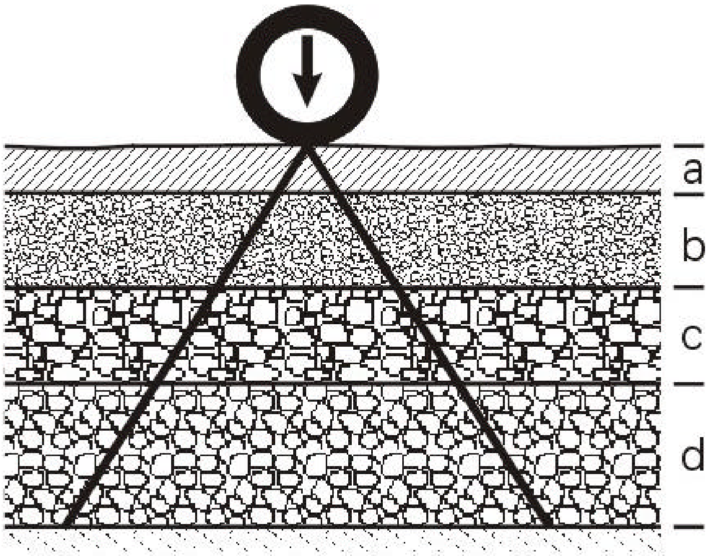
Kent County Council

Road Pavement Design Guide – July 2000



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1 Introduction

In 1984 TRRL published Report LR1132, 'The Structural Design of Bituminous Roads *Powell, Potter Mayhew and Nunn*'. This research document was translated for use by highways design engineers working in Kent and published first as M85/2 in 1985. This document was replaced in 1988 by M88/1. It enlarged upon some aspects of the DTp Design Guide and related it to reconstruction/rehabilitation works.

Over the years changes have occurred, principally in the measurement of sub-grade strength, changes in advice from Central Government (Highways Agency [HA]) in their Design Manual for Road and Bridge Works [DMRB], the introduction of new materials for the structural layer, the demise of Hot Rolled Asphalt as a surfacing material and the need to promote sustainable construction techniques, in particular recycling.

It has been found necessary to revise M88/1 and the similar Report 013 with this document (M99). In addition the subgrade assessment philosophy contained within M88/2 has been incorporated within this document for the sake of convenience

The major changes between this document and M88/1 and Report 013 are as follows:

- Subgrade at time of construction and during the life of the pavement [equilibrium] has to be evaluated
- Traffic levels can be determined in a number of ways
- Whilst designs are based on Type 1 sub-base (Category A material), alternatives have been provided for Contractors to propose in order to encourage the use of secondary aggregates
- Asphalt substitution has been extended to cover other materials and designs for in-situ recycling /stabilisation are included.
- The use of hydraulic bound bases has been enlarged
- Hot rolled asphalt roadbase has been discontinued. Whilst a design based on DBM50 is the norm, information has been provided so Contractors can offer other thickness of other asphalt materials. (Note: The term asphalt is now used for all bitumen bound materials)
- Hot Rolled Asphalt wearing course has been substituted with Thin Surfacing
- Concrete Block paving design is included within British Standards, but the key tables are included.

For the new construction of heavily trafficked roads and motorways the design guide is identical to that published by HA. For other sites it compiles the best current practice. There are projects on-going to improve the design of lightly trafficked pavements and these will be incorporated, as they become available.

Kent County Council publishes a number of reports, specification clauses and notes for guidance these are referred to but not included herein.

This document contains guidance on the evaluation of foundation strength, determination of materials and layer thickness for new works and reconstruction of existing carriageways. The information provided is to be included in Appendix 7/1 of the Contract as applicable.

Contractors may provide alternative materials and construction thickness, with the approval of the engineer, but such alternatives should deliver equivalent performance to those described in this document.

2 Use of the Design Guide and Pavement Options

This document is intended to cover the design of new schemes of any size and reconstruction or rehabilitation on existing highways. However a design carried out in accordance with this guide has no definable maintenance free 'life' as this is significantly affected by the quality of installation/ construction. However an implied structural design life of 20 years has been assumed as the norm.

The key information is given in tables in bold type or with text surrounded thus. Other information is explanatory or for information only

It is intended that the scheme designer should carry out a pavement design based on one foundation design;(sub-base alone or sub-base plus capping layer), and one flexible design for the structural layer (unless a concrete block surface is preferred). The designer may select a different sub-base or structural layer option e.g. stabilised material or a hydraulic bound roadbase, and design information has been provided.

It is expected that a contractor may put forward alternative designs using materials of equivalent performance e.g. recycled materials/techniques as permitted by this document in order to reduce costs. In order to do this the designer will need to put on the drawings or elsewhere in the contract documents the equilibrium CBR and Design traffic so that the necessary calculations can be carried out.

Whilst the Highways Agency expects that the contractor to be given a free choice of pavement construction options between flexible, flexible/composite and rigid pavement for their schemes, in Kent the use of the rigid options is not permitted for a highway. Design guidance for Rigid Pavements is not included. In other situations where this form of construction may be advantageous e.g. hardstandings or other pavements receiving heavy loading from, for example, fork lift trucks, designers should consult the relevant section in the Design Manual for Road and Bridges or other pavement design guidance. Concrete block surfaces are suitable for these applications.

Hydraulic bound binders are preferred for the flexible composite option in order to reduce the possible maintenance requirements caused by reflective cracking.

Portland cement binders are only permitted in the following circumstances:

a) in-situ recycling with cement is to be used, this is in order to promote recycling as a policy.

b) the surfacing layer is to be concrete or clay pavers, setts or flags/slabs.

c) traffic requirements mean that more than 180 mm of asphalt overlay is required i.e. a Total Design flow in excess of 20msa.

A pavement construction may need to satisfy 4 structural functions:

a) to provide a construction access route for building the works if necessary.

b) to provide a layer of sufficient stiffness so that subsequent layers can be compacted properly.

c) to ensure that the traffic loads during the life of the carriageway do not cause rutting or cracking of the foundation, the structural or surfacing layers.

d) to provide adequate protection to frost susceptible soils.

The design of a scheme should enable the maximum use to be made of the material available on the site for capping layer, sub-base or roadbase by using a permitted binder. In addition, the use of construction materials from sources that maximise the amount of recycled materials is strongly encouraged.

This Design Guide is intended for schemes constructed in Kent. Its use elsewhere will require a review by appropriately competent Design Engineers and acceptance of the designs by the Client

Flow Chart 2 given below summarises the design process.

Chart 2 Design Flow Chart

Section 3
Subgrade CBR

Carry out Site Investigation to evaluate CBR
a) during construction and
b) during pavement life

Appendix F gives appropriate methods. Use Soil Type description and moisture (with less accuracy) in Table 3.2

Section 4
Foundation design

Capping and /or Sub-base options

Use Table 4.4.1a or 4.4.1b for thickness during construction
Use Table 4.4.2a or 4.4.2b for thickness during pavement life

Select worst case

Use Table 4.5.1 to provide alternative thickness for other categories of sub-base;
Para 4.5.2 for asphalt substitution/ soil stabilisation:
Section 4.6 for recycled materials

Check for frost protection (at end of design process) (Para 4.4.3)

Section 7
Surfacing Design

Thin surfacing thickness is selected by the contractor and deducted from total asphalt thickness in Section 6

Using commercial vehicles (Section 5) and Appendix C to determine required PSV of coarse aggregate

Choose texture depth to suit traffic speed

Consider colour

Section 5 Traffic

Detailed evaluation from:

Commercial vehicle (c.v.) flow count. (Para 5.2)
Vehicle wear factor: Use Table 5.4.1 to change c.v. to std. axles
Design Life: Normally 20 years (Para 5.4.2)
Traffic Growth: Para 5.4.3. and Appendix A
Left hand lane : Table 5.4.4
Calculate msa (Section 5.4.6)

OR

Obtain OGV1 and OGV2 flow
Use Chart/Table in Appendix A to obtain msa

OR

Select traffic from standard road descriptions Tables 5.5, 5.6 or 5.7 (with less accuracy)

Section 6
Structural layer design

Flexible (Para 6.1)
Use Appendix B1 for total asphalt thickness

Use Appendix B2 or B3 to provide alternative thickness for other classes of asphalt stiffness

Composite Hydraulic bound (Para 6.3)
Use Appendix B4 for thickness of roadbase and total asphalt based on knowledge of material properties and cost

Composite Cement Bound (Para 6.2)
(These include in situ recycled materials)
As for hydraulic bound

Section **8** **Block Paving Design**
Use Appendix B5 or B6 to determine structural layer
Consider skid resistance, abrasion resistance, colour

3 Measurement of Subgrade

The design philosophy introduced by LR1132 and described in M85/2 and M88/1 is retained here. The pavement has to be built on subgrade of known strength. For heavily trafficked roads the principle of the design is that the subgrade is improved as necessary and with the sub-base form a stable platform for the construction of the bound structural layer and surfacing above. For the longer term the capping and/or sub-base prevent water reaching the bound layers and provide a platform on which to compact the bound layers.

The philosophy for both composite and blacktop roads is that the sub-base/ capping layer does not vary in thickness with traffic, but only with the strength of the subgrade. The same thickness is used for both road types.

The California Bearing Ratio (CBR) is still the best indicator of soil strength despite difficulties in measurement particularly on mixed fine and coarse graded materials and taking account of the effects of moisture.

There is a method currently being piloted by HA based upon the Portable Dynamic Plate, which measures the stiffness of the sub-grade under dynamic loading. This is particularly advantageous where a road is being widened so that the foundation will be at or close to equilibrium although for new roads alternative methods will be necessary to determine equilibrium CBR values.

3.1 Site Investigation

A pre-construction geotechnical site investigation shall be carried out for all sites in order to assess a number of design issues; in particular the stiffness (CBR) of the material, its moisture sensitivity and if necessary its suitability for earthworks and stabilisation to form capping layer, sub-base or roadbase material.

The site investigation should be carried out in accordance with the Association of Geotechnical Specialists (AGS) Guidelines for Good Practice in Site Investigation and in accordance with BS5930 (Ref 4).

The scale of the investigations will be dependent upon the scale of the project, but should typically comprise a Desk Study followed by a ground investigation. A separate chemical contamination risk assessment may also need to be undertaken.

A Desk Study is beneficial for even small schemes with valuable data readily available from Well Records, published records, geological maps and memoirs, aerial photographs, local libraries, local authority landfill databases, speleological society records and aquifer protection maps. This literature search will help to optimise and accelerate the planning of the ground investigation and the subsequent design and construction process.

Notwithstanding, any site investigation can, by its very nature, only sample the soils at discrete locations within the site. Variability is inevitable and this should be included for in the design of the works. If necessary advice on the likely range of CBR values may be obtained from a competent Geotechnical Engineer.

In addition to the determination of design CBR values for both short term and long term characterisation of the subgrade performance, many other factors can affect the performance of the subgrade which must be considered during the design stage. Typical issues to be addressed include the following:-

a) Depth to the water table/perched water tables.

b) Chemical contamination risk assessment.

c) Control of piping of fine grained soils.

d) Risk of encountering loose Made Ground.

e) Need for ground improvement of foundation soils (e.g. soft Alluvium, loose Made Ground etc.)

f) Risk of collapse settlement of dry engineered fill.

g) Risk of landslips.

h) Risk of underground caves, deneholes etc.

i) Impact of adjacent developments for sites on soft Alluvium.

j) Frequency and treatment of subgrade solution features in Upper Chalk and Hythe Beds.

k) Treatment of solution features below drainage runs.

l) Frequency and treatment of other subgrade soft spots.

m) Frost susceptibility of subgrade.

n) Differential settlement risks/need for ground improvement.

o) Chemistry of subgrade soils if in-situ lime/cement stabilisation is considered.

p) Shrinkage/swelling potential of over-consolidated clays. (particularly where trees removed)

q) Risk of open fissures in underlying rock.

r) Risk of soft clay layers in a granular soil.

The above list illustrates that laboratory and/or field CBR testing may not be exclusively used to determine the performance of the road pavement foundation. Foundation failure can occur for many other reasons including settlements induced in underlying soft Alluvium/loose Made ground, shrinkage and swelling of cohesive soils, softening/washouts produced by groundwater/poor drainage and frost heave. Many of these are borne out by case histories in Kent which have often been costly to rectify.

Designers should asses the relative impact of the above on the pavement design and incorporate any necessary works to allow for them. Additional specialist advice may need to be sought

3.2 Selection of method for determination of CBR.

There are two cases to be considered for design, the likely CBR at time of construction and the long-term equilibrium value. For the purposes of design both of these are required. Should the ‘as found’ CBR at time of construction be lower than that at site investigation, a change in foundation layer thickness may be required.

The strength of many Kent soils, e.g. Folkestone Sand, Gault Clay, Weald Clay and Chalk are very dependent upon moisture content, condition and density with, for example, rapid loss of strength as the moisture content increases. On such soils, protection during construction as described in the Specification for Highway Works is particularly important together with a conservative view when considering the effect of subgrade drainage.

The method to be selected for determination of CBR should be based upon the size of the scheme, the accuracy required and the likely soils to be encountered, as detailed in Appendix F.

For cohesive soils the plasticity index should be determined, or for other soils the description of the soil type from a grading analysis of a bulk sample and some knowledge of the possibility of saturation in the future evaluated. From this information the CBR can be approximately determined using Table 3.2 below.

Table 3.2 Equilibrium CBR values and Plasticity Index

Soil Type	Plasticity Index	Design CBR %
Plastic Clay	**Greater than 50**	**Less than 2**
Silty Clay	**40**	**3**
Sandy Clay	**30**	**3**
Sandy Clay	**20**	**Less than 2**
Silt	**10**	**Less than 2**
Poorly graded Sand	**-**	**7* (20)**
Well Graded sand	**-**	**10* (40)**
Well Graded sandy gravel	**-**	**15* (60)**
Made Ground		**<2%****
Engineered Fill		**Minimum 2% *****

Notes* This assumes some probability of the material saturating in service. If the drainage and water table position make this very unlikely the figures bracketed may be used.

