Design Manual for Roads and Bridges

Pavement
Design

# CD 226
# Design for new pavement construction

(formerly HD 26/06)

Revision 0

**Summary**
This document gives the requirements for the design of pavement construction for new build carriageways, widening of existing carriageways, or reconstruction of existing pavements on the UK motorway and all-purpose trunk road network.

**Application by Overseeing Organisations**
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

**Feedback and Enquiries**
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

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# Contents

**Release notes** 3

**Foreword** 4
- Publishing information . . . 4
- Contractual and legal considerations . . . 4

**Introduction** 5
- Background . . . 5
- Assumptions made in the preparation of this document . . . 5
- Mutual Recognition . . . 5

**Abbreviations and symbols** 6

**Terms and definitions** 8

**1. Scope** 9
- Aspects covered . . . 9
- Implementation . . . 9
- Use of GG 101 . . . 9

**2. Standard designs** 10
- Foundations . . . 10
- Surface course . . . 10
- Pavement types and materials . . . 10
  - Flexible pavements with an asphalt base . . . 10
  - Flexible pavements with an HBM base . . . 12
  - Rigid pavements . . . 14
- Design . . . 14
  - Options . . . 14
  - Design life . . . 14
- Flexible pavement designs . . . 14
- Rigid construction with continuous reinforcement (CRCP and CRCB) . . . 18
  - Concrete material details . . . 20
  - Termination details . . . 21
- Rigid construction with roller compacted concrete (RCC) . . . 21
- Rigid construction with jointed concrete pavements . . . 23
  - Unreinforced jointed concrete pavement design (URC) . . . 23
  - Reinforced jointed concrete pavement design (JRC) . . . 24
- Design of central reserves, maintenance areas and emergency areas (EAs) . . . 27

**3. On-line widening and upgrading of existing pavements** 28
- General . . . 28
- On-line widening . . . 28
- Upgrading . . . 29

**4. Alternative design procedures** 30
- Analytical pavement design . . . 30
  - Materials . . . 31
- Continuously reinforced concrete pavements (CRCP and CRCB) . . . 31

**5. Use of cold recycled base materials** 32
- Alternative design using cold recycled base materials . . . 32
  - Cold recycled designs using TRL report 611 . . . 32
  - Deep in-situ recycling: the down cut process . . . 32
  - Ex-situ recycling . . . 32

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**6. Pavement design verification** **34**

**7. Normative references** **35**

**8. Informative references** **36**

**Appendix A. Worked examples** **37**
A1 Standard flexible pavement design using Figure 2.20 . . . . . 37
A1.1 Example "A": flexible pavement with an HBM base . . . . . 39
A1.2 Example "B": flexible pavement with an asphalt base . . . . . 39
A2 Standard rigid (CRCP and CRCB) pavement design using Figure 2.26 . . . . . 39
A2.1 Example "A": CRCB . . . . . 41
A2.2 Example "B": CRCP . . . . . 41
A3 RCC design using multi-layer linear elastic analysis and Equation 2.40N4 . . . . . 42
A4 Rigid (JRC) pavement design for widening of an existing pavement using Equations 2.46a and 2.46b . 42

**Notification** **43**

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## Release notes

| Version | Date | Details of amendments |
|---|---|---|
| 0 | Mar 2020 | CD 226 replaces HD 26/06. The full document has been re-written to make it compliant with the new Highways England drafting rules. |

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# Foreword

## Publishing information

This document is published by Highways England.

This document supersedes HD 26/06 and HD 27/15, which are withdrawn.

## Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

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# Introduction

## Background

This document sets out the pavement design approaches to be used when constructing a new carriageway, widening an existing carriageway, upgrading an existing pavement or reconstructing an existing pavement. Standard designs are presented that cover the permitted materials and design thicknesses required for various design traffic volumes and the requirements for designs using alternative procedures are set out.

This revision of the document introduces a new design option using roller compacted concrete (RCC) and updates the terminology for the permitted asphalt base and binder course materials.

## Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 8.N] apply to this document.

## Mutual Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in GG 101 [Ref 8.N].

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# Abbreviations and symbols

**Abbreviations**

| Abbreviations | Definition |
|---|---|
| AC | Asphalt concrete |
| CBGM | Cement bound granular mixture |
| CEMII | Portland composite cement; comprising Portland cement and up to 35% of certain other single constituents |
| CRCB | Continuously reinforced concrete base |
| CRCP | Continuously reinforced concrete pavement |
| des | Design mixtures (that have undergone type testing) |
| EA | Emergency area |
| EME2 | Enrobés á module elevé (2nd generation) |
| FABM | Fly ash bound mixture |
| HBM | Hydraulically bound mixture |
| HDM | Heavy duty mixture |
| HRA | Hot rolled asphalt |
| IT-CY | Indirect tension test on cylindrical specimens |
| JRC | Jointed reinforced concrete |
| msa | Million standard axles |
| PA | Porous asphalt |
| RCC | Roller compacted concrete |
| SBM | Slag bound mixture |
| SMA | Stone mastic asphalt |
| TSCS | Thin surface course system |
| URC | Unreinforced jointed concrete |
| VRS | Vehicle restraint systems |

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**Symbols**

| Symbol | Definition |
|---|---|
| D | Diameter of reinforcement bar (mm) |
| e | Base of the natural logarithm |
| E | Foundation stiffness (MPa) related to foundation class |
| $f_f$ | Mean flexural strength (N/mm$^2$ or MPa) at 28 days |
| GPa | Gigapascal |
| H | Total thickness of asphalt (mm) |
| $H_1$ | Thickness (mm) of the concrete slab without a tied lane or 1m edge strip |
| $H_2$ | Thickness (mm) of the concrete slab with a tied lane or 1m edge strip |
| Hz | Hertz |
| Ln | Natural logarithm |
| MPa | Megapascal |
| R | Level of reinforcement (% of the cross section area) |
| $R_c$ | Mean compressive cube strength (N/mm$^2$ or MPa) at 28 days |
| s | Maximum distance, centre to centre, between bars across the width of the slab (mm) |
| t | Concrete design thickness (mm) |
| T | Design traffic (msa) |

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# Terms and definitions

**Terms**

| Term | Definition |
|---|---|
| Cold recycled base material | Asphalt base material produced using using specialist plant to pulverise and stabilise existing road materials, at ambient temperature, with the addition of hydraulic cement and/or bitumen binders. |
| Full reconstruction | A maintenance treatment that involves replacement of all the bound layers and extends into the foundation. |
| New carriageway | A new road or carriageway (as opposed to an existing lane or one or more new lanes abutting an existing pavement). |
| On-line widening | Where additional carriageway is constructed abutting the existing carriageway. |
| Partial reconstruction | Replacement of all the bound layers. |
| Upgrading of an existing pavement | Upgrading of an existing pavement includes conversion of a hard shoulder to a running lane and incorporation of an existing pavement into new construction. |

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# 1. Scope

## Aspects covered

1.1 The requirements in this document shall be used for the design of the pavement when constructing a new carriageway, widening an existing carriageway, upgrading an existing pavement or reconstructing an existing pavement on the UK motorway and all-purpose trunk road network.

*NOTE 1 This document does not include the estimation of design traffic (see CD 224 [Ref 15.N]).*

*NOTE 2 This document does not cover the design of pavement foundations (see CD 225 [Ref 3.N]).*

*NOTE 3 This document does not cover the design of surfacing materials (see CD 236 [Ref 11.N]).*

1.2 Where the reconstruction of an existing pavement is being undertaken, the design requirements in this document shall be used in conjunction with CD 227 [Ref 4.N].

## Implementation

1.3 This document shall be implemented forthwith on all schemes involving the design of pavement construction for new build carriageways, widening of existing carriageways, or reconstruction of existing pavements on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 8.N].

## Use of GG 101

1.4 The requirements contained in GG 101 [Ref 8.N] shall be followed in respect of activities covered by this document.

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# 2. Standard designs

2.1 This section sets out the requirements that shall be followed for the design of a new pavement using one of the Overseeing Organisations' "standard" pavement design types.

2.2 Where a design other than those given in this section is proposed for the design of a pavement for a new carriageway, approval to proceed shall be obtained from the Overseeing Organisation before the design is finalised.

## Foundations

2.3 Where a pavement is being designed for a new carriageway, the foundation shall be designed in accordance with CD 225 [Ref 3.N].

*NOTE* *Foundation stiffness classes (1 to 4) are defined in CD 225 [Ref 3.N].*

2.4 Where a pavement is being designed for a new carriageway, foundation class 1 shall only be used for design traffic of 20 million standard axles (msa) or less.

*NOTE* *Calculation of design traffic is set out in CD 224 [Ref 15.N].*

2.5 Where a pavement is being designed for a new carriageway, foundation class 2 shall only be used for design traffic of 80 msa or less.

*NOTE* *A departure from standard is not necessary where widening or reconstructing an existing pavement where the foundation is equivalent to a foundation class 2 irrespective of design traffic.*

2.6 Where a rigid pavement is being designed for a new carriageway, this shall use a class 3 or class 4 foundation.

2.7 Where a flexible pavement with an asphalt base using EME2 is being designed for a new carriageway, this shall use a class 3 or class 4 foundation, unless a class 2 foundation can be demonstrated to achieve a minimum stiffness of 120 MPa.

## Surface course

2.8 The surface course shall be designed in accordance with CD 236 [Ref 11.N].

## Pavement types and materials

2.9 Pavement type shall either be "flexible" or "rigid" construction.

*NOTE 1* *Flexible pavements include a lower (base) layer containing asphalt or HBM (hydraulically bound mixture). These are designated as "flexible with an asphalt base" or "flexible with an HBM base" respectively.*

*NOTE 2* *Rigid pavements can be "continuously reinforced" or "roller compacted" concrete pavements.*

*NOTE 3* *Design equations for unreinforced jointed concrete (URC) and jointed reinforced concrete (JRC) rigid pavements are provided in this document for maintaining or widening existing pavements.*

### Flexible pavements with an asphalt base

2.10 For flexible pavements with an asphalt base, the base and binder course materials shall be selected from the materials in Table 2.10.

