Design Manual for Roads and Bridges

Pavement
Design

CD 226
Design for new pavement construction

(formerly HD 26/06)

Version 0.1.0

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
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Latest release notes

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 226	0.**1**.0	November 2021	Core document, England NAA	Incremental change to requirements

Equation 2.43a corrected to include a natural logarithm in the second term plus minor amendments for clarification. Updates made to England National Application Annex.

Previous versions

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 226	0	March 2020		

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Foreword

Publishing information

This document is published by National Highways.

This document supersedes HD 26/06 and HD 27/15, which are withdrawn.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 6.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 6.N].

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Abbreviations and symbols

Abbreviations

Abbreviations	Definition
AC	Asphalt concrete
CBGM	Cement bound granular mixture
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)
FABGM	Fly ash bound granular mixture
HBM	Hydraulically bound mixture
HBGM	Hydraulically bound granular 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
SBGM	Slag bound granular 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 surface modulus
f_f	Mean flexural strength (N/mm^2 or MPa) at 28 days
H	Total thickness of asphalt (mm)
H_1	Thickness (mm) of the concrete slab without a tied lane or 1-m edge strip
H_2	Thickness (mm) of the concrete slab with a tied lane or 1-m edge strip
Ln	Natural logarithm
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 and definitions

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	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 13.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 10.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 6.N].

Use of GG 101

1.4 The requirements contained in GG 101 [Ref 6.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 13.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 100 MPa.

Surface course

2.8 The surface course shall be designed in accordance with CD 236 [Ref 10.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 HBGM (hydraulically bound granular mixture). These are designated as "flexible with an asphalt base" or "flexible with an HBGM 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 of MCHW Series 0900 [Ref 8.N] with the designations: AC 32 dense base 40/60 des AC 32 HDM base 40/60 des	Dense and heavy-duty binder materials designed in accordance with Clause 929 of MCHW Series 0900 [Ref 8.N] with the designations: AC 20 dense bin 40/60 des AC 32 dense bin 40/60 des AC 20 HDM bin 40/60 des AC 32 HDM bin 40/60 des
EME2	EME2 base course asphalt concrete designed in accordance with Clause 930 of MCHW Series 0900 [Ref 8.N] and targeting a penetration value of 10/20 or 15/25	EME2 binder course asphalt concrete designed in accordance with Clause 930 of MCHW Series 0900 [Ref 8.N] and targeting a penetration value of 10/20 or 15/25

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Flexible pavements with an HBGM base

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

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

NOTE *Further details of HBGM materials are given in MCHW Series 0800 [Ref 7.N].*

2.12 Transverse induced cracks shall be formed during installation for HBGM with 28-day compressive strength class C8/10 or higher at a maximum spacing of 5 m under a rigid pavement or 3 m under other pavements induced in accordance with Clause 818 of MCHW Series 0800 [Ref 7.N].

NOTE 1 *Guidance on design considerations for induced cracking of HBGMs is provided in BS 9227 [Ref 3.I].*

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

2.13 For flexible pavements with an HBGM 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 HBGM base

Material type	Base	Binder course
AC 40/60	Dense and heavy-duty base materials designed in accordance with Clause 929 of MCHW Series 0900 [Ref 8.N] with the designations: AC 32 dense base 40/60 des AC 32 HDM base 40/60 des	Dense and heavy-duty binder materials designed in accordance with Clause 929 of MCHW Series 0900 [Ref 8.N] with the designations: AC 20 dense bin 40/60 des AC 32 dense bin 40/60 des AC 20 HDM bin 40/60 des AC 32 HDM bin 40/60 des
EME2	EME2 base course asphalt concrete designed in accordance with Clause 930 of MCHW Series 0900 [Ref 8.N] and targeting a penetration value of 10/20 or 15/25	EME2 binder course asphalt concrete designed in accordance with Clause 930 of MCHW Series 0900 [Ref 8.N] and targeting a penetration value of 10/20 or 15/25
HRA	-	HRA binder course designed in accordance with Clause 943 of MCHW Series 0900 [Ref 8.N]
SMA	-	SMA binder course specified in accordance with Clause 937 of MCHW Series 0900 [Ref 8.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 13.N].

2.19 The minimum design traffic for new roads shall be 1 msa, as calculated in accordance with CD 224 [Ref 13.N].

Flexible pavement designs

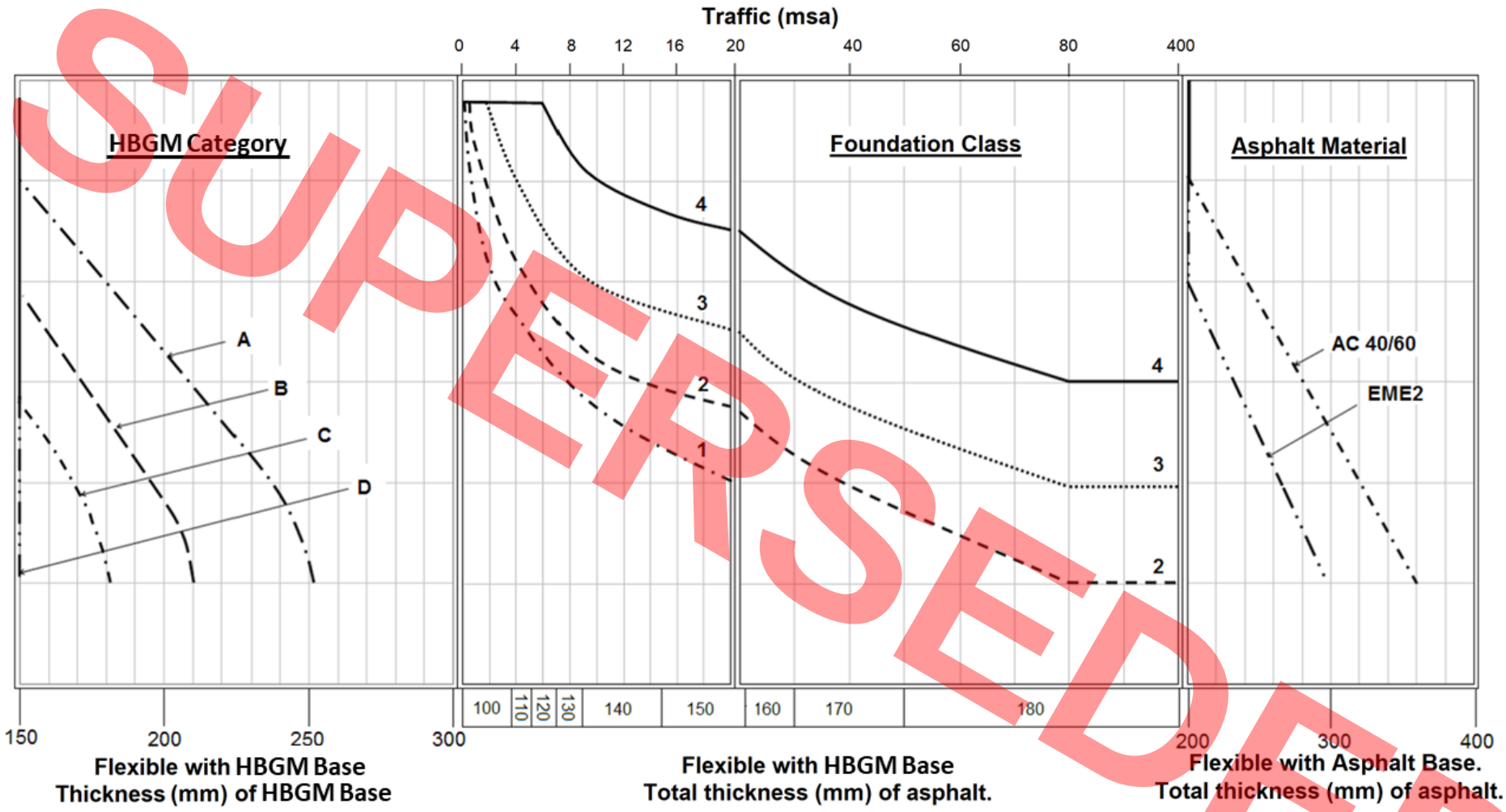
2.20 The design thickness of the layers for flexible pavements shall be determined using the nomograph in Figure 2.20.

