levels

Material	Foundation Class		
	Class 1	Class 2	Class 3 and 4
DBM125	240 mm	210 mm	200 mm
HRA50	230 mm	200 mm	200 mm
DBM50 and HDM50	200 mm	200 mm	200 mm
EME2	n/a	n/a	200 mm

Table 2.1 Total thickness of asphalt for flexible construction with asphalt base for a design traffic of 1 msa

Material	Foundation Class			
	Class 1	Class 2	Class 3	Class 4
DBM125	< 1msa	< 1 msa	2 msa	6 msa
HRA50	< 1 msa	1 msa	2.5 msa	7 msa
DBM50 and HDM50	1 msa	2 msa	4 msa	10 msa
EME2	n/a	n/a	10 msa	32 msa

Table 2.2 Traffic Design values where total asphalt thickness reaches minimum 200mm thickness

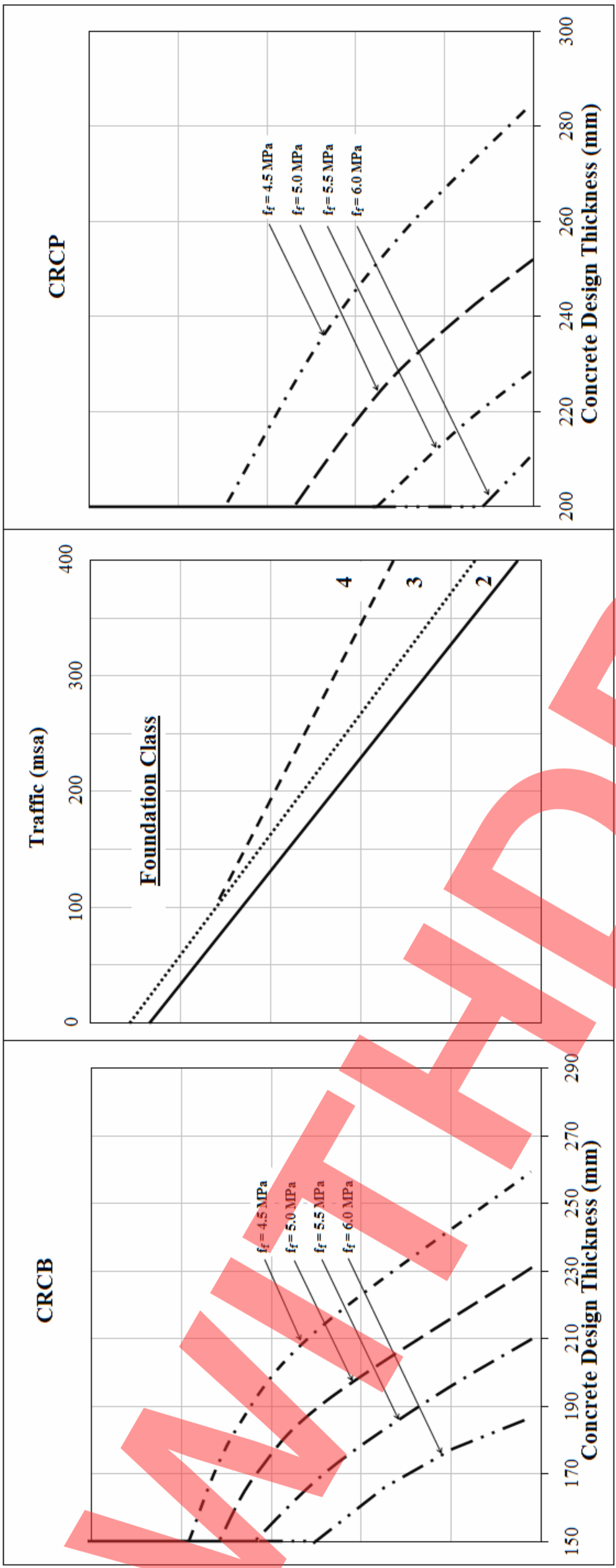


Figure 2.2: Design Thickness for Rigid (Continuous) Pavements

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Notes on Figure 2.2:

Rigid Pavement Construction

1. Thicknesses are to be rounded up to next 10mm.

2. f_f(MPa) denotes mean concrete flexural strength at 28 days.

3. The concrete design thickness value assumes the presence of a minimum 1m edge strip or tied shoulder, otherwise the concrete design thickness shall be increased by 30mm.

