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Pavement & Foundation Design

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For all documents that existed within the NRA DMRB or the NRA MCDRW prior to the launch of TII Publications, the NRA document reference used previously is listed above under 'historical reference'. The TII Publication Number also shown above now supersedes this historical reference. All historical references within this document are deemed to be replaced by the TII Publication Number. For the equivalent TII Publication Number for all other historical references contained within this document, please refer to the TII Publications website.

**Volume 7: Pavement Design &
Maintenance**

Pavement & Foundation Design

Withdrawn

Summary:

This Standard gives the requirements for the design of road Pavements and Foundations.

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**VOLUME 7 Pavement Design and
Maintenance:**

**SECTION 2 Pavement Design and
Construction**

PART 2A

NRA HD 25-26/10

Pavement and Foundation Design

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1. INTRODUCTION

General

1.1 This Standard supersedes the October 2003 version of the NRA Addendum to TD 25/94 “Foundations” and the January 2005 version of the NRA Addendum to TD 26/01 “Pavement Design“. This Standard is written for use with the December 2010 Series 700, 800, 1000 and the January 2010 Series 900 of the NRA Specification for Road Works (MCDRW 1) which implements the latest EuroNorms.

Scope

1.2 This part details various combinations of materials and thicknesses that may be considered for pavement and foundation construction, whether for new build, widening of an existing carriageway, or full reconstruction. The design guidance is also useful when developing recommendations for partial reconstruction or strengthening overlays. It does not include the estimation of design traffic (see NRA Addendum to HD 24). Additional information on surfacing and pavement materials is given in NRA Addendum to HD 36 and NRA Addendum to HD 37.

1.3 Chapter 4, which addresses fully flexible construction consisting of asphaltic concrete over an unbound granular foundation, is based on UK HD 25/94 and HD 26/01. Chapter 5, which addresses flexible composite construction with options for both unbound granular foundations and hydraulically bound foundations, is based on the restricted designs of UK IAN 73/06 and HD 26/06. Chapters 6 and 7, which address rigid, rigid composite and Enrobé à Modulé Elevé (EME2) construction, all of which require hydraulically bound foundations, are based on the restricted designs of UK IAN 73/06 and HD 26/06.

Implementation

1.4 This Standard should be used forthwith for all schemes for the construction and/or improvement of national roads. It supersedes the current NRA addendums to HD 25/94 and HD 26/01. The Standard should be applied to the design of schemes already being prepared unless, in the opinion of the National Roads Authority, application would result in insignificant additional expense or delay progress. In such cases Design Organisations should confirm the application of this Standard to particular schemes with the National Roads Authority.

Mandatory Sections

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

Mutual Recognition

1.6 The construction and maintenance of road pavements will normally be carried out under contracts incorporating the NRA Specification for Road Works. In such cases products conforming to equivalent standards and specification of other Member States (MS) of the European Economic Area (EEA) or a State which is party to a relevant agreement with the European Union and tests undertaken in other MS of the EEA or a State which is party to a relevant agreement with the European Union will be acceptable in accordance with the terms of Clauses 104 and 105 of the NRA Specification for Road Works (MCDRW 1). Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect, regarding which advice should be sought.

2. STANDARD DESIGNS

Design Philosophy

1.7 The designs for asphaltic concrete fully flexible pavements contained in Chapter 4 of this standard are based on LR1132 (1984), while the designs for flexible composite pavements and pavements utilising EME2, given in Chapters 5 and 7 of this Standard, are based on TRL Report 615 (2004). TRL Report 630 (2005) forms the basis for design of rigid (continuous) construction; and TRL Report RR87 (1987) for rigid (jointed) construction as detailed in Chapter 6.

1.8 The adoption of the material specific calibration adjustment factors recommended in TRL Report 615 (2004) will give pavement designs using traditional materials that are in close agreement with the previous flexible designs, which were based on TRL Report LR 1132 (1984).

1.9 All of the designs contained in this standard are based on the assumption that all of the materials used in the earthworks and pavement construction comply with the relevant Series 600, 800, 900 or 1000 of the NRA Specification for Road Works (MCDRW 1).

1.10 For new road design, all lanes, including the hardshoulder and hardstrips, must be constructed to carry the design traffic in the heaviest loaded lane, commonly the left hand lane, as calculated in accordance with the NRA Addendum to HD 24.

1.11 For central reserves, the surface and binder course thickness between hard strips shall be the same as the adjacent traffic lanes, but the base may be reduced to that appropriate to a 1msa traffic loading.

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

1.13 For motorway widening the requirements of the National Roads Authority will depend on

the specific project, and will take account of a range of constraints, including technical, operational and financial. Also see the NRA Addendum to HD 27.

1.14 The minimum design traffic for lightly trafficked national roads shall be 1 million standard axles (msa) as set out in the NRA Addendum to HD 24.

3. FOUNDATION DESIGN - GENERAL

FOUNDATION FUNCTION

3.1 The main purpose of the foundation is to distribute the applied vehicle loads to the underlying subgrade, without causing distress in the foundation layers or in the overlying layers. This is required both during construction and during the service life of the pavement.

During Construction

3.2 The stresses in the foundation are relatively high during construction, although the number of stress repetitions from construction traffic is relatively low and traffic is not as channelised as during the in-service life of the pavement.

3.3 During pavement construction, it is expected that loads will be applied to the foundation by delivery vehicles, pavers and other construction plant. At any level where such loading is applied, the strength and material thickness have to be sufficient to withstand the load without damage occurring that might adversely influence, to any significant extent, the future performance of the pavement.

3.4 Foundation layers also have to be either protected from, or to be of sufficient durability to withstand environmental effects from rain, frost, high temperature etc, without sustaining damage.

3.5 Damage may take the form of rutting or other uneven deformation, cracking in hydraulically bound mixtures (including stabilised soils), or other forms of material specific degradation.

3.6 The designs given in this standard, in conjunction with the tests and material restrictions given in the NRA Specification for Road Works, are intended to ensure that, under normal construction conditions, such damage is avoided.

3.7 The foundation also has to be of sufficient stiffness for the overlying pavement layers to be placed and adequately compacted.

In Service

3.8 During the life of a pavement, its foundation has to be able to withstand large numbers of repeated loads from traffic. It is also likely to experience ingress of water, particularly if the upper pavement materials begin to deteriorate towards the end of their design lives.

3.9 It is essential that the foundation stiffness, assumed in design, is maintained throughout the life of the pavement. If this is not the case, deterioration of the upper pavement layers would typically occur more rapidly than assumed.

3.10 It is also essential that excessive deformation does not accumulate within the foundation under repeated traffic loading, since this is a potential source of wheelpath rutting at the pavement surface.

3.11 The performance of the foundation will also depend on the design, construction and maintenance of the earthworks and associated drainage system. HA 44 provides earthworks information and information on drainage is provided below. It is essential that the drainage system ensures that there is no accumulation of water in the pavement and foundation layers and that all excess moisture is allowed to disperse.

SUBGRADE ASSESSMENT

3.12 The subgrade is normally not strong enough to carry the construction traffic without distress, unless it is rock which is not subject to degradation by weathering. Therefore, unbound or bound foundation layers of adequate stiffness modulus are required to reduce the stresses on the subgrade.

Material Properties

3.13 Unbound aggregates and soils can suffer from permanent internal deformation when subjected to high stresses. They tend to have relatively poorer permanent deformation characteristics and lower shear strength than bound materials. There is no established test to predict susceptibility of these materials to permanent deformation. It is common for the

designer to infer from experience and index tests that materials have an acceptable level of stiffness modulus and shear strength. Both stiffness modulus and shear strength are usually reduced by increases in moisture content.

3.14 Ideally knowledge of the stiffness modulus and shear strength of the subgrade would be required to determine the thickness of the overlying pavement layers in order to avoid under- or over – design. However these two parameters are dependent on soil type (particularly plasticity), degree of remoulding, density and effective stress. Effective stress is dependent on the stress due to overlying layers, the stress history and the pore water pressure or suction. In turn, suction is dependent on the moisture content history, the soil type and the depth of the water table. The number of factors involved makes it necessary to adopt simplifications and to use index tests.

Index tests

3.15 Since direct determination of stiffness modulus and shear strength is not always practical, the California Bearing Ratio (see CBR – paragraphs 3.58, 3.59) is frequently used as an index test: CBR is quoted in percent to two significant figures. The CBR is not a direct measure of stiffness modulus or of shear strength but is widely used and considerable experience with it has been developed. It thus provides a common means of comparison.

The following equation has been derived empirically for typical soils:

$$E = 17.6 (\text{CBR})^{0.64}, \text{ MN/m}^2$$

It provides a means of assessing the stiffness modulus, E, which is approximately valid for values of CBR between 2 and 12%. This may be used with care in analytical design (see Ch 9). For more detailed information refer to CR72 (1987).

DETERMINATION OF SUBGRADE CBR

3.16 The Design CBR is the lower of the long term and short term CBR. Table 3.1 provides a simple means of assessing the equilibrium in-service (i.e. long term) CBR of the subgrade. The Table shall be used to derive a design in-service CBR unless site or laboratory test data clearly

indicate otherwise. Considerable care is required in assessing the lower values of CBR. Note that Table 3.1 is based on calculations rather than measurement. Even though CBRs are quoted to the nearest ½%, this degree of accuracy should not be implied as achievable. As subgrades get softer so the CBR values become less consistent. Values should be rounded down unless positive and consistent CBR determinations have been carried out.

3.17 In Table 3.1, a 'high' water table is one within 300mm of formation (or sub-formation if a capping is present). A 'low' water table is 1 metre down. 'Thick' construction represents a 1200mm pavement (including capping); a 'thin' pavement is 300mm of construction. The construction condition referred to relates to whether the subgrade is allowed to become wet, i.e. protection from rain, and the quality of drainage provided. More detailed advice is given in LR1132 (1984).

3.18 If full information is not available for Table 3.1, then certain assumptions can be made. The worst condition of a high water table can be taken together with construction being carried out to the NRA Specification for Road Works and thus at least 'average' construction conditions pertain. The pavements discussed in this Section vary between "thick" and "thin" constructions; by interpolating between the values in Table 3.1, a table of acceptable Equilibrium Values can be derived. This is shown in Table 3.2. Background information on this table is available in HA 44. Table 3.2 should be used where full information is not available. Laboratory and Insitu methods may be used as a check for the CBR value, but shall only supersede the use of Tables 3.1 and 3.2 with the agreement of the NRA Head of Engineering.

Laboratory Testing

3.19 Laboratory CBR values shall be measured using recompacted specimens, in accordance with BS1377 (1990).

3.20 Laboratory testing has the advantage that realistic conditions of moisture and 'disturbance' can be simulated. Tests should be carried out over a range of conditions to reproduce, as far as possible, the conditions of moisture content and density which are likely to be experienced during construction and in the completed pavement. Cohesive soils should be compacted to not less than 5% air voids, to reproduce the likely

conditions on site. Equilibrium moisture content can be deduced from measurements on a suction plate (LR889, 1979).

3.22 For reconstruction and overlay, equilibrium subgrade CBR values require the testing of existing pavements and HA 44 suggests a suitable procedure.

Site Testing

3.21 For design, the CBR must be estimated before construction commences using one of the procedures given in Chapter 3. Confirmatory testing shall be undertaken as required and at a minimum of 60m intervals for the main works. For fine grained soils, in-situ CBR values can be measured for checking purposes (not to allow design changes) in pits or on trial strips during construction. Plate bearing tests are necessary for coarse materials (BS5930, 1981). If the in-situ CBR is found to be less than the Design CBR, then the subgrade must either be improved to the Design CBR or the foundation redesigned

TYPE OF SOIL	PI	HIGH WATER TABLE						LOW WATER TABLE					
		CONSTRUCTION CONDITIONS:											
		POOR		AVERAGE		GOOD		POOR		AVERAGE		GOOD	
		Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
HEAVY CLAY	70	1½	2	2	2	2	2	1½	2	2	2	2	2½
	60	1½	2	2	2	2	2½	1½	2	2	2	2	2½
	50	1½	2	2	2½	2	2½	2	2	2	2½	2	2½
SILTY CLAY	40	2	2½	2½	3	2½	3	2½	2½	3	3	3	3½
	30	2½	3½	3	4	3½	5	3	3½	4	4	4	6
SANDY CLAY	20	2½	4	4	5	4½	7	3	4	5	6	6	8
	10	1½	3½	3	6	3½	7	2½	4	4½	7	6	>8
SILT*		1	1	1	1	2	2	1	1	2	2	2	2
SAND (POORLY GRADED)		----- 20 -----											
SAND (WELL GRADED)		----- 40 -----											
SANDY GRAVEL (WELL GRADED)		----- 60 -----											

* estimated assuming some probability of material saturating

Table 3.1 Equilibrium Subgrade CBR Estimation

Type of Soil	PI	Predicted CBR %
Heavy Clay	70	2
	60	2
	50	2
	40	2 to 3
Silty Clay	30	3 to 4
	20	4 to 5
Sandy Clay	10	4 to 5
Sand (Poorly graded)		20
Sand (Well graded)		40
Sandy gravel (Well graded)		60

Table 3.2 Equilibrium Subgrade CBR Estimation

SOFT SUBGRADES

3.23 The minimum permitted Design CBR is 2.5%. Where a subgrade has a lower CBR it is considered unsuitable support for a pavement foundation. It must therefore be permanently improved using one of the options given in paragraphs 3.25-3.28.

