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BRITISH PORTS ASSOCIATION PORT AND HEAVY DUTY PAVEMENT DESIGN MANUAL

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

Investment in container handling infrastructure at ports and inland terminals continues at a pace worldwide. Concrete block paving has become the orthodox surfacing for container terminals worldwide and for this reason Interpave with the support of the UK Concrete Centre has extended its partnership with the British Ports Association (BPA) to publish the Fourth Edition of the BPA port and heavy duty pavement design manual.

The "Fourth Edition" represents a significant step forward in the design of heavy-duty pavements, i.e. those pavements subjected to loads higher than those commonly encountered on a highway. It expands the number of design solutions as compared with the previous three Editions by including a wider range of bound base and sub-base materials, whilst at the same time preserving the simplicity of the design process. Also, additional worked examples are included, including those illustrating overlay design for cases where an existing pavement needs to be upgraded.

In keeping with BPA and Interpave's commitment to sustainable solutions, many of the new materials include recycled components such as fly ash and slag: crushed concrete and other waste materials can be used in the foundation courses. Likewise, for the first time, guidance is provided on permeable pavements in order to promote sustainable Drainage Solutions (SuDS). In some design solutions, rainfall can be transmitted directly through the pavement into the underlying subgrade material and in others, rainfall can be detained within the structure of the pavement. This is important because the large size of port and industrial pavements can lead to overloading of surface water drainage systems.

The Fourth Edition is future proof in several areas, for example, it envisages the development of fully automated high-speed container handling terminals and includes all of the factors and data needed for design of such facilities.

1. INTRODUCTION

The aim of the port pavement design process is to safeguard the pavement from failure over a predetermined period of time or number of cargo movements. There are four categories of failure associated with port pavements, viz:

- Environmental failure.
- Structural failure.
- Surface failure.
- Operational failure.

Each of these categories may influence failure in one of the other three so a complete port pavement design must address all of the issues which might on a particular project lead to one or more of these categories of failure. For example a full port pavement design might comprise the following elements:

- Sustainable Drainage Design (SuDS).
- Structural design.
- Surface drainage design.
- Surface operational characteristics.
- Provision of underground services.
- Traffic and storage management markings, signs and structures.
- Interface with other facilities and structures.
- Selection of appropriate construction techniques.
- Working environmental issues.
- Aesthetics.

Ignoring one or more components of the whole design process can lead to progressive reduction in pavement serviceability and performance so that ultimately one or more of the four categories of failure will occur.

The original research upon which the First Edition was based was undertaken in the 1970's when pavements were analysed by programmable calculator technology. This meant that stresses and strains could be calculated accurately at only one or two special points in the proposed pavement structure. The Third Edition used Finite Element analysis for the first time and this Fourth Edition uses a more detailed Finite Element model.

The Fourth Edition continues the theme of evaluating the Single Equivalent Wheel Load (SEWL) by considering the way in which the pavement is trafficked. Likewise, it continues the principle of separating design into its three essentials, i.e. selection of the surface, proportioning the base and providing a suitable foundation. In making this separation, no accuracy is lost and the design process is greatly simplified such that only one Design Chart is required. That Design Chart may be used to proportion the base course of a heavy duty pavement. Table 18 can then be used to select the pavement foundation according to ground conditions. The resulting pavement should remain serviceable throughout its life which can be defined in time or level of usage.

During the last 25 years, a good deal of experience has been gained in the use of Material Conversion Factors (MCFs) or Material Equivalence Factors (MEFs) so that within reason they can now be used as a means of effectively swapping one material for another during the design process and also in the design of an overlay to an existing pavement. This means that when a design has been produced using the Design Chart, the designer can generate many alternative design solutions using different materials and so investigate a full range of solutions.

Table 12 gives Material Equivalence Factors (MEFs) for a full range of commonly used base materials. Finally this Fourth Edition includes three examples showing how pavement design can be undertaken.

2. DESIGN OF CONVENTIONALLY DRAINED TRAFFICKED AREAS

Two conventionally drained pavement types are recommended:

Concrete Block Paving on cement bound base

The pavement comprises the following components:

- 80 mm thickness concrete paving blocks.
- 30 mm thickness laying course material.
- Cement Bound base.
- Crushed rock sub-base.
- Capping if subgrade California Bearing Ratio (CBR) is less than 5%.