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**Table 2.10 Permitted base and binder course materials for flexible pavements with an asphalt base**

| Material type | Base | Binder course |
|---|---|---|
| **AC 40/60** | Dense and heavy duty base materials designed in accordance with Clause 929 MCHW [Ref 9.N] with the designations:<br><br>AC 32 dense base 40/60 des<br>AC 32 HDM base 40/60 des | Dense and heavy duty binder materials designed in accordance with Clause 929 MCHW [Ref 9.N] with the designations:<br><br>AC 20 dense bin 40/60 des<br>AC 32 dense bin 40/60 des<br>AC 20 HDM bin 40/60 des<br>AC 32 HDM bin 40/60 des |
| **EME2** | EME2 base course asphalt concrete designed in accordance with Clause 930 MCHW [Ref 9.N] and targeting a penetration value of 10/20 or 15/25 | EME2 binder course asphalt concrete designed in accordance with Clause 930 MCHW [Ref 9.N] and targeting a penetration value of 10/20 or 15/25 |

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**Flexible pavements with an HBM base**

2.11 For flexible pavements with an HBM base, the hydraulically bound base layer shall be selected from the following materials:

1) cement bound granular mixture (CBGM);
2) fly ash bound mixture (FABM); and,
3) slag bound mixture (SBM).

*NOTE 1* *Further details of HBM materials are given in Series 800 of MCHW [Ref 9.N].*

*NOTE 2* *Use of secondary materials such as fly ash and slag in HBM applications is often favourable in terms of carbon footprint when compared to cement bound alternatives.*

2.12 Where an HBM layer is designed to reach a compressive strength of $\geq$ 10 MPa at 7 days, it shall have cracks at a maximum spacing of 5 m induced in accordance with Clause 818 of the MCHW [Ref 9.N].

*NOTE 1* *Induced cracking is intended to control the frequency of transverse cracks in stiff HBM materials.*

*NOTE 2* *There is a risk that HBM mixtures designed to reach a compressive strength <10 MPa can exceed this strength on site.*

2.13 For flexible pavements with an HBM base, the asphalt base and binder course layers shall be selected from the materials in Table 2.13.

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**Table 2.13 Permitted asphalt base and binder course materials for flexible pavements with an HBM base**

| Material type | Base | Binder course |
|---|---|---|
| **AC 40/60** | Dense and heavy duty base materials designed in accordance with Clause 929 MCHW [Ref 9.N] with the designations:<br><br>AC 32 dense base 40/60 des<br>AC 32 HDM base 40/60 des | Dense and heavy duty binder materials designed in accordance with Clause 929 MCHW [Ref 9.N] with the designations:<br><br>AC 20 dense bin 40/60 des<br>AC 32 dense bin 40/60 des<br>AC 20 HDM bin 40/60 des<br>AC 32 HDM bin 40/60 des |
| **EME2** | EME2 base course asphalt concrete designed in accordance with Clause 930 MCHW [Ref 9.N] and targeting a penetration value of 10/20 or 15/25 | EME2 binder course asphalt concrete designed in accordance with Clause 930 MCHW [Ref 9.N] and targeting a penetration value of 10/20 or 15/25 |
| **HRA** | - | HRA binder course designed in accordance with Clause 943 MCHW [Ref 9.N] |
| **SMA** | - | SMA binder course specified in accordance with Clause 937 MCHW [Ref 9.N] |

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### Rigid pavements

2.14 For rigid pavements designed for a new carriageway, the pavement type shall be selected from the following:

1) continuously reinforced concrete pavement (CRCP);
2) continuously reinforced concrete base (CRCB); and,
3) roller compacted concrete (RCC).

2.15 Design equations for unreinforced jointed concrete (URC) and jointed reinforced concrete (JRC) rigid pavements are provided in this document and these pavement types shall be used only for maintaining or widening existing jointed rigid pavements.

## Design

### Options

2.16 Where designing a pavement for a new carriageway, designs shall be carried out using a minimum of three options covering the range of pavement types from the "standard designs" described in this section.

2.16.1 The design options should include flexible with an asphalt base, flexible with an HBM base and at least one type of rigid pavement.

### Design life

2.17 Where designing a pavement for a new carriageway, the design life shall be 40 years.

2.18 Where designing a pavement for a new carriageway, all lanes, including the hard shoulder and lay-bys, shall be constructed to carry the design traffic in the heaviest loaded lane, commonly the left hand lane, as calculated in accordance with CD 224 [Ref 15.N].

2.19 The minimum design traffic for new roads shall be 1 msa, as calculated in accordance with CD 224 [Ref 15.N].

## Flexible pavement designs

2.20 The design thickness of the layers for flexible pavements shall be determined using the nomograph in Figure 2.20.

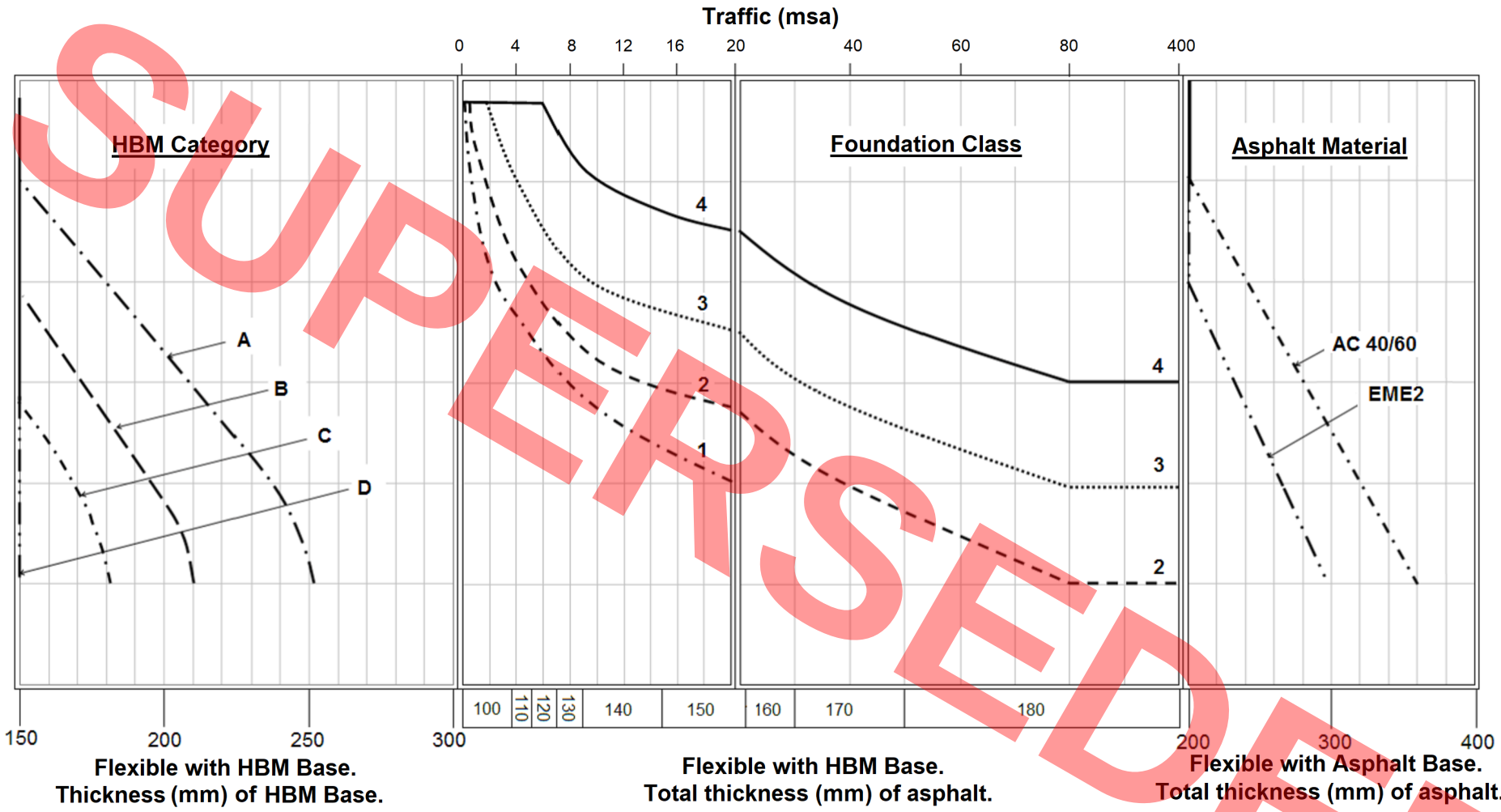
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**Figure 2.20 Nomograph for determining the design thickness for flexible pavements**




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*NOTE 1* *For flexible pavements with an asphalt base, the right hand side of the nomograph is used to determine asphalt thickness (comprising the surface course, binder course and base).*

*NOTE 2* *For flexible pavements with an HBM base, the left hand side of the nomograph is used to determine HBM thickness and the middle section is used to determine asphalt thickness.*

*NOTE 3* *Thicknesses of materials are to be rounded up to the nearest 5 mm.*

*NOTE 4* *Total thicknesses of asphalt shown include the thickness of the surface course.*

*NOTE 5* *AC 40/60 refers to the permitted dense and heavy duty base and binder course materials for flexible pavements with an asphalt base, including SMA and HRA, described earlier in this document.*

*NOTE 6* *For flexible pavements with an asphalt base, the class 2 foundation line can be used with EME2 when widening or reconstructing an existing pavement which has a class 2 foundation.*

*NOTE 7* *Worked examples are included in Appendix A.*

2.20.1 For flexible pavements with an asphalt base, the base and binder course should use the same material type i.e. both layers contain AC 40/60 or both layers contain EME2.

2.21 Where a design for a flexible pavement with an asphalt base combines an EME2 layer with an AC 40/60 layer, the design thickness shall be based on the AC 40/60 line in Figure 2.20.

2.22 Where traffic exceeds 80 msa, the coarse aggregate in all the asphalt materials shall contain only crushed rock or slag.