3.24 The material can be removed and replaced by more suitable material; if the depth is small, all can be replaced but it may only be necessary to replace the top layer. The thickness removed will typically be between 0.5 and 1.0 m. Although the new material may be of good quality, the subgrade should be assumed to be equivalent to one of a CBR of 2.5%, in order to allow for movements in the soft underlying material. A total construction thickness of about 1.5m thickness will often result. A geosynthetic may also be useful.

3.25 If the soil is cohesive, a lime treatment may be an economic option, subject to soil suitability being shown. Details of various soil treatments are given in HA44. The overlying capping is again designed on the basis of a subgrade with a CBR value of 2.5%.

3.26 For certain conditions, the incorporation of a geosynthetic material into the foundation design may be advantageous. Approval under a

3.27 Departure from Standard to adopt an alternative Design CBR value will be necessary, based on testing or previous experience with the specific geosynthetic and the materials being used on the scheme.

3.28 If the soil is reasonably permeable, a deeper than normal drainage system may be considered, together with a system of monitoring the improvement expected. Design of the main foundation may then be based on whatever conditions are achievable in the time available

CAPPING AND SUB-BASE

3.29 Capping is used to improve and protect weak subgrades by using a relatively cheap material between the subgrade and the subbase. The aim is to increase the stiffness modulus and strength of the formation, on which the subbase will be placed. Capping with a laboratory CBR value of at least 15% should provide an adequate platform for construction of the subbase when compacted to appropriate thickness.

3.30 Granular and cemented subbases are permitted for flexible and flexible composite pavements but only cemented subbases are permitted for rigid pavements and pavement utilising and EME2 base.

3.31 The grading for unbound granular subbase is intended to provide a dense layer of relatively high stiffness modulus, which is reasonably impermeable and will thus shed rain water during construction, given adequate fall. It is not necessarily free draining and may exhibit suction, and thus increase in moisture content. Unbound granular subbase with a laboratory CBR of at least 30% should provide an adequate platform for construction of the pavement when compacted to the appropriate thickness.

CAPPING MATERIALS

3.32 The 600 Series of the NRA Specification for Road Works (MCDRW 1) allows a fine graded material (6F1) and a coarser graded (6F2). The latter can be considered as relatively free draining and is thus most suitable for sites with a shallow water table. It should, however, be noted that capping is not required to be a drainage layer as long as contained water does not prevent it from satisfying its primary function of load spreading. The specified gradings also do not guarantee adequate shear strength and a demonstration area should normally be placed and tested to check on the material's characteristics by trafficking with normal site vehicles and construction plant.

3.33 Reuse of crushed excavated road pavement materials as capping may also be carried out provided the compacted material complies with the properties and placement restrictions of the 600 Series of the NRA Specification for Road Works (MCDRW 1).

3.34 The design should allow as wide a range of capping materials as possible and particular materials should only be excluded if there are over-riding engineering or environmental reasons for so doing. For capping thicknesses of below 250mm, if large stone sizes are involved it may be necessary to lay a greater thickness than that required in Chapters 4 and 5.

3.35 Some contamination from weak cohesive soils into granular capping, particularly with 6F2, can be expected and the design thicknesses allow for this. In some cases, a geosynthetic separator may also be beneficial.

SUB-BASE MATERIALS

Material requirements for subbases depend on the intended pavement type and are defined in Chapters 4 and 5.

3.36 Consideration may be given to the use of recycled materials where material of consistent quality is readily available in sufficient quantity. Because of the greater variability and the possibility of contamination of such materials, it may be necessary to increase the frequency of control testing. Agreement of the NRA Head of Engineering shall be obtained and an appropriate material specification agreed before non-standard materials are used.

3.37 Variants of Type B subbase, such as material having a coarser grading and thus increased permeability, may also be used subject to the agreement of the NRA Head of Engineering. Aggregates with gradings that have a pronounced gap or an excess of material passing a 0.075mm sieve are probably unsuitable.

3.38 Resistance to fragmentation is an important characteristic of standard subbase materials. However a high Los Angeles value does not necessarily preclude the use of alternative materials provided compaction trials carried out to check actual particle damage under the type of roller to be used are carried out. Self cementation which occurs with some materials may counteract the weakness. To detect self-cementing properties, trial areas could be tested in-situ at intervals of time. Alternatively, triaxial tests in the laboratory may be used to assess any improvement in stiffness modulus and/or shear strength. Care is required to distinguish between self cementing and suction effects.

THICKNESS DESIGN

3.39 The thickness of capping and subbase shall be obtained from the Figures in Chapters 4 and 5 depending on the type of pavement to be used. The subbase may be omitted on hard rock subgrades that are intact or on granular subgrades with a laboratory CBR of at least 30%, and which do not have a high water table.

3.40 Where a scheme is large enough, it may include several different soil types or moisture conditions. It is not intended that the foundation design should vary frequently along the road but that an appropriate value shall be selected for each significant change in the subgrade properties. For this reason changes in foundation design shall not be made for lengths less than 100m and rarely less than 500m.

3.41 The final design thickness shall be specified to the nearest 10 mm greater than the value obtained from the Figures in Chapter 4 and Chapter 5.

DRAINAGE

3.42 It is of vital importance to keep water out of the subbase, capping and subgrade, both during construction and during the service life of the pavement. This is achieved by excluding incoming water and providing an escape route for water already in the foundation (Figure 3.1)

3.43 . It is good practice and will reduce the opportunity for foundation deterioration if the carriageway drainage is constructed and kept operational, before foundations are constructed. During construction, every effort should be made to protect the subgrade by placing aggregate before rain can soften it.

3.44 Wherever possible the foundation drainage should be kept separate from pavement run-off drainage in all new construction and in reconstruction work. There should always be a downslope route from the subbase to the drain. Further details are in HA 44.

3.45 In reconstruction and widening projects it is necessary to maintain the continuity of drainage from existing capping and subbase materials to adjacent new materials, using appropriate thicknesses and crossfalls. Particular care is required to ensure that the addition of bound subbase materials does not introduce a barrier to such drainage.

3.46 When the water table is high and the subgrade is moisture sensitive (Plasticity Index < 25) a subgrade drain is beneficial. A granular aggregate drainage blanket (see NRA Specification for Road Works, Series 600) of thickness at least 150mm and not more than 220mm thick shall be used. In order to stop pore

clogging by fines from other adjacent layers, geosynthetic separators shall be used when those layers are constructed of fine soil or fine capping. The drainage layers so formed may be treated as capping for structural design purposes.

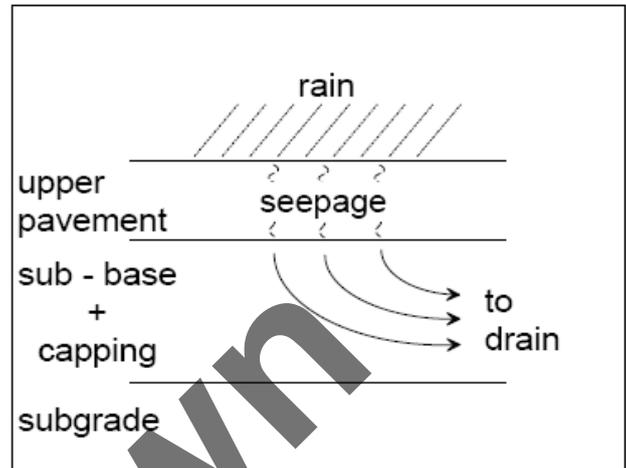


Figure 3.1 Foundation Drainage

3.47 Where a drainage blanket is not used, subgrade drains as detailed in NRA Road Construction Details shall be used. The invert of the drain is placed below the bottom of capping, not because subbase and capping need to be permeable, but so that they will be drained if they are permeable.

3.48 It is useful to check the speed at which water can drain out of a granular subbase, as a result of ingress due, perhaps, to a faulty pavement or a surcharging drain. A procedure for calculating this is given in Jones & Jones (1989a) along with a means of estimating ingress through cracks in the bound layers. On this basis it may be possible to specify a permeability value. Care should be taken to ensure that the value required does not conflict with any limitations imposed by a specified grading, see Jones & Jones (1989 b).

3.49 If it is necessary to determine the permeability of the subbase or capping material, this must be done on the full grading, at the correct density under a low hydraulic head. A suitable permeameter and procedure is described in HA 41

3.50 Drainage of the subbase may be omitted only if the underlying materials (capping and subgrade) are more permeable than the subbase, and the water table never approaches the formation closer than 300mm

FROST PROTECTION

3.51 All material within 350mm of the road surface shall be non frost-susceptible as required by the 700 Series of the NRA Specification for Road Works (MCDRW 1) and tested in accordance with BS812: Part 124.

IN-SITU TESTING

3.52 The two reasons for testing pavement foundation layers are to check compliance with the design during construction and in pavement assessment. The 800 Series of the NRA Specification for Road Works (MCDRW 1) defines a method based approach to construction. An inadequate test result may indicate either that the method was not followed, that the material was sub-standard, that abnormal conditions requiring a variation in procedure were encountered, or that damage has occurred. The following paragraphs introduce some of the tests which are available, most of which are specified in BS1377 (1990). They are for general information and advice only and do not comprise part of the NRA requirements.

Moisture Condition Value (MCV)

3.53 The test takes about half an hour and involves compaction of soil or fine aggregate using a hand operated device. The amount of compactive effort is plotted against the density so that the test gives the amount of effort needed to obtain the specified density. The effort can be compared to that needed at Optimum Moisture Content and a rapid indirect assessment made of whether the material is at the desired moisture content. The size of the apparatus limits its use to fill finer than 20mm maximum particle size.

Density Testing

3.54 The sand replacement test involves excavating and weighing material removed from a small hole and refilling the hole with a uniform sand. The hole volume is calculated from the mass of sand used. The water replacement test is similar except that a plastic liner filled with water is used to determine the volume. The equipment for either is transported by vehicle. The tests are time consuming (up to 1 hour) and thus expensive, and operator sensitive. However they do give a direct means of measuring density, which can then be

compared with values obtained in the laboratory or in trials.

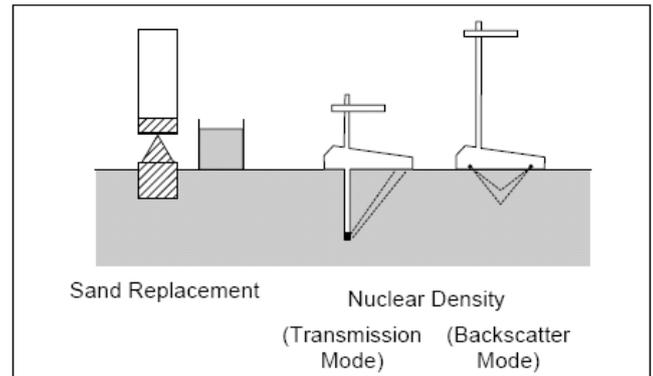


Figure 3.2 Density Testing Apparatus

3.55 An alternative is nuclear density testing. A radiating source is applied to the material. The amount of radiation detected decreases in proportion to the bulk density of the material between source and receiver. To determine the moisture content another source sends out radiation intercepted by hydrogen atoms. The dry density is calculated from the bulk density and moisture content. If the material being tested is carbonaceous, care is required in interpreting moisture content and dry density obtained. Testing is extremely rapid (less than 5 minutes) and a reading may be repeated readily. The machine is portable. Calibration is required for each soil or aggregate tested.

3.56 It should be noted that two modes of nuclear density test are possible. The quickest and easiest is 'backscatter' mode which is influenced only by the density of the top 100 - 150mm of material and is most heavily influenced by material very near the surface. 'Transmission' mode provides a more representative density result.