In-situ concrete pavement

The pavement comprises the following components:
- Plain or reinforced in-situ concrete slab.
- Crushed rock sub-base.
- Capping if subgrade California Bearing Ratio (CBR) is less than 5%.

3. DESIGN OF PERMEABLE PAVEMENTS FOR TRAFFICKED AREAS

There are two alternative types of permeable pavement. In the first, water is detained within the pavement structure to be discharged at a controlled rate in order to avoid overloading downstream drainage.

The pavement comprises the following components:
- 80 mm thickness permeable Concrete Block Paving.
- 30 mm thickness 6 mm single sized grit.
- Cement Bound No-fines Concrete Base.
- Layer of 2 000 gauge polythene waterproof layer lapped to the surface at the perimeter.
- Crushed rock sub-base.
- Capping if subgrade California Bearing Ratio (CBR) is less than 5%.

In the second type of permeable pavement, water enters the pavement through its surface, travels vertically downwards through the pavement and is exfiltrated into the underlying subgrade. This type of pavement is suitable only when the soaked CBR of the subgrade is at least 5%, when it has been established that the subgrade can accommodate the water and when the effects of possible pollution of the underlying groundwater have been evaluated.

The pavement comprises the following components:
- 80 mm thickness permeable Concrete Block Paving.
- 30 mm thickness 6 mm single sized grit.
- Cement Bound No-fines Concrete Base.
- Layer of woven geotextile.

For both types of permeable paving, the No-fines Concrete Base would normally be selected to have a 28 days characteristic cube compressive strength of 10 N/mm^2 and can therefore be considered to be structurally equivalent to C8/10 Cement Bound Granular Mixture (CBGM), i.e. the standard material used in design in this Manual.

4. ANALYSIS TECHNIQUE

In order to produce the Design Charts, pavements have been analysed using the Finite Element method in which a model was developed to represent all components of the pavement. Elastic properties and Poisson's Ratio values were chosen to describe the behaviour of each pavement component. Fatigue is taken into account by defining limiting stresses to which the pavement can be exposed for one load pass and then by reducing those stresses to account for the fatigue effect of multiple load repetitions.

5. PAVEMENT SURFACE, STRUCTURE AND FOUNDATION

Design involves dividing the pavement into foundation, structure and surface so that the base thickness can be proportioned to withstand the applied load regime and the foundation can be proportioned to develop adequate support to the base and surface taking into account ground conditions.

Present highway pavement design procedures include pavement foundation guidance which relates sub-base and capping specification to subgrade strength such that the subgrade is always stressed to a level commensurate with its strength. This technique is replicated in the Fourth Edition but the thickness of the capping layer has been increased to deal with the heavier loads applied on heavy duty pavements.

Essentially, recent developments in pavement design procedures have separated design into foundation design which is based upon subgrade strength, base design which is based upon loading regime and surfacing design which is based upon operational needs (although in most design methods, the structural benefit of the surfacing material is taken into account).

6. CALIBRATION OF THE DESIGN METHOD

All design procedures based upon mechanistic analysis, including Finite Element analysis, require proven criteria for levels of stress or strain which cannot be exceeded. Usually, these criteria are stresses or strains known to exist in successful designs produced by empirical design methods. By this means, the mechanistic model is effectively calibrated and designs produced by it have the same level of integrity as those produced by the design method used in the calibration exercise. Because the stress regime existing in pavements is so complex, design cannot be based upon evaluating strengths of materials from simple tensile or flexural tests because to do so would fail to account for the complex interactions of stress within a pavement.

Any given material does not have a unique tensile, flexural or compressive stress. Those values are dependent on the shape and size of the objects into which the materials are formed and upon stresses existing in other planes. The fact that a cube or a cylinder exhibits a certain strength does not mean that exactly the same material installed in a pavement will have the same strength (even in the case of identically compacted material). The difference between pure tensile strength and flexural strength, which is used in design, is illustrated in TRL Report TRL 615 “Development of a more versatile approach to flexible and flexible composite pavement design” [M Nunn, 2004]. Table E3 shows that CBM3 of tensile strength 0.99 N/mm^2 has a flexural strength of 1.65 N/mm^2.