2.23 For flexible pavements with an HBM base, the minimum design thickness of HBM shall be 150 mm.

*NOTE 1* *HBM materials are defined in Series 800 of the MCHW [Ref 9.N].*

*NOTE 2* *Examples of HBM materials that can be expected to meet the HBM material categories in Figure 2.20 are listed in Table 2.23N2.*

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**Table 2.23N2 Examples of HBM materials**

| HBM Category | A | B | C | D |
|---|---|---|---|---|
| **Crushed rock coarse aggregate: (using aggregate with a coefficient of thermal expansion <10×10 $^{-6}$ per $^{o}$C)** | - | Clause 822 – C8/10 (or T 3)<br>SBM B1 – C9/12 (or T3)<br>FABM1 – C9/12 (or T3) | Clause 822 – C12/15 (or T4)<br>SBM B1 – C12/16 (or T4)<br>FABM1 – C12/16 (or T4) | Clause 822 – C16/20 (or T5)<br>SBM B1 – C15/20 (or T5)<br>FABM1 – C15/20 (or T5) |
| **Gravel coarse aggregate: (using aggregate with a coefficient of thermal expansion ≥10×10 $^{-6}$ per $^{o}$C)** | Clause 822 – C8/10 (or T3)<br>SBM B1 – C9/12 (or T3)<br>FABM1 – C9/12 (or T3) | Clause 822 – C12/15 (or T4)<br>SBM B1 – C12/16 (or T4)<br>FABM1 – C12/16 (or T4) | Clause 822 – C16/20 (or T5)<br>SBM B1 – C15/20 (or T5)<br>FABM1 – C15/20 (or T5) | - |

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2.24 For flexible pavements with an HBM base, the total thickness of asphalt (comprising the surface course, binder course and base, where present) shall be determined using either the middle section of Figure 2.20 or Equation 2.24 (rounded up to the nearest 5 mm):

**Equation 2.24 Total thickness of asphalt (mm) for flexible pavements with an HBM base**

$$H = -16.05(\log T)^2 + 101\log T + 45.8$$

where:

| | |
|---|---|
| H | is the total thickness of asphalt (mm) |
| T | is the design traffic (msa) |

*NOTE 1* *Maximum design traffic is 400 msa.*

*NOTE 2* *The total thickness of asphalt is between 100 mm and 180 mm.*

*NOTE 3* *Where the design traffic is $\geq$ 80 msa, the total thickness of asphalt is 180 mm.*

*NOTE 4* *The total thickness of asphalt is applicable to all permitted base materials in Table 2.13.*

2.25 To minimise the risk of longitudinal cracking, individual construction widths of HBM base shall not exceed 4.75 m unless crack induction is provided.

*NOTE* *Information on crack induction of HBM is provided in Series 800 of MCHW [Ref 9.N].*

## Rigid construction with continuous reinforcement (CRCP and CRCB)

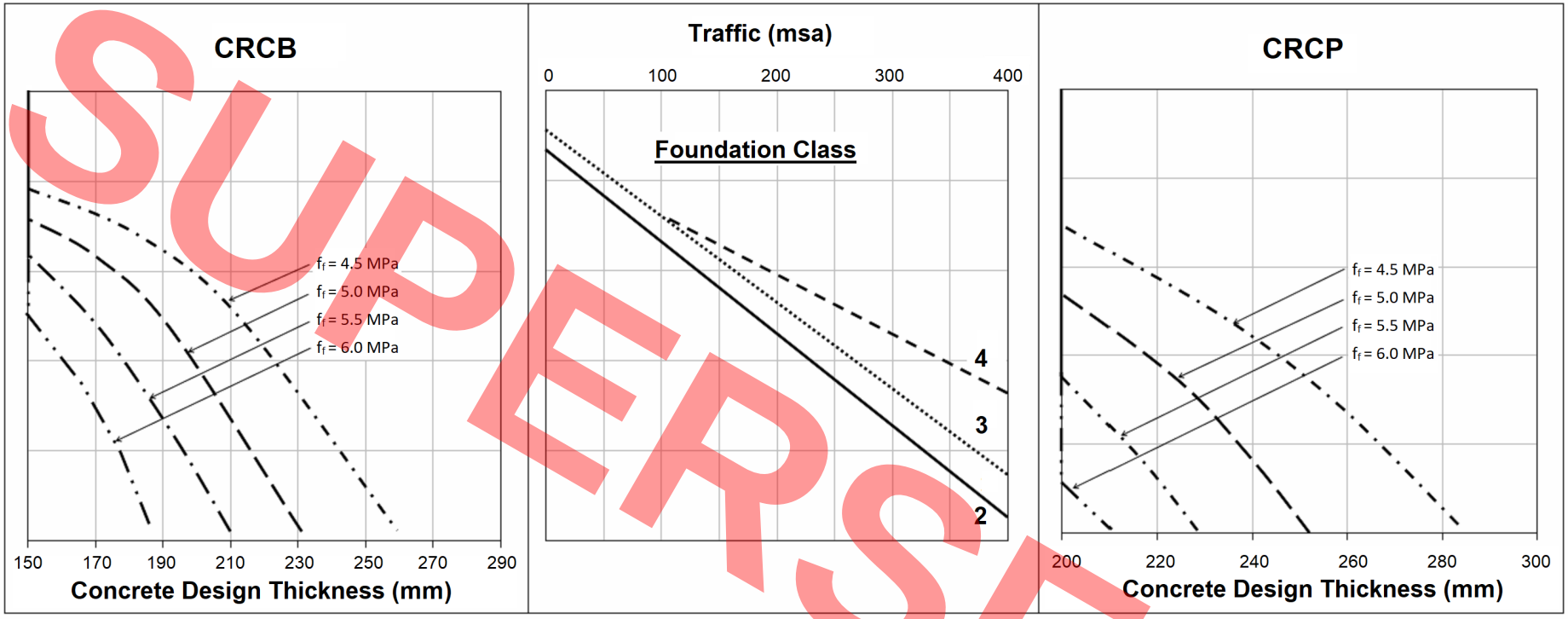
2.26 The design thickness of the concrete layers for continuously reinforced rigid pavements shall be determined using the nomograph in Figure 2.26.

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**Figure 2.26 Nomograph for determining concrete layer design thickness for continuously reinforced concrete pavements (CRCB and CRCP)**




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*NOTE 1* *For CRCP, the right hand side of the nomograph is used to determine the thickness of concrete.*

*NOTE 2* *For CRCB, the left hand side of the nomograph is used to determine the thickness of concrete.*

*NOTE 3* *The class 2 foundation line is provided for reconstruction and widening of an existing pavement which has a the foundation equivalent to a foundation class 2.*

*NOTE 4* *Thicknesses shown are for the concrete layer only i.e. they do not include the asphalt layers, if present.*

*NOTE 5* *Where a concrete surface is used in a CRCP design, its thickness is included in the total concrete design thickness.*

*NOTE 6* *Thicknesses of materials to be rounded up to the nearest 5 mm.*

*NOTE 7* *$f_f$ denotes mean concrete flexural strength (N/mm$^2$ or MPa) at 28 days measured in accordance with BS EN 12390-5 [Ref 12.N].*

*NOTE 8* *The design thickness is based on the presence of a (minimum) 1 m wide edge strip or tied shoulder.*

*NOTE 9* *Worked examples using Figure 2.26 are included in Appendix A.*

2.27 Where an integral minimum 1 m wide edge strip or tied lane is not adjacent to the most heavily trafficked lane, the design thickness for the concrete layer shall be increased by 30 mm.

2.28 Where a CRCP is designed with a TSCS, the TSCS shall have a minimum thickness of 30 mm.

*NOTE* *For CRCP construction with an asphalt surface course, no binder course is required.*

2.29 CRCB shall be designed with a total minimum asphalt thickness of 100 mm with the binder course selected from one of the materials in Table 2.29.

**Table 2.29 Permitted binder course materials for CRCB**

| Material type | Binder course |
|---|---|
| **AC 40/60** | Dense and heavy duty binder materials designed in accordance with Clause 929 MCHW [Ref 9.N] with the designations:<br><br>AC 20 dense bin 40/60 des<br>AC 32 dense bin 40/60 des<br>AC 20 HDM bin 40/60 des<br>AC 32 HDM bin 40/60 des |
| **EME2** | EME2 binder course asphalt concrete designed in accordance with Clause 930 MCHW [Ref 9.N] and targeting a penetration value of 10/20 or 15/25 |
| **HRA** | HRA binder course designed in accordance with Clause 943 MCHW [Ref 9.N] |
| **SMA** | SMA binder course specified in accordance with Clause 937 MCHW [Ref 9.N] |

*NOTE* *The total asphalt thickness includes the thickness of the surface course.*

**Concrete material details**

2.30 The CRCP/CRCB concrete layer shall contain both longitudinal and transverse steel reinforcement.

*NOTE 1* *The continuous longitudinal reinforcement is designed to hold the transverse cracks tightly closed to ensure high load transfer across the cracks and to maintain the structural integrity of the pavement.*

*NOTE 2* *The transverse reinforcement is used for ease and consistency of construction and to prevent longitudinal cracking and local deterioration.*

*NOTE 3* *The maximum spacing of longitudinal steel reinforcement can be calculated using Equation 2.30N3:*

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**Equation 2.30N3 Maximum spacing of longitudinal steel reinforcement**

$$s = \frac{100\pi D^2}{4tR}$$

where:

| | |
|---|---|
| s | is the maximum distance, centre to centre, between bars across the width of the slab (mm) |
| D | is the diameter of reinforcement bar (mm) |
| R | is the level of reinforcement (% of the cross section area) |
| t | is the concrete design thickness (mm) |

2.30.1 Transverse bars may be incorporated into the support arrangement for the steel.

2.31 Where transverse bars are incorporated into the support arrangement for the steel, the required quantities and position of the steel shall be maintained.

2.32 Longitudinal crack control steel in CRCP shall be 0.6% of the concrete slab cross-section area, comprising 16mm diameter deformed steel bars (T16 reinforcement).

2.33 Transverse steel in CRCP shall be 12 mm diameter deformed bars at 600 mm spacing.

2.34 Longitudinal crack control steel in CRCB shall be 0.4% of the concrete slab cross-section area, comprising 12 mm diameter deformed steel bars (T12 reinforcement).

2.35 Transverse steel in CRCB shall be 12 mm diameter deformed bars at 600 mm spacings.

2.36 Where concrete of flexural strength $\geq$ 5.5 MPa is used, this shall use aggregate that has a coefficient of thermal expansion less than 10 x$10^{-6}$ per °C.

2.37 Crack inducers shall not be used with CRCP or CRCB designs.

**Termination details**

2.38 The termination details of CRCP and CRCB pavements shall be designed to ensure that forces are not transmitted to structures and adjacent forms of pavement construction by thermally induced movements.