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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 HBGM base, the left hand side of the nomograph is used to determine HBGM 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, that is 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 HBGM base, the minimum design thickness of HBM shall be 150 mm.

NOTE 1 *HBGM materials are defined in MCHW Series 0800 [Ref 7.N].*

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

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Table 2.23N2 Examples of HBGM materials

HBGM 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 CBGM 1 C8/10 (or T3) Clause 835 SBGM 1 C8/10 (or T3) Clause 830 FABGM 1 C8/10 (or T3)	Clause 822 CBGM 1 C12 /16 (or T4)Clause 835 SBGM 1 C12/16 (or T4)Clause 830 FABGM 1 C 12/16 (or T4)	Clause 822 CBGM 1 C15 /20 (T5)Clause 835 SBGM 1 C15/20 (or T5)Clause 830 FABGM 1 C 15/20 (or T5)
Gravel coarse aggregate: (using aggregate with a coefficient of thermal expansion ≥10×10 $^{-6}$ per ^{o}C)	Clause 822 CBGM 1 C8/10 (or T3)Clause 835 SBGM 1 C8/10 (or T3)Clause 830 FABGM 1 C8/10 (or T3)	Clause 822 CBGM 1 C12/16 (or T4) Clause 835 SBGM 1 C12/16 (or T4) Clause 830 FABGM 1 C12/16 (or T 4)	Clause 822 CBGM 1 C15 /20 (T5)Clause 835 SBGM 1 C15/20 (or T5)Clause 830 FABGM 1 C 15/20 (or T5)	-

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2.24 For flexible pavements with an HBGM 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 For HBGM with 28-day compressive strength class C8/10 or higher individual construction widths of HBGM base shall not exceed 4.75 m unless crack induction is provided.

Rigid construction with continuous reinforcement (CRCP and CRCB)

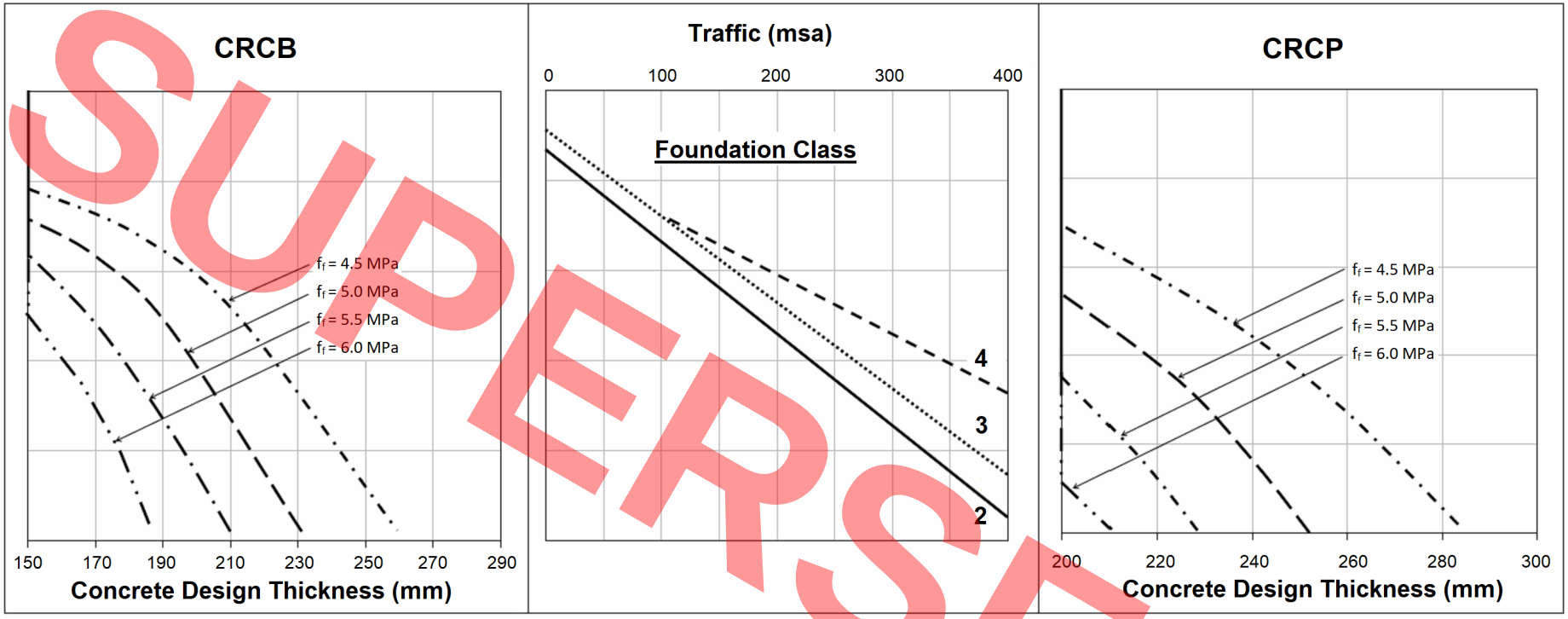
2.26 The design thickness of the concrete layers for continuously reinforced rigid pavements shall be determined using the nomograph in Figure 2.26.

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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; that is ithey 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 11.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 of MCHW Series 0900 [Ref 8.N] with the designations: AC 20 dense bin 40/60 des AC 32 dense bin 40/60 des AC 20 HDM bin 40/60 des AC 32 HDM bin 40/60 des
EME2	EME2 binder course asphalt concrete designed in accordance with Clause 930 of MCHW Series 0900 [Ref 8.N] and targeting a penetration value of 10/20 or 15/25
HRA	HRA binder course designed in accordance with Clause 943 of MCHW Series 0900 [Ref 8.N]
SMA	SMA binder course specified in accordance with Clause 937 of MCHW Series 0900 [Ref 8.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 16 mm-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 x10^{-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 MCHW HCD Series C [Ref 4.I].*

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
Stress ratio	is the 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 5.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 of MCHW Series 0900 [Ref 8.N] and targeting a penetration value of 10/20 or 15/25
HRA	HRA binder course designed in accordance with Clause 943 of MCHW Series 0900 [Ref 8.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)

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

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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: E = 200 MPa for foundation class 3 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 RR 87 [Ref 6.I].*

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: E = 200 MPa for foundation class 3 E = 400 MPa for foundation class 4
R	is the percentage of longitudinal steel reinforcement: 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

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 RR 87 [Ref 6.I].*

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 x 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 5.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 clause 3.9.1 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 1.I].*

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 5.5×10^{-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 13.N].