California Bearing Ratio

3.57 The California Bearing Ratio (CBR) test involves the insertion of a 50mm plunger into the ground surface at a rate of 1mm per minute, whilst the load is recorded. Surcharge rings can be placed around the plunger to simulate an overburden. A laboratory version of the same test is available in which the sample tested is constrained within a 152.5mm diameter mould. The stress at penetrations of 2.5mm and 5mm is compared with the result for a standard aggregate and the ratio given as a percentage. The test is not

suitable for coarse aggregates because the plunger and aggregate particles will be of similar size. The test measures neither stiffness modulus nor shear strength directly - giving a somewhat combined measure of both. It takes around half an hour on site and between 1 and 2 hours in the laboratory and there is a large body of experience of its use.

3.58 There are several variants on the CBR test; laboratory, field, with surcharge, saturated, etc. In the context of this document the laboratory CBR with a surcharge to simulate the appropriate vertical overburden stress of the case being considered should be taken as the standard method used. The appropriate moisture content and wetting or drying condition is also important. Laboratory CBR results for granular soils are often higher than those in the field due to mould confinement effects. The test is penetration controlled and so does not model the stress level imposed by traffic. The time of loading is also much longer than that due to traffic. CBR is an empirical test and is best measured as initially intended although other test devices such as the cone penetrometer, dynamic cone penetrometer and the plate bearing test can be used to determine approximate estimates of CBR.

Cone Penetrometers

3.59 Various sizes of static field cone penetrometer for insertion into a test material exist for the rapid approximate assessment of CBR. In general they only cover a fairly low CBR range and are therefore applicable for soft and medium fine grained subgrades.

3.60 The dynamic cone penetrometer (DCP – Figure 3.3) is similar to other field cone penetrometer except that it is driven into the ground under the action of a weight dropped onto an anvil. It is therefore suited to stronger and coarser materials than other penetrometer. However it is only suitable for use at sub-grade level and is not suitable for use in stoney materials. The rate of penetration into the ground can then be related approximately to CBR following a series of side by side calibration tests for each material type.

3.61 The permitted Dynamic Cone Penetrometer is a device incorporating an 8kg steel drop weight that falls vertically through 575mm and makes contact with a relatively light steel anvil. The anvil is rigidly attached, via steel rods to a 20mm

diameter 60° steel cone, which is thus driven vertically into the ground. The result for each test must be expressed as a 50th percentile penetration rate in millimetres per blow between 50mm and 550mm of penetration from top of subgrade level. If the penetration rate is less than 2mm per blow, then the test should be aborted with one further test attempted nearby. Soil strength expressed as mm/blow must be converted to a CBR value using the following relationship:

$$\text{Log}_{10}(\text{CBR}) = 2.48 - 1.057 * \text{Log}_{10}(\text{mm/blow})$$

where CBR is given as a percentage value and the penetration rate of the cone is given in units of mm/blow.



Figure 3.3 Dynamic Cone Penetrometer Testing

Plate Bearing Test

3.62 For coarser materials the Plate Bearing Test may be found appropriate for determination of subgrade CBR values. This test is described in detail in BS1377 (1990) and its use for testing is described in The 600 Series of the NRA Specification for Road Works (MCDRW 1). For pavement materials no removal of surface material or nonvibratory compaction is needed.

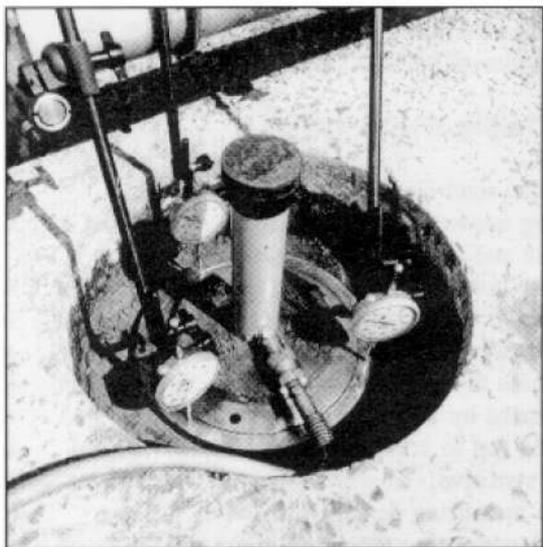


Figure 3.4 Plate Bearing Apparatus

3.63 An approximate empirical correlation with CBR can be made, as follows:

$$\text{CBR} = 6.1 \times 10^{-8} \times (k_{762})^{1.733\%}$$

Where k_{762} is the modulus of subgrade reaction, defined as the applied pressure under the loading platen divided by the displacement (normally 1.25mm) with a plate of 762mm (30 inch) diameter. Figure 3.5 allows conversion for other plate sizes.

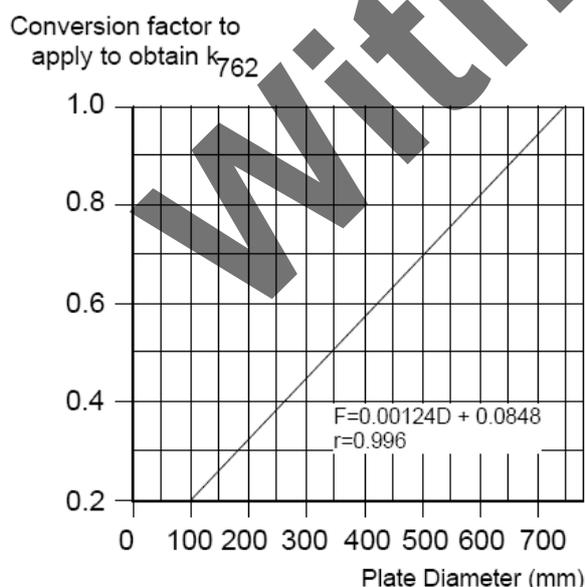


Figure 3.5 Correction for smaller plates

3.64 The test is laborious to set up and carry out, and requires a lorry or excavator to provide reaction. The speed of loading is slow giving poor simulation of traffic loading.

Dynamic plate test

3.65 These tests involve placing a circular plate on a foundation layer and dropping a weight onto a platen. Usually a damping mechanism is incorporated to control the loading time. The area of loading and applied stress may be readily controlled. This test offers a less laborious approach to testing granular materials, but must be calibrated against a series of side by side static load plate tests for each material type.

3.66 The Dynamic Plate Test device must be calibrated to the manufacturer's specification. Regular checking and calibration of the load cell and deflection sensors must be carried out as recommended by the manufacturer. The equipment must be capable of producing a peak stress of 100kPa with a pulse rise time of between 8 to 12 milliseconds, applied through a rigid circular plate of 300mm diameter. Both the applied load and the transient deflection, measured directly on the tested surface, must be recorded. The deflection measurement transducer must be capable of measuring deflections in the range 40-1500 microns. The accuracy of the readings should be ± 0.1 kN for the load and ± 2 microns for deflection. The peak stress applied during each test shall be selected to produce as high a deflection as possible within the measurement range of the deflection sensor.

3.67 The following procedure is to be adopted for dynamic plate testing:-

Each test site should be stable and flat and free from water, ice and snow. The temperature down to 100mm below the surface should be at least 4°C. For a lightweight test device, at least 10 drops are necessary at the beginning of each test session to warm up the rubber buffers. At each test point, 3 initial 'seating' drops shall be carried out to bed the plate into the surface. Three further drops shall then be carried out. The results from the last set of three drops shall be averaged to give the Surface Modulus applicable to that test point.

The stiffness modulus shall be computed at each point tested, using the following formula:

$$E = \frac{2(1-\nu^2) \times R \times P}{D}$$

where:

E = Foundation Surface Modulus (in MN/m² or MPa)

ν = Poisson's Ratio (ν , by default, = 0.35)

R = Load Plate Radius (R, by default, = 150mm)

P = Contact Pressure (in kPa)

D = Deflection under the centre of the plate (in microns)

3.68 The Falling Weight Deflectometer (FWD) measures the stress applied and the deflection at several radial positions. Interpretation is generally in terms of the stiffness modulus of each layer but is not straightforward and should be carried out by an experienced pavement engineer. If only the central deflection is used to determine a surface modulus for the foundation, then interpretation can be carried out as for other dynamic plate tests.

3.69 Lightweight dynamic plate apparatus may not be suitable to test thicker foundations. If a lightweight test device is used, it must be correlated to an FWD which will remain the reference test method. The following procedure must be used to correlate a lightweight device: The FWD and the lightweight devices are to both be used on the same material and at adjacent test positions for 25 measurements points. The Surface Modulus values obtained from the two devices are to be compared and the square of the correlation coefficient (r^2) is to be calculated. If this value is more than 0.45 then there is considered to be sufficient correlation between the two devices. An adjustment factor should then be calculated as the mean of the ratios of each FWD value to lightweight value. The lightweight device readings are to be adjusted by this factor for all further readings on that material for that scheme.



Figure 3.6 Lightweight Dynamic Plate Test

Springbox

3.70 The Springbox equipment (Edwards et al, 2005) (Fig 3.7) is a suitable tool for testing unbound granular and some weak hydraulically bound mixtures. It consists of a steel box containing a cubical sample of material, of edge dimension 170mm, to which a repeated load can be applied over the full upper surface. One pair of the box sides is fully restrained and the other is restrained through elastic springs, giving a wall stiffness of 10-20kN per mm. The equipment enables a realistic level of compaction to be applied to the test material, by means of a vibrating hammer and also includes a facility to introduce water to the sample or drain water from its underside.

3.71 Loading takes the form of repeated vertical load applications of controlled magnitude at a frequency of at least 1Hz and no greater than 5Hz. The load capacity is equivalent to a vertical stress of at least 150kPa. Measurements of both vertical and horizontal (spring restrained) deflection can be made, with 2 measurement transducers for each measure. In the case of vertical deflection measurement, the equipment allows the transducers to make direct contact with the specimen, via holes in the loading platen.

3.72 The stiffness modulus of the material can be calculated from the averaged deflections measured over a series of loading patterns.

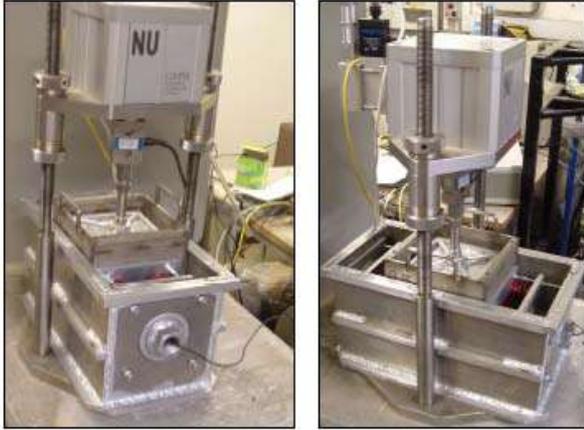


Figure 3.7 SpringboxTest

Test for reconstruction and overlay

3.73 In-situ cone penetrometer, DCP, DPT and FWD testing are particularly appropriate in major reconstruction or widening cases, where an existing road has been present over the same subgrade materials long enough for equilibrium moisture conditions to develop. However, caution must be exercised if the testing is carried out during the summer months when moisture levels are likely to be lower; in this case additional laboratory testing at higher moisture content may be advisable, especially if construction is likely to occur over winter months when it is assumed that the soil is wetter.

3.74 FWD testing of an existing pavement has the further advantage that the stress condition generated in the subgrade is close to that induced by a moving heavy commercial vehicle.

4. FULLY FLEXIBLE DESIGN

General

4.1 This Chapter covers the design of foundations and pavements for all fully flexible pavements i.e. pavements constructed from bituminous materials supported on an unbound foundation. Pavements incorporating hydraulically bound materials are termed Flexible Composite (refer to Chapter 5). This chapter does not apply to EME2 which requires a bound foundation (refer to Chapter 7 for details of EME2 designs).

4.2 The approach taken for fully flexible construction is to design the foundation for construction traffic loading. This approach provides a “standard foundation” for the design of the pavement.

4.3 The designs given in this Part are based on LR1132 (1984), for flexible construction. LR1132 was based on observations and measurements of full-scale road experiments over a 20 year period, supplemented by structural analysis to rationalise and extend the data. The analysis used the elastic stiffness modulus of the various pavement and foundation layers, to calculate the strains developed within the structure. The strains could be related to life for the type of ‘determinate’ pavement structures which then existed.