*NOTE* *Standard examples of terminations are provided in Volume 3, Section 1, C series of the MCHW [Ref 9.N].*

2.39 The termination details of CRCP and CRCB shall be subject to approval by the Overseeing Organisation.

## Rigid construction with roller compacted concrete (RCC)

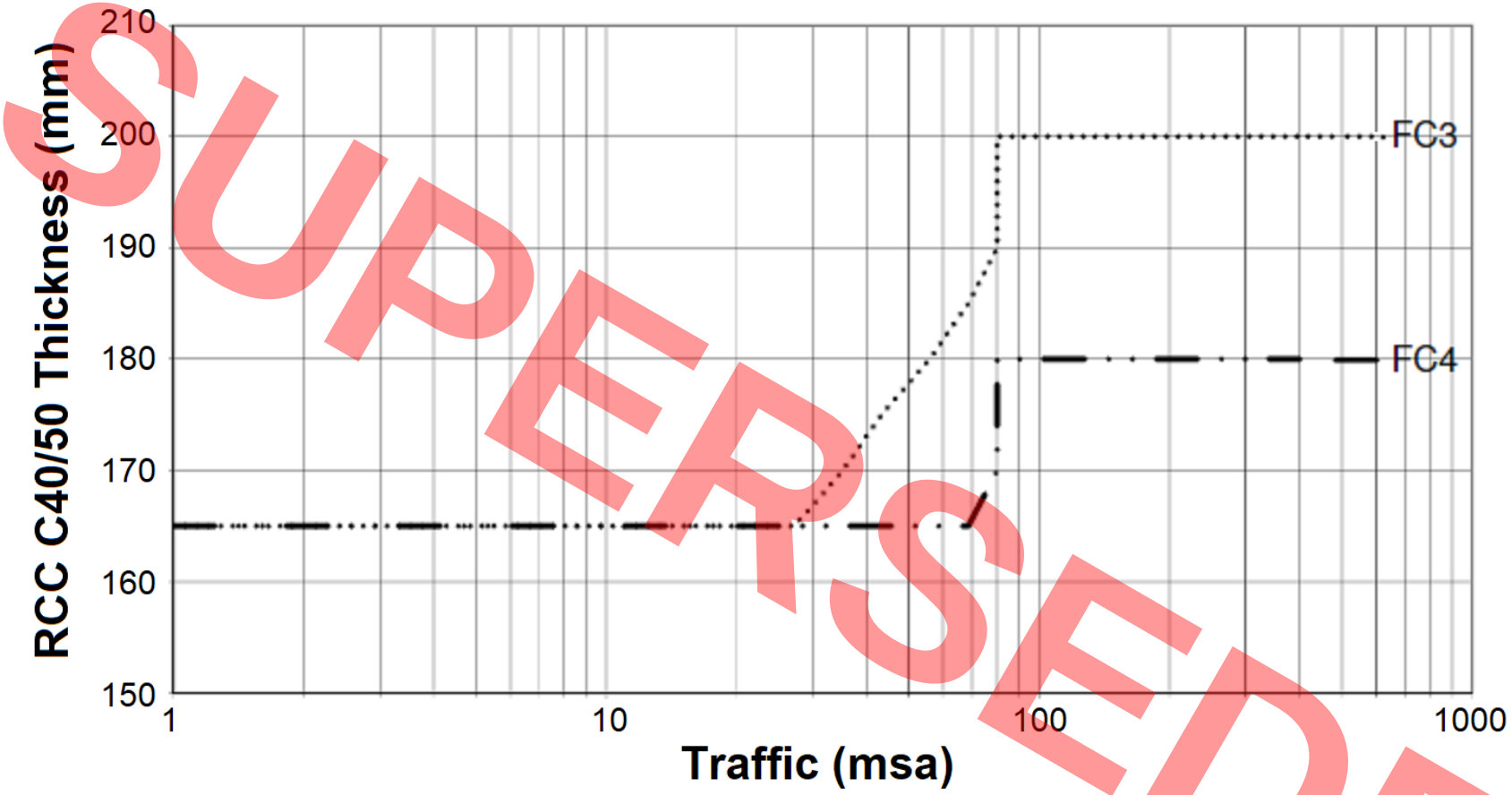
2.40 The design thickness of the concrete layer for RCC pavements shall be determined using Figure 2.40.

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**Figure 2.40 Design thickness for the concrete layer in roller compacted concrete (RCC) pavements**




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*NOTE 1* *Thicknesses of materials to be rounded up to the nearest 5 mm.*

*NOTE 2* *FC3 and FC4 are foundation class 3 and foundation class 4, respectively.*

*NOTE 3* *C40/50 concrete used in RCC is assumed to have the following characteristics:*

*1) flexural Strength of 5.0 MPa;*

*2) modulus E = 50,000 MPa; and,*

*3) Poisson's Ratio = 0.20.*

*NOTE 4* *RCC design (fatigue) life can be determined using multi layer linear elastic modelling and Equation 2.40N4:*

**Equation 2.40N4 Design life calculation for RCC**

$$T = \frac{e^{\frac{StressRatio-0.9157}{-0.039}}}{10^6}$$

where:

| | |
|---|---|
| T | is the design traffic (msa) |
| e | is the base of the natural logarithm (2.718281828) |
| Stress ratio | is the induced tensile stress at the bottom of the RCC due to a standard wheel load divided by the flexural strength of the RCC. |

*NOTE 5* *Further background to the development of RCC in the UK is given in Abouabid et al [Ref 1.I].*

2.41 RCC pavements shall be designed with a total minimum asphalt thickness of 90 mm with the binder course selected from one of the materials in Table 2.41.

**Table 2.41 Permitted binder course materials for RCC**

| Material type | Binder course |
|---|---|
| **EME2** | EME2 binder course asphalt concrete designed in accordance with Clause 930 MCHW [Ref 9.N] and targeting a penetration value of 10/20 or 15/25 |
| **HRA** | HRA binder course designed in accordance with Clause 943 MCHW [Ref 9.N] |

*NOTE* *The total asphalt thickness includes the thickness of the surface course.*

## Rigid construction with jointed concrete pavements

2.42 Where an existing jointed concrete pavement is being reconstructed or widened using the same type of pavement, the design shall be in accordance with either the URC or JRC designs, defined below.

**Unreinforced jointed concrete pavement design (URC)**

2.43 The design thickness of URC pavements shall be determined using Equations 2.43a and 2.43b.

**Equation 2.43a Design thickness of URC pavements (no tied shoulder or edge strip)**

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

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**Equation 2.43b Effect on design thickness of URC pavements of a tied shoulder or edge strip**

$$H_2 = 0.934H_1 - 12.5$$

where:

| | |
|---|---|
| $H_1$ | is the thickness (mm) of the concrete slab without a tied lane or 1 m edge strip |
| $H_2$ | is the thickness (mm) of the concrete slab with a tied lane or 1 m edge strip |
| ln or Ln | is the natural logarithm |
| T | is the design traffic (msa) |
| $R_c$ | is the mean compressive cube strength (N/mm$^2$ or MPa) at 28 days |
| E | is the foundation stiffness (MPa) related to foundation class:<br>E = 200 MPa for foundation class 3<br>E = 400 MPa for foundation class 4 |

*NOTE 1* *Minimum slab thickness ($H_1$) is 150 mm.*

*NOTE 2* *Maximum design traffic (T) is 400 msa.*

*NOTE 3* *Load induced stresses at slab corners and edges are greater than in the slab centre, necessitating dowel bars to distribute loads between slabs.*

*NOTE 4* *Thicknesses to be rounded up to the nearest 5 mm.*

*NOTE 5* *Further information on the design of rigid pavements is given in TRL RR87 [Ref 14.N].*

2.44 For URC pavements, where the slab thickness is $<$ 230 mm, the maximum spacing between transverse contraction joints shall be 4 m.

*NOTE 1* *Contraction joints enable the slab to shorten when its temperature falls and allow the slab to expand subsequently by approximately the same amount.*

*NOTE 2* *The permitted spacing of transverse joints is a function of slab thickness and aggregate type. Joint spacing reflects the capacity of the slab to distribute strain rather than allow damaging strain concentrations.*

2.45 For URC pavements, where the slab thickness is $\geq$ 230 mm, the maximum spacing between transverse contraction joints shall be 5 m.

**Reinforced jointed concrete pavement design (JRC)**

2.46 The design thickness of JRC pavements shall be determined using Equations 2.46a and 2.46b.

**Equation 2.46a Design thickness of JRC pavements (no tied shoulder or edge strip)**

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

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**Equation 2.46b Effect on design thickness of JRC pavements of a tied shoulder or edge strip**

$$H_2 = 0.934H_1 - 12.5$$

where:

| | |
|---|---|
| $H_1$ | is the thickness (mm) of the concrete slab without a tied lane or 1 m edge strip |
| $H_2$ | is the thickness (mm) of the concrete slab with a tied lane or 1 m edge strip |
| Ln | is the natural logarithm |
| T | is the design traffic (msa) |
| $R_c$ | is the mean compressive cube strength (N/mm$^2$ or MPa) at 28 days |
| E | is the foundation stiffness (MPa) related to foundation class:<br>E = 200 MPa for foundation class 3<br>E = 400 MPa for foundation class 4 |
| R | is the percentage of longitudinal steel reinforcement:<br>R = 8.812 for 500 mm$^2$/m reinforcement<br>R = 9.071 for 600 mm$^2$/m reinforcement<br>R = 9.289 for 700 mm$^2$/m reinforcement<br>R = 9.479 for 800 mm$^2$/m reinforcement |

*NOTE 1* *Minimum slab thickness (H1) is 150 mm.*

*NOTE 2* *Load induced stresses at slab corners and edges are greater than in the slab centre, necessitating dowel bars to distribute loads between slabs.*

*NOTE 3* *Thicknesses to be rounded up to the nearest 5 mm.*

*NOTE 4* *Further information on the design of rigid pavements is given in TRL RR87 [Ref 14.N].*

*NOTE 5* *A worked example is included in Appendix A.*

2.47 For JRC, the minimum level of longitudinal reinforcement shall be 500 mm$^2$/m.

2.48 For JRC pavements, where the aggregate has a coefficient of thermal expansion $\geq$ 10 x 10$^{-6}$ per $^o$C, the maximum spacing between transverse joints shall be determined using Table 2.48.