4.6 The minimum design traffic for new roads shall be 1 msa, as calculated in accordance with CD 224 [Ref 13.N].

4.7 The surface course shall be designed in accordance with CD 236 [Ref 10.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 13.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, HBGM or concrete material.*

NOTE 2 *Principles for alternative flexible pavement designs are set out in TRL 615 [Ref 2.I].*

NOTE 3 *Principles for alternative rigid pavement designs are set out in TRL RR 87 [Ref 6.I] (for jointed concrete pavements) or TRL 630 [Ref 9.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 12.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 (such as resistance of the materials to the deleterious effects of water, air and other environmental factors);

2) serviceability (such as skidding resistance and permanent deformation);

3) maintainability (such as 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 (HBGM).

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 TRL 630 [Ref 9.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 TRL 630 [Ref 9.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 10.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 a hydraulic binder, the design shall specify the permitted minimum and maximum strengths of the recycled material.

5.5 Where an HBGM 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 MCHW Series 0800 [Ref 7.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, 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 MCHW Series 0900 [Ref 8.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 MCHW Series 0900 [Ref 8.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 (such as PFA/lime and GBS/lime) excluding bituminous and Portland cement.
Quick viscoelastic	Bituminous binder as the main component but also including Portland cement.
Slow viscoelastic	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 MCHW Series 0900 [Ref 8.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	Transport Research Laboratory. 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. CD 239, 'Footway and cycleway pavement design'
Ref 6.N	National Highways. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 7.N	Highways England. MCHW Series 0800, 'Manual of Contract Documents For Highway Works. Volume 1 Specification for Highway Works. Series 800 Road Pavements — Unbound, Cement and Other Hydraulically Bound Mixtures'
Ref 8.N	Highways England. MCHW Series 0900, 'Manual of Contract Documents for Highway Works. Volume 1 Specification for Highway Works. Series 900 Road Pavements – Bituminous Bound Materials.'
Ref 9.N	TRL. Hassan, KE et al. TRL 630, 'New continuously reinforced concrete pavement designs'
Ref 10.N	Highways England. CD 236, 'Surface course materials for construction'
Ref 11.N	BSI. BS EN 12390-5, 'Testing hardened concrete. Flexural strength of test specimens'
Ref 12.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 13.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	Highways England. CG 501, 'Design of highway drainage systems'
Ref 2.I	TRL. Nunn, M. TRL 615, 'Development of a more versatile approach to flexible and flexible-composite pavement design'
Ref 3.I	BSI. BS 9227, 'Hydraulically bound materials for civil engineering purposes. Specification for production and installation in pavements'
Ref 4.I	Highways England. MCHW HCD Series C, 'MCHW Volume 3: HCD Section 1 Series C - Concrete Carriageway'
Ref 5.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'
Ref 6.I	Transport Research Laboratory. Mayhew, HC & Harding, HM. TRL RR 87, 'Thickness design of concrete roads'

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Appendix A. Worked examples

A1 Standard flexible pavement design using Figure 2.20

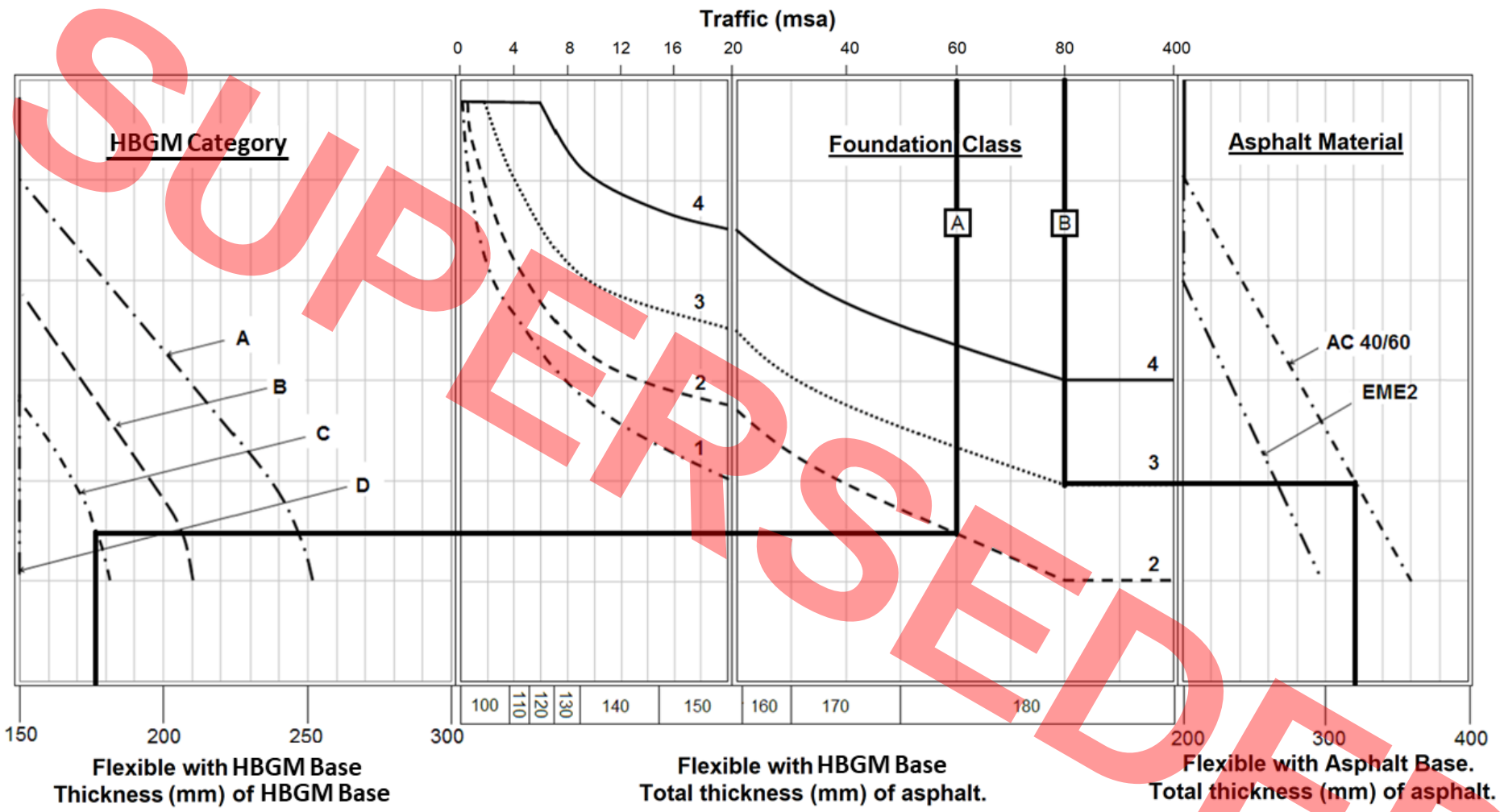
Figure A.1 reproduces Figure 2.20, annotated to show two examples for the design of flexible pavements.

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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 HBGM base

Design factors:

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

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

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

180 mm HBGM Category C (rounded up to the nearest 5 mm).

Note: Table 2.23N2 gives HBGM Category C options e.g.a Clause 822 CBGM 1 with laboratory performance category C12/16 (or T4). Laboratory performance categories are detailed in MCHW Series 0800 [Ref 7.N].

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

Design factors:

1) design traffic >80 msa (that is, '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 (surface course, AC 40/60 binder course and AC 40/60 base).