4. Notes 1, 4 and 5 for Figure 2.1 also apply to Figure 2.2. Notes 7-11 for Figure 2.1 apply to Figure 2.2 for CRCB but not CRCP construction.

5. Foundations below rigid pavements must comprise at least 150mm of bound subbase material, in order to ensure subbase material durability. A bound Foundation Class 2 must only be used with the approval of the Overseeing Organisation.

6. Two options for CRCP are available:

- CRCP with minimum 30mm of TSCS, for noise reduction; hence no binder course is required;

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

7. Minimum allowable concrete material thickness is 200mm for CRCP construction and 150mm for CRCB construction. The concrete thickness in Figure 2.2 does not include any asphalt surfacing; minimum allowable asphalt material thickness is 100mm for CRCB construction.

8. If PA surface course is used over CRCB, it must be modified with a polymer or fibre additive, and laid over a dense binder course that is compacted so that the air voids are less than the maximum in the Specification (MCHW1) Series 900. The PA shall be 50mm thick over a 90 mm binder course or 50 mm thick over a 60 mm binder course with the CRCB increased by 10 mm thickness.

9. Longitudinal crack control steel in CRCP shall be 0.6% of the concrete slab cross-sectional area, comprising 16mm diameter deformed steel bars (T16 reinforcement). Transverse steel must be 12mm diameter deformed bars at 600mm spacings.

10. Longitudinal crack control steel in CRCB shall be 0.4% of the concrete slab cross-sectional area, comprising 12mm diameter deformed steel bars (T12 reinforcement). Transverse steel must be 12mm diameter deformed bars at 600mm spacings.

11. Concrete of flexural strength 5.5MPa or greater must use aggregate that has a coefficient of thermal expansion less than 10 x 10^{-6} per ^{o}C unless a 'Departure from Standard' from the Overseeing Organisation is obtained.

12. Exposed Aggregate Concrete Surfacing (EACS) must not be used without a 'Departure from Standard' from the Overseeing Organisation. For options and details refer to HD 36 and HD 38 (DMRB 7.5.1 and 7.5.3).

Examples for Figure 2.2

1. Design traffic of 200 msa with a bound ('approved' – Ref. Notes on Figure 2.2, Note 4) Foundation Class 2:

CRCB Option [A]:

- 100mm Asphalt, over
- 220mm of 4.5MPa flexural strength concrete (with a tied shoulder or 1m edge strip)
- T12 longitudinal reinforcement bar spacing (i.e. maximum distance, centre to centre, between bars across the width of the slab)

$$\frac{100 \times \pi \times D^2}{4 \times t \times R} = \frac{100 \times \pi \times 12^2}{4 \times 220 \times 0.40} = 129mm$$

where:

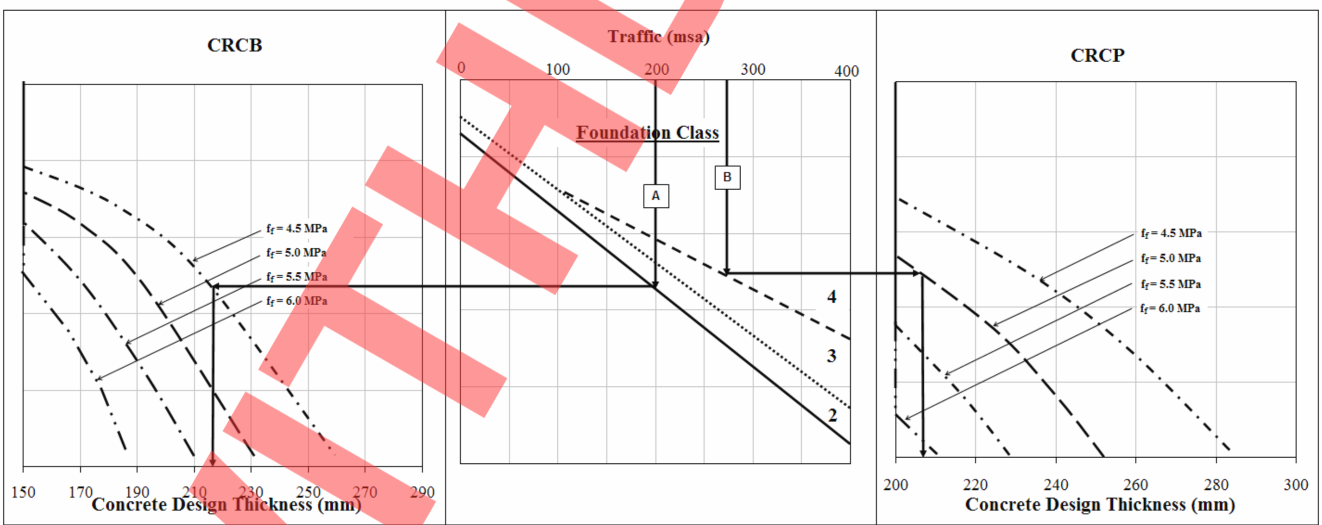
t = concrete design thickness (mm)
R = reinforcement (%)
D = diameter of reinforcement bar (mm)