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**Table 2.48 Maximum transverse joint spacing in JRC**

| Slab thickness (mm) | Level of reinforcement | |
|---|---|---|
| | < 600 mm²/m | ≥ 600 mm²/m |
| | Maximum joint spacing (m) | |
| < 290 | 25 | 25 |
| ≥ 290 to <300 | 24 | |
| ≥ 300 to <310 | 23 | |
| ≥ 310 to <320 | 22 | |
| ≥ 320 to <330 | 21 | |
| ≥ 330 | 20 | |

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

2.48.1 For JRC pavements, where concrete is used with an aggregate that has a coefficient of thermal expansion $<10 \times 10^{-6}$ per $^{o}C$, the maximum transverse joint spacings in Table 2.48 may be increased by 20%.

## Design of central reserves, maintenance areas and emergency areas (EAs)

2.49 Where there is a need for a hardened central reserve, the minimum standard for construction shall be designed using the heavy vehicle loading category for footways/cycleways in CD 239 [Ref 7.N].

2.50 Other forms of central reserve construction are subject to approval by the Overseeing Organisation and shall require a minimum of 70 mm thickness of bound material.

*NOTE 1* *The design thickness of an EA using concrete construction are based on the presence of a (minimum) 1 m wide edge strip or tied shoulder.*

*NOTE 2* *This thickness of material is intended to inhibit weed penetration and minimise future maintenance.*

2.51 EAs shall be based on a minimum design life of 5 msa.

2.52 Where an EA is included, the design shall maintain sub-base and capping drainage paths.

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# 3. On-line widening and upgrading of existing pavements

## General

3.1 This section sets out the pavement design requirements that shall be followed where on-line widening and/or upgrading of an existing pavement on a motorway or all-purpose trunk road is being undertaken.

*NOTE 1* *On-line widening is where additional carriageway is constructed abutting the existing carriageway.*

*NOTE 2* *Upgrading of an existing pavement includes conversion of a hard shoulder to a running lane and incorporation of an existing pavement into new construction.*

3.1.1 Where on-line widening and/or upgrading of an existing pavement is being undertaken, design should be undertaken using at least two options.

3.2 The design of the widened and upgraded pavements shall provide a structural life of 40 years.

3.3 Where a design that results in an increase in pavement height is being proposed, an assessment shall be made of the consequential impacts on the following:

1) headrooms at structures, gantries and overhead lines;
2) carriageway surface geometry;
3) kerb and vehicle restraint system heights;
4) drainage and ironwork;
5) heights of copings and parapet walls adjacent to retaining walls and underbridges; and,
6) overloading at under-bridges and adjacent to retaining walls.

*NOTE* *Requirements for headrooms are set out in CD 127 [Ref 2.N].*

3.4 Where a design that results in an increase in carriageway width or projected traffic flow is being proposed, an assessment shall be made of the consequential impact on the following:

1) headrooms at structures, gantries and overhead lines;
2) carriageway surface geometry (including slip road and weaving length);
3) wide carriageway drainage; and,
4) VRS set back and containment.

3.5 Where on-line widening and/or upgrading of an existing pavement is being undertaken, the condition of the existing pavement, including the foundation, shall be determined in accordance with CD 227 [Ref 4.N].

*NOTE* *The condition and construction thicknesses of the layers in the existing pavement are key to the design of the widened or upgraded pavement.*

## On-line widening

3.6 The design of the widened part of the pavement shall be in accordance with the 'standard designs' for new pavements as set out in Section 2 of this document.

3.7 Where on-line widening is being undertaken, the ground conditions beneath the existing, adjacent pavement, as determined during the investigation and evaluation process, shall be used to inform the assessment of the long-term condition beneath the adjacent new pavement.

*NOTE* *The information from the pavement investigation can be used in the assessment of the condition of the subgrade and to establish whether the existing pavement requires strengthening.*

3.8 The foundation for the widened road shall be designed in accordance with CD 225 [Ref 3.N].

3.9 Where on-line widening is being undertaken, the design, materials and thickness of the new pavement shall be selected to ensure continuity of drainage.

*NOTE 1* *It is a requirement of CD 225 [Ref 3.N] that drainage paths in the existing foundation are maintained.*



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*NOTE 2* *Maintaining drainage paths can result in a thicker bound construction than is required to meet the design traffic. This can be significant where an overlay is applied to strengthen or reprofile the existing pavement.*

3.9.1 The total thickness of the bound materials for the widened pavement should match those of the existing pavement.

*NOTE 1* *Bound materials in this clause excludes bound materials in the foundation.*

*NOTE 2* *Where it is required to provide increased load carrying capacity for the additional lane/s, this can be achieved using stiffer binder and base materials than the existing pavement.*

*NOTE 3* *Where the design thickness for the widened pavement is greater than the existing pavement, drainage paths can be maintained by applying an overlay to the existing pavement.*

3.9.2 Where the new and existing construction cannot be adequately matched, due, for example, to the use of different forms of construction or materials, the use of drainage layers and adjustments to crossfall may be required to ensure water is not trapped beneath the pavement.

*NOTE* *Information on crossfall and other surface drainage factors for wide carriageways is contained in CG 501 [Ref 5.N].*

3.9.3 Where the requirements to match bound layer thickness and to achieve design life cannot both be achieved, the Overseeing Organisation should be consulted.

3.10 Where on-line widening of an existing rigid pavement is being undertaken using a tied-in design, the thermal expansion coefficient of the coarse aggregate used in the new material shall not be more than $5.5 \times 10^{-6}$ per °C different to those in the existing pavement.

3.11 Where on-line widening of an existing jointed rigid pavement (URC or JRC) is being undertaken, this shall not be undertaken using a continuously reinforced concrete construction (CRCP or CRCB).

*NOTE 1* *It is not possible to tie the two construction types to provide satisfactory edge and corner support while accommodating relative movement due to thermal effects.*

*NOTE 2* *When widening an existing jointed rigid pavement, there are advantages in providing continuity across the carriageway by using the same form of construction as a base layer, prior to receiving an asphalt overlay.*

## Upgrading

3.12 The design of upgraded pavements shall be in accordance with CD 227 [Ref 4.N].

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# 4. Alternative design procedures

4.1 This section sets out the requirements that shall be followed for the design of a new pavement using alternative design procedures.

*NOTE* *Alternative pavement designs are designs not covered by Section 2 of this document and normally use analytical methods to model the stresses and strains and assumed material properties to determine design thicknesses.*

4.2 All alternative designs shall require 'departure from standard' approval by the Overseeing Organisation.

4.3 The foundation shall be designed in accordance with CD 225 [Ref 3.N].

4.4 Where designing a pavement for a new carriageway, the design life shall be 40 years.

4.5 Where designing a pavement for a new carriageway, all lanes, including the hard shoulder and lay-bys, shall be constructed to carry the design traffic in the heaviest loaded lane, commonly the left hand lane, as calculated in accordance with CD 224 [Ref 15.N].

4.6 The minimum design traffic for new roads shall be 1 msa, as calculated in accordance with CD 224 [Ref 15.N].

4.7 The surface course shall be designed in accordance with CD 236 [Ref 11.N].

4.8 Where an alternative design is proposed, the pavement design report shall include a justification for the choice and an indication of any additional specification requirements or testing regime necessary for their validation.

*NOTE* *Requirements for the pavement design report are set out in Section 6 of this document.*

## Analytical pavement design

4.9 The steps that shall be followed when undertaking an analytical pavement design are as follows:

1) determine the pavement life requirement in terms of traffic loading (msa) using CD 224 [Ref 15.N];
2) determine the available and permitted pavement materials and design types;
3) estimate the in situ dimensions and long-term performance properties (stiffness and/or strength) of each individual layer of pavement material;
4) carry out a structural analysis using a simplified multi-layer linear elastic model of the pavement structure;
5) compare critical stresses/strain and/or deflections with allowable values;
6) make adjustments to in situ dimensions and long-term performance properties until the pavement life requirement is achieved; and,
7) calculate the embodied carbon compared to that of a standard design.

*NOTE 1* *Critical stresses/strains used in the standard UK design approach include excessive stresses/strains (combination of magnitude and number of load application) causing fatigue cracking (typically at the bottom of the base layer) of the asphalt, HBM or concrete material.*

*NOTE 2* *Principles for alternative flexible pavement designs are set out in TRL615 [Ref 6.N].*

*NOTE 3* *Principles for alternative rigid pavement designs are set out in TRL RR87 [Ref 14.N] (for jointed concrete pavements) or TRL630 [Ref 10.N] (for continuously reinforced concrete pavements).*

4.10 The analysis method used to model the pavement response and to calculate critical stresses and strains shall employ elastic multi-layer analysis based on Burmister's equations described in Burmister [Ref 13.N] with all layers modelled linearly including an infinite depth foundation.

*NOTE* *All new pavements are constructed to behave as a monolithic block, assuming complete bond between layers.*

4.11 For asphalt materials, the elastic stiffness moduli used for pavement design shall be the long-term stiffnesses determined at the reference condition of 20°C and 5 Hz.



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*NOTE* *These conditions are not the same as those used for indirect tension testing (IT-CY) testing which uses the lower frequency of 2.5 Hz. Results for the two sets of conditions are not interchangeable.*

4.12 Unless reliable data is available that indicates a divergence from these figures, the values of long-term elastic stiffness modulus for the following standard UK asphalt materials that shall be used in analytical design (at 20ºC) are shown in Table 4.12.

**Table 4.12 Elastic stiffness moduli for standard UK asphalt materials (at 20 degC and 5 Hz)**

| Material | Stiffness (MPa) |
|---|---|
| TSCS | 2000 |
| HRA binder course | 3100 |
| AC 40/60 des (binder course or base) | 4700 |
| EME2 (binder course or base) | 8000 |

**Materials**

4.13 Where the use of non-standard materials is proposed, the design shall clearly address how the material properties assumed in the design are to be achieved in situ.