7. BASIS OF CALIBRATION

In this manual the limiting stresses upon which the Design Chart is based are determined as follows. A proven semi-empirical pavement design method has been used to assess the levels of stress at critical positions in the following manner. BS 7533-1:2001 “Pavements constructed with clay, natural stone or concrete pavers. Part 1: Guide for the structural design of heavy duty pavements constructed of clay pavers or precast concrete paving blocks” has been used to produce design examples covering pavements trafficked by up to 12 Million Standard Axles (MSA). These pavements have then been analysed using the same Finite Element model as is used in this Manual to establish permissible stresses in heavy duty pavements.

The stresses which the Finite Element model has demonstrated to exist in pavements designed according to BS 7533-1:2001 are used in this Manual as the critical design stresses in heavy duty pavement design. In other words, the Design Chart has been produced using the same Finite Ele-

ment model which has been used to back-analyse a range of pavements produced by BS 7533-1:2001. This means that the experience and methodology underpinning BS7533-1:2001 has been extended in this Manual to deal with all those pavements likely to be encountered in heavy duty pavement design situations.

Pavements designed according to BS 7533-1:2001 were analysed using the Finite Element model to determine stresses and strains at critical locations in each pavement. The pavement sections developed from BS7533-1:2001 are shown in Table 1.

Table 1 shows the design thicknesses taken from Figure 3 of BS7533-1:2001 and the resulting tensile stresses for different pavement design lives. The final column in Table 1 shows Design Stresses which include a Material Safety Factor of 1.5 in line with other design standards for concrete. These Design Stresses are used in the development of the Design Chart for heavy duty pavements. The BS7533-1:2001 pavements in Table 1 were analysed using the same Finite Element model as is used to analyse the heavy duty pavements but this time for a wheel load of only 70kN. This load is typical of the higher Single Equivalent Wheel Loads (SEWLs) which a highway pavement will sustain, taking account of vehicle dynamics and proximity factors.

Table 1. BS7533 pavement course thicknesses used in finite element analysis.

MILLIONS OF STANDARD AXLES	BASE THICKNESSES (mm)	STRESS IN FINITE ELEMENT MODEL (N/mm^2)	DESIGN STRESS (N/mm^2)
0.25 to 1.5	105	1.766	1.178
1.5 to 4	145	1.404	0.936
4 to 8	195	1.046	0.697
8 to 12	245	0.791	0.527

Having used the Finite Element model to calculate the stresses shown in Table 1 which exist in pavements designed according to BS7533-1 : 2001, the output from the heavy duty pavement Finite Element model was used to draw the heavy duty pavement Design Charts shown in Figure 1. The Design Charts have been produced by establishing base thicknesses which provide similar levels of stress to those shown in Table 1 but for heavier loads supported by thicker bases.

8. STRUCTURAL CONTRIBUTION CONCRETE BLOCK PAVING SURFACING

The development of the Manual has shown that large variations in surface stiffness have little effect on the performance of the pavement. To illustrate this, a series of Finite Element analyses has been carried out using the four values of surface stiffness shown in Table 2.

Each of the four surface stiffnesses was used in a Finite Element model of a pavement designed to withstand a patch load of 300 kN over subgrade with a CBR of 3%. Table 2 shows that a change in surface stiffness from 1 000 N/mm^2 to 8 000 N/mm^2 leads to a change of only 4% in maximum tensile stress within the pavement base. Most authorities consider that concrete block paving has a stiffness of between 1 000 N/mm^2 and 5 000 N/mm^2 which would lead to a variation in stress values in the base of less than 2%. This suggests that any enhancement in structural performance which might be engineered into types of pavers is of little or no consequence in heavy duty paving. Essentially, pavers should be selected on the basis that the surface remains stable under the loading regime. Conventional 200 mm x 100 mm plan dimension by 80 mm thickness rectangular pavers have been found to meet this criterion. Many non-rectangular pavers also achieve this level of stability.