2. Design traffic of 275 msa and Foundation Class 4:

CRCP Option [B]:

- 30mm Asphalt, over
- 210mm+**30mm** = 240mm of a 5.0MPa flexural strength concrete (**without** a tied shoulder or 1m edge strip)
- T16 longitudinal reinforcement bar spacing

$$\frac{100 \times \pi \times D^2}{4 \times t \times R} = \frac{100 \times \pi \times 16^2}{4 \times 240 \times 0.55} = 152mm$$



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Designs for jointed concrete pavements are based on work contained in TRL Report RR 87 (1987) and are related to the compressive strength of the concrete.

For unreinforced jointed concrete pavements (URC):

$$Ln(H_1) = \{Ln(T) - 3.466\ Ln(R_c) - 0.484\ Ln(E) + 40.483\} / 5.094$$

For reinforced jointed concrete pavements (JRC):

$$Ln(H_1) = \{Ln(T) - R - 3.171\ Ln(R_c) - 0.326\ Ln(E) + 45.150\} / 4.786$$

Where R = 8.812 for 500 mm^2/m reinforcement
R = 9.071 for 600 mm^2/m reinforcement
R = 9.289 for 700 mm^2/m reinforcement
R = 9.479 for 800 mm^2/m reinforcement

$$H_2 = 0.934\ H_1 - 12.5$$

Where: H_1 is the thickness (mm) of the concrete slab without a tied shoulder or 1m edge strip
= minimum 150mm
H_2 is the thickness (mm) of the concrete slab **with** a tied shoulder or 1m edge strip
Ln is the natural logarithm
T is the design traffic (msa) = maximum 400msa
R_c is the mean compressive cube strength (N/mm^2 or MPa) at 28 days
E is the Foundation Class Stiffness (MPa)
= 200MPa for Foundation Class 3 or
= 400 MPa for Foundation Class 4

Figure 2.3 Design Thicknesses for Rigid (Jointed) Pavements

Notes on Figure 2.3:

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 must be 25m (where the aggregate has a coefficient of thermal expansion not less than 10 x 10^{-6} per °C) except for slabs having <600mm²/m reinforcement, where the maximum joint spacing depends on the slab thickness, as follows:

<280mm slab thickness:	maximum 25m
290mm slab thickness:	maximum 24m
300mm slab thickness:	maximum 23m
310mm slab thickness:	maximum 22m
320mm slab thickness:	maximum 21m
>330mm slab thickness:	maximum 20m

3. For JRC pavements, the minimum longitudinal reinforcement permitted is 500mm²/m.

4. If concrete is used with aggregate that has a coefficient of thermal expansion less than 10 x 10^{-6} per °C transverse joint spacings may be increased by 20%.

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

Example for Figure 2.3

Pavement Type JRC:

- Design Traffic 130 msa;
- Reinforcement 500mm²/m;
- Aggregate that has a coefficient of thermal expansion less than 10 x 10^{-6} per °C;
- Mean compressive cube strength of 50N/mm²;
- Foundation Class 3.

Design Thickness =285mm without a tied shoulder
Transverse Joint Spacing = 25m x 1.2 = 30m;

or

Design Thickness =255mm **with** a tied shoulder
Transverse Joint Spacing = 25m x 1.2 = 30m.

3. MATERIALS

FROST PROTECTION

3.1 All material within 450mm of the road surface, where the mean annual frost index (MAFI) of the site is ≥50 must be non frost-susceptible in the long-term. Where the MAFI is < 50 the thickness of non-frost susceptible material may be 350 mm. For slower curing HBM appropriate measures must be taken to prevent frost damage in the short term. Further guidance is provided in HD 25.