4.4 Monitoring the performance of heavily trafficked roads has indicated that deterioration, in the form of cracking or deformation, is far more likely to be found in the surfacing rather than deeper in the structure for the thicker pavements which are more typical today. Therefore a well constructed flexible pavement, built above a threshold strength, will have a very long structural life - provided that distress, seen as cracks and ruts at the surface, is treated before it begins to affect the structural integrity of the road. Further background information is available in TRL Report 250 (1 997).

4.5 Generally for “long life” indeterminate flexible pavements designed to carry traffic for at least 40 years, it is not necessary to increase the pavement thickness beyond that required for 80msa. Nevertheless, “long life” designs are not recommended to be thinner than 200mm, in order

to help avoid structural rutting and to retard the progression of cracks from the surface down through the asphalt layers.

Pavement Deterioration

4.6 There are four main phases of structural deterioration for a flexible pavement that is not defined as indeterminate.

- a) When a new or strengthened pavement is reaching equilibrium with a steady improvement in load spreading ability.
- b) When load spreading ability is fairly stable, and the rate of structural deterioration may be predicted with some confidence.
- c) When structural deterioration becomes less predictable. Pavements entering this phase should be monitored and investigated to determine what, if any, maintenance is appropriate to ensure that the next phase is not reached; hence this phase is termed the “investigatory” phase. (The term “critical” is no longer used). Residual life is the time period before a pavement is expected to enter its investigatory phase.
- d) When the pavement deteriorates to a “failure” condition from which it can be strengthened only by total reconstruction. It is important to realise however that such pavements may not need reconstruction immediately, but will probably have several years of useful life, before increasing routine maintenance costs trigger the need for reconstruction.

Subbase Materials

4.7 Granular subbase material in accordance with Clause 804 of the NRA Specification for Road Works (MCDRW 1) is the standard unbound material for use with flexible pavements. The use of any alternative material beneath a fully flexible pavement shall require a Departure from Standard.

Pavement Materials

4.8 Pavement base and binder course materials shall be Asphalt Concrete, complying with Clause 906 or 929 of the NRA Specification for Road Works (MCDRW1) for recipe and design mixes respectively. Designs are provided for the following two material groups and require that all base and binder layers are selected from the same group. :

- Asphalt Concretes utilising 70/100 Pen Bitumen
 - AC32 dense base 70/100 rec;
 - AC32 dense bin 70/100 rec
 - AC20 dense bin 70/100 rec;
- Asphalt Concrete utilising 40/60 Pen Bitumen
 - AC32 dense base 40/60 rec;
 - AC32 HDM base 40/60 rec;
 - AC32 dense base 40/60 des;
 - AC32 HDM base 40/60 des;
 - AC32 dense bin 40/60 rec;
 - AC20 dense bin 40/60 rec;
 - AC20 dense bin 40/60 des;
 - AC32 HDM bin 40/60 rec;
 - AC20 HDM bin 40/60 rec;
 - AC20 HDM bin 40/60 des;

Note – Recent research in the UK suggests that HDM gradings have not delivered the anticipated improved performance when compared to dense gradings in the long term, and therefore a single design line has been provided for all Asphalt Concrete using 40/60 Pen Bitumen.

Surface course must be one of the permitted materials presented in the NRA Addendum to HD 36 and comply with the relevant clauses of the NRA Specification for Road Works (MCDRW 1). For further details refer to the NRA Addendum to HD 37.

Ground Subject to Movement

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

Foundation Thickness Design

4.10 The thickness of capping and subbase shall be obtained from Figure 4.1 for flexible pavements. Options are provided for subbase over capping or subbase only. For a sub-grade having a CBR greater than 15% the thickness of foundation is 150mm (subbase only). When the sub-grade CBR is below 2.5% capping with subbase may be insufficient to support the pavement, refer to paragraphs 3.25-3.28.

4.11 The CBR value used for design must be determined using the lowest value of the long term and short term CBR. The short term CBR must be confirmed in each area of the site before foundation construction starts, as defined in paragraph 3.21.

4.12 Design thicknesses shall be rounded up to the nearest 10 mm.

4.13 Thicknesses derived from Figure 4.1 are subject to the normal construction tolerances as given in Series 700 of the NRA Specification for Road Works (MCDRW 1).

4.14 It is permitted to replace some or all of the subbase by bituminous material. A substitution rate of 30mm of Asphaltic Concrete base to 100mm of Granular subbase material in accordance with Clause 804 of the NRA Specification for Road Works (MCDRW 1) shall be used. This technique must not be applied to capping, or to the lowest 150mm layer of subbase where subbase lies directly on soil of less than CBR 5% (at the time of construction). Construction practices on thin foundations may have to be modified compared with normal procedures due to the reduced ability of the foundation to carry construction traffic.

Pavement Thickness Design

4.15 The thickness of pavement material appropriate for the specified design traffic shall be obtained from Figure 4.2. Options are provided for Asphalt Concrete using 70/100 Pen Bitumen (the least stiff material requiring the thickest construction) and Asphalt Concrete utilising 40/60 Pen Bitumen (a stiffer material requiring a reduced pavement thickness to provide the same structural equivalence.)

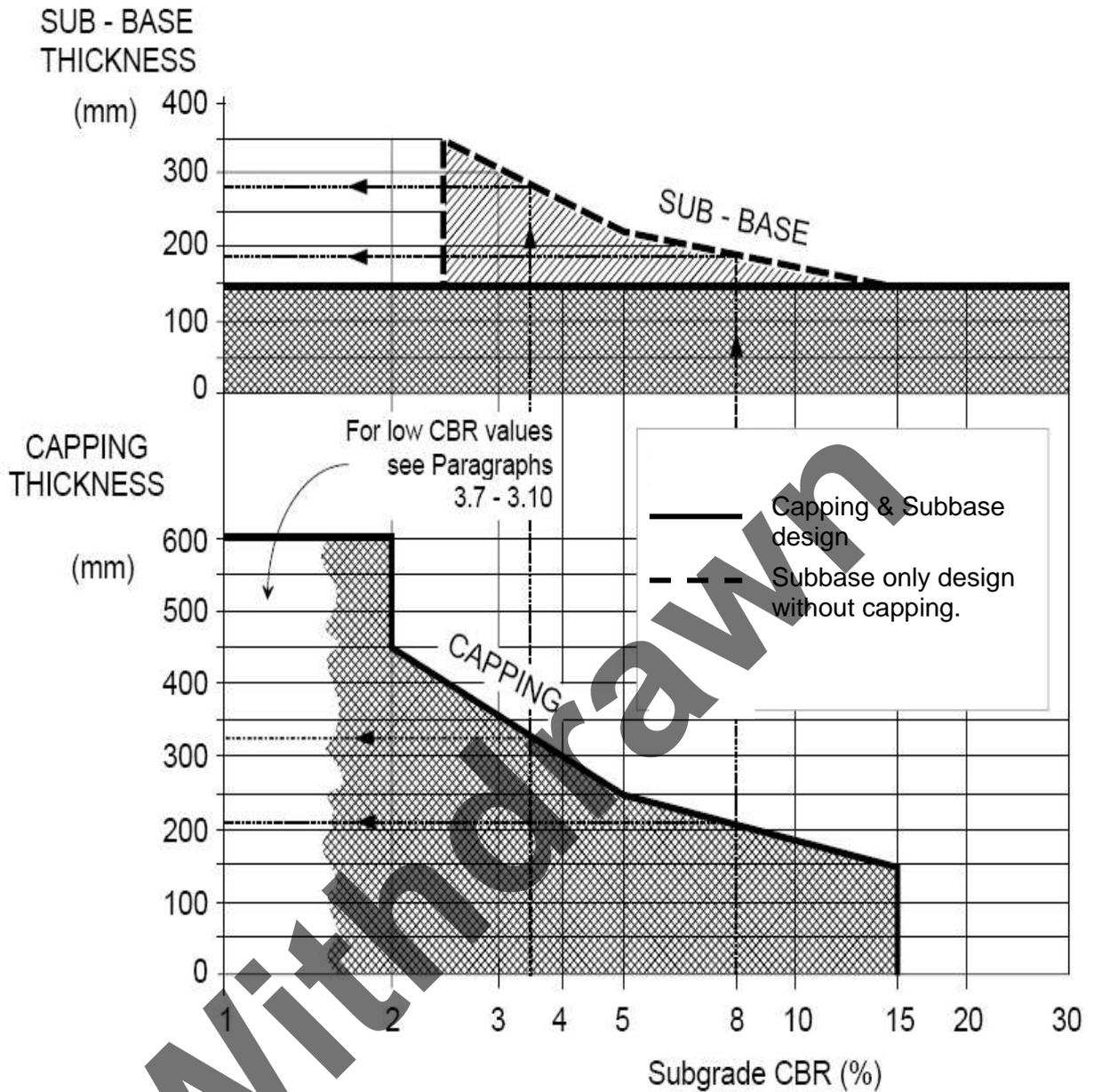


Figure 4.1 Foundation design charts for flexible pavement

Example 1: CBR 3.5%

Alternative designs

- a. Subbase 150mm
on Capping 330mm
- b. Subbase 280mm
No Capping

Example 2: CBR 8%

Alternative designs

- a. Subbase 150mm
on Capping 210mm
- b. Subbase 190mm
No Capping

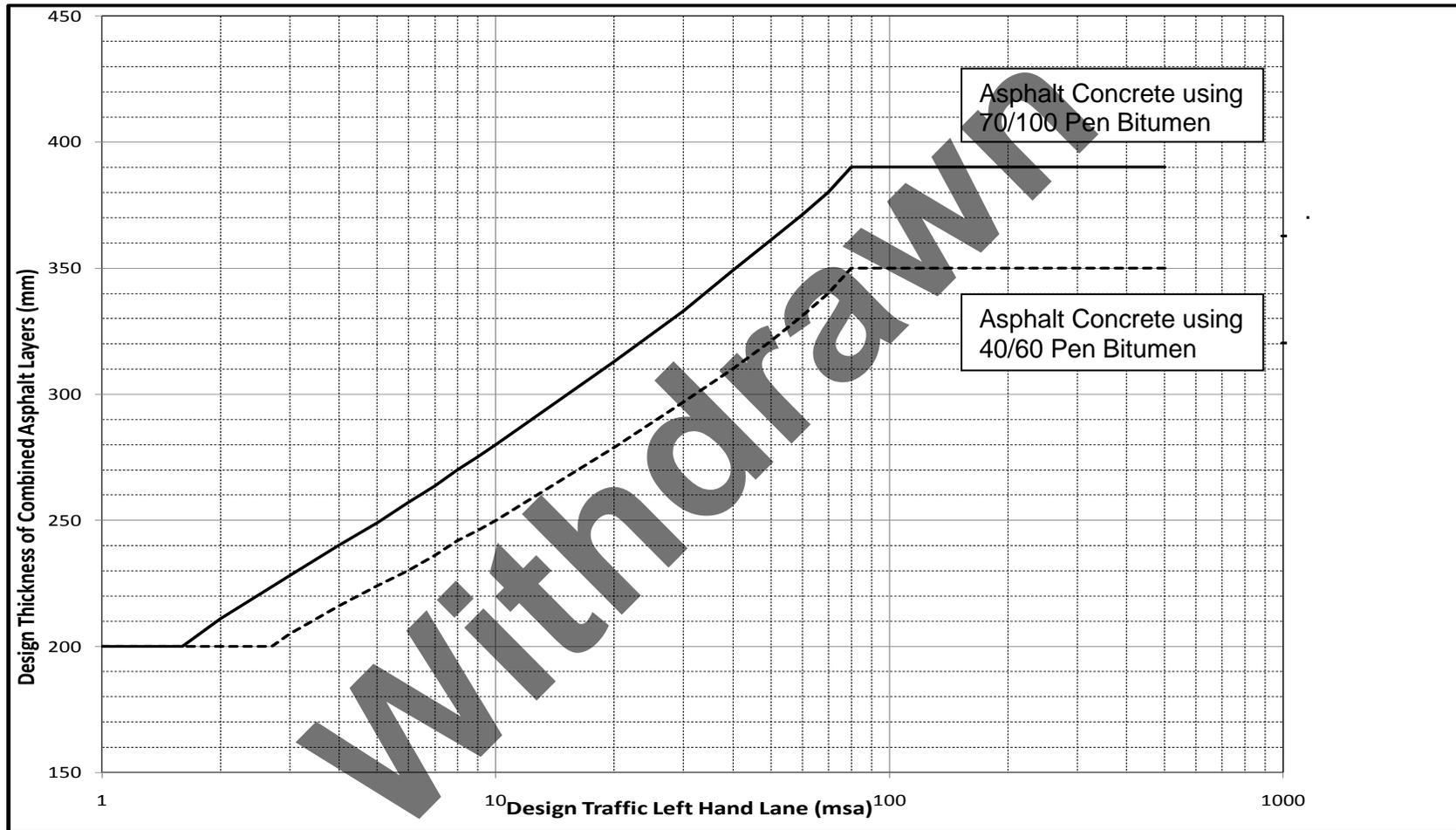


Figure 4.2 Design chart for fully flexible pavement

Notes on Figure 4.2:

1. Thickness to be rounded up to the next 10mm.
2. Where the asphalt design thickness is 300mm or less, the material is to be laid with no negative tolerance on the overall thickness.
3. A binder course, compacted to meet the maximum air voids requirements in the 900 Series of the NRA Specification for Road Works (MCDRW 1) is required beneath the surface course. It shall be of any permitted material (subject to Note 4) and be at least 50mm thick.
4. If 50mm of Porous Asphalt (PA) surfacing is to be used its contribution to the material thickness is only 20mm. A 60mm Asphalt Concrete binder course is required beneath PA surfacing, compacted so that the air voids are less than the maximum specified in Series 900 (MCDRW1).
5. This figure assumes that the binder course is material of the same bitumen penetration grade as the base. However any permitted material may be used as long as the overall pavement thickness is adjusted to give equivalent load spreading ability in accordance with Chapter 9.

