TECHNICAL GUIDELINES

HBM AND STABILISATION

3 The design and specification of HEAVY-DUTY PAVING

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The British In-situ Concrete Paving Association

This publication provides design and specification guidelines for clients, designers and contractors wishing to use hydraulically bound mixtures for heavy-duty paving.

Britpave, the British In-situ Concrete Paving Association, was formed in 1991. It is active in all areas of transport infrastructure including roads, airfields, light and heavy rail, guided bus, safety barriers and drainage channels, soil stabilisation and recycling.

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Ref. BP/28
Price code B
Published 2007
ISBN 978-0-9551272-7-4

Published by Britpave
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Britpave acknowledges financial support from The Concrete Centre in the production of this publication. **www.concretecentre.com**

HBM and stabilisation 3

The design and specification of heavy-duty paving

Contents

Glossary

Surface course	previously known as wearing course
Binder course	previously known as basecourse
Surfacing	surface course or combination of surface and binder courses
Base	previously known as roadbase
Subbase	previously hyphenated i.e. sub-base
HBM	hydraulically bound mixture; a mixture that hardens through the hydraulic reaction between the constituents and water
CBM	cement bound mixture (previously cement bound material); an HBM that hardens through hydration of cement
CBGM	cement bound granular mixture; a type of CBM
FABM	fly ash bound mixture; an HBM that relies on the pozzolanic/hydraulic combination of coal fly ash (also known in the UK as pfa, the acronym for pulverized fuel ash) with quick or hydrated lime, or cement
SBM	slag bound mixture; an HBM that relies on the hydraulic/sulfatic combination of granulated blast furnace slag (GBS) with other slags and or with quick or hydrated lime
HRB	hydraulic road binder – a factory blended hydraulic binder, typically made from GBS and or fly ash, lime and gypsum, specifically formulated to be slow setting for road and stabilisation use
HRBBM	HRB-bound mixture; an HBM that uses HRB as the binder
CBGM A	graded aggregate mixture which includes sandy mixtures (ref. SHW 821)
CBGM B	well graded aggregate mixture (ref. SHW 822)
FABM 1, SBM B1-2 & HRBBM 1	0/31.5 mm graded mixtures (ref. SHW 830)
FABM 3, SBM B3 & HRBBM 3	0/6.3 mm mixtures (ref. SHW 831)
msa	millions of standard axles
sa	standard axles
SC	soil (treated by) cement (ref. SHW 840)
SFA	soil (treated by) fly ash (ref. SHW 840)
SS	soil (treated by) slag (usually ggbs, which is ground GBS) (ref. SHW 840)
SHRB	soil (treated by) HRB (ref. SHW 840)
SHW	*Specification for Highway Works*

1 Introduction

These guidelines provide thickness design, specification and construction advice for the use of hydraulically bound mixtures (HBM) including cement bound mixtures (CBM) for heavy-duty paving. Heavy-duty paving is defined in this document as areas subject to wheel/axle loading in excess of that permitted on public roads.

These guidelines are applicable to:

- The use of hydraulically bound mixtures (HBM) mixed in central plants where the aggregate may comprise natural, artificial or recycled material.
- In-situ stabilised mixtures, also referred to here as HBM, produced by stabilising granular materials that occur naturally in the ground at paving level or of granular materials that have been placed in advance of paving works.
- Binders or hydraulic combinations based on Portland cement, quicklime (CaO) or hydrated lime [$Ca(OH)_2$], ground granulated blast-furnace slag (ggbs) and coal fly ash (also known in the UK as pulverized fuel ash or pfa).

Thickness design advice is based on practice and data from well-established and proven documentation [1–3]. The strength characterisation and specification of HBM is in accord with the concepts and terminology in the European standard for HBM introduced as a British Standard in 2004 and 2006 [4, 5] and the Highways Agency's *Specification for Highway Works* (SHW) [6].

2 Design parameters

2.1 General

In order to design a paved area, the primary input parameters are:

- Long-term or equilibrium subgrade strength.
- Traffic to be carried during the design life.

In addition, the following issues should be considered: subgrade strength during construction, general construction issues, durability, drainage, sulfates and client expectations.

2.2 Subgrade strength (long term and during construction)

Limited guidance on typical subgrade strengths for a range of soil types is given in Table 1. For further information, reference should be made to Appendix C in LR 1132 from TRL [7], which provides more detailed advice on both short- and long-term (equilibrium) subgrade strength and stiffness for high and low water tables under differing construction conditions.