BITUMEN BOUND MATERIALS

3.2 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 10/20 to 100/150pen. 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) sets out the requirements for the materials. 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 and deformation resistance.

Premature Rutting

3.3 Early age deformation (rutting) in surface and binder course layers may be linked to trafficking by slow moving commercial vehicles (e.g. in a contraflow), especially on uphill lengths and when pavement temperatures are high, relatively soon after the materials have been laid (e.g. after major maintenance in the summer). Therefore, such situations should be avoided. Where Hot Rolled Asphalt (HRA) (if permitted) is used, Clause 943 of the Specification (MCHW1) sets out the requirements for performance-based surfacing.

Bond Between Layers

3.4 The designs contained in this part are based on the principle that full adhesion is achieved between the individual layers of asphalt materials, such that they act as a single monolithic layer. For this to be achieved in practice and to ensure good long-life performance, a tack or bond coat is required between all layers.

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

3.6 TSCSs normally have a higher void content (with larger individual air voids) than traditional HRA. This is often because they have been derived from gap-graded Stone Mastic Asphalt (SMA) type mixtures. It is essential that the chosen binder course under the TSCS provides an effective barrier to water entering the lower pavement layers. It is also vital that surface and sub-surface drainage arrangements are designed to avoid water being introduced into the pavement from the sides. Particular care is required for resurfacing schemes, where the existing layer beneath the new surfacing has to provide the necessary impermeable layer or be replaced. Such durability issues are particularly important where the base may be manufactured with a low binder content to provide high stiffness and rut resistance. For SMA binder courses an air void content of between 2 and 4% is required for durability as well as the wheeltracking limits imposed by the Series 900 (MCHW1).

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

- PA can be significantly more expensive than other surfacings;
- PA may have a shorter life than other surfacings;
- PA can cost more to repair than other surfacings;
- other noise reduction measures, or other surfacings, may be more appropriate in Whole Life Value terms;
- although spray may be reduced, there may be no reduction in accidents.

3.8 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. In Scotland, prior approval is required from the Overseeing Organisation for PA to be used. Further details on PA are contained in HD 37 (DMRB 7.5.2).

PAVEMENT CONCRETE

3.9 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 require a bound (minimum 150mm thickness) subbase, since this would erode less readily than an unbound subbase material and is less water susceptible should joint sealants fail.

3.10 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.

Continuously Reinforced Concrete (CRCP and CRCB)

3.11 CRCP/CRCB 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 steel holds the cracks tightly closed, ensuring load transfer by aggregate interlock and minimising corrosion of the steel. The crack propagation in CRCP/CRCB pavements is closely related to the sub-surface friction, the aggregate used, the strength of the concrete and the proportion of steel.

3.12 The separation membrane is omitted from CRCP/CRCB construction in order to give a higher level of friction between the concrete slab and the subbase than for jointed slabs. The restraint provided by the subbase reduces the amount of movement and is related to the desired crack pattern. The use of a layer of material under the CRCP/CRCB 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 asphalt material may be considered as part of the bound subbase.

3.13 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/CRCB 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).

3.14 Where a CRCP has a surface course, surface noise generation is reduced and water penetration (and the potential for steel 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 TSCS is used, the bond coat required by the approved system is important to ensure good adhesion. It will be necessary for the TSCS to comply with the requirements of the Specification (MCHW1) Clause 942 and any additional BBA HAPAS requirements for the TSCS being used.

Jointed Pavements

> 3.15 Temperature and, to a lesser extent, moisture changes cause contraction/expansion of the slab which, if restrained, induce stresses in the concrete. A separation membrane is required between slab and subbase 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 the loss of water from the fresh concrete.

3.16 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).

3.17 **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 cater for the expansion movement that would naturally occur at temperatures higher than that of the concrete at the time the slab was constructed and allow the slab to shorten. 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.

3.18 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.

3.19 There is an advantage for concrete containing aggregate that has a lower coefficient of thermal expansion than other aggregate types, resulting in less expansion/contraction of the slab, with greater joint spacings being allowed.

3.20 The effectiveness of reinforcement, as a distributor of strain, increases with the amount of reinforcement 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.

HYDRAULICALLY BOUND MIXTURES

3.21 HBMs comprise either cement, slag or fly ash binder; or a factory blend of these binders. HBM must be produced, constructed and tested in accordance with the Specification (MCHW1) Series 800.