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

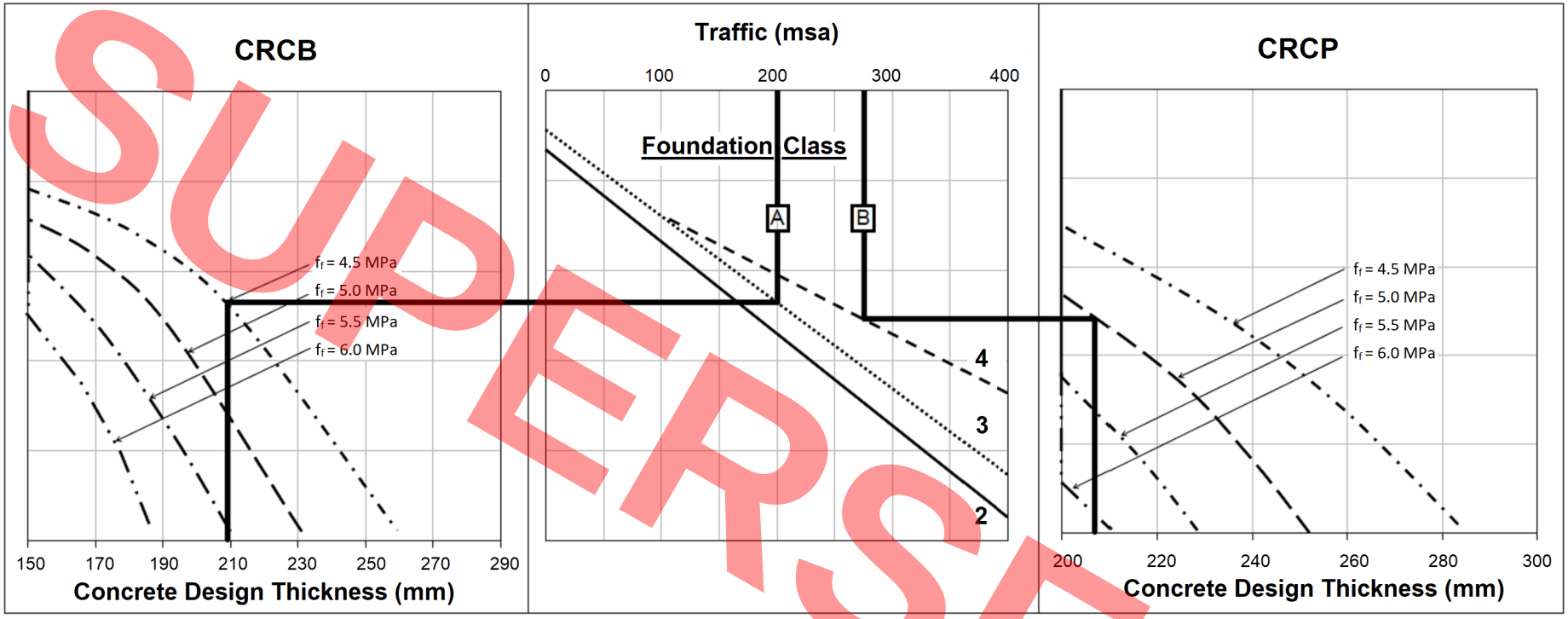
Figure A.2 reproduces Figure 2.26, annotated to show two examples for the design of rigid pavements.

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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 1-m 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.2):

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.2, 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 0.6%. 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

$$\frac{100 \cdot \pi \cdot 16^2}{4 \cdot 240 \cdot 0.6} = 140mm$$

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)	∞	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)

Version 1.0.0

Summary
This National Application Annex gives the National Highways-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 National Highways team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

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Latest release notes

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 226	**1**.0.0	November 2021	England NAA	Change to policy, major revision, new document development

New sections on whole life cost method, traffic delay costs plus corresponding appendices added. Terms, definitions and abbreviations updated.

Previous versions

Document code	Version number	Date of publication of relevant change	Changes made to	Type of change
CD 226	0	March 2020		

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Foreword

Publishing information

This document is published by National Highways.

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 National Highways-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 5.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 5.N].

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Abbreviations

Abbreviation	Definition
AADF	Annual average daily flow (1-way traffic)
AADT	Annual average daily traffic (2-way traffic)
CRDc	Capacity-related delay in closure conditions
CRDn	Capacity -elated delay in normal conditions
DC	Direct costs
DF	Discount factor
DTc	Drive time in closure conditions
DTn	Drive time in normal conditions
EF	Economic factor
EV	Equivalent value
HBGM	Hydraulically bound granular mixtures
HGV	Heavy goods vehicle
IC	Indirect costs
NPSV	Net present service value
PCF	Project control framework
RV	Residual value
TSCS	Thin surface course system
TTM	Temporary traffic management
TVD	Total vehicle delay
VC	Vehicle cost (per hour)
VCS	Visual condition survey
WLC	Whole life cost

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Terms and definitions

Term	Definition
Analysis period	period over which the life-cycle cost appraisal is to be undertaken. Normally 60 years
Pavement design option	pavement design selected for inclusion in the analysis
Direct costs	this is the direct cost of undertaking planned maintenance activities on site
Discounting	discounting is a technique used to compare costs (and benefits) that occur at different times throughout the analysis period. It works by adjusting these future costs (and benefits) to their present-day values. This enables competing pavement design options to be compared on a common basis
Discount rate	the rate at which future costs are discounted to the present value year. This is set by Government and can be found in the Green Book produced by HM Treasury at the time of writing. (See Green Book [Ref 10.N])
Discounted residual value	present-day value of the asset at the end of the analysis period
Discounted direct costs	present-day cost of all future maintenance activities. It provides a basis for comparing alternative pavement design options by indication of the level of investment that will be required to meet future expenditure
Hard strip	a surfaced strip that abuts the carriageway to provide additional paved width, often in the absence of a hard shoulder
Indirect costs	these costs are not borne by National Highways. These are costs incurred by road users, the public and industry during the asset's lifetime
Life-cycle plan	a plan for managing a pavement comprising a schedule of all construction, routine maintenance, inspection, and maintenance activities together with associated costs on a pavement over the analysis period. After a number of alternatives have been appraised in accordance with this document the life-cycle management plan is the outcome for the preferred option
Maintenance activity	individual maintenance activity undertaken to a pavement in a particular year, which may include works, inspection or monitoring
Narrow width widening	where additional carriageway of less than a full lane width is constructed to abut the existing carriageway
Net present service value	the whole life cost of maintaining the asset throughout the analysis period. It is the sum of the discounted costs minus the discounted residual value
Preliminaries	pavements share of preliminaries costs for the construction contract including site establishment and accommodation
Residual value	the value associated with the pavement asset condition at the end of the analysis period

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(continued)

Scheme or project	a plan or arrangement that includes the construction of a new pavement asset or undertaking of activities to upgrade or replace elements of the existing pavement asset
Serviceable life	the remaining life in the pavement design option at the end of the analysis period
Unit cost	this is the cost per unit measure (number/length/area/volume) to maintain the pavement asset or part of the asset
Whole life cost	summation of all the costs incurred in the construction and maintenance of an asset over the evaluation period
Works duration	time in days that a particular inspection, maintenance, or construction activity could take

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E/1. Pavement design verification

Pavement design report (CD 226, 6.1)

E/1.1 A pavement design report shall be produced for all designs developed under National Highway's PCF.

NOTE 1 *The report can be used by National Highways 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 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 appended.