Example for Figure 4.2:

- Design Traffic: 30msa
- Assuming AC 32 dense base 40/60 rec (formerly known as DBM50) base as an example.
- Design thickness: 300mm (295mm rounded up to the nearest 10mm)
- Surfacing options permitted for each scheme will vary but some examples are given below:
 - a) 35mm SMA 14 surf PMB 65/105-60 des + 55mm AC 20 dense binder 40/60 rec + 210mm AC 32 dense base 40/60 rec.
 - b) 45mm HRA 30/14 F surf 40/60 + 55mm AC 32 dense binder 40/60 rec + 200mm AC 32 dense base 40/60 rec

5. COMPOSITE PAVEMENT DESIGN

General

5.1 This Chapter covers the design of foundations and pavements for all flexible composite pavements i.e. pavements incorporating hydraulically bound materials.

5.2 Composite pavements are not suitable where differential movement, subsidence or appreciable settlements are expected.

5.3 Design thicknesses for Flexible Composite Pavements are based on two foundation stiffness classes, defined as follows:

- Foundation Class 2: $\geq 100\text{MPa}$
- Foundation Class 3: $\geq 200\text{MPa}$

Pavement Materials

5.4 Foundation Class 2 designs shall make use of unbound subbase to Clause 808, Cement Bound Granular Mixtures to Clause 821 and 822 and Soil Cement to Clause 824 of the NRA Specification for Road Works (MCDRW 1). For Class 2 foundations, a capping layer may also be incorporated as part of the foundation

5.5 Cement Bound Granular Mixtures and Soil Cements must achieve a compressive strength of at least C3/4 when tested in accordance with Clause 825 of the NRA Specification for Road Works (MCDRW 1). A cement bound subbase must be used for design traffic in excess of 80msa.

5.6 Foundation Class 3 designs are restricted to those using Cement Bound Granular Mixtures to Clause 821 and 822 achieving at least the compressive strength class C8/10 when tested in accordance with Clause 825 of the NRA Specification for Road Works (MCDRW 1).

5.7 The upper bound layers (base and binder) of composite pavements are bound in bitumen and the lower (base) layers are bound with a hydraulic binder. The permitted upper bound materials layers are as follows:

- Asphalt Concrete to Clause 906 or Clause 929 of the NRA Specification for Road Works (MCDRW 1)

5.8 The permitted lower bound material layer (base) is as follows:

- Cement Bound Granular Material to Clause 822 of the NRA Specification (MCDRW 1).

5.9 Surface course must be one of the permitted materials presented in the NRA Addendum to HD 36 and comply with the relevant clauses of the NRA Specification (MCDRW 1). For further details refer to the NRA Addendum to HD 37.

Foundation Thickness Design

5.10 The design thicknesses for Class 2 and Class 3 flexible composite foundations are shown in Figures 5.1 and 5.2.

5.11 For Class 2 foundations there are four different design options depending on whether unbound or bound subbase is chosen and whether a capping is used. For Foundation Class 3 a cement bound subbase only design must be utilised

5.12 Figures 5.1 and 5.2 are based on subgrade CBR values. The subgrade CBR used for design must be determined using the lowest value of the long term and short term CBR. The short term CBR must be confirmed for each area of the site by testing before foundation construction starts, as defined in paragraph 3.21

5.13 For a subgrade having a CBR greater than 15 %, the thickness of foundation is 200mm (subbase only design) or 300mm (150mm subbase on 150mm capping design), this being controlled by the minimum practicable thickness for spreading and compaction.

5.14 Foundation design thicknesses are to be rounded up to the nearest 10 mm. Thicknesses derived from Figures 5.1 and 5.2 are subject to the normal construction tolerances as given in Series 700 of the NRA Specification (MCDRW 1)

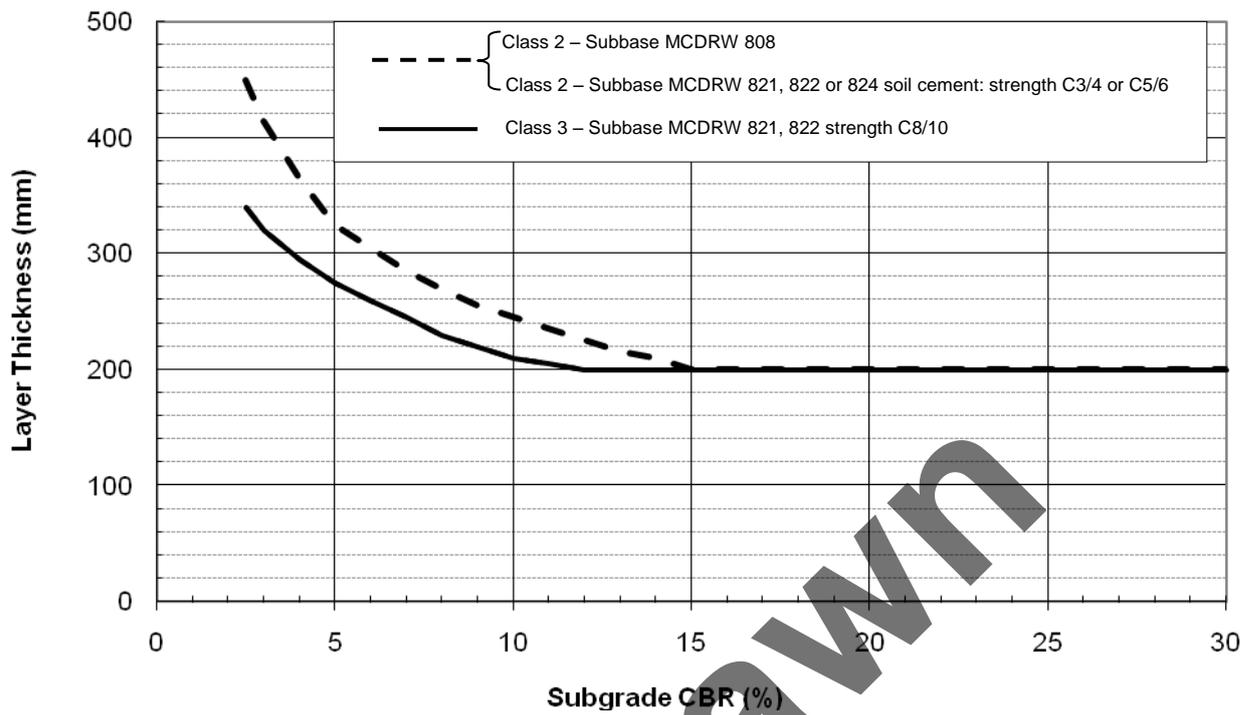


FIGURE 5.1 – Foundation Design options for Flexible Composite Pavements – Subbase Only

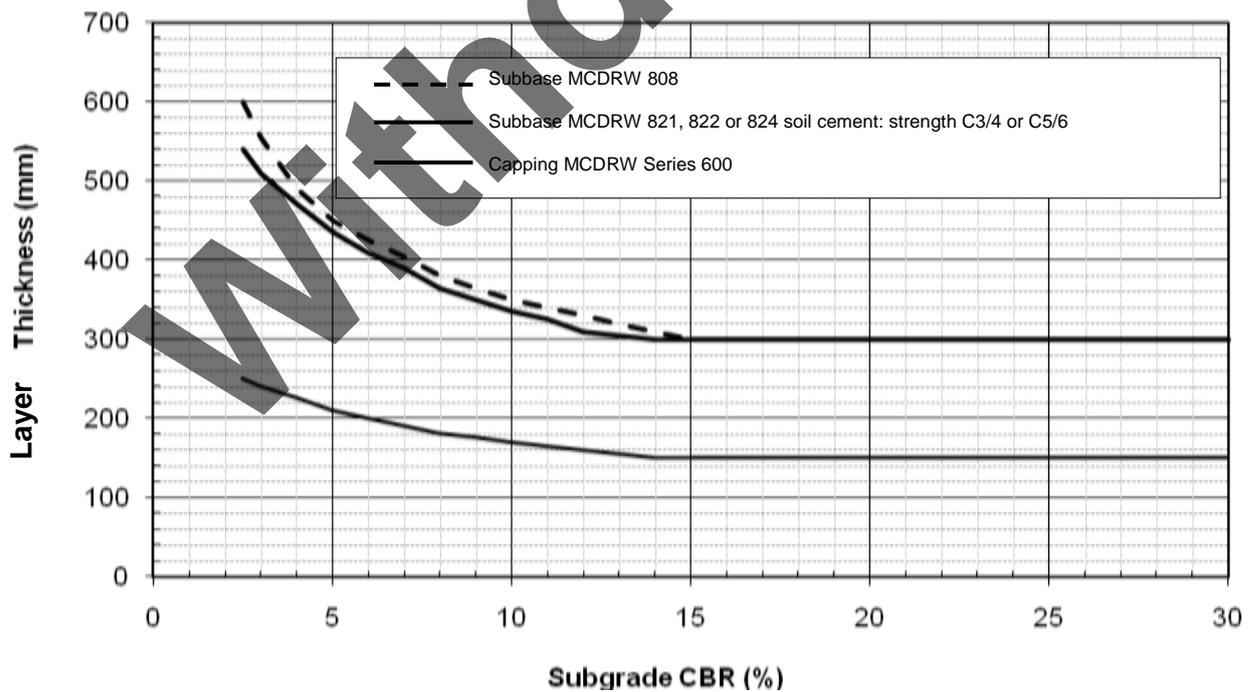


FIGURE 5.2 – Foundation Design options for Flexible Composite Pavements – Subbase on Capping (Foundation Class 2)

Pavement Thickness Design

5.15 The thickness of flexible composite pavement layers appropriate for the specified design traffic is given in Figure 5.3.

5.16 For a flexible composite pavement, the left hand portion of Figure 5.3 gives the thickness of HBM for a given strength, with the thickness of overlying asphalt in the right portion of the nomograph. Better performance is expected for those mixtures made with a crushed rock coarse aggregate that has a coefficient of thermal expansion less than 10×10^{-6} per °C (typically limestone).

5.17 Previous HBM base designation are not directly comparable with the new HBM base designations now detailed in Series 800 of the NRA Specification for Road Work. This is due to differences in aggregates grading; compressive strength measured at different ages; and a wider range of HBM designations with different strength properties. For standard design purposes some of the materials with nominally similar equivalence are identified in the supporting Table in Figure 5.3.

5.18 Individual construction widths of HBM base must not exceed 4.75m without the introduction of longitudinal crack inducers as required by Series 800 of the NRA Specification for Road Works (MCDRW 1). This minimises the risk of longitudinal cracking induced by combined stresses in a 'long life' HBM base pavement. Flexible roads with an HBM base with thinner construction are expected to deteriorate by general cracking of the HBM such that restricting the individual construction width will not necessarily lead to improved performance.

5.19 For long-life heavily trafficked flexible pavements with an HBM base, a total 180mm thickness of asphalt overlay to HBM base is required to sufficiently delay the onset of reflection cracking, provided transverse cracks have been induced in the HBM base at 3m intervals, where required by Series 800 of the NRA Specification for Road Works (MCDRW 1).