** Specialist investigations will be required to determine the extent of ground improvement required.

*** Design CBR dependant upon choice of fill material. Minimum 2% CBR assumed limit of trafficability of fill.

Note For CBR less than 2% special measures are necessary to provide adequate foundation support. These are described in Section 4.3.

4 Design of Foundation Layer

4.1 Role of Foundation Layer

The strength of the foundation layer is dependent upon the three factors applicable to all pavement engineering design.

i) the support provided by the underlying material, in this case the subgrade. This is measured as described in Section 3.

ii) the strength of the foundation material itself.

iii) the thickness of the layer.

During construction, it is important that an adequate base is provided to support the traffic which will use the road foundation. In addition the foundation layer enables subsequent structural layers to be adequately compacted during construction. This will vary with the season, the moisture susceptibility of the soil, any subsurface drainage that is provided and whether the surface water can drain readily. Notes on drainage are included in Section 4.2.

Unless the works are such that the subgrade may be exposed for periods long enough for the climate to affect it, the equilibrium CBR (that pertaining at a moisture content 0.5m. below the surface) should be selected as the construction CBR. The sub-grade in winter may have a lower CBR, this will need to be checked at the time, and if necessary the design thickness increased.

For the long term condition, the equilibrium subgrade stiffness needs to be used. This is the condition the soil will reach under a pavement in the long term. It is affected by the condition at the time of construction, provision of sub-soil drainage and to an extent the kind of pavement construction used; stabilised and hydraulic bound sub-base materials are generally less permeable than unbound aggregates, cement bound materials are prone to cracking which can permit ingress of water.

The foundation layer has a role in providing a uniform layer with known characteristics and solving potential problems from pore water pressure, the water table and the drainage of water which may penetrate the overlying bound layers.

Foundation layer strength is dependent upon the material being fully compacted as described in the Specifications. If possible and in addition the actual stiffness of the material prior to overlaying should be monitored for stiffness using the Portable Dynamic Plate. This may for example permit materials other than Type 1 sub-base to be used.

Materials must also be laid and compacted within the specified level tolerances for such layer, as given in the Specification. The thickness of materials in the design tables are nominal thicknesses, application of tolerances means that actual thickness may be more or less.

4.2 Drainage

In times past, axle loads and speeds were not large enough to create a problem in the sub-base or subgrade if these were saturated. Ancient roads are therefore unlikely to have any sub-soil drainage. However the foundation will have been consolidated and compacted. The existing road may therefore perform much better than a new road of the same construction. When reconstruction, statutory undertakers works or maintenance is carried out, it is unlikely that the new materials can be installed to the same level of compaction.

Surface water can enter the pavement construction though the porous surface, through cracking as the pavement ages and at the edge of the carriageway if it cannot enter gullies grips or edge drainage easily. Wherever possible drainage via grips to ditches, kerbs and channels or continuous channel drainage should be provided. Over the edge drainage to combined surface water/sub-soil drainage is not recommended as it softens the carriageway edge and clogs with time.

Ground water will rise beneath any pavement in cuttings or where the water table is near the surface. Sidelong ground can lead to saturation from surface and sub-soil water flow. Cut-off sub-soil drainage should be provided in these circumstances. The design of such sub-soil drainage is a specialist skill outside the scope of this document.

Modern traffic loads can create serious problems in the road foundation if it is saturated, as follows:

- reduction in strength of the subgrade, capping layer and unbound sub-base as pore water pressures are generated and particle interlock is lost.
- movement of fines within the capping layer and unbound sub-base leading to further loss of aggregate interlock, loss of strength and possible risk of frost damage.
- degradation of unbound aggregate generating even more fine material.
- friction between the sub-base and structural layers is reduced, lowering the strength of the total construction.
- the base of the asphalt layer may be subjected to scouring by water stripping the bitumen, creating voids and reducing strength. Water can also be forced into micro-cracks leading to rapid failure.

If the water table is well below the formation level and both the capping layer material and sub-base have adequate permeability to carry away surface water, it is possible that sub-surface drainage is not necessary.

For unbound sub-base, it is necessary to ensure that the sub-base cannot become saturated, by installing sub-base drainage.

For 'sub-base only' options on sub-grade CBR less than 3%, as an additional safeguard, it is recommended that a non-woven geotextile separation layer is inserted to prevent fines migration into the sub-base should drainage become ineffective with time. This should be designed based upon the grading of the sub-grade

For bound sub-base, it is necessary to ensure that the interface between the sub-base and asphalt road base is drained so that friction is maintained at the interface.

Designs are based upon the sub-grade and sub-base being wet but not saturated, drainage should be provided as necessary to ensure this is the case. This is particularly pertinent where the saturated state could lead to a CBR of <2% as this leads to a dramatic increase in the total pavement thickness.

4.3 Foundation Material Selection

The foundation can be constructed of capping layer plus sub-base or sub-base alone. The choice of whether to use capping layer plus sub-base or sub-base alone can be made on economic grounds or other construction programme considerations (unless the CBR is less than 2% in which case a capping layer is obligatory). It may be advantageous to provide the contractor with both options as he is in the best position to make the selection.

Where the CBR is <2%, a significant increase in capping layer is necessary. It may be more economical to dig out the soft area separately and refill with material similar to the surrounding materials. If the soft area is as a result of localised water ingress this may be solved by local drainage. As a further alternative, and taking specialist advice, it may be economic and require less imported materials to reinforce the subgrade with a geogrid, together with a geotextile membrane if necessary.

Capping layer can be formed from a wide range of materials including lime and cement stabilised subgrade soils, secondary aggregates and other quarry or demolition waste.

Any of these materials may be used provided they satisfy the requirements of the Specification. Further information is provided in Section 4. 6. The capping layer is not expected to have the same stiffness as sub-base and so requires a greater layer thickness. This should be offset by the reduced cost, particularly of in-situ recycling. However even potentially strong materials will not achieve high stiffness when they are not fully compacted, achieving this may be more difficult on a weak sub-grade.

Experience suggests that the use of imported capping layer material may only be economic on a subgrade stiffness with CBR less than 3% at time of construction.

Sub-base materials are formed from cement stabilised soils, hydraulic bound materials and well graded granular material. The former are particularly relevant below similarly bound roadbase materials. Well graded granular material has been put into three Categories. An example of Category A material on which the design charts are based is Type 1 sub-base. Further details on materials that are suitable for use as sub-base is given in Section 4.6.

4.4 Design of foundation layer thickness

Two cases need evaluation and the worst case design selected	
1 Construction foundation	**2 Equilibrium foundation**
sub-base only (Table 4.4.1 a)	**Sub-base only (Table 4.4.2 a)**
capping layer and sub-base (Table 4.4.1 b)	**Capping layer and sub-base (Table 4.4.2 b)**

The tables below are based on a capping layer having a stiffness of 75MPa (Approximately equivalent to an in-situ CBR of 8%), and Category A material (cf. Section 4.6) being used as a sub base.

Normally the construction phase will be the worst case and only a check required for the long term condition.

4.4.1 Foundation during construction

The standard level of construction traffic assumed within the Department of Transport Design Manual for Roads and Bridges Vol 7 HD25 is 1000 standard axles. For new works or larger areas of reconstruction this value has been used.

LR1132 gave the thickness of sub-base required for a range of construction traffic loadings and subgrade strengths. This permits other levels of construction traffic to be accommodated.

For maintenance schemes, patching, haunching, local reconstruction or the like, or where in situ recycling is used, the sub-base will not be trafficked during construction and hence can be significantly thinner. For design purposes, however, the minimum construction traffic loading has been taken to be 100 standard axles. The thickness given presumes adequate compaction as described in the Specification has been achieved. This may require special measures to control the moisture content within the permitted range and use of suitable plant.

Table 4.4.1a – Thickness of Sub-Base (mm) : Construction

Sub-base thickness (mm) for Type of Work	**CBR of Subgrade (%)**

Haunching, In situ recycling or Local Reconstruction	**Use Table 4.4.1b**	**275***	**225**	**175**	**150**	**150**
New Works or Major Areas of Reconstruction	**Use Table 4.4.1b**	**400***	**300**	**225**	**200**	**150**

Note 1 * denotes a non-woven geotextile is recommended to prevent contamination of granular sub base material (if used). In addition the contractor may choose to increase the thickness of the sub-base or use a geogrid to maintain a strong construction platform. This will not affect the long term performance of the pavement.

Note 2 If material other than Category A material is used for the sub base, the thickness should be increased or reduced as described in Section **4.5.**

Table 4.4.1 b – Thickness of Capping Layer and Sub-Base (mm): Construction

Capping Layer is always used in conjunction with 150 mm sub-base to ensure adequate compaction.

	CBR (%) at time of construction					
	< 2	**2 to 3**	**>3 to<5**	**5 to<10**	**10 to 14**	**15+**
Foundation layer thickness for Type of Work	**150 mm sub base** **PLUS the capping layer thickness (mm) below**					
Haunching, or Local Reconstruction	**450***	**315***	**240**	**200**	**150**	**0**
New Works or Major Areas of Reconstruction	**600**	**450**	**350**	**250**	**180**	**0**

Note 1 * denotes a non-woven geotextile is recommended to prevent contamination of granular sub base material (if used). In addition the contractor may choose to increase the thickness of the sub-base or use a geogrid to maintain a strong construction platform. This will not affect the long term performance of the pavement.

Note 2 If material other than Category A material is used for the sub base, (cf Section 4.6) the sub-base thickness should be amended as given in Section 4.5.

4.4.2 Design for Equilibrium foundation stiffness.

Long term the stiffness (CBR) of the subgrade will change, largely dependent upon the extent to which water is present. The equilibrium CBR must be estimated from the Site Investigation as discussed in Section 3 and knowledge of site drainage and water table.

Table 4.4.2a – Thickness of Sub-Base (mm) Long Term

Equilibrium CBR (%)	< 2	2 to 3	>3 to <5	5 to <10	10 to 14	15 +
Sub-base thickness(mm) for all Classes of Road Traffic	Use Table 4.4.2b	170	150	150	150	150

Table 4.4.2b – Thickness of Capping Layer and Sub-Base (mm) Long Term

	Equilibrium CBR (%)					
	< 2	2 to 3	>3 to<5	5 to<10	10 to 14	15+
Foundation layer thickness for Class of Road	150 mm sub base PLUS the capping layer thickness(mm) below					
Traffic 1 msa or more	600	150	150	150	0	0
Traffic < 1 msa	470	150	150	150	0	0

Note 1 If material other than Category A material is used for the sub base, (cf Section 4.6) the sub-base thickness should be amended as given in Section 4.5.

WORKED EXAMPLE FOR FOUNDATION LAYER DESIGN

A haunching job is to take place alongside an existing highway.

The site investigation described the subgrade material as a silty sand, MEXE probe CBR values were 20% but when a moisture content/CBR relationship was plotted the saturated CBR was found to be 5% Therefore given the location of the site with no sub-grade drainage affordable this was the equilibrium CBR.

When the road was opened up in the springtime the CBR of the subgrade was checked and found by MEXE probe to be 6%

A sub-base only option was selected

From Table 4.4.1a Thickness of sub-base at construction (based on 6% CBR) = 175 mm.

From Table 4.4.2a Thickness of sub-base long term (based on 5% CBR) = 150 mm

Design thickness of sub-base 175 mm

4.4.3 Frost Protection

For the whole of Kent, there is a requirement for a minimum total highway pavement construction thickness of 450 mm for frost protection This must be checked at the end of the design process and may require a thickening of the construction.

However for commercial vehicle footway crossovers and other areas with less than 5 commercial vehicles per day (e.g. Homezones, car parks, or town centre pedestrianisation project) the thickness of frost protection layer may be reduced to 300 mm.

There is no requirement for footways or cycleways

WORKED EXAMPLE

The minimum total foundation and structural layer thickness of 450 mm will occur with a Category A sub-base on a CBR of 4% (haunching or patching), *[Table 4.4.1a gives 225 mm thickness]* with traffic levels below 5 msa (DBM50*) [Appendix B1 gives 225 mm thickness]* If traffic levels are below this, increasing total construction thickness can be achieved by: substituting a Grade 1 (DBM(100)) Asphalt (up to the maximum recommended traffic level), increasing the sub-base thickness (at increased cost), the type of sub base may be changed to a Category B or C (which may be cheaper in unit cost terms), or the capping layer option selected using non-frost susceptible material.

4.5 Alternative materials for Category A material as sub-base

Where materials of different stiffness to Category A are used, the thickness from the tables above may be adjusted. Adjustment factors may be used for weaker materials and also for stiffer materials. Clearly the selection of the appropriate material must be made before works commence in order that formation can be prepared at the correct level. Materials' suppliers should provide appropriate data.

Where the sub-base is replaced with asphalt, this is known as asphalt substitution. Details of this are given in Section 4.5.2.

4.5.1 Less Stiff Materials

Category A materials are made primarily of high quality crushed aggregates e.g. Type 1 sub-base. The policy of the County Council is to help promote recycling of waste materials. Some of these have less stiffness, therefore they can only be used in a greater thickness.

The description and properties of these materials is given in Section 4.6. The performance factors for these materials is given below.

The sub-base design thickness from the tables in Section 4.4 should be multiplied by the performance factor to determine the new thickness

Table 4.5.1 Equivalent performance of Foundation layer materials

	Performance Factor
Category A material	**1.0**
Category B material	**1.25**
Category C material *	**1.5**

Note 1 * denotes limited traffic applicability See Section 4.6.2

Note 2 The overall thickness should satisfy frost resistant thickness requirements in Para. 4.4.3.

WORKED EXAMPLE OF SUB-BASE EXCHANGE

A haunching job is to take place alongside an existing highway.

The worst case for a sub-base alone foundation was during construction when the formation was found to have 4% CBR.

From Table 4.4.1 a Thickness of sub – base required = 225 mm

The 225 mm Category A material can be replaced 225 x 1.25 = 282 mm (rounded to 285 mm) of Category B material or 225 x 1.5 = 338 mm (rounded to 340 mm) of Category C Material.

4.5.2 More stiff materials

Provided that a minimum of half of the thickness of granular material given in Table 4.4.1a remains after carrying out a substitution, or there is a capping layer, part, or all of the Category A material , as applicable, can be replaced with stiffer material using the Equivalence Factors given in Appendix D.