*NOTE 1* *Non-standard materials are those not included in Section 2 of this document as permitted materials.*

*NOTE 2* *Proprietary materials cannot be specified in a design.*

*NOTE 3* *Factors that can affect pavement performance include:*

*1) durability of the pavement structure (e.g. resistance of the materials to the deleterious effects of water, air and other environmental factors);*

*2) serviceability (e.g. skidding resistance and permanent deformation);*

*3) maintainability (e.g. reflection cracking in composite pavements, and surface initiated fatigue cracking in thicker/long-life pavements); and,*

*4) construction tolerances (allowable construction thickness reductions to be added to the minimum analytical design thickness).*

4.14 For non-standard bound materials, the properties to be characterised shall include:

1) effective stiffness modulus;
2) deformation resistance (asphalt);
3) fatigue resistance (asphalt); and,
4) strength (HBM).

*NOTE* *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.*

## Continuously reinforced concrete pavements (CRCP and CRCB)

4.15 Where designing an alternative CRCP or CRCB pavement, the design shall be based on the principles set out in TRL630 [Ref 10.N].

4.16 Where designing a CRCP or CRCB pavement, the longitudinal reinforcement value of 900 $mm^2/m$ width is the maximum value that shall be used for design calculations, despite the pavement containing more reinforcement than this.

*NOTE* *This design limit is explained in TRL630 [Ref 10.N].*

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# 5. Use of cold recycled base materials

## Alternative design using cold recycled base materials

5.1 The surface course for all pavements incorporating cold recycled base materials shall be designed in accordance with CD 236 [Ref 11.N].

### Cold recycled designs using TRL report 611

5.2 Pavement designs containing cold recycled base material shall only be used for a design traffic of 30 msa or less.

5.3 The design method shall be in accordance with the process set out in TRL report TRL 611 [Ref 1.N].

5.4 Where the design incorporates an hydraulic binder, the design shall specify the permitted minimum and maximum strengths of the recycled material.

5.5 Where an HBM layer is designed to reach a compressive strength of 10 MPa at 7 days, it shall have cracks at a maximum spacing of 5 m induced in accordance with Clause 818 of the MCHW [Ref 9.N].

5.6 The minimum thickness of bituminous surface course shall be 20 mm provided that a compensating increase in the thickness of the cold recycled base following is made as described in Equation 7.5 of TRL report TRL 611 [Ref 1.N].

*NOTE 1* *The minimum thickness replaces those in Table 7.3 of TRL report TRL 611 [Ref 1.N].*

*NOTE 2* *Polymer fibres and rubberising additives can be incorporated into the surface course to delay the onset of reflective cracking if an hydraulic binder has been used.*

### Deep in-situ recycling: the down cut process

5.7 Alternative designs utilising the down cut process shall require departure from standard approval by the Overseeing Organisation.

5.8 A detailed pavement investigation shall be carried out, including recovery of cores at 100 m intervals, and bulk samples before design can be carried out to provide:

1) depths and types of bound materials present; and,
2) samples of materials for laboratory design.

5.9 A separate design shall be carried out for each area where the existing construction thickness or material types vary.

5.10 The existing surface course shall be planed out and stockpiled.

5.11 Only bound layers shall be recycled.

5.12 Materials shall be recycled to depths of between 100 mm and 300 mm below the existing surface layer.

*NOTE* *The pulverising drum can operate down to 450 mm but complete compaction of the recycled material to this depth can be difficult to attain.*

5.13 The recycling mixture design shall determine the amount of hydraulic binder (CEMII), bituminous binder and water to be added during the recycling process to achieve an indirect tensile stiffness modulus between 3.1 GPa (min) and 6.5 GPa (max).

5.14 The design shall be carried out using bulk samples that have been crushed using a pulveriser identical to that to be used on site.

5.15 A water resisting layer below the surface course, complying with Clause 929 asphalt concrete, Clause 930 EME2 or Clause 943 performance related HRA, laid on a bond coat complying with Clause 920 of the MCHW [Ref 9.N], shall be applied on top of the compacted recycled material prior to installation of a surface course.

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**Ex-situ recycling**

5.16 The design process shall assume that the recycled material has a minimum stiffness equivalent to Class B3 materials complying with Clause 948 of the MCHW [Ref 9.N].

5.17 The design shall specify the type of recycled material to be produced from Table 5.17.

**Table 5.17 Types of recycled material**

| Type | Primary binder |
|---|---|
| Quick hydraulic | Cement as the main component and excluding bituminous binders. |
| Slow hydraulic | Hydraulic binders (e.g. PFA/lime and GBS/lime) excluding bituminous and Portland cement. |
| Quick visco-elastic | Bituminous binder as the main component but also including Portland cement. |
| Slow visco-elastic | Bituminous binder as main component but excluding Portland cement. |

5.18 All recycled materials shall be mixed in a plant with additional binder, aggregates and other additives and comply with the requirements of Clause 948 of the MCHW [Ref 9.N].

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# 6. Pavement design verification

6.1 Where pavement design verification is required by the Overseeing Organisation, the requirements set out in the appropriate National Application Annex shall be followed.

*NOTE* *Pavement design verification can involve production of a pavement design report or the need to follow an alternative design checking procedure.*

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# 7. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

| | |
|---|---|
| Ref 1.N | TRL. Merrill, D et al. TRL 611, 'A guide to the use and specification of cold recycled materials for the maintenance of road pavements ' |
| Ref 2.N | Highways England. CD 127, 'Cross-sections and headrooms' |
| Ref 3.N | Highways England. CD 225, 'Design for new pavement foundations' |
| Ref 4.N | Highways England. CD 227, 'Design for pavement maintenance' |
| Ref 5.N | Highways England. CG 501, 'Design of highway drainage systems' |
| Ref 6.N | TRL. Nunn, M. TRL615, 'Development of a more versatile approach to flexible and flexible-composite pavement design' |
| Ref 7.N | Highways England. CD 239, 'Footway and cycleway pavement design' |
| Ref 8.N | Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges' |
| Ref 9.N | Highways England. MCHW, 'Manual of Contract Documents for Highway Works' |
| Ref 10.N | TRL. Hassan, KE et al. TRL630, 'New continuously reinforced concrete pavement designs' |
| Ref 11.N | Highways England. CD 236, 'Surface course materials for construction' |
| Ref 12.N | BSI. BS EN 12390-5, 'Testing hardened concrete. Flexural strength of test specimens' |
| Ref 13.N | American Institutue of Physics, Journal of Applied Physics, Vol 23, pp 126-128. Burmister, DM. Burmister, 'The General Theory of Stresses and Displacements in Layered Soil Systems III' |
| Ref 14.N | TRL. Mayhew, HC & Harding, HM. TRL RR87, 'Thickness design of concrete roads' |
| Ref 15.N | Highways England. CD 224, 'Traffic assessment' |

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# 8. Informative references

The following documents are informative references for this document and provide supporting information.

| | |
|---|---|
| Ref 1.I | AECOM Pavement and Materials Team. Abouabid M, Casey D & Jones, M. Abouabid et al, 'Roller Compacted Concrete - Background to the Development of Highways England's Design Guidance and Specification' |

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# Appendix A. Worked examples

## A1 Standard flexible pavement design using Figure 2.20

Figure A.1 reproduces Figure 2.20, annotated to show two examples for the design of flexible pavements.

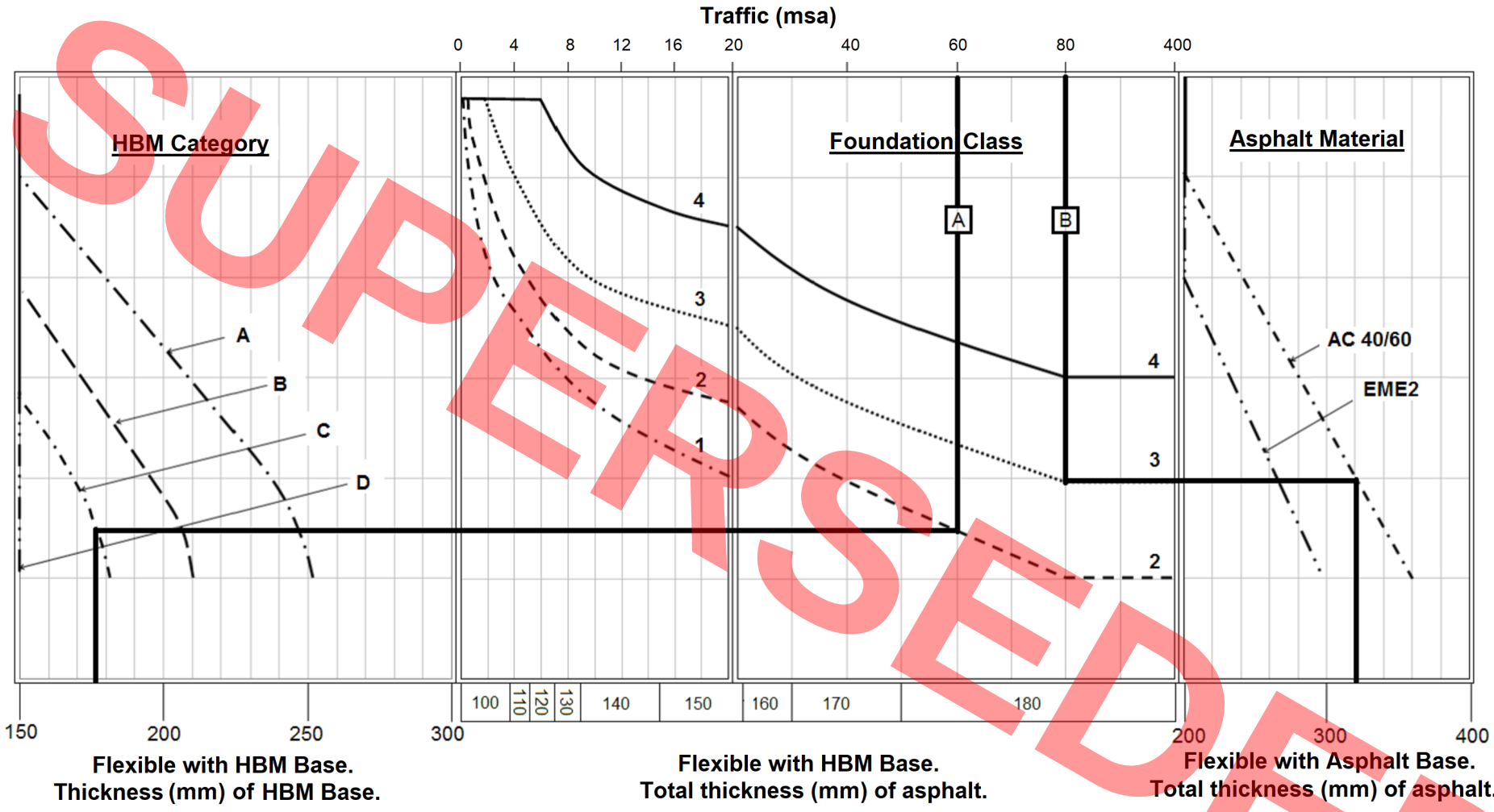
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**Figure A.1 Nomograph for determining the design thickness for flexible pavements**




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### A1.1 Example "A": flexible pavement with an HBM base

Design factors:

1) design traffic = 60 msa;
2) foundation stiffness class 2.