NOTE 1 *It is not anticipated that draft contract specific appendices will be submitted with a pavement design report until the final design option has been selected (PCF stage 5).*

NOTE 2 *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 identified as options;
3) technical justification for why particular designs were rejected as options (where appropriate);
4) interpretation 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) including any assumptions made;
7) details of the design thicknesses and materials proposed for each design option identified;
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 DMRB GG 103 [Ref 4.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 2.N] were rejected as options (if appropriate);
4) interpretation 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 proposed) including any assumptions made;

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7) for each design option proposed:
   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, for examples 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 DMRB GG 103 [Ref 4.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	
PCF Stage:	
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: 1) constitute an adequate and economic design for the project; 2) the work intended is accurately represented and conforms to National Highways' requirements; 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, 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. National Highways Pavement Engineering Adviser****	
This Certificate (and the submission accompanying the certificate) is: (a) received*: (b) received with comments as follows*: (c) returned marked with comments as follows*:	
Signed:	National Highways Pavement Engineering Adviser
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 any departures from relevant standards. If none write "none".*

NOTE 4 ***** Section E to be completed by National Highways pavement engineering adviser including comments on the submission and any amendments or revisions expected before resubmission.*

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 National Highways.*

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E/2. Whole life cost (WLC) (additional to CD 226)

Pre-WLC screening criteria

E/2.1 When constructing a new carriageway, widening an existing carriageway, upgrading an existing pavement or reconstructing an existing pavement on England's motorway and all-purpose trunk road network, designs shall be carried out using a minimum of three options covering the range of pavement types from the "standard designs" described in CD 226 [Ref 2.N].

E/2.2 The design options shall include flexible with an asphalt base, flexible with an hydraulically bound granular mixture (HBGM) base and at least one type of rigid pavement.

E/2.2.1 Technical justification should be provided if a particular pavement type is to be excluded from the analysis.

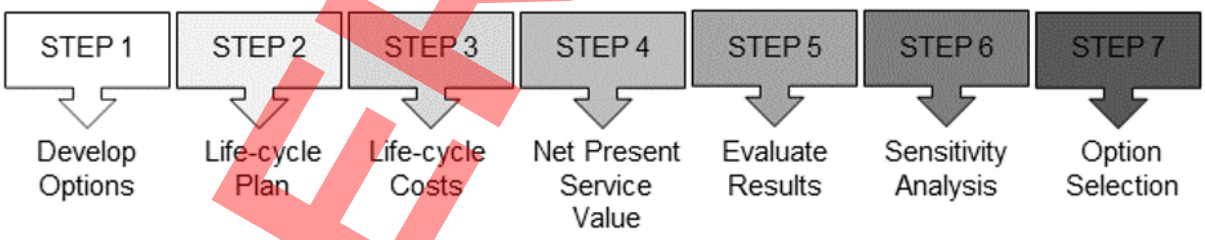
NOTE 1 *Where there is only one clear design option for pavement improvement works (for example, hard strip widening) a WLC analysis is not necessary. Where design options are available for narrow widening a WLC analysis is necessary (for example to compare the use of wet lean concrete with a tied-in design).*

NOTE 2 *Whole life costing is only one factor when selecting a preferred design option. Other factors such as engineering judgement, network operations, affordability, compatibility, buildability, sustainability, environment and risk management also require identification and assessment for the design throughout the analysis period.*

WLC procedure

E/2.3 The preferred pavement design option shall be determined by an appraisal following the steps outlined in Figure E/2.3.

Figure E/2.3 WLC Procedure



Step 1 - Develop options

E/2.4 The pavement design options that have passed the prescreening criteria shall be analysed.

E/2.5 Each design shall be clearly described and highlighted as part of the design report.

E/2.6 Valid pavement design options shall explore a range of pavement types and materials meeting the requirements of CD 226 [Ref 2.N] and MCHW Series 0800 [Ref 7.N], MCHW Series 0900 [Ref 8.N] or MCHW Series 1000 [Ref 6.N] where appropriate.

Step 2 – Life-cycle plan

E/2.7 For each of the options identified in Step 1, a maintenance life-cycle plan shall be produced.

E/2.8 The analysis period shall be for a period of no less than 60 years in accordance with WebTAG Unit A1-1 [Ref 1.N].

E/2.9 The same analysis period shall be used for all design options.

E/2.10 Maintenance activities that shall be included in the life-cycle plan are those expected to be required during the life of the pavement asset, including:

1) routine maintenance (such as sealing or filling of cracks, local pothole repairs);

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2) periodic maintenance (such as renewal of road markings and road studs);
3) renewal (such as replacement of surface, binder or base layers); and,
4) reconstruction (that is to design and construct an entire new pavement).

E/2.11 Costs of procuring technical surveys and investigations in accordance with CD 227 [Ref 3.N] shall also be included in the life-cycle plan.

E/2.11.1 The timing, costs and work duration of each of the activities for each of the pavement design options should be estimated.

E/2.11.2 Justifications should be given for the values chosen to show why they are appropriate for that scheme.

E/2.11.3 When modelling future maintenance interventions, historical maintenance records and experience with similar materials performance should be used to inform potential maintenance activities to be included in the life-cycle plan.

E/2.11.4 Any scheme specific requirements that impact on future maintenance activities should be recorded, that is if special temporary traffic management (TTM) arrangements are needed.

NOTE *Future maintenance interventions vary depending upon the type of pavement, materials used, construction details, time of year and the quality of construction.*

E/2.12 A life-cycle plan showing future maintenance activities, timings and preliminaries shall be produced for each pavement design option using the template in Appendix Table E/B.2.

NOTE 1 *The monetary values used for examples in the appendices are not based on true unit costs.*

NOTE 2 *Although other (non-pavement) works need not be explicitly included in the analysis, it is expected that the works associated with the timing of current work and future maintenance activities are taken into account when developing the life-cycle plan for each design option.*

E/2.13 The life-cycle plan for the recommended pavement design option shall be included in the pavement design report.

NOTE *It is important that accurate usable survey/condition data is obtained prior to developing pavement design options and undertaking the whole life cost analysis. Changes to the pavement design, details or materials required to overcome difficulties encountered on site can have a significant impact on the whole life cost of the pavement.*

Step 3 – Life-cycle costs

E/2.14 Direct costs (DC), that is works costs, shall be estimated using current unit cost data relevant to the location/situation of the road.

E/2.15 Indirect costs (IC) such as user delay costs and temporary traffic management costs for all of the activities identified in Step 2 shall be estimated.

NOTE *How to calculate user delay and temporary traffic management costs is set out in subsequent sections.*

E/2.16 The construction and life-cycle costs of the pavement design options shall be compared to determine the most cost-effective solution.

E/2.17 All data and assumptions (for all pavement design options) shall be shown.

Discounting

E/2.18 All costs and benefits over the analysis period for each pavement design option shall be calculated using Equation E/2.22 using the discount factors (DF) applied in accordance with the Green Book [Ref 10.N].

E/2.19 The discounting of all future costs and the discount rates that shall be applied are contained in the Green Book [Ref 10.N].

E/2.20 Discounting costs when a single discount rate applies (years 1 to 30 at time of writing) shall be calculated using Equation E/2.20.

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Equation E/2.20 Calculation of discount factor when a single discount rate applies

$$DF = \frac{1}{\left(1 + \frac{r}{100}\right)^n}$$

where:

n	is the year discount factor is to be applied
r	is the discount rate (in percent)

E/2.21 Discounting costs when two discount rates apply in the analysis year shall be calculated using Equation E/2.21.