Where the substituted material is asphalt this has been known as Asphalt substitution. The methodology is given in Section 9, using asphalt materials as described in Section 6,

The use of Equivalence Factors is also suitable for the evaluation of maintenance schemes as discussed in Section 9.

4.6 Alternative Materials for capping layer and sub-base

4.6.1 Recycled aggregates and secondary materials

Kent County Council is committed, wherever possible, to implementing a policy of carrying out road construction and maintenance in as sustainable way as possible.

Wherever possible designers should increase recycling of reclaimed and marginal materials and reduce demand on finite sources of natural aggregates.

This can be implemented by using stabilised materials and or secondary aggregates for capping layer materials and sub-base. These should satisfy the relevant specification clauses.

Existing cohesive soils at formation can be stabilised with lime (if below the zone of frost influence (See Para. 4.4.3), or lime and/or cement if above this level, to provide an acceptable capping layer material.

In order to be acceptable as capping layer, lime stabilised material must satisfy the requirements for a Category A Sub base (after a curing period), and be non- frost susceptible, if relevant.

Silty and granular soils can be stabilised with cement to provide an acceptable capping layer material and possibly a sub-base material as well.

Cement stabilised material must satisfy the minimum requirements for CBM 1.

It is recognised that stabilised materials should produce a formation of similar bearing strength to the top of sub-base. Sub-base should still be laid in order to achieve the relevant surface tolerances, to allow for the considerable variations in strength possible with in-situ stabilisation and to ensure the frost protection layer is provided.

Available secondary aggregates include:

Crushed concrete, demolition waste, asphalt planings, domestic incinerator bottom ash (IBA), furnace bottom ash (FBA) , PFA, Phosphorus Slag, Steel Slag and Blast Furnace Slag .

4.6.2 Categories of Alternative Granular Materials

In order to assist in the specification and use of alternative materials, granular material has been placed into three Categories as given below:

Category A material

This may include Type 1 sub-base and well-graded asphalt planings, crushed concrete and kerbstones, granulated asphalt complying with the grading for Type I material, steel, phosphorus and blast furnace slag. These materials may be used without restriction on traffic level.

In order to enable 100% processed demolition waste to be used, Type 3 sub-base has been designed. It may comply with the requirements for Category A material but its use is limited to Road Types 3 and 4, or the maximum traffic for these road types. (c.f. Table 5.6) as a result of possible quality variability.

The strict grading requirement may be relaxed provided the materials satisfy the requirements of Table 4.6. This should be readily achievable by materials: having a continuous grading, the fine fraction of which should be angular and with a low percentage of very fine material (passing 63 micron sieve), when laid and compacted close to optimum moisture content and with a maximum particle size appropriate for the layer.

Category B material

This may include Type 2 sub-base materials and some Type 3 sub-base materials, incinerator bottom ash and other recycled and secondary granular materials.

The material should be well graded and the stiffness should satisfy the requirements of Table 4.6.

Where the laboratory approval suggests that the materials may rut under construction traffic a trafficking trial may be necessary as part of the approval process.

Its use is limited to Road Types 3 and 4, or the maximum traffic for these road types. (c.f. Table 5.6)

Category C material

This may include recycled and secondary granular materials.

The material should be well graded and stiffness should satisfy the requirements of Table 4.6.

Where the laboratory approval suggests that the materials may rut under construction traffic a trafficking trial may be necessary as part of the approval process.

It shall only be used on Road Type 4, or the maximum traffic for these road types. (c.f. Table 5.6)

Capping Layer Material

Capping Layer Material includes a very wide range of Granular Materials complying with the Specification for Highway Works for Capping Layer. This includes all the materials satisfying the requirements for Categories A, B and C above plus local sands, hard chalk and other materials which , when compacted can satisfy the requirements of Table 4.6 below in the laboratory and in-situ.

Where the laboratory approval suggests that the granular materials may rut under construction traffic a trafficking trial may be necessary as part of the approval process.

Stabilised Material for Capping Layer will typically be the existing sub-grade stabilised, normally in-situ, with lime to produce materials of equivalent stiffness to Category A granular material and /or cement) to produce materials of equivalent strength as CBM 1. Stabilised materials should be checked for stiffness/compressive strength after a curing period in the laboratory and must be checked on site for compliance with the specification.

It is recognised that stabilised materials can produce a formation of similar bearing strength to the top of sub-base. However sub-base should still be laid in order to achieve the relevant surface tolerances, to allow for the considerable variations in strength possible with in-situ stabilisation, to ensure the frost protection layer is provided, and in the case of Cement Bound Materials on lightly trafficked roads, to delay the onset of reflective cracking.

4.6.3 Approval of Alternative granular materials

In order that these materials can be promoted without a requirement for a detailed recipe specification that could be unduly restrictive, alternative materials may be used by submitting them to a Type Approval process. The relevant specification Clause should be used and the stiffness below achieved.

They should achieve a minimum value of stiffness modulus for the Category of material, when measured by the Portable Dynamic Plate on the surface of the layer after installation in the laboratory box and on site as given in Table 4.6.3 below. Achievement of the requirements in the laboratory does not exonerate the contractor from achieving the appropriate values in the field. In addition after installation they should have sufficient mechanical interlock not to rut under construction traffic.

Note: Some of these materials are limited as to the traffic levels for which they are deemed suitable.

Table 4.6.3 Stiffness of granular materials

Stiffness at top of layer	In-situ	Laboratory
Category A material	100 MPa	150 MPa
Category B material	70 MPa	105 MPa
Category C material	50 MPa	75 MPa
Capping Layer	40 MPa	60 MPa

5 Traffic

5.1 General

The thickness of a road pavement is dependent upon the number, weight and speed of load repetitions from the tyres of commercial vehicles. This has led to the concept of millions of standard axles during the design life of the road (m.s.a.) as the parameter for thickness design, though for very lightly trafficked applications the number of commercial vehicles may be more appropriate.

The total number of Standard Axles is built up of four factors:-

(1) Number of commercial vehicles per lane per day.

(2) Their vehicle wear factor i.e. how many standard axles per vehicle.

(3) The design life of the pavement.

(4) The anticipated growth in commercial vehicles over the design life.

The speed of load repetitions has more effect on the performance of the materials in the surfacing layer rather than its thickness and is taken into account in designing the required deformation resistance.

5.2 Numbers of Commercial vehicles

Where traffic count data or the predicted commercial vehicle flow is available or can be economically commissioned this should be used. Where this is not available alternative means of determining the Total Design Traffic are suggested.

Commercial vehicles can be measured at two levels of detail, by number of axles, or grouped into two classes of Goods Vehicles (PSV+OGV1 and OGV2).

Determining the traffic based on a detailed classified traffic count is given in Section 5.3 and 5.4.

Determining the traffic based on OGV1 and OGV2 is given in Section 5.4.

Alternative methods, but with significantly less accuracy, are by using:

a) From a total count and estimate of commercial vehicle traffic (the average for Kent Principal Roads is 14%) the total flow with a 20 year design life and 2% growth is given in Table 5.5).

b) the NRSWA Road Type from the Road and Streetworks Act Gazetteer may be used. All existing roads in Kent are designated one of 4 broad categories, plus a special category for above 30 msa. (See Table 5.6)

c) the Road type from the description in the Kent Design Guide may be used, this is particularly applicable to residential developments. (See Table 5.7)

d) for areas with low numbers of heavy goods vehicles surfaced with pavers e.g. car parks or pedestrianised areas, an estimate based on the site description alone may suffice .(See Appendix B6)

5.3 Commercial Vehicles Classification and numbers per day

Commercial vehicles are defined as those vehicles with an unladen weight exceeding 15kN (1.5T).

These are separated for the purposes of evaluating their effect on the road pavements into three categories which themselves are subdivided to give the following

Buses and Coaches = PSV (Public Service Vehicles

2 axle rigid 3 axle rigid 3 axle articulated	= OGV1 (Other Goods Vehicles)
4 axle rigid 4 axle articulated 5 axles and more	= OGV2

The figure to be obtained from a traffic engineer is the best estimate of the 24 hr Annual Average Daily Flow (AADF) each way in the year of opening for each of these 7 categories as a Classified Count.

Note 1 If this is not available the total number of commercial vehicles per day and number of OGV2 might be available. (OGV1 +OGV2 = total commercial vehicle flow)

Note 2 Occasionally the total flow may have been measured and the percentage commercial vehicles for this kind of road may be available. This can be used, with loss of accuracy to determine the cumulative traffic.

Note 3 If a 16 hr or longer count is not available, a specially commissioned short duration count of at least half a day should be commissioned, but this will further reduce accuracy. The figures will have to be adjusted to a 24 hr count and to the average month.

It may also be necessary to use different factors to expand the count period for each class of vehicles. This is especially true for routes in Kent where considerable numbers of heavy goods vehicles travel at night. The advice of traffic specialists should be sought.

5.4 Computation of total traffic using a detailed traffic count

The total traffic = the count for each type of commercial vehicle x the relevant factors in the Paragraphs below i.e. wear factor (Table 5.4.1); the design life *(Para. 5.4.2);* the growth factor *(Para 5.4.3)*; the left hand lane factor (if any) *(Para 5.4.4);* the channelisation factor (if any) *(Para 5.4.5)*.

A WORKED EXAMPLE is provided in Appendix A

5.4.1 Vehicle Wear Factor

Vehicle wear factors are dependant upon the total vehicle weight and its distribution on the vehicle, which affects the load on each axle. Tyre size and pressure and axle configuration affect the load pattern on the structural layers but are not considered for overall structural pavement design in the UK.

A Standard 8T axle is said to have a wear factor of 1.0.

Axle Loads and their wear factors have been found to have a fourth power law, in that Wear $\cong 0.0002 \times [\text{Axle Load}]^4$

Typical wear factors are as follows

Axle load Wear Factor

1T	.0002
5T	0.15
8T	1.0
10T	2.3
13T	6.5

From this it can be seen that the wear factor for a car is negligible compared to a commercial vehicle, it is for this reason that they are ignored in structural calculations.

Approximate national average wear factors for various vehicle classes are as follows

Table 5.4.1 Vehicle Wear Factors

Class of vehicle	Wear Factor	
Buses and Coaches	**1.3**	**PSV**
2 axle rigid	**0.34**	**OGV1**
3 axle rigid	**1.7**	
3 axle articulated	**0.65**	
4 axle rigid	**3**	**OGV2**
4 axle articulated	**2.6**	
5 axles and more	**3.5**	

By counting the number of vehicles in each class and multiplying by the wear factor the total numbers of equivalent standard axles during the count can be determined.

5.4.2 Design Life

The aim of a good pavement design is that the whole life cost of the road will be the minimum to a given terminal condition. This whole life cost is made up of three elements, “construction” costs, “maintenance” costs and “traffic delay during maintenance” costs.

Construction costs can be assessed with a relatively good degree of accuracy.

Maintenance costs are dependent upon the quality of the historical information which is poor for other than the Motorway and Trunk Road network, but which is addressed in Kent Maintenance Plan 1999.

For the thick pavements in the strategic network, deterioration and hence maintenance of the network is largely traffic related. For the lighter rural network it is much more climate related together with poor initial construction standards. In the urban network statutory undertakers works and aesthetic/political factors are most important.

Traffic costs are related to the charge set against delay of a particular vehicle and the number and duration of the delays. The evidence indicates that traffic delay costs of frequent intervention on the heavily trafficked network are a very large percentage of the whole life cost, whilst the increased cost of providing a thicker pavement is small.

It is accepted that for the heavily trafficked network that a structural design life of 20 years is the optimum figure with a maintenance overlay planned soon after this time. After 40 years full reconstruction may be required. Note that for total traffic in excess of 80 msa after 20 years, changing the design life to 40 years makes no difference to the pavement thickness.

If the prediction of traffic growth is too low the design life of the pavement may be less than 20 years as the actual traffic will reach the total design traffic before this. Conversely, if traffic predictions are too high, initial construction costs will be unnecessarily high but life may be extended.

Choosing a design life exceeding 20 years means making very long term predictions relating to commercial vehicle numbers and damaging power at a time of rapidly changing technology both in terms of vehicles and their usage and road construction materials.

Whilst a structural design life of 20 years may be selected, it is possible that a surface treatment may need to be applied before this, for example to correct deficient skid resistance, and that this may itself provide some structural enhancement.

In urban schemes the dilemmas surrounding the selection of a 'design life' can be significant.

On the one hand, threshold problems may make it unlikely that the life of an asphalt road can be prolonged by a structural overlay whilst maintaining kerb heights. The only maintenance possible in those circumstances would be reconstruction or replacement of kerbs with a flush channel. Engineers should decide for themselves whether it is prudent to increase total structural thickness initially for the 40 years life, so that future maintenance can be carried out to the surfacing layer alone.

On the other hand, it should also be borne in mind that Statutory Undertakers have only the obligation to restore their trenches to the 20 year design criteria for that Type of Road and they make up a considerable part of the carriageway. If maintenance is necessary it may be prudent to check the completed design against the Standard design for the NRSWA Road Type (c.f. Table 5.6).

In addition requirements for aesthetic improvements in town centres may make resurfacing more frequent. Surfacing using modules (small element paving) (pavers or small slabs) has a significant structural enhancement.

Where a road is to pass beneath or over a bridge it may be prudent to either increase the structural thickness initially to prevent total reconstruction being necessary during the 40 year life, or alternatively for overbridges the thickness of overlay likely after 20 years should be allowed, plus a tolerance, when calculating headroom clearances.

Within the Kent Design Guide used for Residential Developments the implied 'design life' is 20 years.

Unless there are special factors for new highway schemes or for maintenance reconstruction a design life of 20 years should be used.

5.4.3 Growth Factor

The Growth factor for each type of commercial vehicle should be obtained.

Traffic engineers will normally provide the National Road Traffic Forecast using the upper estimate.

If the growth rate is only available for groups of traffic, PSV+OGV1 and OGV2, this is should be used and applied to the types of commercial vehicle that make up the group as shown in Table 5.4.1. In the absence of other data, a growth rate of 2% should be used.

The Growth factor shall be calculated which is dependent upon the selected design period and the growth rate. It represents the proportional difference between the average vehicle flow over the entire design period and the present flow (or flow at opening

The Chart and/or Table in Appendix A shall be used to derive the Growth factor from the Growth Rate.