Notes on Figure 5.3

Composite Pavement Construction

1. Minimum allowable HBM base thickness is 150mm for flexible construction with HBM base.

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

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

where:

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

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

3. The asphalt material is to be laid with no negative tolerance on the overall thickness.

4. Surface course must be one of the permitted materials presented in the NRA Addendum to HD 36. For further details refer to the NRA Addendum to HD 37.

5. A binder course at least 50mm thick (subject to Note 7) and compacted to meet the maximum air voids requirements in the 900 Series of the NRA Specification for Road Works (MCDRW 1) is required beneath the surface course.

6. If 50mm of Porous Asphalt (PA) surfacing is to be used its contribution to the material thickness is only 20mm. A 60mm Asphalt Concrete binder course is required beneath PA surfacing, compacted so that the air voids are less than the maximum specified in Series 900 of the NRA Specification (MCDRW1).

7. This figure assumes that the binder course is material of the same bitumen penetration grade as the base. However any permitted material may be used as long as the overall pavement thickness is adjusted to give equivalent load spreading ability in accordance with Chapter 9.

8. HBM designations shown in the table insert to Figure 5.3 are consistent with those detailed in the Notes for Guidance to the Specification (MCDRW 2) Table NG 8/1.

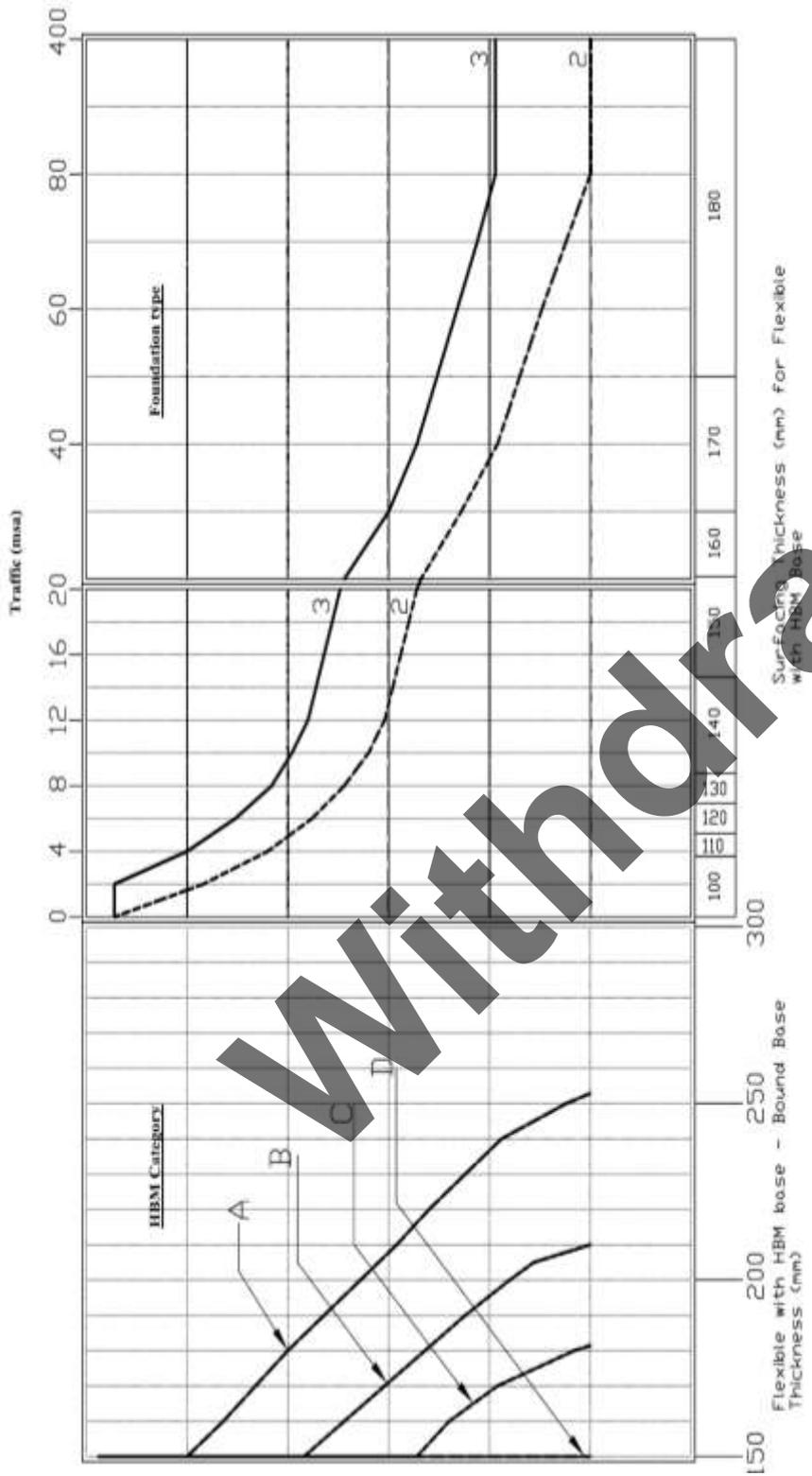
9. All HBM layers that are expected to reach a compressive strength of 10MPa at 7 days must have cracks induced in accordance with the NRA Specification (MCDRW 1) Clause 818.

Example for Figure 5.3:

- Design traffic of 60 msa and Foundation Class 2
- 180mm Asphalt *, over
- 180mm HBM Category C**

Note *: The total asphalt thickness from Figure 5.3 comprises the surface course, binder course and base

Note **: Refer to the table insert to Figure 5.3 for allowable HBM materials, e.g. a CBMG B with laboratory performance category C12/15 (or T4) containing crushed rock aggregates with low thermal expansion characteristics. Laboratory performances are described in the 800 Series of the NRA Specification (MCDRW 1).



Hydraulic Bound Base Material Category

HBM Category	A	B	C	D
Crushed Rock Coarse Aggregate: (with coefficient of thermal expansion < 10x10 ⁻⁶ per °C)	-	CBGMB - C8/10 (T3)	CBGMB - C12/15 (T4)	CBGMB - C16/20 (T5)
Gravel Coarse Aggregate: (with coefficient of thermal expansion ≥ 10x10 ⁻⁶ per °C)	CBGMB - C8/10 (T3)	CBGMB - C12/15 (T4)	CBGMB - C16/20 (T5)	-

Figure 5.3 Design Nomograph for Flexible Composite Pavement

6. RIGID PAVEMENT DESIGN

General

6.1 This Chapter covers the design of foundations and pavements for rigid pavements. Continuously Reinforced Concrete Pavement (CRCP) and Continuously Reinforced Concrete Base (CRCB) pavements are the only pavement types suitable where large or significant differential movement or settlement is expected, because they can withstand large strains while remaining substantially intact. The designs given in this Part are based on TRL Report 630 (2005) for rigid (continuous) construction and TRL Report RR87 (1987) for rigid (jointed) construction.

6.2 Rigid concrete construction is a permitted option for national roads including motorways if it has an asphalt surfacing, see NRA Addendum to HD 36 for permitted surfacing options in Ireland. This requirement generally makes jointed construction unsuitable for consideration, due to reflective cracking of the surfacing and the potential for future increased maintenance. The requirement for asphalt surfacing does not apply to lay-bys and hardstanding locations, which may have a concrete surface.

6.3 Use of continuously reinforced concrete pavements with a Polymer Modified Stone Mastic Asphalt (PMSMA) can provide a 'long life' with all the advantages offered by the noise reducing properties of the surfacing. Such pavements are ideally suited to the application of further asphalt overlays at stages during the future pavement life.

6.4 Permissible rigid pavement options are either:

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

Other forms of rigid construction such as Unreinforced Jointed Concrete (URC) or Jointed Reinforced Concrete (JRC) are not permitted

except where required to accommodate traffic detection equipment within toll plazas.

Foundation Design

6.5 The foundation shall be a Class 2 or a Class 3 foundation designed in accordance with the requirements of Chapter 5. For rigid construction a cemented subbase is required to minimise the risk of water penetrating cracks and joints, causing erosion and weakening the subbase. Cement bound subbases also aid the compaction of the overlying pavement concrete. A sprayed bituminous membrane is required over the subbase to prevent suction of water from the pavement concrete.

Pavement Design

6.6 For a rigid pavement, the total thickness (excluding any asphalt surfacing) is obtained from the right hand portion of Figure 6.1 for CRCP; and the left hand portion for a CRCB. Thickness for a given design traffic depends on the flexural strength of concrete and the Foundation Class.

6.7 The following design concrete flexural strength shall be assumed unless specific material testing has been undertaken to demonstrate the achievement of higher values:

- 1) 4.5MPa for C32/40 concretes with gravel coarse aggregate
- 2) 5.0MPa for C32/40 concretes with crushed rock coarse aggregate

Higher flexural strengths may only be used with the agreement of the NRA Head of Engineering. Concrete of flexural strength 5.5MPa or greater must use aggregate that has a coefficient of thermal expansion less than 10×10^{-6} per °C unless a 'Departure from Standard' from the National Roads Authority is obtained

6.8 To ensure that forces are not transmitted to structures and adjacent forms of pavement construction by thermally induced movements of the slab, the ends of the CRCP and CRCB must be

addressed in the design. Typical details are shown in the NRA Road Construction Details.

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

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

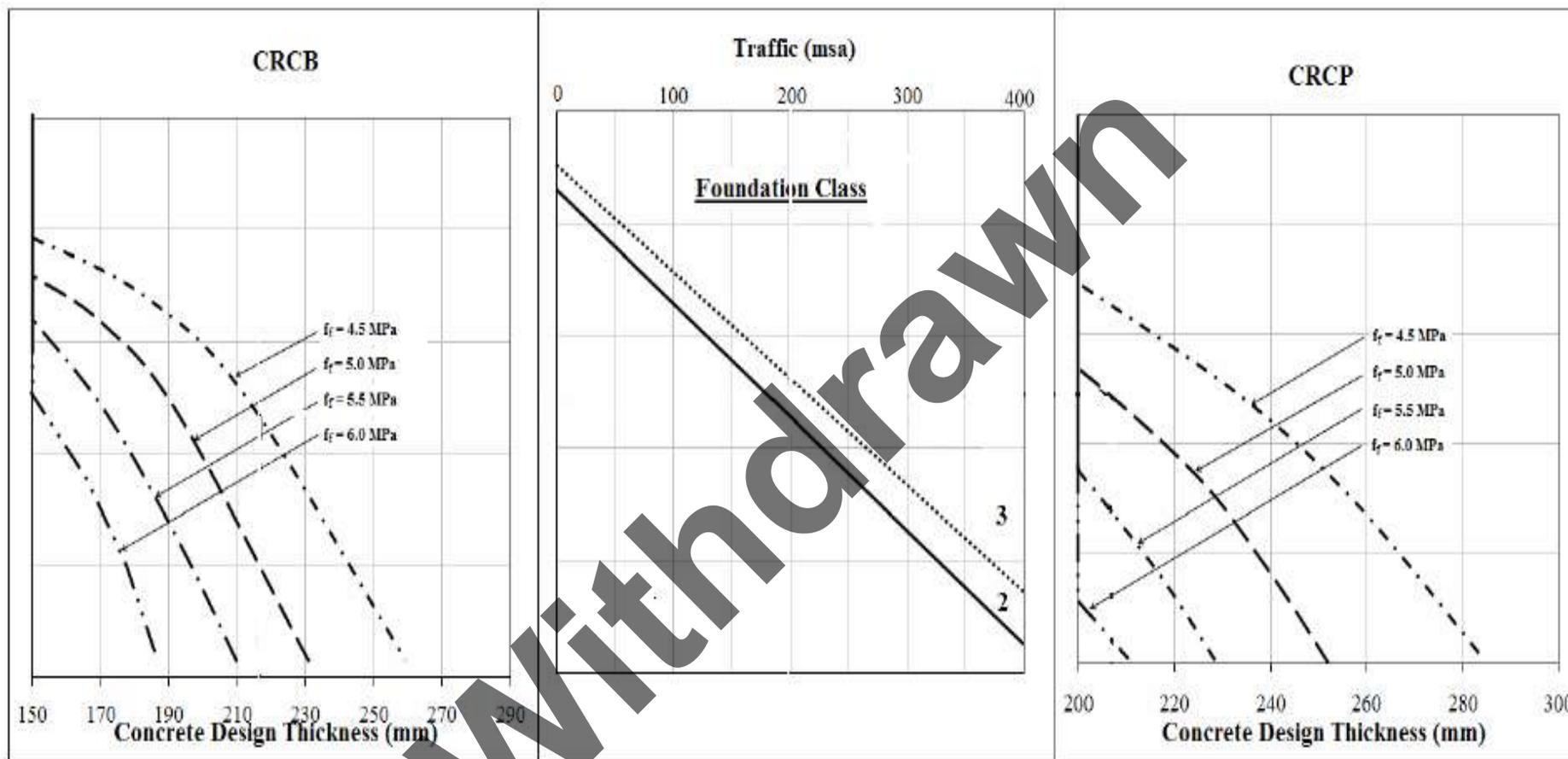
6.11 Transverse steel is required for ease and consistency of construction, and to prevent longitudinal cracking and local deterioration. Transverse bars may be incorporated into the support arrangement for the steel, so long as the required quantities and position of the steel is maintained.