3.22 The UK has traditionally characterised Cement Bound Material in terms of compressive strength at seven days for compliance purposes; and in terms of both dynamic stiffness modulus and flexural strength for design purposes.

3.23 The European Standard, adopted in the UK, characterises cement-bound HBM in terms of compressive strength at 28 days; and in terms of both static stiffness modulus and direct tensile strength.

3.24 360-day values of HBM stiffness modulus and strength are now used for UK design purposes, enabling slow curing HBMs to be included.

3.25 Hydraulic-bound base materials comprising binders other than cement typically have lower early age performance properties. This may have implications on construction programme due to the need to avoid early trafficking (although some HBMs can be trafficked satisfactorily due to the inherent stability of the aggregate skeleton) and a need for protection from frost. For design purposes the HBM 360-day strength and stiffness are required. For materials with a history of use these properties can be extracted from performance data on in-service roads, but for other materials it may be necessary to carry out laboratory testing.

RECYCLED AND SECONDARY AGGREGATES

3.26 Advice on recycled and secondary materials and their uses is given in HD 35 (DMRB 7.1.2). Materials should be produced in accordance with BS EN 13242 and BS EN 13285 and Series 800 and 100 (MCHW1). Procedures for production are also described in the Waste and Resources Action Programme's "The Quality Protocol for the Production of Aggregates from Inert Waste" or "The Quality Protocol for the Production of Aggregates from Inert Waste in Scotland" as appropriate for each Overseeing Organisation. The purpose of the Quality Protocol is to provide a uniform control process for producers from which they can reasonably state and demonstrate that their product has been fully recovered and is no longer considered a waste.

3.27 Users of these materials often express concerns over the potential for leaching of contaminants and subsequent pollution of the local environment, particularly the pollution of controlled waters. Research demonstrates that the perceived risk of leaching from recycled and secondary aggregates is often overstated, even when used in unbound engineering applications. Furthermore, the risk of deleterious leaching is significantly reduced by binding aggregates in bitumen, hydraulically bound mixtures or concrete. The majority of recycled and secondary aggregates pose no significant risk to controlled waters when used in properly designed and constructed engineering applications that account for the sensitivity of the local environment. It is important that the use of all materials of this type is agreed with all bodies responsible for the local environment and for water quality.

3.28 Further information and details of material properties for many of these materials can be found on the websites for WRAP, Britpave and the UK Quality Ash Association.

4. ALTERNATIVE DESIGN PROCEDURES

Alternative Pavement Designs

4.1 TRL Report 615 follows TRL Report LR1132 and provides guidance that should be considered in the preparation of alternative flexible pavement designs. TRL Report RR87 (1987) and TRL Report 630 (2005) provide guidance that should be considered in the preparation of alternative rigid pavement designs.

4.2 Pavement design guidance comprising cold recycled base material is presented in TRL Report 611 (2004). These designs require a 'Departure from Standard' from the Overseeing Organisation, with the exception of an ex situ stabilized Quick Visco-Elastic (QVE) base material comprising a minimum 3% bituminous binder and a minimum 1% cement, known as foamed asphalt, and classified as Zone B2 material, for a maximum cumulative design traffic up to 30msa.

Alternative 'Analytical' Pavement Design

4.3 An analytical design approach provides a means of customising a pavement to locally available materials and/or construction methods, in an attempt to maximize the whole life value. However, it is essential that the material properties assumed in the design are actually achieved in situ, and that due consideration is given to the following:

- durability of the pavement structure (e.g. resistance of the materials to the deleterious effects of water, air, and other environmental factors);
- serviceability (e.g. skidding resistance, and permanent deformation within the asphalt);
- maintainability (e.g. reflection cracking in composite pavements, and surface initiated fatigue cracking in thicker/long-life pavements);
- construction tolerances (allowable construction thickness reductions to be added to the minimum analytical design thickness).

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

4.5 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) identify the pavement life requirement in terms of traffic loading (see HD 24, DMRB 7.2.1), in terms of an equivalent number of 'standard axle' loads (i.e. 40kN wheel loads);

b) consider available and permitted pavement materials (see HD 35, DMRB 7.1.2);

c) estimate the in situ dimensions and long-term performance properties (stiffness and/or strength) of each individual layer of pavement material;

d) carry out a structural analysis, e.g. using a simplified multi-layer linear elastic model of the pavement structure;

e) compare critical stresses/strains and/or deflections, with allowable values;

f) make adjustments to c) until the pavement life requirement is achieved;

g) consider the whole life value of the resultant pavement design(s).