Using Figure 2.20 (reproduced as Figure A.1) and with HBM category C base material:

Total asphalt thickness of 180 mm asphalt (i.e. surface course, binder course and base), over

180 mm HBM Category C (i.e. rounded up to the nearest 5 mm).

Note: Table 2.23N2 gives HBM Category C options e.g.a Clause 822 CBGM B with laboratory performance category C12/15 (or T4). Laboratory performance categories are detailed in Series 800 of the MCHW [Ref 9.N].

### A1.2 Example "B": flexible pavement with an asphalt base

Design factors:

1) design traffic >80 msa (i.e. 'long life' pavement);
2) foundation stiffness class 3.

Using Figure 2.20 (reproduced as Figure A.1) and with AC 40/60 selected as the binder and base material:

Total asphalt thickness of 320 mm (i.e. surface course, AC 40/60 binder course and AC 40/60 base).

## A2 Standard rigid (CRCP and CRCB) pavement design using Figure 2.26

Figure A.2 reproduces Figure 2.26, annotated to show two examples for the design of rigid pavements.

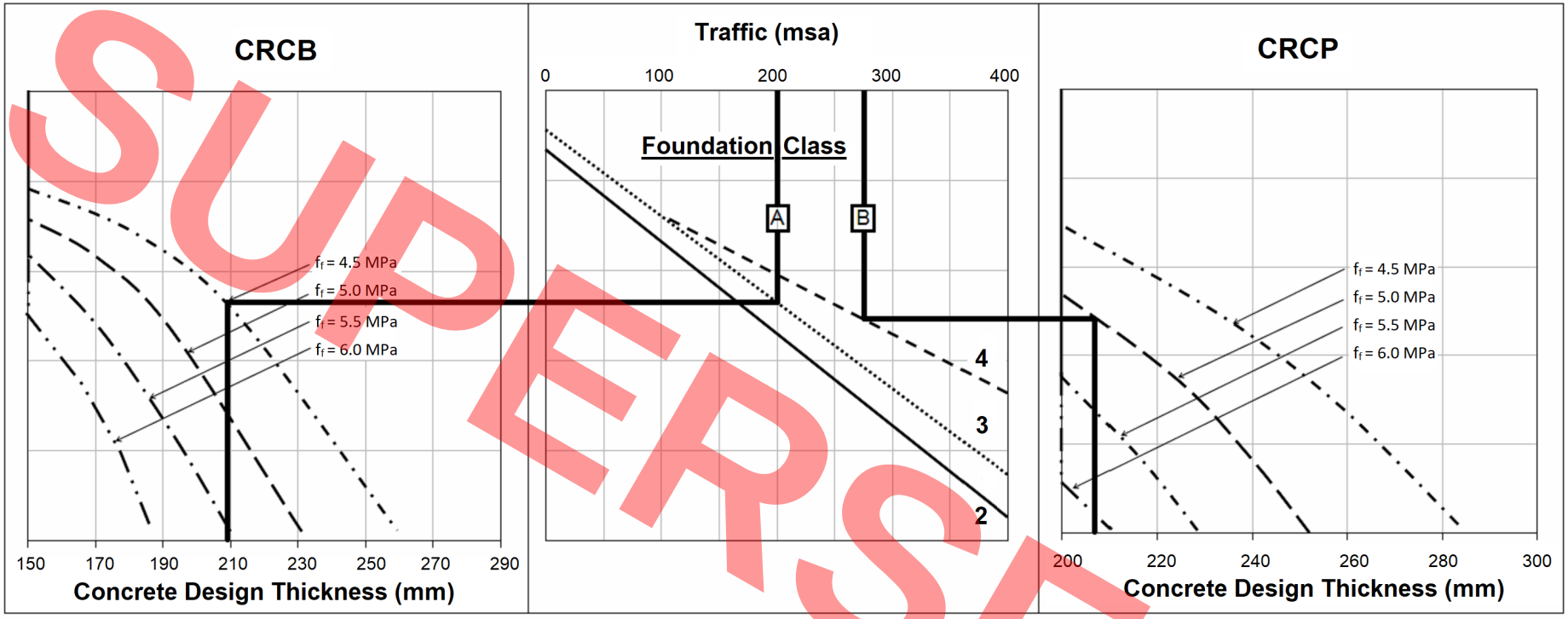
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**Figure A.2 Nomograph for determining concrete layer design thickness for continuously reinforced concrete pavements (CRCB and CRCP)**




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## A2.1 Example "A": CRCB

Design factors:

1) design traffic of 200 msa;
2) foundation stiffness class 3;
3) design uses concrete with a flexural strength of 4.5 MPa and a 1m edge strip.

Using Figure 2.26 (reproduced as Figure A.2) and with concrete with a flexural strength of 4.5 MPa:

100 mm asphalt, over

210 mm of concrete (with a tied shoulder or 1 m edge strip).

Note: All CRCB designs require 100 mm asphalt.

Note: CRCB designs require T12 longitudinal reinforcement at 0.4%. The spacing of the T12 longitudinal reinforcement can be calculated using Equation 2.30N3 (reproduced as Equation A.1):

**Equation A.1 Maximum spacing of steel reinforcement**

$$s = \frac{100\pi D^2}{4tR}$$

where:

| | |
|---|---|
| s | is the maximum distance, centre to centre, between bars across the width of the slab (mm) |
| D | is the diameter of reinforcement bar (mm) |
| R | is the level of reinforcement (% of the cross section area) |
| t | is the concrete design thickness (mm). |

Using Equation A.1, the reinforcement spacing is:

$\frac{100 \cdot \pi \cdot 12^2}{4 \cdot 210 \cdot 0.4} = 135$ mm

## A2.2 Example "B": CRCP

Design factors:

1) design traffic of 275 msa;
2) foundation class 4;
3) design uses concrete with a flexural strength of 5.0 MPa and no edge strip or tied shoulder;
4) asphalt TSCS surfacing.

Using Figure 2.26 (reproduced as Figure A.2) and with concrete with a flexural strength of 5.0 MPa:

30 mm asphalt surfacing, over

210 mm + 30 mm = 240 mm of a 5.0 MPa flexural strength concrete (without a tied shoulder or 1 m edge strip).

NOTE: CRCP designs require T16 longitudinal reinforcement at 0.55%. The spacing of the T16 longitudinal reinforcement using Equation 2.30N3 (reproduced as Equation A.2) is:

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**Equation A.2 Example equation for reinforcement spacing**

$$\frac{100 \cdot \pi \cdot 16^2}{4 \cdot 240 \cdot 0.55} = 152mm$$

## A3 RCC design using multi-layer linear elastic analysis and Equation 2.40N4

Using linear elastic modelling, a standard 40 kN wheel load with a contact radius of 0.151 m and the pavement material properties in Table A.1 results in a tensile stress at the bottom of the RCC layer of 1.10 MPa.

**Table A.1 Material properties for RCC design example**

| Layer description | Thickness (mm) | Stiffness (MPa) | Poisson's ratio |
|---|---|---|---|
| TSCS | 40 | 2000 | 0.35 |
| HRA binder course | 50 | 3100 | 0.35 |
| RCC | 180 | 50,000 | 0.2 |
| Foundation (class 3) | $\infty$ | 200 | 0.35 |

Using Equation 2.40N4:

Stress ratio (= induced tensile stress / RCC flexural strength) = 0.220.

Design life (msa) =

**Equation A.3 RCC design life equation example**

$$e^{\frac{0.220-0.9157}{-0.039}}/10^6 = 56msa$$

## A4 Rigid (JRC) pavement design for widening of an existing pavement using Equations 2.46a and 2.46b

Design factors:

1) design traffic of 130 msa;
2) foundation class 3;
3) reinforcement 500 mm$^2$/m;
4) aggregate has a coefficient of thermal expansion less than 10 x 10$^{-6}$ per $^o$C;
5) concrete has a mean compressive cube strength of 50 N/mm$^2$.

Using Equation 2.46a:

Design thickness of JRC slab is 285 mm (without a tied shoulder or 1 m edge strip).

The transverse joint spacing (using Table 2.48) is 25 m which may be increased by 20% to 30 m.

Using Equation 2.46b:

Design thickness of JRC slab is 255 mm (with a tied shoulder or 1 m edge strip).

The transverse joint spacing (using Table 2.48) is 25 m which may be increased by 20% to 30 m.

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## Notification

This document was notified in draft to the European Commission in accordance with Technical Standards and Regulations Directive 2015/1535/EU.

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Pavement
Design

# CD 226
# England National Application Annex to CD 226 Design for new pavement construction

(formerly HD 26/06, HD 27/15)

Revision 0

**Summary**
This National Application Annex gives the Highways England-specific requirements for the design of pavement construction for new build carriageways, widening of existing carriageways, or reconstruction of existing pavements on the UK motorway and all-purpose trunk road network.

**Feedback and Enquiries**
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

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# Contents

**Release notes** **2**

**Foreword** **3**
Publishing information . . . 3
Contractual and legal considerations . . . 3

**Introduction** **4**
Background . . . 4
Assumptions made in the preparation of this document . . . 4
Mutual Recognition . . . 4

**Abbreviations** **5**

**E/1. Pavement design report** **6**
Pavement design report (CD 226, 6.1) . . . 6
Pavement design report . . . 6
Pavement design certificate . . . 7

**E/2. Normative references** **9**

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## Release notes

| Version | Date | Details of amendments |
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| 0 | Mar 2020 | Highways England National Application Annex to CD 226. |

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# Foreword

## Publishing information

This document is published by Highways England.