6.12 Figure 6.1 assumes the presence of an integral minimum 1m edge strip or tied hardshoulder adjacent to the most heavily trafficked lane. Urban roads, and any other roads that do not have either of these adjacent to the left hand lane, will require 30mm thicker slabs. Heavy trafficking of right hand lanes and hardshoulders during future maintenance will be of relatively short duration and need not be considered in the design.

6.13 The use of a tied shoulder or 1m edge strip ensures that the untied edge is remote from the wheelpaths, with a consequent reduction in stress at slab corners and edges. This load distribution occurs whether or not a longitudinal construction joint or wet-formed joint is included adjacent to the edge line. Edge treatments and other construction drawings are given in the NRA Road Construction Details. For further advice on edge of pavement drainage, refer to HA 39.

6.14 The design equations for jointed concrete pavements are given in Figure 6.3. Load induced stresses at slab corners and edges are greater than in the slab centre, necessitating dowel bars to

distribute loads between slabs. Joint associated distress occurs principally when dowels do not function properly.



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Figure 6.1 Thickness for Rigid (Continuous) Pavements

Notes on Figure 6.1:-

1. Thicknesses are to be rounded up to next 10mm.
2. f_t (MPa) denotes mean concrete flexural strength at 28 days. Refer to Clause 6.7 to select appropriate flexural design strength.
3. The concrete design thickness value assumes the presence of a minimum 1m edge strip or tied shoulder; otherwise the concrete design thickness shall be increased by 30mm.
4. Surface course must be one of the permitted materials presented in NRA Addendum HD 36. For further details refer to NRA Addendum HD 37.
5. A binder course compacted to meet the maximum air voids requirements in the 900 Series of the NRA Specification (MCDRW 1) is required beneath the surface course for CRCB construction. It shall be of any permitted material specified in Series 900(MCDRW1) and be at least 50mm thick.
6. Foundations below rigid pavements must comprise at least 150mm of bound subbase material, in order to ensure subbase material durability.
7. If Porous Asphalt (PA) surface course is used over CRCB, it must be laid over a dense binder course that is compacted so that the air voids are less than the maximum in the 900 Series of the NRA Specification for Road Works (MCDRW 1). The PA shall be 50mm thick over a 90 mm binder course or 50 mm thick over a 60 mm binder course with the CRCB increased by 10 mm in thickness
8. Where CRCP is used a minimum 30mm of PMSMA is required, for noise reduction; hence no binder course is required. The use of CRCP with no surfacing is not permitted.
9. Minimum allowable concrete material thickness is 200mm for CRCP construction and 150mm for CRCB construction. The concrete thickness in Figure 6.1 does not include any asphalt surfacing; minimum allowable asphalt material thickness is 100mm for CRCB construction.

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

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

Example for Figure 6.2

1. Design traffic 200msa with a bound, Foundation Class 2

CRCB Option [A]:

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

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

2. Design traffic 275msa with a bound, Foundation Class 3

CRCP Option [B]:

- 30mm PMSMA over,
- 220mm+30mm = 240mm of 5.0MPa flexural strength concrete (without a tied shoulder or 1m edge strip)
- T16 longitudinal reinforcement bar spacing (i.e. maximum distance, centre to centre, between bar across the width of the slab).

$$\frac{100 \times \pi \times D^2}{4 \times t \times R} = \frac{100 \times \pi \times 16^2}{4 \times 250 \times 0.60} = 134\text{mm}$$

Where:

t = concrete design thickness

R = reinforcement (%)

D = diameter of reinforcement bars

Consider Line A in the design Nomograph.

- Consider Line B in the design Nomograph.

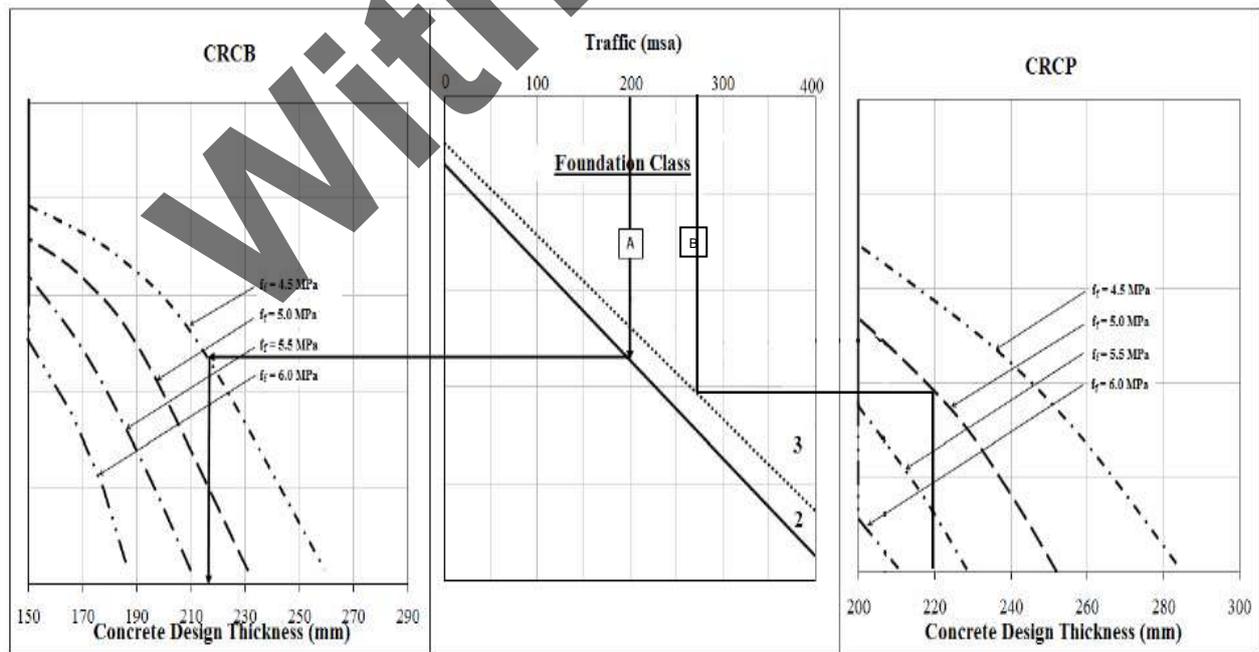


Figure 6.2: Design Thickness for Rigid (Continuous) Pavements

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

For unreinforced jointed concrete pavements (URC):

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

For reinforced jointed concrete pavements (JRC):

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

Where R = 8.812 for 500 mm²/m reinforcement
R = 9.071 for 600 mm²/m reinforcement
R = 9.289 for 700 mm²/m reinforcement
R = 9.479 for 800 mm²/m reinforcement

$$H_2 = 0.934 H_1 - 12.5$$

Where: H₁ is the thickness (mm) of the concrete slab without a tied shoulder or 1m edge strip
= minimum 150mm
H₂ is the thickness (mm) of the concrete slab with a tied shoulder or 1m edge strip
Ln is the natural logarithm
T is the design traffic (msa) = maximum 400msa
R_c is the mean compressive cube strength (N/mm² or MPa) at 28 days
E is the Foundation Class Stiffness (MPa)
= 200MPa for Foundation Class 3

Figure 6.3 Design Thicknesses for Rigid (Jointed) Pavements

Notes on Figure 6.3:

1. Maximum transverse joint spacings for URC pavements:

- a) for slab thickness up to 230mm
- 4m for contraction joints;
- b) for slab thickness 230mm and over
- 5m for contraction joints

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

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

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

4. If concrete is used with aggregate that has a coefficient of thermal expansion less than 10×10^{-6}

per °C transverse joint spacings may be increased by 20%.

5. For details of permissible concrete surfacing refer to the NRA Addendum to HD 36 and HD 38.

7. EME2 DESIGN

General

7.1 EME2 is a durable, deformation resistant, high performance base and binder course mixture, based on established French technology. The designation EME is from the French name Enrobe à Module Elevé (“High Modulus Coated”), and this acronym is being retained to differentiate these mixtures from the traditional High Modulus Base (HMB) materials which have significantly lower binder contents. Further information on the background to the material and the reasons for its introduction are explained in TRL report TRL 636 (2005).

7.2 EME2 base and binder shall conform to Clause 930 of the NRA Specification (MCDRW1). Permitted base and binder options are as follows:

- AC10 EME2 base 10/20 des;
- AC10 EME2 base 15/25 des;
- AC14 EME2base 10/20 des;
- AC14 EME2 base 15/25 des;
- AC20 EME2 base 10/20 des;
- AC20 EME2base 15/25 des.

- AC10 EME2 bin 10/20 des;
- AC10 EME2 bin 15/25 des;
- AC14 EME2 bin 10/20 des;
- AC14 EME2 bin 15/25 des;
- AC20 EME2 bin 10/20 des;
- AC20 EME2 bin 15/25 des.

EME2 base and binder course must target a penetration of 15-20, which can be achieved using 10/20 or 15/25 penetration grade binder.

Foundation Design

7.3 The foundation shall be a Class 3 Foundation designed in accordance with the requirements of Chapter 5.

Pavement Thickness Design

7.4 The thickness of pavement material appropriate for the specified design traffic is given in Figure 7.1.

1. Thicknesses are to be rounded up to next 10mm.
2. Minimum allowable total asphalt thickness is 200mm for flexible construction with EME2 base.
3. Where the asphalt design thickness is 300mm or less, the material is to be laid with no negative tolerance on overall thickness.
4. Surface course must be one of the permitted materials presented in the NRA Addendum to HD 36. For further details refer to the NRA Addendum to HD 37.
5. An EME2 binder course must be provided beneath a Polymer Modified Stone Mastic Asphalt course but is optional beneath other materials such as HRA where this is permitted. If used, the binder course shall be compacted to meet the maximum air voids requirements in the 900 Series of the NRA Specification (MCDRW 1).
6. If 50mm of Porous Asphalt (PA) surfacing is to be used its contribution to the material thickness is only 20mm. A 60mm EME2 binder course is required beneath PA surfacing, compacted so that the air voids are less than the maximum specified in the 900 Series of the NRA Specification (MCDRW 1).

Example for Figure 7.1:

- Design traffic >80 msa (‘long life’ pavement)
- Design thickness - 270mm EME2 on Foundation Class 3 (rounded to nearest 10mm)
- Surfacing options permitted for each scheme will vary but some examples are given below:
 - a) 35mm SMA 14 surf PMB 65/105-60 des + 55mm AC 14 EME2 bin/base 10/20des + 180mm AC 20 EME2 bin/base 10/20des.