The Growth rate curves for each class of vehicle should be used to determine the appropriate growth factor for that class. Normally a 20 year design period is selected.

5.4.4 Left hand lane factor

Where a dual carriageway is being constructed or maintained it can be reasonably assumed that the number of commercial vehicles which will travel in the Left hand lane is given in Table 5.4.4 below

Table 5.4.4 Traffic in Left Hand Lane of Dual Carriageways

Traffic Flow (cv/day	Percentage in Lane 1(Left hand lane)
100	97%
500	95%
1000	93%
3000	85%
6000	75%

The total vehicle flow, i.e. initial numbers plus growth will be constrained by the capacity of a lane at saturation; this figure will be different for a high speed motorway or trunk road than a scheme which forms part of an urban network of limited capacity. The advice of Traffic Engineering Specialists on saturation flows on urban schemes should be sought.

5.4.5 Channelisation

Where traffic is constrained within a narrower than normal width, e.g. at traffic calming gateways, at entrances to bus stations or at bus stops the normal spread of vehicle tyres over the carriageway cannot occur.

A channelisation factor of 2 should be applied to the total traffic flow prior to assessing the required structural pavement thickness.

5.4.6 Calculation of Cumulative Design Traffic

The cumulative design traffic can be simply obtained by multiplying the various factors above, i.e.

Total Design Traffic for each traffic category (msa) =

Present Daily Traffic Flow x365 x Design Period (Years) x Wear Factor x Growth Factor $x10^{-6}$

Total Design Traffic (msa) = Sum of all traffic categories x Left hand lane factor x Channelisation Factor

5.5 Computation of total traffic using a Classified goods vehicle count or estimate

There may be cases where a classified count by each commercial vehicle class is not available.

If a count by total commercial vehicles and OGV2 is available; these are described in Para 5.2 above, the Total Design Traffic (msa) can obtained from the Chart given in Appendix A. This assumes the road has a standard spectrum of traffic over 20 years and 2% growth.

If only a commercial vehicle volume is available, possibly from a total vehicle count (one way) and percentage commercial vehicle estimate, the Total Design Traffic for a typical highway over 20 years and 2% growth may be estimated from Table 5.5 below. This relates to a single carriageway.

If channelisation will occur the Total Design Traffic shall be multiplied by 2

Note Channelisation may occur where a pedestrian refuge or splitter island is added to the carriageway

Table 5.5 Approximate conversion cv/day to total design traffic

Volume of traffic cv/day	Total Design Traffic (20 year design life) msa
50	0.4
100	0.8
150	1.4
250	3.0
340	5.0
500	9.0

Note This is suitable for use only up to the volume of traffic shown)

5.6 Estimation of total traffic using NRSWA Road Type

If no traffic figures are available and funding is not available for collecting data, the Road Type from the published Streetworks Gazetteer should be used. This will place the road in one of the following categories.

Table 5.6 Design Traffic and NRSWA Road Type

Road Type	Design Traffic Range msa	Total Design Traffic msa
1	>10 but < 30	20
2	>2.5 up to 10	7
3	>0.5 up to 2.5	1.5
4	Up to 0.5	0.5

5.7 Traffic from the Kent Design Guide Description

For the purposes of this design guide the following traffic figures have been assumed.

Road Type Kent Design Guide	Commercial Vehicles per day	Standard axles over the design life (millions)
Local Distributor	120	1.2
Major Access Road	50	0.5
Minor Access Road	10	0.3
Minor Access Way	1	0.05
Homezone	0.3	0.01

Note District Distributor roads have such a wide range of traffic that a detailed traffic evaluation is required, as described in this Section.

6 Structural Layer Design

The structural layer is that part of the pavement above the sub-base, which provides the principal load spreading function of the pavement.

It must be of adequate strength (stiffness) to perform this function and be of itself deformation and crack resistant. It must also be capable of being installed (constructed) to the required thickness and tolerances and to the required standard at that location.

Structural layers may be flexible construction or composite construction where the base material is hydraulic bound material.

Surfacing is applied to a flexible construction to provide the necessary surface characteristics. It must retain these during the design life and be deformation (rut) and crack resistant.

It is assumed in the structural design that the surfacing layer will be Thin Surfacing, 30 mm thick. If a different thickness of Thin Surfacing is to be used this is acceptable, however the total thickness of structural layer plus surfacing should remain unchanged.

Where traffic figures are approximate, it may be prudent to make an allowance for this uncertainty in the structural design. Inspection of Appendix B1 indicates that an addition of 20 mm of asphalt gives a 50% increase in the load carrying capacity (e.g. from 10 to 15 msa).

6.1 Flexible Construction

Flexible construction for the structural layer is carried out using bitumen macadam with a 'dense' grading and penetration grade bitumen binder.

Whilst historically this has been carried out using recipes derived from BS4987 Part 1: *Coated Macadams for Roads and Other Paved Areas*, the introduction by the HA of Designed Macadam now permits suppliers to produce mix designs, based on BS 4987 grading curves, which ensure good mechanical interlock, but with binder type and quantity to suit the aggregates available to them and the site. These are known as Designed Asphalt Roadbase.

Note: In the new terminology all asphalt and macadam is now known generically as 'asphalt' not bituminous material.

Designed Asphalt Roadbase also permits stiff and rut resistant products to be produced for what used to be called basecourse. BS4987 mixtures for these materials were weak and prone to rutting under heavy traffic.

Designed Asphalt Roadbase mixtures are denoted by stiffness grade. The Grade refers to the Characteristic Strength in GPa measured in the Nottingham Asphalt Tester [NAT]. The stiffness for the three 'standard' grades is given in Appendix B3. They can also be denoted by the typical binder penetration e.g. DBM50 or HMB35 provided that the required stiffness is achieved. Details are given in the Specification Clause. The pen of binder normally used to achieve the standard grades is given in Table 6.1 below

The stiffness of the material is strongly related to the penetration of the bitumen as given below. However the actual stiffness achieved is also dependent on binder quantity, the properties of the aggregate used and full compaction being carried out. For example one would expect that a mixture made with crushed rock fines would achieve a higher stiffness than one with sand aggregate. However the former will be harder to compact than the latter. It is also possible to reduce the binder content and increase stiffness but at some risk of reduced durability and increased problems of workability and segregation of the material.

The stiffness of the material is evaluated in a Type Approval trial and should be above the values given in Appendix B3. This is carried out with materials and plant exactly the same as would be used in the main works. To monitor the trends during the works, cores are taken periodically to monitor the stiffness actually achieved.

Table 6.1 Grade of Roadbase and typical binder penetration to achieve it

Grade of Designed Asphalt Roadbase	Pen of Binder normally used
1	100
3	50
6	35

Note In the near future 100 pen binder as currently specified by BS 3690 will be replaced with bitumen specified using a European Standard. This is either slightly stiffer or slightly less stiff than 100 pen (the latter would appear to be preferred). The stiffness of the mix using the new binder will have to be checked for compliance with Grade 1 if the material is to be used in the same thickness otherwise the thickness of the roadbase layer can be adjusted as described in Appendix B3.

For flexible construction the design chart in Appendix B1 gives the structural layer thickness based on the most commonly used material, DBM50.

The thickness shown includes the thickness of the surface course .

e.g. 5 msa total traffic gives a total structural layer thickness of 226 mm including surfacing.

The thickness should be rounded to the 5 mm above i.e. 226 mm becomes 230 mm.

If the design stiffness of the proposed material from the local supplier is different from DBM50, the thickness may be adjusted. For commonly used materials the Chart in Appendix B2 may be used. For any intermediate stiffness the factors given in the chart in Appendix B3 may be used to determine the appropriate thickness.

WORKED EXAMPLE

DBM50 material has an equivalence factor of 1.12 (Appendix B3 and D) (Stiffness 2.5 GPa).

If the design stiffness of the proposed material is 3.5 Gpa, the stiffness factor is 1.18 (Appendix B3).

For a design life of 2 msa, the Design Chart (Appendix B1) gives a 192 mm Asphalt.

Using the proposed material the thickness becomes 192 x (1.12/1.18) = 182 mm i.e. 185 mm including 30 mm surfacing. (This material could actually be designated Grade 3)

Other considerations when selecting roadbase:

a) Cracking Resistance

Bitumen characteristics change over time as a result of the effects of water, air and sunlight. This depends upon the bitumen source and the extent to which these elements can penetrate the material. It becomes stiffer and ultimately brittle. As the structural layer gets thinner the deflections under individual truck axles increase and harder binders are closer to a brittle state than softer binders. The design charts above take some account of this increased stiffness over the life of the pavement.

For very heavily trafficked pavements, the use of stiffer binders offer significant savings as a result of the reduced thickness possible as a result of increased stiffness. The rate at which cracking occurs is a combination of daily and seasonal thermal stresses and traffic stress. Currently there is no laboratory test which simulates these effects, although materials can be ranked for their performance using the fatigue test in the NAT. Research work is ongoing.

To minimise the risk of premature cracking, the minimum thickness for a design using Grade 1 (DBM100) Asphalt Roadbase has been set at 110 mm, for DBM50, Grade 3 and HMB 35 Asphalt Roadbase has been set at 150 mm and for Grade 6 at 200 mm.

In maintenance applications, to prevent reflective cracking when overlaying a cracked carriageway, a non-woven geotextile membrane is recommended if the overlay thickness is less than 180 mm.

b) Deformation resistance

Deformation resistance is an important characteristic of the structural layer just below the surfacing. There are many examples of basecourse/upper roadbase materials rutting under heavy traffic and this will be exacerbated with the thinner surfacing materials now used.

There is a laboratory test for deformation (the confined creep test using the NAT) but levels of performance have not yet been set. Research work is ongoing.

In order to prevent premature deformation of basecourse (binder course) or roadbase a maximum traffic level is proposed as given below:

Grade 1 material (DBM100) is not recommended for total traffic greater than 5 msa i.e. thickness above 250 mm

For other Grades the maximum traffic level should be equivalent to a thickness of 300 mm e.g. for DBM50 material <30 msa traffic (cf Appendix B2).

6.1.1 Selection of Grade of material

Under normal circumstances the thinnest permissible option should be selected. However the premium for small quantities of material with binder of pen less than 50 may make it uneconomic.

Material made with 50 pen binder can be laid by hand and still give adequate time for compaction in air temperatures above 10^{O} C but it becomes more difficult below this. There may be cases in winter when hand laying is required when material with a higher pen should be selected, this should not be greater than 100 pen.

6.1.2 Layer thickness

The contractor may select in how many layers the roadbase will be laid.

Thinner layers cost more to lay, cool faster in winter limiting time for compaction, but permit the achievement of better surface tolerances.

Typically layer thickness between 80 mm and 120 mm are used for the 28 mm nominal sized coarse aggregate material. Surface tolerance compliance becomes increasingly difficult with layer thickness above 100 mm.

Achieving the required stiffness Grade becomes more difficult as the coarse aggregate size reduces but material with 14 mm nominal size is possible and may be used for regulating purposes from 30 mm up to 70 mm thick.

An SMA type thin surfacing with a wheel tracking rate satisfying the requirements of HA for a Category 2 site i.e. measured at 60^{O}C, may be used up to 50 mm thick as a basecourse(binder course) or as regulating on top of an existing roadbase. Its stiffness for the purposes of design is deemed to be the same as DBM100 (Grade 1).

6.2 Cement Bound Roadbase

Whilst provision is made in the HA Design Guide for CBM 3 , CBM 4 and CBM 5 as an optional roadbase and this must be made available to contractors on HA new roads, experience in Kent has shown that the determinate life option, i.e. with between 100 mm and 180 mm of bituminous surfacing to the cement bound material, leads to a persistent maintenance problem of joint sealing and premature overlaying.

The use of Cement bound roadbase is limited to the following circumstances. For a) and b) below the materials is particularly recommended:

a) in-situ recycling with cement to produce CBM 3, CBM 4 or CBM 5. This is to promote KCC policy on recycling. Note The contractor will have to determine the coefficient of thermal expansion based on experience or laboratory trials using site materials.

b) where the surfacing layer is concrete or clay pavers, setts or flags/slabs.

c) where traffic flows require that more than 180 mm of asphalt overlay is laid i.e. a Total Design flow in excess of 20msa. (Appendix B4). This thickness may be reduced to 150 mm using a geotextile SAMI(Stress absorbing membrane interlayer).

Cement bound roadbase thickness should be selected from the Chart in Appendix B4.

Note The design Charts for Composite Construction in Appendix B4 include a reduced thickness of Bound Roadbase if the granular sub-base is substituted with a bound sub-base of strength to satisfy the requirements of CBM 1A or 2A.

6.2.1 Asphalt overlay to Cement Bound Roadbase

For Kent Schemes, the overlay thickness should be selected depending upon whether or not a geotextile SAMI (Stress absorbing membrane interlayer) is provided on top of the CBM as shown in the chart in Appendix B4.

For schemes for HA only, the HBM line in the chart in Appendix B4 may be used for traffic levels less than 20msa

A geotextile has been found to be approximately equivalent to 30 mm asphalt in its ability to delay the onset of reflective cracking. HA are prepared to accept the ongoing maintenance liability implied by using an overlay thickness less than 180 mm.

For details of surfacing materials see Section 7 – Note a SMA Thin wearing course is preferred.

6.3 Hydraulic Bound Roadbase

Hydraulic bound materials contain binders similar in composition to Portland Cement but with different proportions of the constituent chemicals. They gain strength slowly. This gives adequate time for manufacture, storage (if necessary) laying and compacting. The slow strength gain means that the initial thermal cracking, which generates the problems with Cement Bound Materials and Concrete, occurs at such a close spacing that it is imperceptible. The material has the additional advantage that it reuses a currently produced industrial waste product.

Hydraulic binders include PFA, blast furnace and air cooled slag. They may need to be combined with phosphorus slag or activators such as lime or gypsum to produce the required strength. Aggregate interlock is also essential to enable the surface of hydraulically bound materials to resist rutting and provide adequate strength in the early life of the pavement. This is addressed in the design mix approval procedure.

It is essential that the materials are laid and fully compacted as described in the Specification to ensure that the strength potential measured in the laboratory is achieved in practice. On-site monitoring of this activity must be carried out.