4.6 The following performance properties of materials need to be considered when designing pavements:

- effective stiffness modulus, which governs load spreading behaviour;
- deformation resistance of asphalt materials only, which governs rutting behaviour;
- fatigue resistance of asphalt materials, and strength of HBM, which governs cracking behaviour.

4.7 Critical stresses/strains considered in the standard UK design approach include:

- excessive stress/strain (combination of magnitude and number of load applications) causing fatigue cracking (typically at the bottom of the base layer) of the asphalt, HBM or concrete material;

- excessive subgrade strain, resulting in structural deformation. [Note: This parameter becomes redundant in the TRL Report 615 (2004) for flexible designs but could still be important for thinner, lightly trafficked pavement constructions, typical of those used in local authority highways.]

4.8 Relationships between pavement life and these critical strains or stresses have been derived for historically standard UK materials from a combination of laboratory testing and pavement performance monitoring, see Chapter 5 of this Part for references and bibliography.

4.9 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 (e.g. a HDM50) could yield different pavement lives, depending on the aggregate structure and binder content. Similarly, the permanent deformation behaviour of a sandy subgrade will differ from a clay subgrade, even if they have the same stiffness.

4.10 For non-standard materials especially those from European standardisation, it is essential that the material properties are known. Properties should include stiffness modulus related to testing age, to curing regime and related to degrees of confinement. Properties can be tested in various ways depending on the nature of the material and the properties required in relation to the needs of the design.

4.11 Where stiffness is to be measured as the design criteria for hydraulically bound materials, testing must be carried out in accordance with BS EN 13286-43.

4.12 To help inform the design process, the NAT 'Springbox' can also be used for unbound and slightly bound materials and this can be used to identify both short-term and longer term stiffness moduli. Site testing as part of demonstration trials can also be used to measure on-site properties. Further details of testing for foundation materials is given in HD 25 (DMRB 7.2.2).

4.13 For Highways Agency schemes, values of long-term elastic stiffness modulus of standard UK asphalt materials for use in analytical design must be as follows, unless reliable data clearly reveals a divergence from these typical figures:

DBM125	2,500 MPa
HRA50	3,100 MPa
DBM50/HDM50	4,700 MPa
EME2	8,000 MPa

Design stiffness moduli used for pavement design are values for the reference condition of 20°C and 5 Hz. They are not interchangeable with Indirect Tensile Stiffness Modulus (ITSM) values, which are measured for compliance testing at the lower frequency of 2.5 Hz.

4.14 Until further research is undertaken, a maximum reinforcement value of 900mm^2/m width of a CRCP (and CRCB) concrete slab shall be used in calculations (despite more reinforcement than this being used in construction, according to the concrete strength as detailed in Figure 2.2), consistent with TRL Report 630.

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

- comparisons with other published designs, especially from countries with similar trafficking levels, climatic conditions and material properties to the UK;

- information on the analytical pavement design model adopted;

- material properties assumed and supporting information, e.g. from in situ or laboratory testing, or published data;

- information on the failure mechanisms considered by the designer;

- experience of long term performance of similar pavements, both in the UK and overseas;

- 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;
- End Performance Test Procedures to ensure that the mean and minimum properties of materials assumed in the design, are achieved on site.

4.16 It should be noted that a specific analytical design method has not been defined. The available methods referenced in Chapter 5 of this Part may differ in their mathematical formulation, but each method is internally consistent. It should be appreciated that inadequate designs can result if elements from different methods are combined inappropriately.

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Asphalt Materials:
www.asphaltindustryalliance.com

Cement Bound Materials:
www.britpave.org.uk

6. ENQUIRIES

All technical enquiries or comments on this Standard should be sent in writing as appropriate to:

Chief Highway Engineer The Highways Agency 123 Buckingham Palace Road London SW1W 9HA	G CLARKE Chief Highway Engineer

Chief Road Engineer Scottish Executive Victoria Quay Edinburgh EH6 6QQ	J HOWISON Chief Road Engineer

Chief Highway Engineer Transport Wales Welsh Assembly Government Cathays Parks Cardiff CF10 3NQ	M J A PARKER Chief Highway Engineer Transport Wales

Director of Engineering The Department for Regional Development Roads Service Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	G W ALLISTER Director of Engineering