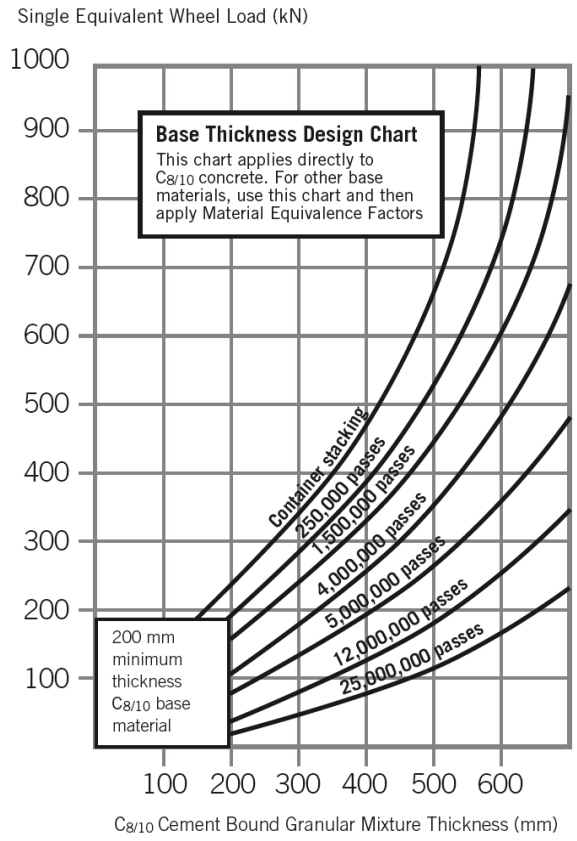

Figure 1. British Ports Association Design Manual Base Thickness Design Chart.

Note that the above reasoning does not mean that the contribution of the pavers to structural performance is small. The main structural benefit of pavers is in raising the load through the height of the pavers and their laying course material (110 mm). If the pavers and their laying course material are omitted from the Finite Element model, stresses in the base increase significantly. What this analysis shows is that providing the pavers are installed and providing they remain stable, there is no benefit in considering different types of pavers. Additional thickness of pavers, say to 100 mm or 120 mm, will help but is usually not required and has cost disadvantages.

Table 2. Effect of change in surface stiffness on tensile stress in base.

STIFFNESS OF SURFACE (N/mm^2)	MAXIMUM TENSILE STRESS IN BASE (N/mm^2)
1 000	1.18
2 000	1.16
4 000	1.15
8 000	1.13

9. PAVING MATERIALS

With the general introduction of Front Lift Trucks and Reach Stackers capable of placing a fifth heavy container over four stacked containers, concrete block paving has become the normal heavy duty pavement surfacing material. Hydraulically Bound Mixtures (HBM), i.e. Cement Bound Granular Mixtures (CBGM), Slag Bound Mixtures (SBM) and Fly Ash Bound Mixtures (FABM) have been found to be a cost effective and low maintenance base material, although bitumen bound materials are sometimes included. Therefore, in the design method presented in this Manual, HBM

supporting concrete block paving is the assumed pavement buildup. This Manual does allow the user to consider other materials but would recommend that they should be specified only when there is a specific need to deviate from what has over the last 30 years developed an orthodoxy.

10. STRUCTURAL PROPERTIES OF HYDRAULICALLY BOUND MIXTURES

Tables 3 and 4 set out the structural properties of HBM materials. In this Manual, the design process comprises selecting a pavement using the category of CBGM referred to as $C_{8/10}$ (see below) then substituting alternative materials on a Material Equivalence Factor (MEF) basis when the designer prefers other materials. Note that in the UK, the term Cement Bound Material (CBM) has been used for many years to refer to cement bound roadbases.

$C_{8/10}$ is equivalent to CBM3 which was the standard material used in the Third Edition of the Manual which was published in 1996. Adopting one standard base material in the analysis then substituting other materials on a MEF basis greatly simplifies the design process and at the same time facilitates an immediate comparison of alternative design solutions. It is a methodology with which many heavy duty pavement designers are now familiar. It is the Author's experience that this approach may be quicker and more rigorous that the alternative approach of using multi-layer elastic analysis software. Also, it is free in this Fourth Edition and this should enhance its worldwide acceptability and thereby lead to more successful heavy duty pavements.