2.3 In-service traffic

Heavy-duty paving is defined as paved areas that are designed and constructed to cater for loading beyond the UK legal maximum road axle load. Such loading is often a feature of industrial pavements where the use of handling plant such as container 'straddle-carriers' and fork-lift trucks can be commonplace. These types of vehicles can have wheel loads of 12 to 50 tonnes, far in excess of the current legal wheel loads for public roads. Applications where such pavement loading is usual include ports and harbours, and commercial and military aircraft pavements. Developed by the British Ports Association (BPA) and Property Services Agency (PSA), design guidance for these applications is currently available from both organisations [1, 2]. These documents are recommended as primary sources of information for heavy-duty pavement design.

Both the BPA and PSA documents provide procedures for designing and specifying heavy-duty paved areas where the main structural layer is cement bound material (CBM). The BPA document uses an analytical approach for design and provides a choice of in-situ concrete, concrete blocks and brick pavers or asphalt surfacing layers.

The PSA document uses an empirically-based design procedure to provide asphalt surfaced CBM. Both approaches can be used for HBM in general (not just CBM) as will be described in Section 3. The choice of surfacing is the responsibility of the designer and will depend on client requirements, spillage, wear and ground settlement expectations. This is discussed later in Section 2.4.

Despite the availability of these design sources, design traffic loading for heavy-duty paved areas other than ports and airfields may be difficult to define and assess. Overall design is a function of design life, the type and frequency of handling vehicle or plant that will use the pavement and client requirements, all of which can sometimes be difficult to quantify.

Against this background, the advice given in this publication avoids this problem by basing advice on the maximum wheel load that will use the pavement without the need to quantify frequency of loading nor design life. This approach is based on the fact that unlike roads, which are subject to many passes of relatively light axles, heavy-duty pavements are usually subject to relatively few passes of heavy loads. In such situations, it can be argued that it is the maximum intensity of load rather than frequency of loading that needs to be considered for design purposes. This is particularly relevant for CBM and to HBM in general, all of which are particularly susceptible to cracking and failure from over-loading.

The design advice in this publication is based on the simplified analytical approach described by Williams in *Cement treated pavements* [3], which requires knowledge of the maximum wheel load only. Where frequency of loading is considered an issue, the BPA and/or PSA documents should be used.

This somewhat simplistic approach introduces a degree of conservativeness into the recommendations compared with, say, the BPA approach. This approach may provide an advantageous and safe procedure for pavements where in-service loading and client expectations are difficult to quantify.

2.4 Client expectations and surfacing

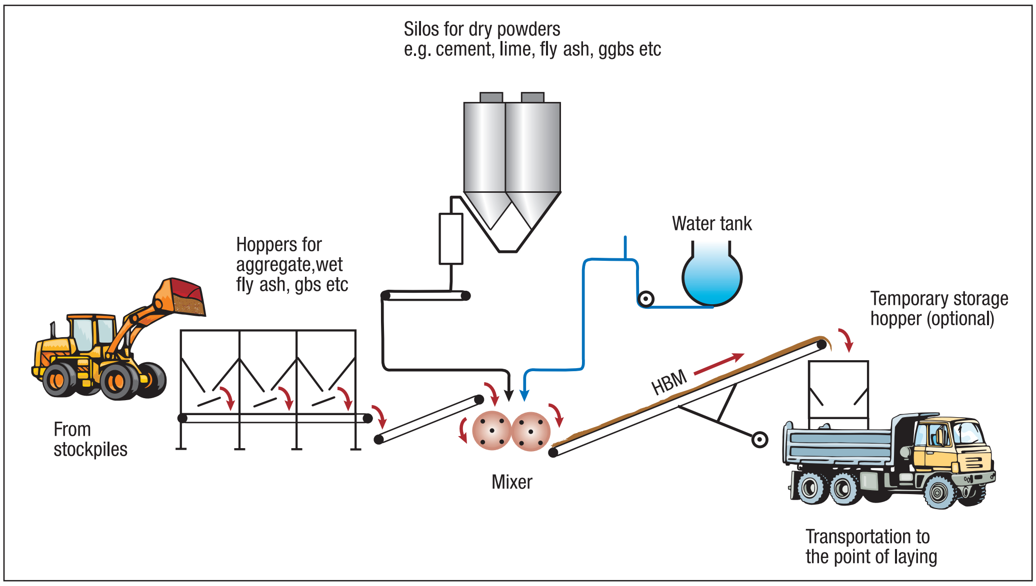
In-service life expectations and serviceability requirements will vary. With regard to structural performance, the design approach used in these guidelines is sufficiently robust to remove these issues from design considerations. However, with regard to maintaining structural integrity, the type and thickness of surfacing is important.