The thickness design for hydraulic bound roadbase is the same as for relevant CBM given in Appendix B4.

The design approval process for hydraulic bound material provides information on the strength of the material based on accelerated curing of specimens in the laboratory and on the coefficient of thermal expansion. This permits the appropriate design thickness curve to be selected. Where necessary, interpolation between CBM 3, 4 and 5 may be carried out.

In order to determine the equivalent strength of hydraulic bound material, it is compacted into a 160 mm cylinder, 160 mm long and cured in water at 40^{O}C for 14 days. This accelerated curing regime is designed to produce a material with the same equivalent strength to CBM cubes at 7 days cured at 20^{O}C.

As an additional precaution against deformation during the early life of the pavement the sub-base shall be the same hydraulic bound material as the road base, without any change in sub-base thickness.

Since the roadbase and sub-base are of the same material, the total thickness can be made up of layers of material of suitable thickness for the nominal aggregate size to assist laying to tolerance and compaction

6.3.1 Asphalt overlay to Hydraulic Bound Material

The thickness of asphalt overlay for hydraulic bound material is given in Appendix B4 using the HBM design line.

Grade 3 material should be used for 4 msa and above.

Grade 1 or 3 material may be used for below 4 msa.

The thickness of asphalt roadbase can reduce to 100 mm for low traffic situations as reflective cracking is not a problem.

For details of surfacing materials see Section 7.

7 Surfacing Design

7.1 Materials Selection

Hot Rolled Asphalt has been the surfacing material of choice over the last 40 years for heavily trafficked and high-speed roads. Skilled design procedures made it rut resistant whilst enabling pre-coated chippings to be applied to ensure skid resistance; a combination of microtexture provided by the aggregate PSV and macrotexture (Texture Depth).

Many Authorities used Dense or Medium Textured Macadam on their lower speed or less heavily trafficked network as it had lower first cost. These materials have shorter life than HRA and in many cases less texture depth.

Microtexture is a primary component in skid resistance at slow speeds. Macrotexture is a major factor influencing skidding resistance at high speeds but it also has an effect at low speeds.

Since 1992, Thin surfacing materials, based on European experience, have become increasingly common and have now completely superseded Hot Rolled Asphalt for new works in accordance with this guide. They also have improved durability compared with Macadam mixtures as a result of the thicker binder films. Where maintenance works involve overlay to a cement bound or concrete road and the minimum overlay thickness to the rigid base cannot be provided, hot rolled asphalt may still be considered as an alternative to a Thin Surfacing and Geotextile.

Thin surfacing is designated Type A, B or C depending upon its nominal thickness. In new construction, provided it meets the specified requirements and cognisant of the comments below, any thin surfacing may be used without preference.

<u>Thin Surfacing Type C.</u>

This has a nominal thickness greater than 25 mm. A Stone Mastic Asphalt (SMA) type thin surfacing containing fibres to enhance binder film thickness is used.

Note SMA is the preferred material for use round roundabouts as it is very resistant to abrasion and lateral forces, in this application low texture is normally applicable. It is also the preferred surfacing when overlaying a CBM structural layer or a cracked road. For very heavily trafficked sites, in excess of 50 msa, particular attention should be paid to the supplied evidence on retained texture performance.

<u>Thin Surfacing Type B</u>

This is laid in the target range (18 to 24)mm thick.

<u>Thin Surfacing Type A</u>

This is laid less than 18 mm thick.

For Type A and B materials polymer modified binder is used in the thin surfacing mix and normally laid on a specially formulated bond coat, this also acts as a sealant below the thin surfacing. At these thicknesses, thin surfacing is generally porous in order to maintain an adequate texture depth. This is particularly beneficial to reduce spray and tyre noise.

For new works, the selection of thickness should be made by the contractor to satisfy the texture depth requirements using the coarse aggregate of appropriate PSV to satisfy the skid resistance requirements of the site as given in Appendix C.

In exceptional circumstances most commonly experienced in maintenance applications, the Client may wish to specify a surfacing thickness, but this will limit the range of suppliers.

The total asphalt thickness remains unchanged when the choice of thin surfacing type changes i.e. a thinner surfacing layer must be offset with a thicker asphalt Roadbase.

Thin surfacing should have a HAPAS (Highway Authorities Product Approval Scheme) Certificate Alternatively, until all currently acceptable products are Certificated, the Kent Performance related Clause may be used, this ensures the material has adequate durability and rut resistance.

7.2 Skid resistance

Skid resistance is a combination of microtexture, specified by the Polished Stone Value (PSV) of the aggregate exposed at the surface, and the macrotexture measured by the texture depth. The correct level of both is required. Higher values than the minimum are not necessarily beneficial to the performance of the road surface; excessive texture depth can be detrimental.

In order to achieve the correct skid resistance for the site, the PSV of the coarse aggregate should be selected for the Site Category and total commercial vehicle traffic level in accordance with Appendix C. (This is identical to DMRB HD28).

However there is some evidence that Thin Surfacing is more effective in translating PSV into skid resistance than HRA and pre-coated chippings, largely because there is a greater percentage of the surface covered with aggregate. The HAPAS Certification process provides the facility for Thin Surfacing material to have skid resistance measured.

If the thin surfacing can demonstrate equivalent performance to a HRA with pre-coated chippings the material may be used although the PSV of the coarse aggregate may be less than would be required by the chart in Appendix C.

The Thin surfacing approval process includes ensuring that the material has adequate initial and retained texture depth.

Texture depth should be selected as low, medium or high as required by the speed of vehicles on the site, The requirements used in Kent are repeated in Appendix C for completeness.

The minimum PSV of the coarse aggregate site and texture depth requirements should be included in Appendix 7 of the contract.

7.3 High Friction Surfacing (HFS)

For heavily stressed sites, approaches to roundabouts crossings and the like, High Friction Surfacing using Calcined Bauxite Aggregate is required. Depending upon the site category (c.f. Appendix C) and the volume of commercial vehicles, three generic types of HFS are available. Type 1 material is for the heaviest applications Types 2 and 3 material is intended for lighter applications, where the design life may be reduced or installation of Type 1 materials is not possible. The details are given on the HAPAS Certificate for the product.

High Friction Surfacing should be placed on a thin surfacing with low texture depth. This normally means a Type C thin surfacing material. Alternatively the HFS supplier may have an approved system of pre-filling the voids in the thin surfacing in a way not deleterious to performance.

High Friction Surfacing (HFS) should have a HAPAS Certificate for the Type appropriate to the site.

7.4 Colour

The colour of surfacing materials is becoming increasingly important for delineation purposes and safety considerations.

Buff coloured calcined bauxite is preferred where required for high skid resistance, as it provides additional visual evidence of the hazard.

Generally, bus lanes are recommended to be red; cycleways green. The exact colour is given in the Kent CC Guidance Note on Coloured Surfacing

Bus lanes and other trafficked areas should have the colour provided by Thin Surfacing with both binder and aggregate being coloured. Alternatively a coloured High Friction Surfacing or Resin Bonded Surfacing of Type suitable for the site category may be used. As part of a programme, surface dressing with red aggregate may be viable. The choice may be determined by the cost and predicted life for the material. Other types of Surface Coatings are unlikely to have adequate life.

Cycleways may have the colour applied by a surface coating. This should be Resin Bonded Coloured Surfacings of appropriate Type for the use. E.g. if the cycleway is likely to be over-run by vehicles, e.g. because of road geometry,

High Friction Surfacing and Resin Bonded Coloured Surfacings should have a HAPAS Certificate of appropriate Type for the use

HAPAS Certificated coloured surfacing materials have had the durability of the colour assessed to prevent excessive fading over time or the wear of foot or vehicular traffic.

Natural or coloured concrete block and clay pavers may be used as described in Section 8.

8 Block Pavement Design

Concrete and Clay Block Pavements can be used where traffic speeds do not exceed 40 mph.(64 kph). This is because of noise within the vehicle and the difficulty of maintaining a good ride.

The foundation design and total traffic forecast for Block paving can be carried out in accordance with Sections 3, 4 and 5 of this document.

The structural layer should be designed using the chart in Appendix B5 (technically identical to BS 7533:1999 Part 1) for traffic levels above 0.5 msa and in accordance with Appendix B6 (technically similar to BS 7533:2000 Part 2) for traffic levels below 0.5 msa.

Concrete Blocks and Clay Pavers shall comply with BS 6717:2000 and BS 6677 respectively. Appropriate values for skid resistance or abrasion resistance may need to be inserted into the Contract. (Appendix 7/85)

Bedding Sand needs attention particularly for very heavily trafficked pavements. The appropriate Class of sand given in BS 7533 :1998 Part 3 should be inserted into the Contract. (Appendix 7/85)

8.1 Slip/Skid Resistance

Unpolished skid resistance values, and polished paver values should be included in the contract where pavers are being trafficked by vehicles. The polished value should be selected from Appendix C as it is numerically equivalent to the PSV test.

For pedestrian use, a polished and unpolished skid resistance values in excess of 40 is recommended when measured with the British Pendulum using a TRL (CEN) rubber slider.

8.2 Abrasion Resistance

Under normal circumstances, Flags, Blocks, and Pavers complying with the appropriate British Standard do not cause any problems as a result of surface wear and no special requirements need be put in the contract.

However, in front of major stores, some excessive wear by stiletto heels has been experienced and specifiers may wish to minimise the risk of this occurring. In those circumstances an abrasion resistance not exceeding the following would be acceptable.

for clay pavers 300 m^{m3} maximum

for concrete products Class A2 should be specified

(For clay pavers the number refers to the volume of material abraded during the test.).

The manufacturer will supply information.

8.3 Colour

Manufacturers provide mono-colour concrete blocks and blocks with a mixture of colours within the block (multi-colour or brindled). Clay pavers can have within them a variety of colours depending upon the composition and degree of firing. Manufacturers' brochures are not a good guide to the colour of their products. Where a new supplier is to be used, specifiers are strongly recommended to demand a representative number of samples of the products, the number depending upon the variation in colour expected, to form an approval test panel, which can be referred to in case of dispute.

8.4 Chamfers

Chamfered blocks, flags and pavers are necessary where the pavement is used by vehicular traffic to prevent spalling of edges and corners and ensure a complete filling of the joints by fine jointing sand.

For use in areas where vehicular traffic is unlikely, e.g. pedestrian precincts, footways and the like, unchamfered or products with small rounded arrises have proved popular with pedestrians. Unchamfered products should satisfy all the other requirements of the relevant British Standard and this specification.

9 Alternative Designs for Maintenance

It may be necessary to reduce the total pavement thickness if the new construction could lead to problems with services. In this case, substituting stiff DBM for weak sub-base/capping can reduce the total construction thickness. This is known as Asphalt Substitution and uses the equivalence factors given in Appendix D.

Note Where sub-base substitution is employed it is particularly important that the compacted density of the thicker roadbase is checked during construction to ensure that the required strength is obtained

Note Where sub-base substitution leads to a total thickness of asphalt greater than the maximum for that material in Appendix B2, this is acceptable.

WORKED EXAMPLES OF SUB-BASE SUBSTITUTION

1 *From Table 4.4.1a* 225 mm sub-base is required for construction purposes with CBR 4%

Leaving 115 mm sub-base (1/2 x 225 rounded) makes 110 mm sub-base available for substitution

From Appendix D: If the material proposed as roadbase is Asphalt Grade 1 (Dense Bitumen Macadam with 100 pen binder) this has an Equivalence Factor of 1.0, the upper layer of Sub base Category A has Equivalence Factor 0.3 .

110 mm x sub-base @ 0.3 is equivalent to X mm of Asphalt Grade 1 @ 1.0

X = 35 mm.

The revised design is 110 mm sub base with an extra 35 mm DBM50 structural layer laid concurrently with it. The total road pavement thickness is reduced by 75 mm.

2 *From Table 4.4.1b* 150 mm sub-base is required above the capping layer. This sub-base can all be replaced with the same material as the structural layer e.g. DBM50 Roadbase.

From Appendix D: Equivalence factor for sub-base =0.3. Equivalence factor for DBM50 = 1.12

150 mm x sub-base @ 0.3 is equivalent to X mm of DBM50 @ 1.12

X = 40 mm.

This reduces the total pavement thickness by (150-40)mm = 110 mm.

The principal of substitution is particularly applicable to in-situ recycling design where the totality of the granular material as sub-base or sub-grade can be upgraded.

Where cold in-situ recycling with foamed bitumen or cement is a possible maintenance treatment, the principle is that the existing asphalt, sub-base and underlying subgrade if necessary is converted to new asphalt using foamed bitumen binder or CBM. A worked example of this is given in Appendix E. It is recommended that a flexible pavement design is carried out and an equivalence factor design substituted rather than a composite design carried out.

Note There should always be at least half the thickness of granular material shown in Table 4.4.1a to maintain a platform for compaction. However the required specified level of compaction must be achieved if the performance of the material and hence the pavement is to be as predicted.

Where the existing road is to be overlaid to increase the structural strength, as an alternative to the designs based upon the use of the Deflectograph, Falling Weight Deflectometer or Benkelman Beam, the strength of the existing road can be evaluated as follows:

From the site investigation the stiffness of the surfacing layers can assessed, the thickness of foundation materials (sub-base) measured and the strength (CBR) of the foundation measured.

The strength of the existing pavement (also known as the structural number) can be determined by multiplying the thickness of each layer found by the equivalence factor and Condition Factor if applicable from Appendix D.

The requirements for the new construction can be determined using the Table 4.4.1a for sub-base and flexible thickness for Class 1(DBM100) asphalt from the relevant traffic from Appendix B3 and applying the relevant equivalence factors.

By subtraction the required overlay can be evaluated. This can be translated into an appropriate combination of materials by using their equivalence factors.

A WORKED EXAMPLE is included in Appendix E.

Engineers who have not carried out Alternative Design procedures may request assistance from a competent Pavement Engineer if necessary.

10 Construction Issues

When work commences the assumptions made concerning subgrade stiffness (CBR) should be rechecked and the assumptions made concerning trafficking by the contractor reviewed to ensure that site traffic will not overstress the subgrade.

Where time has elapsed between the design being carried out and construction commencing it is prudent to review whether traffic levels (actual) or predicted have changed.