11. STANDARD $C_{8/10}$ CEMENT BOUND GRANULAR MIXTURE

The design charts allow designs to be developed for pavements including a base comprising Cement Bound Granular Mixture (CBGM) according to BS EN 14227-1:2004 "Hydraulically bound mixtures- Specifications – Part 1: Cement bound granular mixtures". BS EN 14227 includes two classification systems for Cement Bound Granular Mixtures (CBGM). System I classifies CGBM by its Characteristic Compressive Strength as shown in Table 3 and System II classifies CBGM by tensile strength and modulus of elasticity at 28 days. Only System I is used in this Manual. Table 3 includes the mean axial tensile strength which is calculated from the formula:

$$\textbf{Mean Axial Tensile Strength} = 0.3\,(\textbf{Characteristic Cylinder Compressive Strength})^{2/3} \quad (1)$$

(Taking the H/D = 2 cylinder dimensional ratio).

12. MATERIAL EQUIVALENCE FACTORS

Table 3 shows the properties of CBGM as defined in BSEN 14227: Part 1: 2004 "Hydraulically bound mixtures – Specifications. Part 1: Cement Bound Granular Mixtures." The tensile strength values in Table 3 are used in Material Equivalence Factor (MEF) analysis which allows materials to be exchanged during the design process. However, the tensile strength values shown in Table 3 can be exceeded within the pavement structure because the extreme condition of pure tension never develops within the pavement (this is shown in the stress maps on the Fourth Edition web site where the Mohr's circle diagrams show that a significant compressive stress acts on planes normal to the line of maximum tensile stress). Table 1 includes those values which back analysis shows to be present in pavements designed by a well established empirical design method and it is those values which have been used to construct the Design Chart.

The standard material used to construct the Design Chart in the Third Edition of the BPA Manual was C10 lean concrete i.e. material with a characteristic 28 days compressive cube strength of 10 N/mm^2 or Cement Bound Material 3, i.e. material with an average seven days compressive cube

strength of 10 N/mm^2 which is very close to a characteristic 28 days compressive cube strength of 10 N/mm^2. This is because the multiplying factor normally used to related 7 day strength to 28 day strength is 1.2. Therefore, a 7 days average strength of 10 N/mm^2 would normally lead to a 28 days average strength of 12 N/mm^2. Given the normal distribution of individual cube strengths, an average strength of 12 N/mm^2 would give a characteristic strength of approximately 10 N/mm^2.

C10 concrete was defined in BS 5328-1:1997 "Concrete – Part 1: Guide to Specifying Concrete." The corresponding material in BS EN 14227-1:2004 is $C_{8/10}$, i.e. material with a 28 days characteristic compressive cube strength of 10N/mm^2 and this is now the standard design material used the construct the Design Chart. Note that TRL Report TRL615 "Development of a more versatile approach to flexible and composite pavement design" (M Nunn, 2004) recommends that CBM3 be equated with $C_{8/10}$ for design purposes (Table E2 Design classifications).

Table 3. Classification of Cement Bound Granular Mixtures by Characteristic Compressive Strength.

Note that the standard material used to construct the Design Chart is shown in bold.			
CHARACTERISTIC 28 DAY COMPRESSIVE STRENGTH (N/mm^2)		**STRENGTH CLASS**	**MEAN AXIAL TENSILE STRENGTH (N/mm^2)**
CYLINDER STRENGTH (H/D = 2)	**CYLINDER OR CUBE STRENGTH (H/D = 1)**		
No requirement		**C_0**	**0**
1.5	2.0	$C_{1.5/2.0}$	0.39
3.0	4.0	$C_{3/4}$	0.62
5.0	6.0	$C_{5/6}$	0.87
8.0	**10.0**	**$C_{8/10}$**	**1.18**
12	15	$C_{12/15}$	1.55
16	20	$C_{16/20}$	1.87
20	25	$C_{20/25}$	2.17

In instances where materials other than $C_{8/10}$ CBGM are being evaluated, the design should be undertaken as if for $C_{8/10}$ CBGM and Table 5 should then be used to alter the design thickness of the resulting $C_{8/10}$ CBGM base on the basis of Material Equivalence Factors (MEFs). The flexural strength of a pavement course is proportional to the square of its depth and is directly proportional to its tensile strength. The stiffness of a pavement course is proportional to the cube of its depth and is directly proportional to its tensile strength. In the case of HBMs, Material Equivalence Factors are based upon strength. Therefore, the Material Equivalence Factors by which $C_{8/10}$ CBGM base thickness needs to be multiplied to convert to other materials are shown in Table 5.