As a rule-of-thumb, increasing the thickness of surfacing provides more durable pavements. Minimum surfacing recommendations are given in Table 1 for asphalt, concrete block or clay paver solutions.

Clearly in-situ concrete is a pavement solution offering inherent structural benefits as well as fuel-resistant, durable, rutting- and abrasion-resistant running surfaces. However, as the focus of this document is the design of pavements where the main structural contribution is provided by HBMs, concrete options are not included in Table 1. Further guidance on these pavements types is available elsewhere [1, 2].

The fuel resistant properties of surfacing layers are also important since oil, diesel and petrol spillage will be an everyday occurrence with heavy-duty pavements. Where such spillage is identified as a problem, consideration should be given to the use of ‘cementitious’ grouted macadam or block paving surfacing.

Key elements of mix-in-plant production



2.5 Drainage

With regard to surface water drainage, it is imperative that surface water is not allowed to stand and seep into pavements. This will cause saturation of stabilised layers or the upper part of a layer that, if subject to freezing temperatures, may suffer damage. Adequate cross falls must be employed to prevent the possibility of standing water. Surfacing, or, the first course of surfacing, should be placed as soon as possible to provide a weather-proof seal.

Provision for the collection of surface water and the prevention of the ingress of ground water should, as with all large area paving works, be provided at the edges of the pavement and elsewhere if necessary.

3 Design

3.1 General

Illustrative design guidance is provided in Table 1, based on Williams' simplified analytical approach (see Annex A for further details). It is stressed that the guidance in Table 1 may not be the only solution available. Where successful use and experience of other methods exists, this may be applicable, for example those given in BPA and PSA design sources, in which case, the advice given here can be used as a check against the adopted approach.

The majority of the depths of HBM illustrated in Table 1 will require a two- or even three-lift construction. In theory, multi-lift HBM, where the bond between lifts may be only partially effective, will not be as structurally effective as the same depth placed and compacted in one lift. However, as it is recognised that it is difficult to achieve compaction that provides acceptable and specified levels of density with lifts in excess of 250 mm, multi-lift work is inevitable.

Nevertheless, the designs shown here should cater for multi-lift work without an increase in thickness provided the following lift is placed and compacted before setting and drying out takes place in the underlying lift. In this regard, it is definitely more advantageous to use HBM based on slow setting, slow hardening binders; this is likely to provide a more positive bond between lifts than with fast setting and hardening HBM materials.

3.2 Settlement

Where settlement, and differential settlement in particular, is an issue, HBM that possess the property of autogenous healing can be beneficial because of the ability to self-heal at settlement cracks in the short to medium term. Thus it is advantageous to use HBM using binders based on fly ash and/or granulated blast-furnace slag particularly when used in combination with lime or other lime-bearing products such as air-cooled steel slag.

3.3 Durability

The strength advice given in Table 1 produces HBM that will be durable to cycles of 'wetting and drying' and 'freezing and thawing' and, provided it is surfaced promptly, durable to traffic and weather during the construction period. There is therefore no need to carry out durability testing.

With regard to the frost susceptibility of subgrades and the potential for frost heave, the construction depths recommended in rows E & F of Table 1 will provide a minimum cover depth over the subgrade of 320 mm. This should provide sufficient frost insulation in the unlikely situation that the sandy or sandy gravelly subgrade is frost susceptible. In the case of row F, there should also be no problem provided the recommendations in Table 1 are followed. Where there is any doubt, however, frost heave testing should be carried out and, if necessary, the depth of cover increased to at least a minimum of 350 mm for milder regions of the UK or 450 mm elsewhere.

3.4 Sulfates

The existence of sulfates and other materials capable of causing volume instability in the stabilised layer, which can be a problem with some stabilised clays and some recycled/industrial materials, should be explored at the site investigation stage and if applicable, the mixture design stage using immersion and/or swell testing. Advice on this is detailed in references 6 and 8.