Equation E/2.21 Calculation of discount factor when two discount rates apply in the anlaysis year

$$DF = \frac{1}{\left(1 + \frac{r}{100}\right)^n} \times \frac{1}{\left(1 + \frac{r}{100}\right)^n}$$

NOTE *Example: Year 45 of the analysis period; years 1 to 30 have a discount rate of 3.50% and years 31 – 60 have a discount rate of 3.00%*

Equation E/2.21N Example equation where two discount rates apply in the analysis year

$$DF = \frac{1}{\left(1 + \frac{3.50}{100}\right)^{30}} \times \frac{1}{\left(1 + \frac{3.00}{100}\right)^{15}} = 0.2287$$

E/2.22 Discounted direct and indirect costs shall be calculated using Equation E/2.22

Equation E/2.22 Calculation of discounted costs (direct and indirect)

$$\text{discounted cost} = \text{cost}(DC \quad \text{or} \quad IC) \times DF$$

where:

cost	is the sum of the costs incurred during the analysis year
DC	is direct cost
IC	is indirect cost
DF	is the discount factor

E/2.22.1 It should be made clear in the analysis if the costs at the start of the analysis period (in the base year) are n = 1 or n = 0. If the base year costs are not discounted, then n = 0 in that year and n = 1 is the first year of trafficking.

Step 4 – Net present service value (NPSV)

E/2.23 The NPSV of each pavement design option shall be determined by using Equation E/2.23.

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Equation E/2.23 Calculation of NPSV

$$\sum NPSV = \sum DC_{\text{discounted}} + \sum IC_{\text{discounted}} - RV_{\text{discounted}}$$

where:

$DC_{\text{discounted}}$	is the discounted direct costs incurred over the analysis period
$IC_{\text{discounted}}$	is the discounted indirect costs over the analysis period
$RV_{\text{discounted}}$	is the discounted residual value at the end of the analysis period

NOTE *Whereas the direct costs (DC) and indirect costs (IC) included in the whole life costing process are expenditures, residual value is instead regarded as a benefit (or income) when calculating the NPSV.*

E/2.24 To allow comparison between different pavement design options calculated within the analysis period and for the purposes of this document the residual value (RV) in £ shall be determined using Equation E/2.24.

Equation E/2.24 Calculation for residual value

$$RV = \frac{D_1}{D} \times \text{cost}$$

where:

cost	is the cost of most recent pavement maintenance activity (in £)
D	is the design life (in years)
D_1	is the remaining service life at the end of the analysis period (in years)

NOTE 1 *This allows for an equal comparison between a scheme that leaves no serviceable life in the pavement to a scheme that intervenes just before the end of the analysis period leaving the pavement in good serviceable condition.*

NOTE 2 *Pavements designed to provide a service life of 40 years are deemed to be long-life pavements, and each maintenance activity prescribed throughout the life-cycle plan needs to assess what treatment is required in order to restore the design life to its original value.*

NOTE 3 *It is acknowledged that different running lanes will often have differing remaining service lives at the end of the analysis period, due to the variation of traffic type and maintenance activities. It is acceptable to base the residual life for the purpose of this analysis on lane 1 only.*

E/2.25 The residual value of each pavement design option shall be calculated and the discount factor at the end of the analysis period applied using Equation E/2.25.

Equation E/2.25 Calculation of discounted residual value

$$RV_{\text{discounted}} = RV \times DF$$

Step 5 – Evaluate results

E/2.26 The pavement design option with the lowest WLC based on NPSV shall be regarded as the most economically beneficial pavement option.

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Step 6 – Sensitivity analyses

E/2.27 The following input parameters can be subject to uncertainty and shall be included in the sensitivity analyses;

1) unit rates; and,
2) required timings and temporary traffic management (TTM) costs of predicted activities.

E/2.28 These input parameters shall be varied across all pavement design options developed as part of the design report in Step 1.

E/2.29 The life expectancy of equivalent pavement surfaces shall be consistent for all pavement design options, showing all data and assumptions.

E/2.30 When undertaking this process only one input parameter should be varied at a time. The outcomes shall reveal:

1) whether the selection of a preferred pavement design option (based on lowest NPSV) is affected; and,
2) the likely variability in the resulting whole life cost of the preferred design option.

E/2.31 Variability represents a risk that needs to be managed. The effect of variability shall be assessed when selecting the preferred pavement design option with conclusions presented in the design report.

E/2.32 All assumptions made, and input parameter variations undertaken shall be documented and included in the pavement design report for the selected pavement design option.

Step 7 – Option selection

E/2.33 Step 5 shall be revisited when the outcome of any sensitivity analyses become available.

E/2.34 The data used in each pavement design option shall be presented using the example whole life cost summary sheet in Appendix Table E.B/1 to be included as part of the results of the analyses.

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E/3. Traffic delay costs

E/3.1 An assessment of traffic delay costs shall be undertaken throughout the analysis period for the pavement asset for the following:

1) the initial construction of the pavement; and,

2) the subsequent maintenance and renewal activities.

E/3.2 The TTM required for the initial construction or improvement activity shall be well defined.

NOTE *For subsequent life-cycle activities the temporary traffic management requirements and their duration can be less clear. Due to this lack of precision a sophisticated traffic delay analysis is not warranted in most cases.*

E/3.3 For future TTM arrangements, current practice shall be assumed for each intervention unless there is good reason for knowing methods and costs are likely to change and what they will change to.

E/3.4 The assessment of traffic delay costs shall be undertaken using a methodology that includes each of the following:

1) characteristics of the roads affected, that is the number of lanes, road type;

2) predicted traffic flows;

3) characteristics of the lane closures; and,

4) potential diversion routes.

E/3.4.1 Lane closures should represent the length closed, which can be longer than the length maintained, or shorter if the work is carried out in shorter part-lengths of the intervention, due to site geometry etc.

NOTE *The expected way of working also affects the costs (for examples, day/night/weekend working, lane closures/contraflow etc).*

E/3.5 The carriageways that are to be affected by the life-cycle activities shall be identified from the location and extent of the activity to be undertaken.

E/3.6 The annual average daily flow (AADF) or annual average daily traffic (AADT) traffic figures along with the year of the traffic data shall be given for the length of route that can be affected by the activities.

E/3.7 Traffic flows shall be determined from available sources.

NOTE *The primary source of AADT is http://webtris.highwaysengland.co.uk (WebTRIS [Ref 1.I])*

E/3.8 AADT shall be converted into AADF assuming a 50:50 directional split, unless traffic counts or studies show a directional bias.

E/3.9 The impact of the life-cycle activities on the affected carriageways shall be assessed to determine:

1) the number of lanes available at pinch points which have the greatest potential to cause delay to traffic;
2) the length over which the restrictions apply;
3) any temporary speed limits;
4) length of diversion routes and probable speed of travel (if diversions applicable);
5) time of day (that is day or night closures); and,
6) day of the week.

NOTE *An example of an acceptable approach to calculating traffic delay costs is given in Appendix E/A. Where life-cycle activities for a pavement form part of a larger project for which a detailed analysis is required then the more detailed analysis can be used to determine the traffic delay costs.*

Total vehicle delay (TVD) through roadworks

E/3.10 Calculations for TVD shall be calculated using Equation E/3.10a.