13. TABLE OF MATERIAL EQUIVALENCE FACTORS

Table 4 includes Material Equivalence Factors (MEFs) for HBMs and other materials. It includes MEFs for several grades of concrete defined in BS8500: Part 1: 2006 "Concrete – Complementary British Standard to BSEN 206-1. Part 1: Method of specifying and guidance for the specifier." as well as Cement Bound Granular Materials and bitumen bound materials previously defined in UK Highways Agency's "Specification for Highway Works" (SHW) which forms part of Highways Agency's Design Manual for Roads and Bridges.

Experience in the use of Material Equivalence Factors indicates that within a limited range, they can prove to be an efficient means of expanding one design solution into many alternatives, each of

similar structural capability. Whenever a material swap is made, the designer should ensure that the proposed material is suitable for the purpose, taking into account its proposed function and position within the pavement. For example, it would be wrong to introduce say, crushed rock in place of a bound material in a location where stresses could lead to instability of the material. Only those materials with a proven track record in the proposed location should be considered and materials should only be used in combination where that combination is proven. The relationship between relative base thicknesses and allowable stresses is:

$$\mathbf{d_{new} = d_{stand} \times (\sigma_{stand}/\sigma_{new})^{1/2}} \qquad \mathbf{(2)}$$

where:

d_{new} = The revised base thickness for alternative material.
d_{stand} = The design thickness specified $C_{8/10}$ CBGM.
σ_{stand} = Tensile strength of $C_{8/10}$ CBGM.
σ_{new} = Tensile strength of alternative material.

For example, if the Design Chart shows the required $C_{8/10}$ CBGM thickness to be 450 mm and it is proposed to install $C_{5/6}$, then the correct thickness is 450 x 1.16 = 522 mm.

Table 4. Material Equivalence Factors relating C 8/10 CBGM to other materials.

Note that the thicknesses derived from the Design Charts need to be multiplied by the factors in this table to obtain thicknesses for materials other than C 8/10.			
PREFERRED PAVEMENT BASE CONSTRUCTION MATERIAL			**MATERIAL EQUIVALENCE FACTOR (MEF)**
C 1.5/2.0	to	BS EN 14227-1	1.74
C 3/4	to	BS EN 14227-1	1.38
C 5/6	to	BS EN 14227-1	1.16
C 8/10	**to**	**BS EN 14227-1**	**1.00**
C 12/15	to	BS EN 14227-1	0.87
C 16/20	to	BS EN 14227-1	0.79
C 20/25	to	BS EN 14227-1	0.74
C 1.5/2.0	to	BS EN 14227-2&3	1.74
C 3/4	to	BS EN 14227-2&3	1.38
C 6/8	to	BS EN 14227-2&3	1.10
C 9/12	to	BS EN 14227-2&3	0.95
C 12/16	to	BS EN 14227-2&3	0.85
C 15/20	to	BS EN 14227-2&3	0.79
C 18/24	to	BS EN 14227-2&3	0.76
C 21/28	to	BS EN 14227-2&3	0.72
C 24/32	to	BS EN 14227-2&3	0.68
C 27/36	to	BS EN 14227-2&3	0.63

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Table 4…(Continues from previous page).