Designs produced in accordance with This Design Guide are based on construction being carried out by skilled and competent contractors using materials complying with the Specification and installed correctly.

An appropriate Quality Assurance scheme incorporating adequate supervision and checking should be implemented to ensure the works are constructed as designed and specified.

11 Overlays and bridges.

No overlay can proceed over or under a bridge except with the approval of the Area Bridge Engineer or the Bridge Manager. There must be an initial assumption against it.

Overlaying road surfaces under a bridge has consequences for the available safe headroom and there are only limited situations where such a course of action is acceptable. Whilst there are clear KCC guidelines on this they must be administered by Bridge Management to ensure consistency and avoid the temptation of local departures. Bridge strikes are a serious economic and safety issue which we must continually seek to reduce and hopefully eventually avoid.

Overlaying on bridge decks has consequences for the capacity of the bridge for traffic loading, the expansion joints and the geometry of the footway and parapet. Again these are significant issues which will need investigation and costing and which will generally determine against the overlay option.

Early contact must be made with Bridge Management if considering any of these options.

Resurfacing in the vicinity of bridges.

Any scheme proposing resurfacing along a length of road which includes a bridge, should not simply ignore the bridge. Early contact must be made with the Area Bridge Engineer to determine what work is necessary to include the bridge in the resurfacing scheme so that the full stretch of road can be properly maintained. Any specialist work can either be included in the contract or be done as advance work to the resurfacing contract.

Much damage can be done to a bridge by indiscriminate planing as for example to a depth deeper than the surfacing thickness on the bridge, which can vary significantly form bridge to bridge and even across a bridge.

At no time should any planing off extend over a bridge deck unless the method has been fully discussed and agreed with the Area Bridge Engineer

12 Further Information

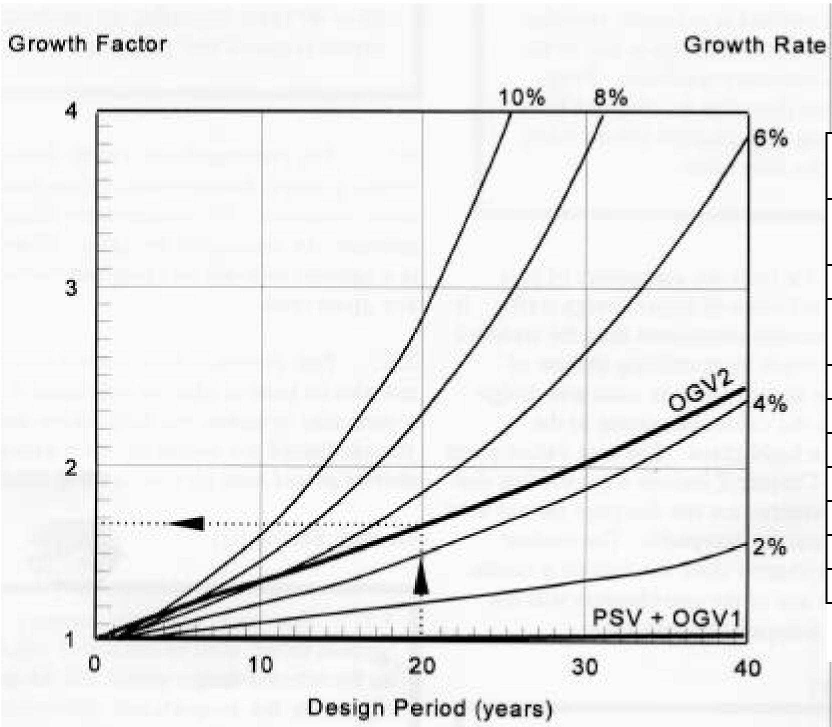
Further information concerning the contents of this Design Guide may be obtained from I.D. Walsh Babtie Engineering Laboratory (01622 605875) – e-mail ian.walsh@babtie.co.uk

APPENDIX A

Design Traffic Chart for 20 year life (ex DMRB HD24/96)

Design
Traffic
msa

Derivation of Growth Factor



Growth Factors for 20year design life	
Growth Rate (%)	Growth Factor
0	1.00
0.5 PSV&OGV1	1.03
1	1.10
2	1.25
3	1.40
4	1.55
OGV2	1.66
5	1.72
6	1.80

Worked example of cumulative traffic calculation

Typical Inter-urban Principal Road (Single carriageway)

Vehicle Class	Total Count(1) No/day	Wear Factor(2)	Growth Factor(3) %	Design Period (4) Years	Cumulative Traffic msa
Buses and Coaches	39	1.3	1.2	20	0.4
OGV1					
2 Axle Rigid	600	0.34	1.2	20	1.8
3 Axle Rigid	62	1.7	1.2	20	0.9
3 Axle Articulated	20	0.65	1.0	20	0.1
OGV2					
4 Axle Rigid	60	3.0	1.66	20	2.2
4 Axle Articulated	323	2.6	1.66	20	10.2
5Axle Articulated	300	3.5	1.66	20	12.7
Total	1404				**28.3**
Average		*1.74*			

Note 1 24 Hours classified Count (Total Flow one way) Para 5.3 refers.

18hr flow = 105% 16hr flow.

24hr flow = 109% 16hr flow.

No lane calculation for a dual carriageway has been necessary.

Note 2 Para 5.4.1 refers

Note 3 Para 5.4.3 refers. Data supplied by traffic engineers for each vehicle class separately (as illustrated for OGV1) or for PSV, OGV1 and OGV2 as groups (as illustrated for OGV2. using Appendix A).

Data here assumes 2% growth for PSV and 2/3 axle rigid; no growth for 3 axle rigid and uses OGV2 line as a group (all from Appendix A).

Note 4 Para 5.4.2 refers

No left hand lane factor has been applied to total flow Para 5.4.4. refers.

No channelisation factor has been applied to total flow Para 5.4.5. refers.

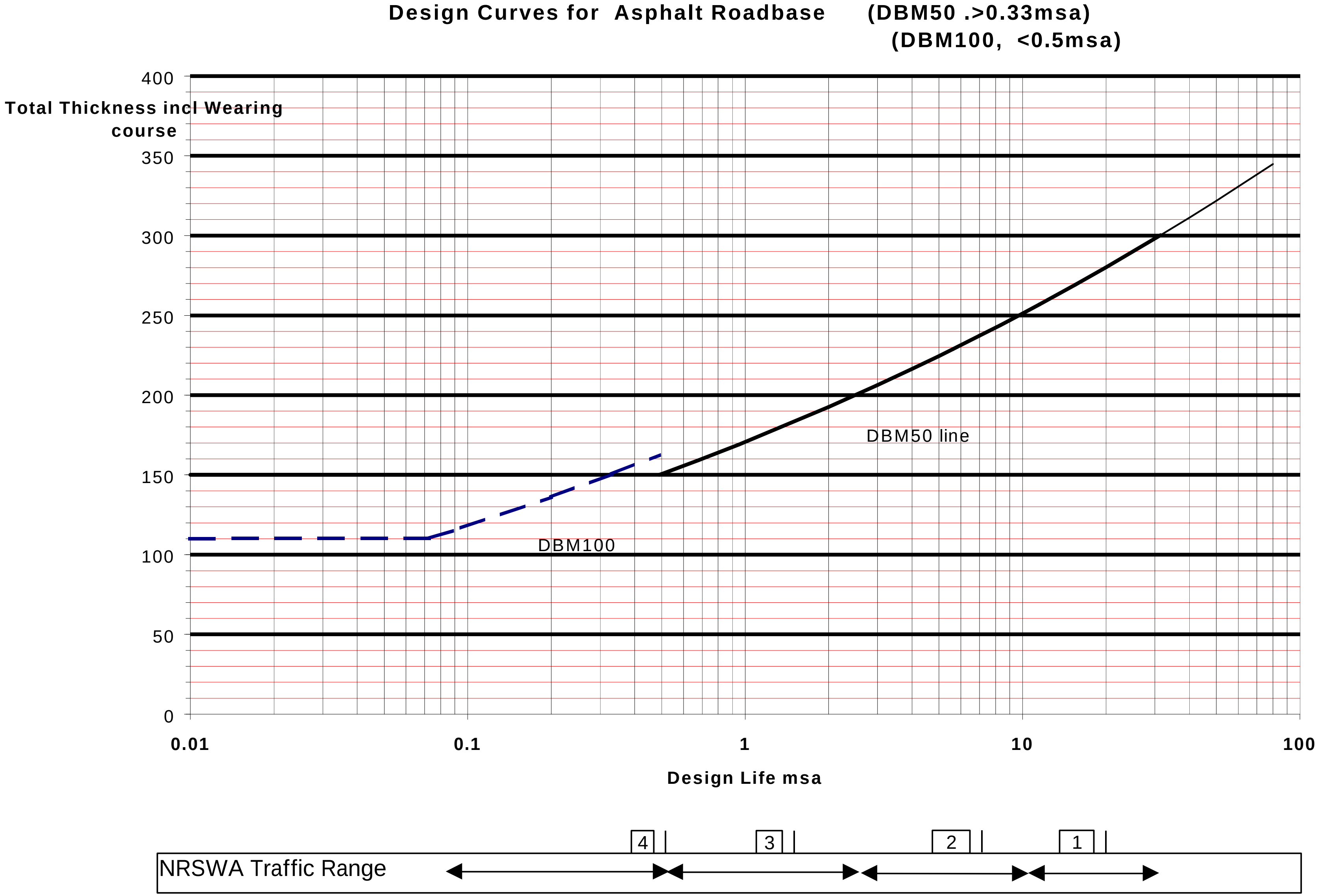
Total Design Traffic for each traffic category (msa) =

Present Daily Traffic Flow x365 x Design Period (Years) x Wear Factor x Growth Factor x10^{-6}

Other factors to be applied at end of calculation as required.

The average wear factor of 1.74 is provided as an indicator only of the typical number of standard axles in a spectrum of vehicles at this traffic level

APPENDIX B1 Design Chart for Flexible Construction



Minimum total thickness to prevent cracking with DBM100 110mm; DBM50 150mm

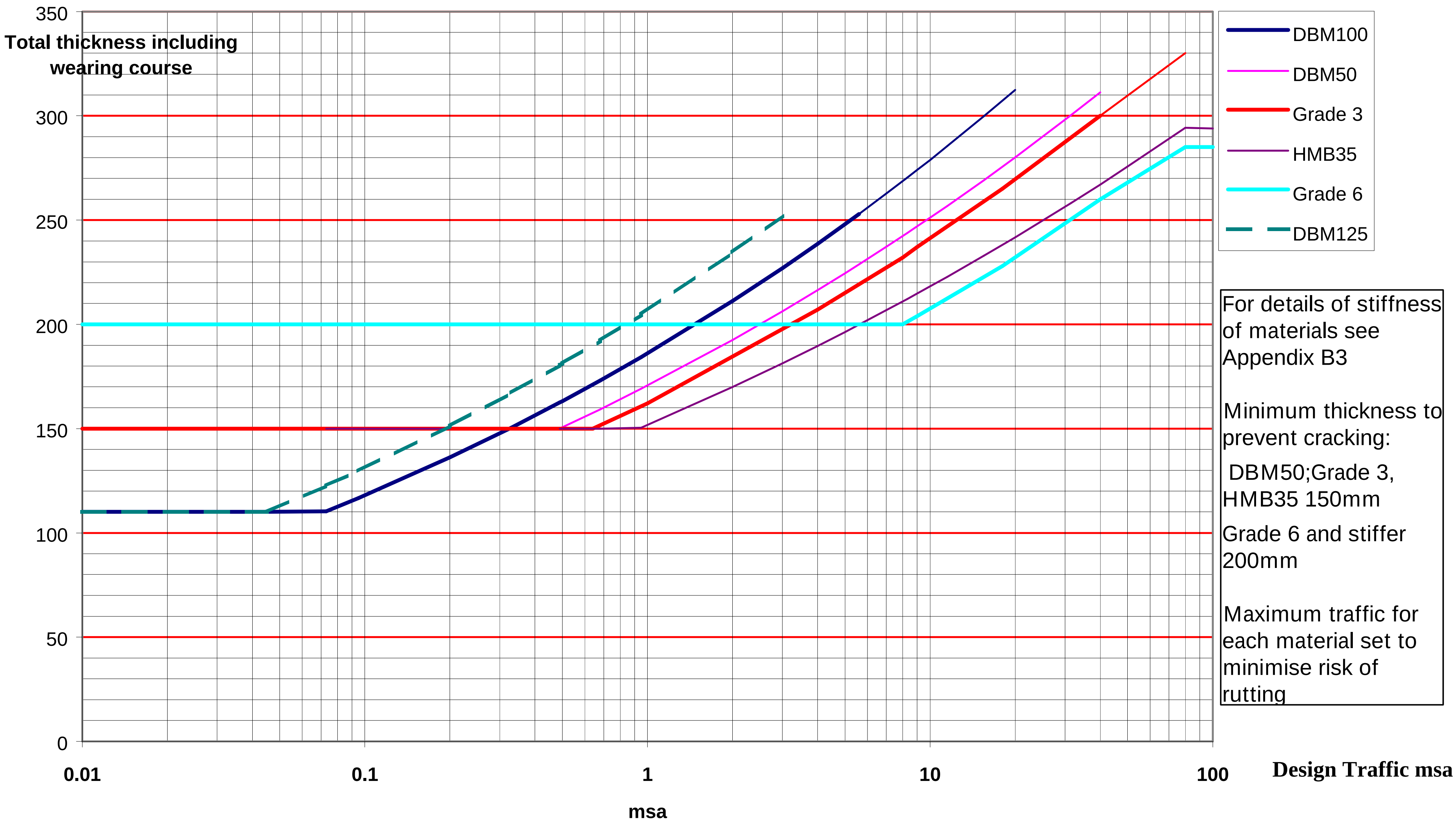
Maximum design life for DBM50 30msa to prevent premature deformation