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Equation E/3.10a Calculating TVD

$$TVD = \left(\frac{(DTc + CRDc) - (DTn + CRDn)}{60} \right) \times EV \times EF$$

where:

TVD	is the total vehicle delay in hours
DT_c	is the expected drive time (in minutes) in lane closure conditions over the length of the restriction at the restricted speed limit (in km/h) using Equation E/3.10b
DT_n	is the expected drive time (in minutes) in normal conditions over the length of the proposed restriction at the normal speed limit (in km/h) using Equation E/3.10c
CRD_c	is the capacity related delay time in lane closure conditions (in minutes) using Equation E/3.10e
CRD_n	is the capacity related delay time in normal conditions (in minutes) using Equation E/3.10f
EV	is the expected equivalent hourly volume of traffic for each closure period using Equation E/3.10d
EF	is an economic factor to be applied to the cost to take account of the extent of planning and forewarning that has been provided prior to imposition of the lane closure(s) EF = 0.3 for planned works with advanced notice to users EF = 1.0 for unplanned works, e.g. required to rectify defects

Equation E/3.10b Calulation of expected drive time in lane closure conditions

$$DTc = \frac{L \times 60}{SL_R}$$

where:

L	is length of closure (including tapers), in metres
SL_R	is the restricted speed limit (in km/h)

Equation E/3.10c Calculation of the expected drive time in normal conditions

$$DTn = \frac{L \times 60}{SL_N}$$

where:

L	is the length, in kilometres
SL_N	is the speed limit for the road/motorway, in km/h

Equation E/3.10d Calculation of the expected equivalent hourly volume of traffic for each closure period

$$EV = \text{AADF} \times T_f$$

where:

AADF	is the annual average daily flow
T_f	is the traffic factor from Table E/3.10

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Table E/3.10 Traffic factors for closure periods

Day	Time	Traffic factor
Mon-Fri	Night-time 22:00-06:00	0.011
Sat-Sun		0.010
Mon-Fri	Day-time 06:00-22:00	0.062
Sat-Sun		0.048

Equation E/3.10e Calculation of capacity-related delay time in lane closure conditions

$$CRD_C = \left[\left(\frac{\text{EV}}{1925 \times n_c}\right) \div 0.94\right]^{7.5}$$

where:

n_c is the number of running lanes available to traffic during the lane closure(s)

EV is the expected equivalent hourly volume of traffic for each period

Equation E/3.10f Calculation of capacity-related delay time in lane normal conditions

$$CRD_N = \left[\left(\frac{\text{EV}}{1925 \times n}\right) \div 0.94\right]^{7.5}$$

where:

n is the number of running lanes in normal conditions

EV is the expected equivalent hourly volume of traffic for each period

E/3.10.1 The values of the factors used in the equations should be shown in the design report with the life-cycle analysis results.

Monetary cost

E/3.11 If the traffic data for the site does not show the proportion of cars to heavy goods vehicles (HGVs), a ratio of 85:15 shall be used.

E/3.12 To give a monetary cost to the delay, the weekly average vehicle operating cost (per hour) for cars and HGVs shall be in accordance with the TAG Data Book [Ref 9.N] Table A 1.3.6.

NOTE *The cost of user delays can be established from the online data provided in the TAG Data Book [Ref 9.N] .*

E/3.13 The vehicle cost (VC) per hour calculated using Equation E/3.13 shall be shown in the pavement design report with the life-cycle analysis results.

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Equation E/3.13 Calculation of vehicle cost per hour

$$VC = \left(\frac{P_{\text{HGV}}}{100} \times C_{\text{HGV}}\right) + \left(\frac{P_{\text{cars}}}{100} \times C_{\text{cars}}\right)$$

where:

P_{HGV}	is the proportion of HGVs
P_{cars}	is the proportion of cars
C_{HGV}	is the weekly average operating cost (£)
C_{cars}	is the weekly average operating cost (£)

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E/4. 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	Department for Transport (UK). WebTAG Unit A1-1, 'Cost-Benefit Analysis'
Ref 2.N	National Highways. CD 226, 'Design for new pavement construction'
Ref 3.N	Highways England. CD 227, 'Design for pavement maintenance'
Ref 4.N	Highways England. GG 103, 'Introduction and general requirements for sustainable development and design'
Ref 5.N	National Highways. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 6.N	Highways England. MCHW Series 1000, 'Manual of Contract Documents for Highway Works. Volume 1 - Specification for Highway Works. Series 1000 Road Pavements – Concrete Materials'
Ref 7.N	Highways England. MCHW Series 0800, 'Manual of Contract Documents For Highway Works. Volume 1 Specification for Highway Works. Series 800 Road Pavements — Unbound, Cement and Other Hydraulically Bound Mixtures'
Ref 8.N	Highways England. MCHW Series 0900, 'Manual of Contract Documents for Highway Works. Volume 1 Specification for Highway Works. Series 900 Road Pavements – Bituminous Bound Materials.'
Ref 9.N	Department for Transport . TASM Division. TAG Data Book, 'TAG Data Book'
Ref 10.N	HM Treasury. Green Book, 'The Green Book: Central Government guidance on appraisal and evaluation'

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E/5. Informative references

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

Ref 1.I	Highways England. WebTRIS, 'http://www.webtris.highwaysengland.co.uk/'

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Appendix E/A. Guidance on traffic delay cost

In the absence of a more detailed method the following has been devised as a quick, though unrefined, method of calculating traffic delay costs due to restrictions imposed on the network. This method has been developed for use in pavement design option WLC analyses described in this document for the life-cycle plan and is not intended for other applications.

Formulae are given on the following pages to allow a quick assessment of cost. Different factors apply if the lane closures are to be imposed on a weekday, weekday night, weekend day or weekend night. The approximate length of the restriction is estimated and the AADF derived for the carriageway where the works are to be located.

E/A1 Worked example

Scheme with AADF of 80,000 vehicles along a 3-lane motorway with a national speed limit of 113 km/h (70 mph). Reduced to two lanes at a restricted speed limit of 80 km/h (50mph) for 10 weekday shifts during the hours of 06:00 until 22:00. Length of restriction is 3 km (including tapers). Vehicle cost per hour = £12.56. Activity is planned works with advanced notice to road users.

Equation E/A.1 Calculation of the expected drive time in normal conditions

$$Dtn = \frac{3 \times 60}{113} = 1.59$$

Equation E/A.2 Calculation of the expected drive time in closure conditions

$$Dtc = \frac{3 \times 60}{80} = 2.25$$

Equation E/A.3 Calculation of the expected equivalent hourly volume of traffic (week day shifts)

$$EV = 80,000 \times 0.062 = 4960$$

Equation E/A.4 Calculation of capacity related delay time in lane normal conditions

$$CRD_N = \left[\left(\frac{4960}{1925 \times 3}\right) \div 0.94\right]^{7.5} = 0.51$$

Equation E/A.5 Calculation of capacity related delay time in closure conditions

$$CRD_C = \left[\left(\frac{4960}{1925 \times 2}\right) \div 0.94\right]^{7.5} = 10.63$$

Equation E/A.6 Economic factor for planned works with advanced notice to users

$$EF = 0.3$$

Equation E/A.7 Total vehicle delay

$$TVD = \frac{(2.25 + 10.63) - (1.59 + 0.51)}{60} \times 4960 \times 0.3 = 267hrs$$

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Equation E/A.8 Cost per vehicle per hour over 267 hours

$$£12.56 \times 267 = £3,354$$

Total delay cost (per shift of 16 hours) for restriction over 10 shifts:

Equation E/A.9 Cost of delay for duration of closure

$$16 \times 10 \times 3,800 = £536,600$$

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Appendix E/B. WLC analysis example

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Table E/B.1 Whole life cost analysis summary sheet