C 8/10	**to**	**BS8500-1**	**1.00**
C 12/15	to	BS8500-1	0.87
C 16/20	to	BS8500-1	0.79
C 20/25	to	BS8500-1	0.74
C 25/30	to	BS8500-1	0.65
C 25/30	to	BS8500-1 including 20 kg/m^3 steel fibre	0.60
C 25/30	to	BS8500-1 including 30 kg/m^3 steel fibre	0.55
C 25/30	to	BS8500-1 including 40 kg/m^3 steel fibre	0.50
C 28/35	to	BS8500-1	0.62
C 32/40	to	BS8500-1	0.60
C 32/40	to	BS8500-1 including 20 kg/m^3 steel fibre	0.55
C 32/40	to	BS8500-1 including 30 kg/m^3 steel fibre	0.50
C 32/40	to	BS8500-1 including 40 kg/m^3 steel fibre	0.45
C 35/45	to	BS8500-1	0.58
CBM1 to SHW (4.5 N/mm^2 minimum 7-days compressive cube strength)			1.60
CBM2 to SHW (7.0 N/mm^2 minimum 7-days compressive cube strength)			1.20
CBM3 to SHW (10.0 N/mm^2 minimum 7-days compressive cube strength)			**1.00**
CBM4 to SHW (15.0 N/mm^2 minimum 7-days compressive cube strength)			0.80
CBM5 to SHW (20.0 N/mm^2 minimum 7-days compressive cube strength)			0.70
No-fines Lean Concrete for Permeable Paving			**1.00**
HDM as defined by SHW			0.82
DBM as defined by SHW			**1.00**
HRA as defined by SHW			1.25
Crushed Rock sub-base material of CBR ≥ 80%			3.00
Concrete Block Paving as a surfacing (80 mm blocks and 30 mm laying course)			**1.00**

Notes: Concrete referred to as C 16/20 means concrete with a 28 d characteristic compressive cube strength of 20 N/mm^2. Where two subscripts follow C, the first is characteristic compressive cylinder strength and the second is characteristic compressive cube strength.

HDM = Heavy Duty Macadam.

DBM = Dense Bitumen Macadam.

HRA = Hot Rolled Asphalt.

SHW = UK Highways Agency "Specification for Highway Works".

Note that those materials in italic would not normally be specified as a pavement base but may be used as part of the pavement foundation (see Foundation Design).

The Design Chart has been drawn for CBGM with Design Flexural Strength values as shown in Table 1 (see Table 5).

Table 5. Values for CBGM

SEWL = SINGLE EQUIVALENT WHEEL LOAD			**N/mm^2**
Up to 250 000			1.3
250 000	to	1.5 x 10^6	1.1
1.5 x 10^6	to	4 x 10^6	0.9
4 x 10^6	to	8 x 10^6	0.7
8 x 10^6	to	12 x 10^6	0.5

These are the values which can be used for C $_{8/10}$ CBGM, even though they may be greater than pure tensile strength values (because the material is not subjected to pure tension but is always subjected to compression in planes orthogonal to the tension plane).

14. STRUCTURAL PROPERTIES OF PAVEMENT COURSES

The properties of pavement courses are shown in Table 6. It is assumed that the surface comprises 80 mm thick concrete pavers installed in 30 mm thickness laying course material. Experience has shown that alternative pavement surfacing materials have little influence on overall pavement strength and alternative surfacing materials can be substituted with little influence on overall structural performance. In the Finite Element analysis, the surface has been modelled as a homogeneous 110 mm thick layer of material having an elastic modulus of 4 000 N/mm^2 and a Poisson's Ratio of 0.15. This has been found to equate closely with the properties of both concrete block paving and bituminous bound surfacing materials. The Elastic Modulus of $C_{8/10}$ base has been assumed to be 40 000 N/mm^2 which is a high value.

By comparison, the UK Highways Agency recommends values of 33 000 for CBM3, 39 000 for CBM4 and 43 000 for CBM5 with gravel aggregate and 35 000 for CBM3, 40 000 for CBM4 and 45 000 for CBM5 with crushed rock aggregate. Taking a high Elastic Modulus value in the model is in fact a conservative assumption and this may seem counter intuitive. The reason for this is that a stiff element within any structure attracts load and therefore develops higher internal stresses than would a more flexible element.

The dynamic elastic modulus is used in this Manual. Dynamic elastic modulus is the pure elastic response of the material which does not take creep (the tendency of stressed concrete to change shape to as to shed the stress) into account and is similar to the initial tangent modulus determined in a static test. This means it is higher than the static modulus.

Table 6. Pavement material properties used in producing design charts.

LAYER	ELASTIC MODULUS, E (N/mm^2)	POISSON'S RATIO
Surfacing (pavers)	4 000	0.15
Base ($C_{8/10}$)	40 000	0.15
Sub-base	500	0.30
Capping	250	0.35
Subgrade	10 x CBR	0.40

15. REFERENCE

NUNN M (2004). TRL Report TRL615 *"Development of a more versatile approach to flexible and composite pavement design".* Transport Research Laboratory, Crowthorne, UK.