For other materials see Appendix B2

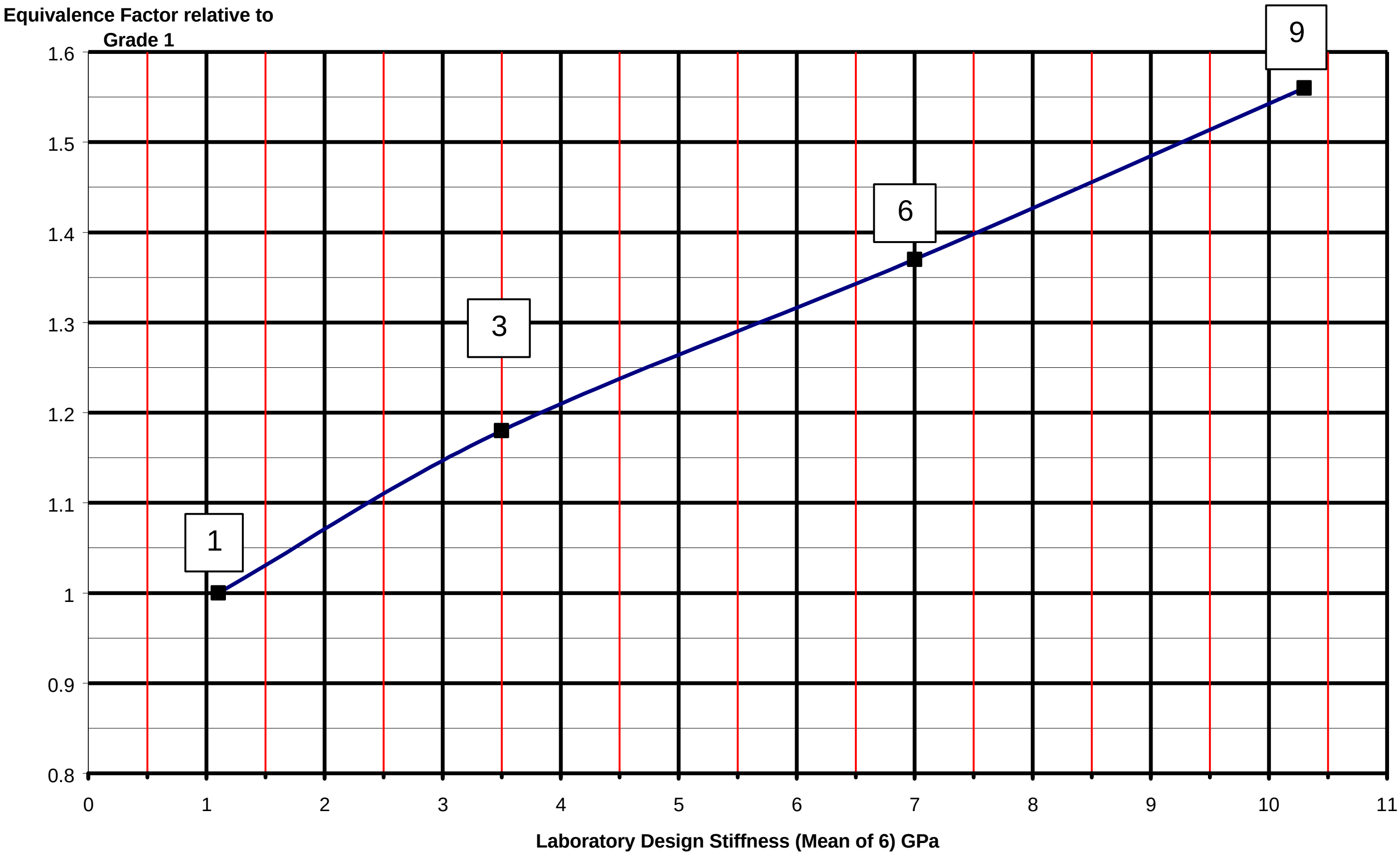
Total thickness of material includes Th 4 Surfacing wearing course

NRSWA Road Type design traffic (Table.5.6)

APPENDIX B2 Design Chart for Flexible Construction (all common roadbase materials.)



Appendix B3 Equivalence Factor adjustment for roadbase stiffness



Laboratory stiffness and equivalence factors are as follows:
The values shown are the Design Stiffness' pertaining to the Grades in the design charts. The values are required for their use in accordance with Performance related design mix asphalt Specifications . Grades stiffer than Grade 6 are currently not permitted

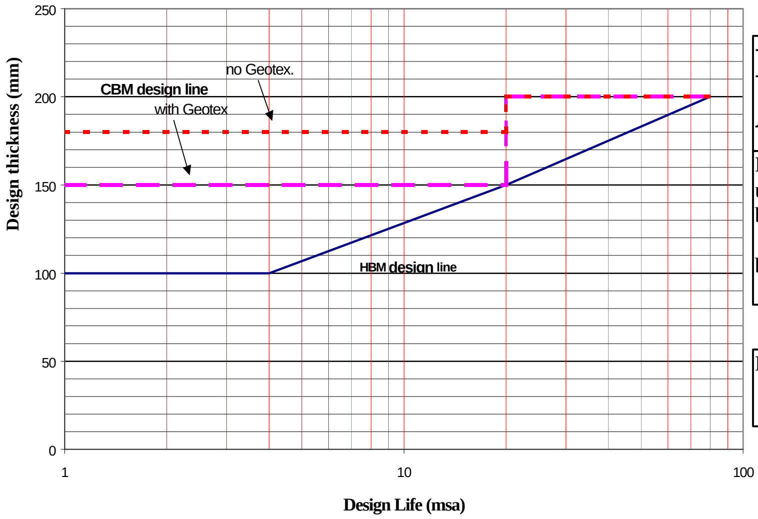
Grade	Characteristic Value (GPa) (5th Percentile)	Minimum moving mean of 6 values (GPa)	Minimum individual value (GPa)	Equivalence Factor	
					Rebased on DBM50
1(*DBM100*)	1.0	1.1	0.7	1.0	*0.89*
DBM50	*2.2*	*2.5*	*1.7*	*1.12*	*1.0*
3	3.0	3.5	2.5	1.18	*1.05*
HMB35	*4.8*	*5.6*	*4.0*	1.30	*1.16*
6	6.0	7	5.0	1.37	*1.22*

WORKED EXAMPLE (Using chart above) (See also Section 6.1)

If a scheme was designed requiring a total thickness of 260mm material with Grade 1 (DBM100) roadbase, and the proposed mix has a laboratory design stiffness of 5.0GPA (Mean of 6), this will require a total thickness of 260/1.27=205mm of material. (Values should be rounded up to the next 5mm)

NOTE The Chart in Appendix B2 is more accurate for standard materials.

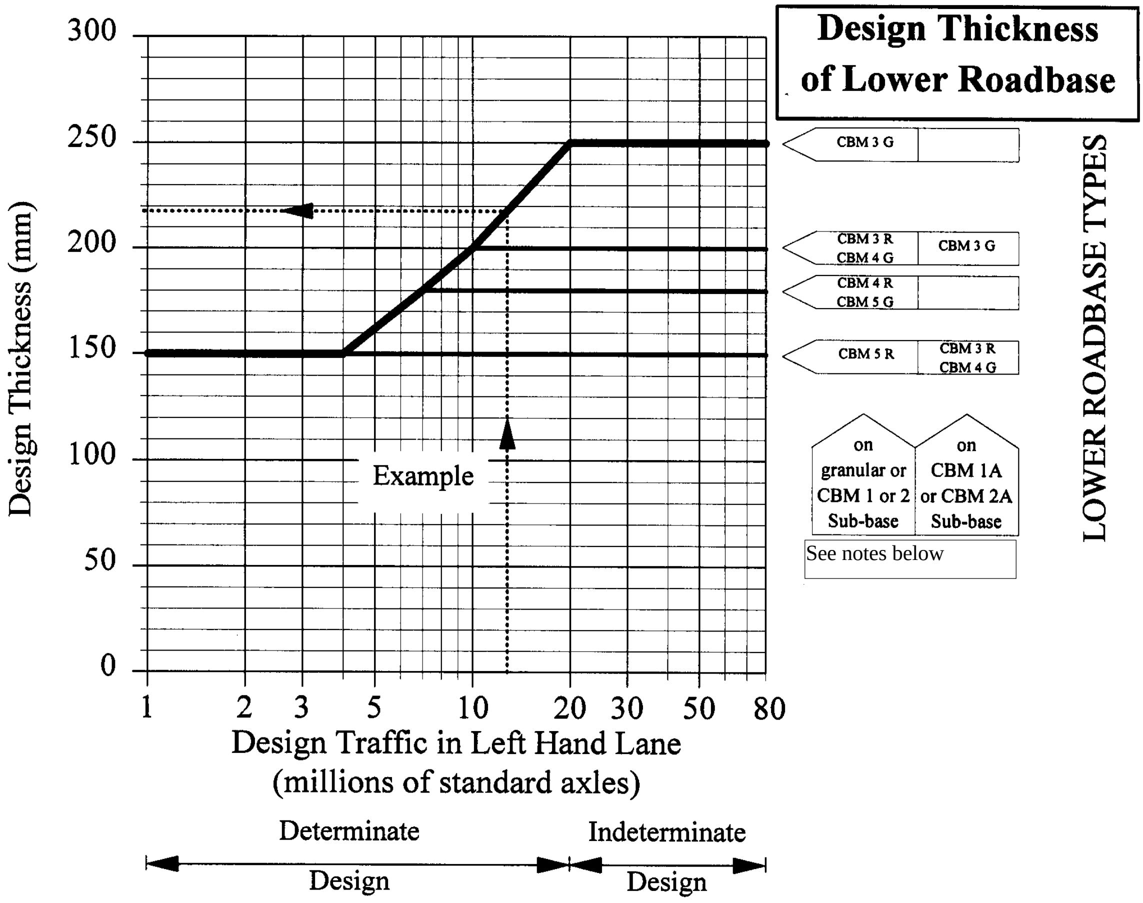
APPENDIX B4   Design Charts for composite construction. Cement Bound and Hydraulic Bound Base



Design Thickness Asphalt Layers

Min thickness 180mm asphalt above CBM, unless a geotextile used when minimum becomes 150mm
For HA schemes HMB line to be used below 20msa)

Min thickness 100mm asphalt above HBM



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

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

Hydraulic Bound Material is used in the same thickness as equivalent CBM Material (See Section 6.3)

Appendix B5 Pavement design for roads surfaced with pavers

Design Foundation layer in accordance with Section 4

Place structural layer and paver surfacing as described below on foundation layer.

Apply the special factors to the traffic determined in accordance with notes below (not Section 5)

Determine cumulative standard axles (msa) for design

Design msa	0.5 to 1.5				> 1.5 to 4				> 4 to 8		> 8 to 12	
CBM3 roadbase thickness (in mm) or	130	130	130	130	160	150	145	130	195	180	245	230
Dense butumen macadam roadbase 100 pen (in mm)	130	130	130	130	160	150	145	130	170	155	185	170
Laying course (in mm)	30	30	30	30	30	30	30	30	30	30	30	30
Paver thickness (in mm)	50[a]	60	65	80	50[b]	60	65	80	65[c]	80	65	80

End

[a] For clay pavers type PB and concrete pavers only.

[b] For clay pavers type PB only.

[c] There is no long term evidence concerning the performance in service of 65 mm pavers beyond 4 msa, so this design information has been extrapolated.

Special factors as follows should be applied to the traffic:

Channelisation: The traffic figures should be multiplied by 3 before carrying out the design.

Speed: Where speeds in excess of 30mph (50km/hr) occur the traffic figures should be multiplied by 2 to allow for dynamic loading effects.

Channelisation and Speed together: the traffic figures should be multiplied by 3 before carrying out the design.

Appendix B6

Construction thickness for pavers and flags in lightly trafficked applications

			Thickness of compacted Category A sub-base (mm)					Nominal compacted thickness (mm)		
	Design CBR %		≤ 2	3	4	5	≥6	Road-base	Laying Course	Min Paver thickness
Category	Traffic Description msa	Vhgv/ day								
IIA	0.1-<0.5		400	350	250	150	150	125	30	60
IIB	0.03-<0.1		200	150	150	150	100	100	30	60
IIIA	<0.03	5	250	150	100	0	0	70	30	50
IIIB		1	300	250	175	100	100	Nil	50	50
IV		<1	200	150	125	100	0	Nil	50	50

Note1   For CBR of 3% or less a geotextile separating membrane should be used.
Note 2   For alternative sub-base types see Section 4.6.
Note 2   Roadbase shall be Asphalt Grade 1. (DBM 100pen)
Note 3 Vhgv are defined as OGV2 in Section 5. i.e 4axle or 5 axle commercial vehicles.

Typical applications for these categories are as follows:

Category II   Adopted Highways.
Pedestrianised projects subject to regular heavy trafficking.

Category IIIA   Car parks receiving some heavy traffic.
Footways regularly over run by vehicular traffic.
Small shopping areas over run by delivery vehicles

Category IIIB   Pedestrian projects receiving only occasional heavy traffic, e.g emergency access.
Car parks receiving no heavy vehicles.
Footways where only occasional overrunning by cars is possible.

Category IV   Private drives, patios, hard landscaping, school playgrounds.
Areas receiving only pedestrian traffic.