Whole Life Cost Analysis Summary	
Scheme Name	PCF 0123
Scheme Location	M123 Junction A to B
Description of Works	NB + SB HS - New construction NB + SB Lane 1 - New construction NB + SB Lane 2 - Inlay NB + SB Lane 3 - Inlay
Scheme Length	8 km NB, 8 km SB
Pavement Design Option 1 **Flexible pavement with an HBGM base** **Design Life: 40 years**	690 mm New Construction - 80 msa, Class 3 foundation, HBGM B + AC 40/60 310 mm Class 3 Foundation 200 mm HBGM B (CBGM 1 C8/10) 180 mm Flexible surfacing using AC 40/60
Pavement Design Option 2 **Flexible pavement with an asphalt base** **Design Life: 40 years**	575 mm New Construction - 80 msa, Class 3 foundation, EME2 310 mm Class 3 foundation 265 mm EME2
Pavement Design Option 3 **Rigid pavement** **Design Life: 40 years**	590 mm New Construction - 80 msa, Class 3 foundation, RCC, EME binder, TSCS 310 mm Class 3 foundation 190 mm RCC 60 mm AC 10 EME2 base/bin 30 mm thin surface course system (TSCS)
Associated carriageway works	24 (No.) Traffic loop counters Renew road markings + studs every 8 years
Traffic delay costs	£30,400 per shift/closure Based on: Vehicle cost per hour = £12.56 80,000 AADF 3 km of TTM 3 lanes, 113 km/h in normal conditions 2 lanes, 80 km/h in closure conditions Traffic flow profile: 0.062 (week day shifts) 16 hour shift (06:00 - 22:00) EF = 0.3 for planned works with advanced notice to users 3 phases of TTM required to cover 8 km

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Table E/B.1 Whole life cost analysis summary sheet (continued)

Discounted Costs option 1	£190,805,000
Discounted Costs option 2	£222,009,000
Discounted Costs option 3	£155,240,000
Residual Value option 1	£29,600,000
Residual Value option 2	£29,600,000
Residual Value option 3	£13,200,000
NPSV Option 1	£186,460,000
NPSV Option 2	£217,664,000
NPSV Option 3	£153,302,000
Sensitivity tests	Expected service life of surfacing: 10 and 12 years (HS, L1) 14 and 16 years (L2, L3)
Promoted Option	Pavement design option 3

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Table E/B.2 Life-cycle plan

Pavement Design Option 3		590mm New Construction - 80msa, Class 3 foundation, RCC, EME binder, TSCS						
Year	Life-cycle Plan	Extent of work (units)	Works Duration (days)	Direct costs		Indirect Cost (£)	Discounted direct cost (£)	Discounted indirect cost (£)
				Works Cost (£)	Prelimi-nary			
0	New pavement construction HS, L1 (NB + SB)	8 km x 4	80	75,000,000	375,000	5,264,000	75,375,000	5,264,000
0	Inlay L2, L3 (NB + SB)	8 km x 4	18	10,000,000	50,000	1,184,400	10,050,000	1,184,000
0	Install traffic loops (12No. NB, 12No. SB)	24 (No.)	14	500,000	500	921,200	501,000	921,200
8	Renew road markings + Studs HS, L1, L 2, L3 (NB + SB)	8 km x 8	18	2,000,000	10,000	1,184,400	1,526,000	899,000
12	30-mm inlay HS, L1 (NB + SB), Resurfacing at loops (L2,L3 NB + SB)	8 km x 2 0.015 km x 24	20	10,500,000	52,500	1,316,000	6,983,000	871,000
12	Install traffic loops (12 No. NB, 12 No. SB)	24 (No.)	14	500,000	500	921,200	331,000	610,000
12	Renew road markings + Studs HS, L1 (NB + SB) and at loop locations L2, L3 (NB + SB)	8 km x 2 0.015 km x 24	16	2,100,000	10,500	1,052,800	1,397,000	697,000
16	30 mm inlay L2, L3 (NB + SB)	8 km x 4	18	10,000,000	50,000	1,184,400	5,796,000	683,000
16	Renew road markings + Studs L2, L3 (NB + SB)	8 km x 4	12	2,000,000	10,000	789,600	1,159,000	455,000
24	90 mm inlay HS, L1 HS, L1 (NB + SB) Resurfacing at loops L2,L3 (NB + SB)	8 lane km x 2 0.015 km x 24	24	25,000,000	125,000	1,159,200	11,004,000	692,000
24	Install traffic loops (12No. NB, 12No. SB)	24 (No.)	14	500,000	500	921,200	219,000	403,000
24	Renew road markings + Studs HS, L1 (NB + SB) and at loop locations L2, L3 (NB + SB)	8 km x 2 0.015 km x 24	16	2,100,000	10,500	1,052,800	924,000	461,000

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Table E/B.2 Life-cycle plan (continued)

32	100 mm inlay L2, L3 (NB + SB)	8 lane km x 4	20	30,000,000	150,000	1,316,000	10,125,000	442,000
32	Renew road markings + Studs HS, L1, L2, L3 (NB + SB)	8 km x 8	18	2,000,000	10,000	1,184,400	675,000	398,000
36	30 mm inlay HS, L1 (NB + SB), Resurfacing at loops (L2,L3 NB + SB)	8 km x 2 0.015 km x 24	20	10,600,000	53,000	1,316,000	3,179,000	393,000
36	Install traffic loops (12 No. NB, 12 No. SB)	24 (No.)	14	500,000	500	921,200	149,000	275,000
36	Renew road markings + Studs HS, L1 (NB + SB) and at loop locations L2, L3 (NB + SB)	8 km x 2 0.015 km x 24	16	2,100,000	10,500	1,052,800	630,000	314,000
40	Renew road markings + Studs L2, L3 (NB + SB)	8 km x 4	12	2,000,000	10,000	789,600	533,000	209,000
48	90 mm inlay HS, L1 HS, L1 (NB + SB) Resurfacing at loops L2,L3 (NB + SB)	8 lane km x 2 0.015 km x 24	24	25,000,000	125,000	1,579,200	5,258,000	330,000
48	Install traffic loops HS, L1, L2, L3 (NB + SB)	24 (No.)	14	500,000	500	921,200	105,000	193,000
48	Renew road markings + Studs HS, L1, L2, L3 (NB + SB)	8 km x 8	18	2,000,000	10,000	1,184,400	421,000	248,000
56	Renew road markings + Studs HS, L1, L2, L3 (NB + SB)	8 km x 8	18	2,000,000	10,000	1,184,400	332,000	196,000
60	30 mm inlay HS, L1 (NB + SB), Resurfacing at loops (L2,L3 NB + SB)	8 km x 2 0.015 km x 24	20	10,600,000	53,000	1,316,000	1,564,000	193,000
60	Renew road markings + Studs HS, L1 (NB + SB) and at loops location L2, L3 (NB + SB)	8 km x 2 0.015 km x 24	16	2,100,000	10,500	1,052,800	310,000	155,000
60	Install traffic loops (12 No. NB, 12 No. SB)	24 (No.)	14	500,000	500	921,200	73,000	135,000
Residual Life (yrs)		40						
Design Life (yrs)		40						
Residual Value (£)		13,200,000						

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Table E/B.2 Life-cycle plan (continued)

Discounted residual value (£)	1,938,000	
∑ Discounted direct costs (£)	138,619,000	
∑ Discounted indirect costs (£)	16,621,000	
NPSV (£)	153,302,000	

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NOTE: The monetary values used for this example are not based on true unit costs.

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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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Release notes

Version	Date	Details of amendments
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
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 Transport Scotland team. The email address for all enquiries and feedback is: TSStandardsBranch@transport.gov.scot

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Release notes **2**

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Release notes

Version	Date	Details of amendments
0	Mar 2020	Transport Scotland National Application Annex to CD 226.

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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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Release notes

Version	Date	Details of amendments
0	Mar 2020	Welsh Government National Application Annex to CD 226.

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