This document supersedes HD 26/06 and HD 27/15, which are withdrawn.

## Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

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# Introduction

## Background

This National Application Annex gives the Highways England-specific requirements for the design of pavement construction for new build carriageways, widening of existing carriageways, upgrading of existing pavements or reconstruction of existing pavements on the UK motorway and all-purpose trunk road network.

Specifically, it covers the requirements for the reporting and certification requirements for pavement designs.

## Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 3.N] apply to this document.

## Mutual Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the mutual recognition clause in GG 101 [Ref 3.N].

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# Abbreviations

**Abbreviations**

| Abbreviation | Definition |
|---|---|
| PCF | Project control framework |

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# E/1. Pavement design report

## Pavement design report (CD 226, 6.1)

E/1.1 A pavement design report shall be produced for all designs for new pavements or when widening or upgrading an existing pavement.

*NOTE 1* *The report can be used by Highways England to review the proposed designs and assess their appropriateness.*

*NOTE 2* *The information in the report can be used to support the application for any departures from standard.*

*NOTE 3* *The content of the pavement design report depends on the nature and complexity of the designs.*

E/1.2 The pavement design report shall:

1) be produced at the preliminary design stage (PCF stage 3);
2) be considered a live document until it is finalised at the construction preparation stage (PCF stage 5); and,
3) at each stage of its production, be submitted along with a pavement design certificate.

*NOTE* *Any changes made at the construction stage (PCF stage 6) are beyond the scope of this procedure and are captured and recorded as part of the PCF process.*

### Pavement design report

E/1.3 For standard designs, for a new pavement or the widening of an existing pavement, the pavement design report shall include the following information:

1) scheme details;
2) the range of standard designs considered;
3) technical justification for why particular designs have not been considered (where appropriate);
4) details of the current condition of the pavement or the adjacent pavement (where appropriate);
5) detailed design traffic calculations;
6) foundation design outputs (for each foundation design considered) including any assumptions made;
7) details of the design thicknesses and materials proposed for each design option considered;
8) details of the surfacing proposed (including aggregate properties);
9) details and results of the whole life cost analysis;
10) a recommendation for the preferred design option with justification for its selection;
11) any proposed departures from standard; and,
12) outline how GG 103 [Ref 2.N] Introduction and general requirements for sustainable development and design has been implemented in the design.

E/1.4 For designs for new pavements undertaken using alternative design procedures, the pavement design report shall include the following information:

1) scheme details;
2) the range of designs considered;
3) technical justification for why standard designs described in Section 2 of CD 226 [Ref 1.N] have not been considered (if appropriate);
4) details of the current condition of the pavement or the adjacent pavement (where appropriate);
5) detailed design traffic calculations;
6) foundation design calculations (for each foundation design considered) including any assumptions made;
7) for each design option proposed:

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a) comparisons with other published designs, especially from countries with similar trafficking levels, climatic conditions and material properties to the UK (if appropriate);
b) material properties assumed and supporting information, e.g. from in situ or laboratory testing, or published data;
c) details of the pavement design approach used and any assumptions, including failure mechanisms, made in the design;
d) experience of long term performance of similar pavements, both in the UK and overseas;
e) details of the analysis software/model used;
f) details of the design thicknesses and materials proposed (including calculations);
g) sensitivity analysis to identify the parameters that have most influence on life;
h) details of the surfacing proposed (including aggregate properties);
i) procedures to be adopted on site to reduce the variability of pavement construction, in particular the most influential parameters identified from the sensitivity analysis;
j) details of end performance test procedures proposed to ensure that the mean and minimum properties of materials assumed in the design, are achieved on site,

8) details and results of the whole life cost analysis;
9) a recommendation for the preferred design option with justification for its selection;
10) any proposed departures from standard; and,
11) outline how GG 103 [Ref 2.N] Introduction and general requirements for sustainable development and design has been implemented in the design.

**Pavement design certificate**

E/1.5 The pavement design certificate shall contain the information and be certified as set out in the template shown in Table E/1.5.

**Table E/1.5 Pavement design certificate template**

| **Pavement design certificate** | |
|---|---|
| **Scheme name:** | |
| **Scheme details:** | |
| **Certificate version number:** | |
| **Certificate version date:** | |
| A. We certify that the reports*, design data*, drawings* and/or other documents* for the pavement design activities listed below have been prepared by us with reasonable professional skill, care and diligence, and that in our opinion:<br>1) constitute an adequate and economic design for the project;<br>2) the work intended is accurately represented and conforms to Highways England's requirements;<br>3) has been prepared in accordance with the relevant standards from the Design Manual for Roads and Bridges and the Manual of Contract Documents for Highways Works; and,<br>4) where departures from standards are being requested, these are detailed in the accompanying documents and are listed in "C" below. | |
| The design elements covered by this certificate are not detrimental to the design elements previously certified and not amended by this certificate.** | |

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**Table E/1.5 Pavement design certificate template** (continued)

| **Pavement design certificate** | |
|---|---|
| **B. List of reports, design data, drawings or documents submitted with this certificate:** | |
| **C. Details of departures from standards:*** ** | |
| **Authorisations** | |
| **D. Designer (Designer's Pavement Design Engineer)** | |
| **Signed:** | Designer (Designer's Pavement Design Engineer) |
| **Name:** | |
| **Date:** | |
| **On behalf of:** | |
| **E. Highways England Pavement Engineering Advisor**** | |
| This Certificate (and the submission accompanying the certificate) is:<br>(a) received*:<br>(b) received with comments as follows*:<br>(c) returned marked with comments as follows*: | |
| **Signed:** | Highways England Pavement Engineering Advisor |
| **Name:** | |
| **Date:** | |

*NOTE 1* ** Delete as appropriate.*

*NOTE 2* *** This statement is only to be included where the certificate is accompanying a revision to design data that has already been certified.*

*NOTE 3* **** List of any departures from relevant standards. If none write "none".*

*NOTE 4* ***** Section E to be completed by Highways England pavement engineering advisor including comments on the submission and any amendments or revisions expected before re-submission.*

*NOTE 5* *'received' = submission accompanying the certificate is accepted.*

*NOTE 6* *'received' with comments = submission accompanying the certificate is generally acceptable but requires amendment.*

*NOTE 7* *'returned marked with comments' = submission accompanying the certificate is unacceptable and requires revision before resubmitting.*

E/1.6 The pavement design engineer authorising the certificate (Section D) shall be a certified pavement engineer.

*NOTE* *Details of how to attain certified pavement engineer status are available from Highways England.*

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## E/2. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

| | |
|---|---|
| Ref 1.N | Highways England. CD 226, 'Design for new pavement construction' |
| Ref 2.N | Highways England. GG 103, 'Introduction and general requirements for sustainable development and design' |
| Ref 3.N | Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges' |

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Department for Infrastructure
An Roinn Bonneagair

Pavement
Design

# CD 226
# Northern Ireland National Application Annex to CD 226 Design for new pavement construction

(formerly HD 26/06)

Revision 0

**Summary**
This National Application Annex gives the Department for Infrastructure Northern Ireland specific requirements for the design of pavement construction for new build carriageways, widening of existing carriageways, upgrading of existing pavements or reconstruction of existing pavements on the Northern Ireland motorway and all-purpose trunk road network.

**Feedback and Enquiries**
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated team in the Department for Infrastructure, Northern Ireland. The email address for all enquiries and feedback is: dcu@infrastructure-ni.gov.uk

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# Contents

**Release notes** **2**

**Foreword** **3**
Publishing information . . . . . 3
Contractual and legal considerations . . . . . 3

**Introduction** **4**
Background . . . . . 4
Assumptions made in the preparation of this document . . . . . 4
Mutual Recognition . . . . . 4

**NI/1. Pavement materials** **5**
Pavement materials (Tables 2.10 and 2.13) . . . . . 5

**NI/2. Pavement design verification** **6**

**NI/3. Normative references** **7**

SUPERSEDED

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## Release notes

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| 0 | Mar 2020 | Department for Infrastructure Northern Ireland National Application Annex to CD 226. |

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# Foreword

## Publishing information

This document is published by Highways England on behalf of Department for Infrastructure, Northern Ireland.

## Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

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# Introduction

## Background

This National Application Annex gives the Department for Infrastructure Northern Ireland specific requirements for the design of pavement construction for new build carriageways, widening of existing carriageways, upgrading of existing pavements or reconstruction of existing pavements on the NI motorway and all-purpose trunk road network.

## Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 3.N] apply to this document.

## Mutual Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard" or other technical specification, that requirement may be met by compliance with the mutual recognition clause in GG 101 [Ref 3.N].

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# NI/1. Pavement materials

## Pavement materials (Tables 2.10 and 2.13)

NI/1.1 In addition to the materials outlined in Tables 2.10 and 2.13 of CD 226 [Ref 2.N], in Northern Ireland recipe mixes to BS EN 13108-1 [Ref 1.N] shall be used where considered appropriate by the Department for Infrastructure.

NI/1.2 Hot rolled asphalt shall be used as a base and binder course material if considered appropriate by the Department for Infrastructure.

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## NI/2. Pavement design verification

NI/2.1 The requirements for pavement design checks and certification shall be set out within the project-specific contract documentation.

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## NI/3. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

| | |
|---|---|
| Ref 1.N | BSI. BS EN 13108-1, 'Bituminous mixtures – Material specifications. Asphaltic concrete.' |
| Ref 2.N | Highways England. CD 226, 'Design for new pavement construction' |
| Ref 3.N | Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges' |

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Pavement
Design

# CD 226
# Scotland National Application Annex to CD 226 Design for new pavement construction

(formerly HD 26/06)

Revision 0

**Summary**
There are no specific requirements for Transport Scotland supplementary or alternative to those given in CD 226.

**Feedback and Enquiries**
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# Contents

**Release notes** **2**

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Llywodraeth Cymru
Welsh Government

Pavement
Design

# CD 226
# Wales National Application Annex to CD 226 Design for new pavement construction

(formerly HD 26/06)

Revision 0

**Summary**
There are no specific requirements for the Welsh Government supplementary or alternative to those given in CD 226.

**Feedback and Enquiries**
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# Contents

**Release notes** **2**

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