Notes on Figure 7.1:-

b) 45mm HRA 30/14 F surf 40/60 + AC 14
EME2 bin/base 10/20des + 200mm AC 32
dense base 40/60 rec

Withdrawn

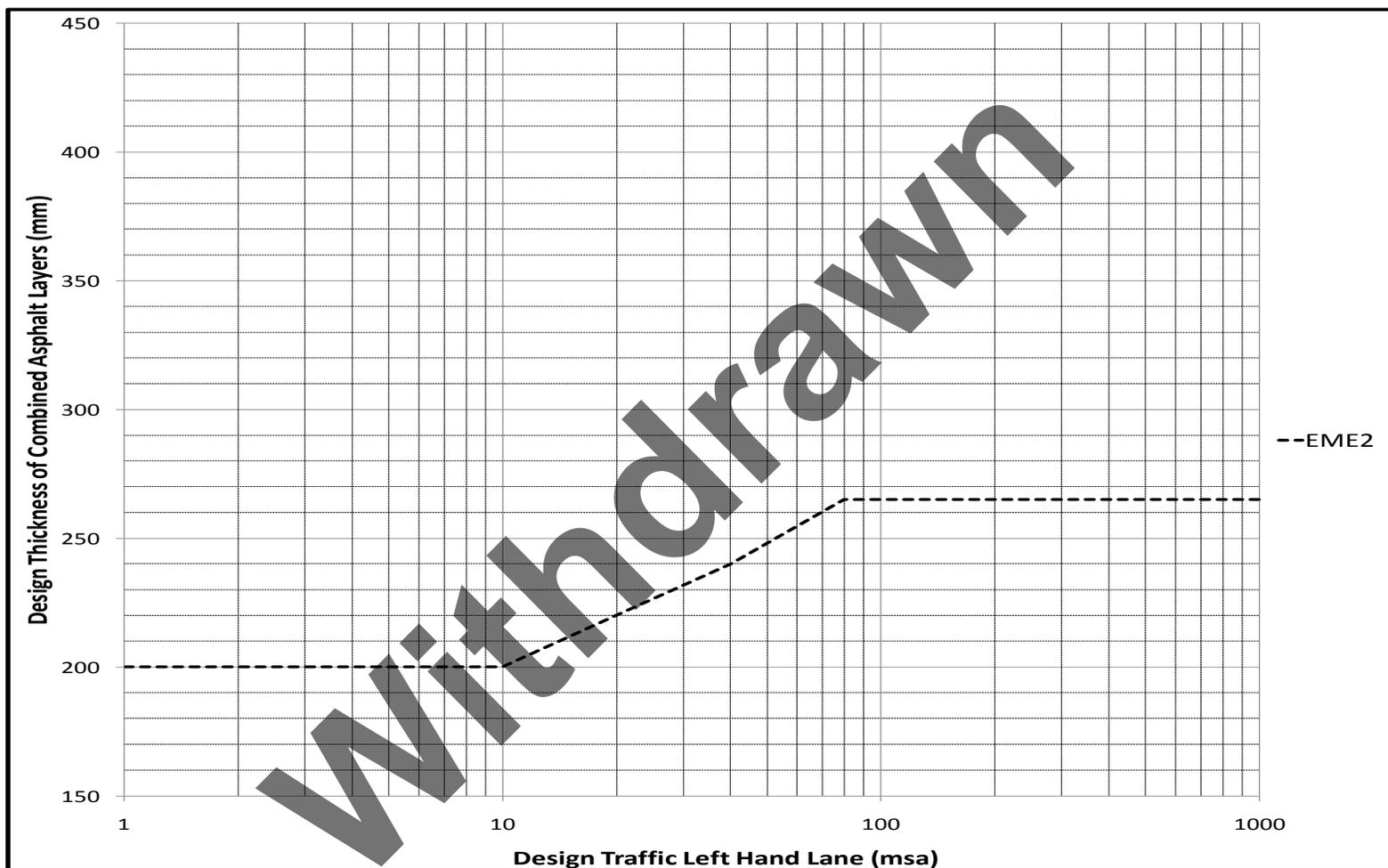


Figure 7.1 Design chart for EME2 pavement

8. BOUND MATERIALS

BITUMEN BOUND MATERIALS

8.1 Most asphalt binder course and base materials are characterised by an aggregate skeleton, where the individual particles are mechanically interlocked, bound with penetration grade bitumen in the range 10/20 to 70/100pen. The aggregate skeleton provides deformation resistance (provided that in-situ air voids are typically in the range 2-6%), as well as contributing to stiffness. The 900 series of the NRA Specification for Road Works (MCDRW 1) sets out the requirements for the materials. The binder content should be sufficient to provide thick enough binder films on the aggregate to create fatigue resistance and achieve durability. Generally, the lower penetration binders are used to obtain increased stiffness and deformation resistance.

Premature Rutting

8.2 Early age deformation (rutting) in surface and binder course layers may be linked to trafficking by slow moving commercial vehicles (e.g. in a contraflow), especially on uphill lengths and when pavement temperatures are high, relatively soon after the materials have been laid (e.g. after major maintenance in the summer). Therefore, such situations should be avoided.

Bond Between Layers

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

8.4 Particular attention should be paid to specifying and achieving good bond between a Polymer Modified Stone Mastic Asphalt (PMSMA) and the underlying flexible or rigid construction. This is because, under certain circumstances (e.g. braking vehicles), high shear stresses can be developed at these shallow interfaces.

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

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

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

8.7 A decision to use PA should be taken only after consideration of all relevant factors. The National Roads Authority shall be consulted for advice on the suitability of using PA in particular circumstances. Further details on PA are contained in the NRA addendum to HD 37.

PAVEMENT CONCRETE

8.8 The stress generated in a concrete slab partly depends on the stiffness ratio between the slab and its underlying support. To maximise the pavement life, all rigid pavements require a bound (minimum 150mm thickness) subbase, since this would erode less readily than an unbound subbase material and is less water susceptible should joint sealants fail.

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

Continuously Reinforced Concrete (CRCP and CRCB)

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

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

8.12 Discontinuities in the slab should be avoided wherever possible as they encourage the formation of closely spaced cracks, with increased risk of spalling. Gullies and manholes should be located outside the main CRCP/CRCB slab for this reason. If this is not possible, the slab around the gullies and manholes should be

heavily reinforced as shown in the NRA Road Construction Details.

8.13 A CRCP surface course, reduces noise generation and water penetration (and the potential for steel corrosion). If the surfacing is 100mm thick (or more) it also provides a degree of thermal protection from rapid temperature changes for the concrete base. If the 30mm minimum PMSMA is used, the bond coat required by the approved system is important to ensure good adhesion. It will be necessary for the PMSMA to comply with the requirements of Clause 942 of the NRA Specification for Road Works (MCDRW 1).

Jointed Pavements

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

8.15 Three different types of joints are used in concrete pavements. They are contraction, expansion and warping joints, typical details of which are illustrated in the NRA Road Construction Details

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

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

.HYDRAULICALLY BOUND MIXTURES

8.18 HBMs shall comprise cement binder. HBM must be produced, constructed and tested in accordance with the 800 Series of the NRA Specification for Road Works (MCDRW 1).

8.19 Traditionally Cement Bound Material have been characterised in terms of compressive strength at seven days for compliance purposes; and in terms of both dynamic stiffness modulus and flexural strength for design purposes.

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

Withdrawn

9. ALTERNATIVE DESIGN PROCEDURES

Alternative Pavement Designs

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

9.2 Pavement design guidance comprising cold recycled base material is presented in UK TRL Report 611 (2004). These designs require a 'Departure from Standard' from the National Roads Authority.

Alternative "Analytical" Pavement Design

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

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

9.4 Alternative designs to those contained in Chapters 4, 5, 6 and 7 require a Departure from Standard and must be justified by analytical design in accordance with this Chapter 9.

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

- a) Identify the pavement life requirements in terms of traffic loading (see NRA Addendum to HD 24) in terms of an equivalent number of standard axle loads (40kN wheel).
- b) Consider available and permitted pavement materials (see NRA Addendum to HD 35)
- c) Estimate the in situ dimensions and long-term performance properties (stiffness and / or strength) of each individual layer of pavement material).
- d) Carry out a structural analysis e.g. using a simplified multi layer linear elastic model of the pavement structure.
- e) Compare critical stresses/strains and/or deflections with allowable values.
- f) Make adjustments to c) until the pavement life requirement is achieved
- g) Consider the whole life value of the resultant pavement design(s).

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

- Effective stiffness modulus which governs load spreading behaviour.
- Deformation resistance of asphalt materials only, which governs rutting behaviour.
- Fatigue resistance of asphalt materials, and strength of HBM, which governs cracking behaviour.

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

- excessive stress/strain (combination of magnitude and number of load applications) causing fatigue cracking (typically at the bottom of the base layer) of the asphalt, HBM or concrete material;
- excessive subgrade strain, resulting in structural deformation. [Note: This parameter becomes redundant for flexible composite designs which are based on TRL 615]

9.8 Relationships between pavement life and these critical strains or stresses have been derived for historically standard materials from a combination of laboratory testing and pavement performance monitoring; see Chapter 10 of this Part for references and bibliography.

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

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

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

9.12 To help inform the design process, the NAT 'Springbox' can also be used for unbound and slightly bound materials and this can be used to identify both short-term and longer term stiffness moduli. Site testing as part of demonstration trials can also be used to measure on-site properties.

9.13 For National Road schemes, values of long-term elastic stiffness modulus of standard asphalt materials for use in analytical design must be as

follows, unless reliable data clearly reveals a divergence from these typical figures:

AC 32 dense base 70/100 rec	3,100 MPa
AC 32 dense base 40/60 rec	4,700 MPa
EME2	8,000 MPa

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

9.14 Until further research is undertaken, a maximum reinforcement value of 900mm²/m width of a CRCP (and CRCB) concrete slab shall be used in calculations (despite more reinforcement than this being used in construction, according to the concrete strength as detailed in Figure 6.1), consistent with UK TRL Report 630.

9.15 In other cases, in order to assist with the evaluation of the alternative, the following should also be supplied to the National Roads Authority:

- comparisons with other published designs, especially from countries with similar trafficking levels, climatic conditions and material properties to Ireland or the UK;
- information on the analytical pavement design model adopted;
- material properties assumed and supporting information, e.g. from in situ or laboratory testing, or published data;
- information on the failure mechanisms considered by the designer;
- experience of long term performance of similar pavements, both in Ireland and overseas;
- sensitivity analysis to identify the parameters that have most influence on life;
- procedures to be adopted on site to reduce the variability of pavement construction, in particular the most influential parameters identified from the sensitivity analysis;

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

9.16 It should be noted that a specific analytical design method has not been defined. The available methods referenced in Chapter 10 of this Part may differ in their mathematical formulation, but each method is internally consistent. It should be appreciated that inadequate designs can result if elements from different methods are combined inappropriately.

Withdrawn

10 REFERENCES

NRA Design Manual for Roads and Bridges (NRA DMRB):

NRA Addendum to HD 24 (NRA DMRB 7.2.1)
Traffic assessment

NRA Addendum to HD 27 (NRA DMRB 7.2.4)
Pavement construction methods

NRA Addendum to HD 35 (DMRB 7.1.2)
Conservation and the use of secondary and recycled materials

NRA Addendum to HD 36 (NRA DMRB 7.5.1)
Surfacing materials for new and maintenance construction

NRA Addendum to HD 37 (NRA DMRB 7.5.2)
Bituminous surfacing materials and techniques

NRA Addendum to HD 38 (NRA DMRB 7.5.3)
Concrete surfacing and materials

UK Design Manual for Roads and Bridges (DMRB):

Interim Advice Note 73/06

HD 25/94 (Superseded version of DMRB 7.2.2)
Foundations

HD 26/01 (Superseded version of DMRB 7.2.3)
Pavement Design

HD 26/06 (DMRB 7.2.3) Pavement Design

HA 39 (DMRB 5.3) "Edge of pavement details"

HA 41 (DMRB 4.2) "Permeability Testing of Aggregates".

HA 44 (DMRB 4.1.1); "Earthworks: Design and Contract Documents".

NRA Manual of Contract Documents for Road Works:

Volume 1: Specification for Road Works (MCDRW 1)

Volume 2: Notes for Guidance on the Specification for Highway Works (MCDRW 2)

Volume 4: Road Construction Details (MCDRW 4)

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TRL Report 615; Nunn, M., “Development of a more Versatile Approach to Flexible and Flexible Composite Pavement design”.

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TRL Report 630; Hassan, K., Chandler, J., Harding, H., Dudgeon, R., “New Continuously Reinforced Concrete Pavement Designs”.

TRL Report 636: Sanders, P.G. and Nunn, M., “The application of Enrobe a Module Elevé in flexible pavements”

British Standards

1981

BS5930; “Code of Practice for Site Investigations”, BSI.

1990

BS1377; Part 4; “Compaction Tests”, BSI.

BS1377; Part 9; “In Situ tests”, BSI.

BS812; Part 124; “Methods for Determination of ten per cent fines value (TFV)”, BSI.

2003

BS EN 13286-43 “Unbound and hydraulically bound mixtures. Test method for the determination of the modulus of elasticity of hydraulically bound mixtures”. BSI

Others

2005

Edwards, J.P., Thom, N.H. Fleming, P.R. and Williams, J., 2005. “Accelerated Laboratory Based Mechanistic Testing of Unbound Materials within the Newly Developed NAT Springbox”. Transportation Research Record. Issue Number 1913. Journal of the Transportation Research Board

11 ENQUIRIES

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

Head of Engineering
National Roads Authority
St Martin's House
Waterloo Road
Dublin 4



.....
Tim Ahern
Head of Engineering

Withdrawn

Withdrawn

Withdrawn



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