APPENDIX C PSV Requirements for Site Classification and Traffic

IL Band	Default IL	Site Categories											
			Site Definitions	**0-250**	**251-500**	**501-750**	**751-1000**	**1001-2000**	**2001-3000**	**3001-4000**	**4001-5000**	**5001-6000**	**Over 6000**
I	0.35	A, B	Motorway (mainline), Dual carriageways (non-event)	50	50	50	50	50	55	60	60	65	65
Ia	0.35	A1	Motorway mainline, 300 m approaches to off-slip roads	50	50	50	55	55	60	60	65	65	65
II	0.40	C, D	Single carriageways (non-event), dual carriageways approaches to minor junctions	50	50	50	55	60	65	65	65	65	68+
IIII	0.45	E, F, G1, H1	Single carriageways minor junctions, approaches to and across major junctions, gradients 5-10% >50m (dual, downhill only), bends <250m radius >40mph	55	60	60	65	65	68+	68+	68+	68+	70+
IV	0.50	G2	Gradients >50m long >10%	60	68+	68+	70+	70+	70+	70+	70+	70+	70+
V	0.55	J, K	Approaches to roundabouts, traffic signals, pedestrian crossings, railway level crossings and similar	68+	68+	68+	70+	70+	70+	70+	70+	70+	70+
VI	0.55 (20 km/h)	L	Roundabouts	50-70+	55-70+	60-70+	60-70+	60-70+	65-70+	65-70+			
VII	0.60 (20 km/h)	H2	Bends <100m	55-70+	60-70+	60-70+	65-70+	65-70+	65-70+	65-70+			

Notes:

1. Where ‘68+’ material is listed in this Table, none of the three most recent results from consecutive tests relating to the aggregate to be supplied shall fall below 68.
2. Throughout this Table ‘70+’ means that specialist high-skidding resistance surfacing complying with MCHW1 Clause 924 will be required.
3. For site categories L and H2, a range is given and the PSV should be chosen on the basis of local experience of material performance. In the absence of other information, the highest values should be used.
4. Investigatory Level (IL) is defined in Chapter 3 of HD 28 (DMRB 7.3.1).
5. The PSV refers to the coarse aggregate in the thin surfacing, precoated chipping or surface dressing aggregate. It also refers to the PPV test for pavers and flags.
6. A HAPAS certificated Thin Surfacing with a lower PSV stone may be used provided it demonstrates that it can produce equivalent skid resistance performance to that of a HRA with precoated chippings of PSV given above.

Texture Depth Requirements

Site Speed	Site Grade
<30 mph	Low Texture
30 to 60 mph	Medium Texture
>60mph	High

Appendix D   Equivalence Factors for design and maintenance

Category of Material	Material equivalence factor	
	Suggested Value	Range
Cement bound material 1 (CBM1)	0.4	0.2 to 0.6
Cement bound material 2 (CBM2)	0.5	0.3 to 0.7
Cement bound material 3 (CBM3)	0.7	0.5 to 0.9
Cement bound material 4 (CBM4)	0.7	0.5 to 0.9
Pavement quality concrete	1.7	1.5 to 1.9
DBM50 Asphalt Roadbase	1.12	1.10 to 1.2
DBM (100 pen) Asphalt Roadbase Grade 1	1.0	0.9 to 1.1
Hot rolled Asphalt Base	1.0	0.9 to 1.1
Thin Surfacing Types A and B (Voids ≤12%) and C	1.0	0.9 to 1.1
HRA wearing course	0.8	0.8 to 1.0
Thin Surfacing Types A and B (Voids >12%)	0.8	0.8 to 1.0
Cold Bitumen Stabilisation	0.75	0.7 to 1.0
Open textured macadam	0.7	0.5 to 0.9
Porous Asphalt	0.65	0.6 to 0.8
Wet-mix or dry-bound macadam	0.45	0.3 to 0.6
Type 1 (Category A) granular sub base material over material with a CBR of ≥ 5%	0.3	0.15 to 0.4
Type 1 (Category A) granular sub base material over material with a CBR of ≤ 5% but not<2%	0.25	0.1 to 0.3
Category B granular sub base material over material with CBR of ≥ 5%	0.25	0.1 to 0.3
Category C granular sub base material over material with CBR of ≥ 5%	0.2	0.1 to 0.25
Category C granular sub base material over material Capping Layer materials with CBR of ≤ 5%	0.15	0.05 to 0.15
Capping Layer and other sub grade improvement materials	0.1	0.05 to 0.15

Condition Factors for existing pavements
The equivalence factors above should be multiplied by these to give current equivalence

As new	1.0
Slight Cracking	0.8
Substantial Cracking	0.5
Wide and frequent cracks and fretting	0.2

Appendix E

Worked example for equivalence factors in maintenance

Cumulative traffic loading: 15msa. Existing surface level to be maintained. Sub-grade CBR 5% (e.g. silty sand). For equivalence factors see Appendix D

Existing Road Construction		Equivalence
40mm	HRA Wearing Course	40 x 0.8 = 32
220mm	Miscellaneous Macadam with slight cracking	220 x 1.0 x 0.8 =176
150mm	Type 1 Sub-Base	150 x 0.3 = 45
75mm	Ash or other poor granular	75 x 0.1 = 8
485 mm Total Thickness	Structural Number (SN)	261

Conventional Flexible Design (Total reconstruction)

40mm	HRA Wearing Course	40 x 0.8 = 32
260mm	DBM (100)	260 x 1.0 = 260
220mm	Type 1 Sub-Base	220 x 0.3 = 66
Total 520 mm	Required structural Number (SN)	358

Maintenance solution

The existing road could be upgraded by overlaying the whole road with a material to give an extra 97 SN e.g. 25mm Thin Surfacing on 72/1.12 = 64[Rounded to 65]mm DBM 50 roadbase. However if the option of overlay is not possible e.g. because of kerb heights then recycling/conventional haunching must be considered.

Recycled Option with Cement

Minimum surfacing thickness for this traffic level: Thin Surfacing plus 2 layers of 60mm DBM50 as inlay or overlay

30mm	SMA Wearing Course	30 x 1.0 = 30
2 x 60mm	DBM 50	120 x 1.12 = 135
	SN	155
Ignoring underlaying structural material the contribution from recycled required is		358-155 = 203
The calculated thickness is 290 mm. Recommended in-situ recycled layer <u>300</u>mm thick.		<u>290</u> x 0.7 is equivalent to 203
Total Thickness		460
Remaining Underlaying granular (inlay option)		25 x 0.1 = 2
Total Structural number (inlay)		360
Remaining Underlaying granular (overlay option)		*195x 0.1 = 19*
Total Structural number (overlay)		*377*

Appendix F

Preferred Methods of Determining Subgrade CBR

F1. General.

It is evident from Table F that any one method will not provide an accurate evaluation of the CBR of the subgrade in every case. Each is best suited to different circumstances. In addition to precision and cost factors, the type of material may also influence the choice. For example, the plastic and liquid limits can only be performed upon cohesive soils and consequently a granular subgrade must be investigated by another method.

An investigation of the likely surface geology and groundwater conditions may assist in planning the investigation as described in Section 3.1. Previous local investigations may be particularly useful in this evaluation.

This section sets out the recommended choice for measuring the CBR, taking into account the size of the scheme, thus reflecting the cost implications, and the subgrade geology. Each of the following sub-sections is headed by the type of scheme and the recommended test procedure given for each soil type. Materials, other than cohesive and granular deposits, such as chalk are discussed under separate headings.

F2. Reconstruction/Widening of Minor Roads.

Scheme costs are likely to limit the suitability of the method used in the investigation. The hand excavated inspection pits, through the existing road pavement, for reconstruction schemes would be infrequently spaced while for the widening projects the machine-dug trial pits would be at more regular intervals. From the trial or inspection pits it is recommended that all of the following methods be used and the results given expert evaluation to determine an appropriate value.

Cohesive Soils -	(i) MEXE probe (ii) Hand Vane. (iii)Plastic and Liquid Limit.
Granular Soils (Fine Grained)	(i) MEXE probe. (ii) Particle Size Distribution.
Granular Soils (Coarse Grained)	(i) Grading.

In all cases the geology of the subgrade should be accurately described in accordance with BS 5930 (Ref 4). The natural moisture content for clayey, silty and sandy soils should also be measured.

F3 Major Road Schemes.

With the larger schemes the potential for financial savings is greater and consequently the potential benefits in additional investment in investigation are greater. Therefore more trial pits and road inspection pits can be justified. All of the following methods should be used, as applicable, and the results given expert evaluation to determine an appropriate value of CBR for this type of scheme.

Cohesive Soils (i) MEXE Probes.
(ii) Hand Vane.
(iii) Plastic and Liquid Limits.
(iv) Compaction/CBR relationship where it is considered that the soils are moisture sensitive.

Granular Soils (Fine Grained) (i) MEXE Probe.
(ii) Particle Size Distribution.
(iii) Compaction/CBR relationship.

Granular Soils (Coarse Grained) (I) Grading.

In all cases the geology of the subgrade should be accurately described in accordance with BS 5930. The natural moisture content for clayey, silty and sandy soils should also be measured.

F4. New Schemes on 'Greenfield' Sites.

With new highway projects the material excavated to subgrade level should be balanced by embankment fill requirements, if possible. Consequently there is a dual purpose in investigating the underlying soils, one for the material's acceptability for earthworks fill and the other for the subgrade strength. The following are tests which are useful for both. All of the following methods should be used, as applicable, and the results given expert evaluation to determine an appropriate value of CBR for this type of scheme.

Cohesive Soils (i) MEXE probe - shallow cuttings only.
(ii) Hand Vane - shallow cuttings only
(iii) Plastic and Liquid Limits - shallow and deep cuttings.
(iv) Compaction/CBR relationship - shallow cuttings only.
(v) Triaxial Tests - deep cuttings only.

Granular Soils (Fine Grained) (i) MEXE probe - shallow cuttings only.
(ii) Particle Size Distribution - shallow and deep cuttings.
(iii) Compaction/CBR relationship - shallow cuttings only.
(iv) Compaction/Moisture Content vs CBR.

Granular Soils (Coarse Grained) (i) Grading.

In all cases the geology of the subgrade should be accurately described in accordance with BS 5930 (Ref 4). The natural moisture content for clayey, silty and sandy soils should also be measured.

F5. Chalk.

Subgrades founded upon chalk, whether it is lying in-situ or remoulded in an embankment, will normally have sufficient strength to obviate the need for a capping layer. The measured in-situ CBR may be generally in excess of 7% and often well in excess of this value. Highly weathered chalk, chalk head or chalk mixed with overlying deposits is likely to have a lower design CBR. A minimum 7% CBR value is applicable to intact soils and fill materials that have been subjected to compaction levels which are equivalent to that given in the 600 series clauses of the Department of Transport's Specification for Highway Works (Ref 5). Badly compacted chalk which has a significant proportion of voids poses certain problems, the solution to these requiring specialist advice from a Geotechnical or Materials Engineer. Well compacted or intact chalk which exhibits a featureless structure may also pose problems, especially if wet and allowed to remain so. Again specialist advice should be obtained.

If chalk is considered for use as embankment fill then the prospective material has historically been investigated by performing Chalk Crushing Value (CCV) tests and more particularly the natural moisture content (NMC) and saturation moisture content (SMC) tests. These would probably be carried out for a suitability assessment (Ref 17) and will give an indication of the fragility of the chalk. The performance of the chalk is particularly sensitive to the degree of weathering, SMC and the ratio of SMC to NMC. Trafficability and compaction problems are likely to occur for wet chalk as the ratio NMC/SMC approaches unity and may require rest periods to allow the material to dry out and compaction induced pore water pressures to dissipate. Conversely very dry chalk may be susceptible to collapse settlement.

F6. Composite Soils.

If the soil contains a mixture of materials, such as Clay-with-Flints which can be flints bound in a matrix of silty clay, then an assessment must be made as to which is the dominant portion of the lithology. It is likely, therefore, that a grading/particle size distribution will be required to determine which fraction of the soil will control the behaviour of the mass. An assessment of the CBR can be established by performing the series of tests which conform to the dominant lithology. Other combinations of soils, such as Chalk/Head or Ragstone/Hassock may require considerable skill and experience in the interpretation of test results, as they may be affected by construction techniques.

F7. THE DESIGN VALUE OF CBR.

The measurement of CBR provides an indication of the subgrade strength at the present time and to estimate the worst case prediction for future service within the pavement.

In reality the present value could underestimate the strength of the subgrade at the time of construction because the prevailing pessimistic conditions may not manifest themselves, for example during summer construction. Conversely the current value could have been taken during the summer and the scheme constructed in the winter when the subgrade may be weaker due to the moisture accumulated at that time of year.

It is therefore important to consider the implications of the timing of the site investigation results in relation to those at the time of the construction. Unfortunately there are no 'hard and fast' rules and consequently the field results may need expert interpretation.

A local knowledge of the effect of moisture on the relevant soil and the compaction/moisture content vs CBR relationship , together with the investigations carried out by a laboratory should be used to produce an interpretative statement on the equilibrium CBR for design purposes. This will need to be requested. Other factors affecting the performance of the subgrade as discussed in Section 3, notably drainage and the risk of settlement of the foundation materials, must also be considered in the design in addition to the determination of CBR.

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TABLE F- Advantages and Disadvantages of the methods for determining CBR values.

METHOD	ADVANTAGES	DISADVANTAGES
1.CBR's performed upon pot samples	(i)It allows the possibility of evaluating the CBR of a soil in varying degrees of saturation. (soaked/unsoaked CBR's)	(i) Appreciable disturbance is caused during the sampling procedure which significantly affects the test results. ii)Large trial pit required.
2. Plastic and Liquid Limits	(i) it allows a lower bound assessment of the CBR under recompacted conditions for a variety of effective stresses (i.e. construction conditions)	(i) The analytical procedure is expensive unless standard graphs are used. (ii) The standard graphs assume a worst case (iii) Can only be used on soils containing cohesive material (iv) Can be difficult to interpret on mixtures of granular and cohesive material
3. Soil Assessment Cone Penetrometer (MEXE Probe)	(i) Quick and inexpensive to perform	(i) Correlation dependent (ii) Only provides the existing value of CBR (iii) Insensitive to the effects of the soils macrostructure (iv)Cannot be used in stony soils
4. Measurement of Shear strength (hand vane/Triaxial tests)	(i) The hand vane is quick and inexpensive to perform (ii) Triaxial measurements of the undrained shear strength takes into account the soil macrostructure (iii) Remoulded tests provide a lower bound for recompacted subgrades	(i) Only provides the existing value of CBR when using the hand vane (ii) The triaxial measurements are moderately expensive to perform, sampling and testing time can be long (iii) Dependant upon a correlation although this does have a theoretical basis (iv) can only be used for cohesive soils
5. In-situ CBR	(i) Realistic measurement of the CBR (ii)Takes into account the macrostructure of the soil account (iii) can be used to assess current value for chalk.	(i) Very expensive to perform (ii) Only provides the existing value of CBR (iii) Difficult to perform below existing ground surface (iv) Not suitable for coarse granular soils
6. Laboratory compaction test	(i) Determines the CBR of remoulded soils for a variety of moisture contents	(i) Insensitive to the effects of the soils macrostructure (ii) Expensive to perform (iii) Requires a large sample (iv) variable results with coarse granular soils.