Table 1: Illustrative surfacing and plant-mixed HBM thickness and strength advice for heavy-duty paved areas

	1	2	3	4	5	6	7
		Maximum wheel load (tonnes)					
A		Up to 5	Up to 5	> 5 to 10	> 5 to 10	> 10 to 20	> 20 to 40
Surfacing layer guidance (Note 1)							
B	Thickness of asphalt surfacing	80 mm	80 mm	100 mm (possibly 80 mm)	100 mm (possibly 80 mm)	100 mm	100 mm
C	Concrete block paving	80 mm block on 30 mm bedding sand layer					
Base layer guidance							
D	HBM strength (MPa) (Note 2)	C8/10 or C9/12	C5/6 or C6/8	C8/10 or C9/12	C5/6 or C6/8	C8/10 or C9/12	C12/15 or C12/16
E	HBM thickness for subgrade design CBR ≥ 15% (typically a sandy gravel subgrade)	240 mm	290 mm	340 mm	410 mm	480 mm	550 mm
F	HBM thickness (Note 3) for subgrade design CBR 8% – 14% (typically a sandy subgrade)	260 mm	310 mm	360 mm	440 mm	510 mm	590 mm
G	HBM thickness for subgrade design CBR less than 8%	Depending on subgrade strength and type, at least 250 mm to possibly 750 mm depth of subbase/capping/subgrade treatment, frost resistant in the case of columns 2 & 3, will be necessary between the subgrade and HBM and then design based on row F.					

Notes

1. *The surfacing or first course of surfacing should be laid as soon as possible to provide a weather-proof seal. Grouted macadam or concrete block paving should be given particular consideration where fuel and oil resistance is required. Refer to specification in Annex B.*
2. *The HBM and strength classes shown are compatible with the European standards for cement bound granular mixtures (BS EN 14227–1), other hydraulically bound mixtures (BS EN 14227–2, 3 & 5) and the 800 series of the SHW. The first number of each class relates to the compressive strength of cylindrical specimens with a slenderness ratio of 2 and the second number to a cylindrical ratio of 1 or to cubes. The first class in each column relates to CBGM and the second to SBM, FABM and HRBBM. Refer to specification in Annex B.*
3. *Subject to the achievement of the specified density for the layer, mix-in-place construction is only permitted for columns 2 & 3 provided the required depth is constructed in one lift, and for the first lift of multi-lift work for columns 4 to 7 inclusive. Refer to specification in Annex B.*

4 Specification

The HBM and classes recommended in Table 1 should conform, not only to the footnotes to the table, but also to the specification framework included in Annex B.

The use of Table 1 and Annex B is illustrated in Annex C.

5 Mixture design, construction and control testing

Mixture design, construction and control of construction are covered by the *Specification for Highway Works*, but further advice and understanding can be found in publications from Britpave [9] and The Concrete Centre [10].

The design recommendations given in Table 1 will also cover trafficking during construction when loading will be light (being based on haulage and placing plant common to normal road construction) compared with in-service loading, but consideration will need to be given to the ability of the subgrade to accommodate the HBM placing operations.

Construction of multi-lift work should conform to the specifications in Annex B.

ANNEX A: Williams' simplified analytical pavement design approach

The design approach taken by Williams [3] ignores the contribution of the surfacing and 'idealises' the pavement as a two-layer system of an HBM layer on a supporting layer. This approach also recognises that HBM will crack to form discrete slabs (not unlike paving concrete) and considers the stress situation at slab edges, corners and away from edges and corners (i.e. at an interior position). For the interior loading condition, the tensile stress (s) at the bottom of the HBM layer is given by the expression:

$$s = 1.8p \left(\frac{a}{h}\right)^{1.85} \log_{10}\left(\frac{E_1}{E_2}\right) \quad \text{(A)}$$

where

- p = tyre pressure
- a = radius of tyre contact
- h = HBM thickness
- E_1 = HBM modulus of elasticity
- E_2 = foundation modulus of elasticity

Equation A can be simplified by making use of the relationship between maximum wheel load (P) and tyre pressure (p):

$P = p\text{p}a^2$ so that $p = \frac{P}{\text{p}a^2}$

and also by changing the power function from 1.85 to 2.

Thus equation A approximates to:

$$s = 0.57\left(\frac{P}{h^2}\right)\log_{10}\left(\frac{E_1}{E_2}\right) \quad \text{(B)}$$

or, rearranged:

$$h = \text{R}\,\overline{0.57\left(\frac{P}{s}\right)\log_{10}\left(\frac{E_1}{E_2}\right)} \quad \text{(C)}$$

The thickness of the HBM relative to its tensile strength can be derived from equation C by assuming the following:

- The surfacing, either 80 or 100 mm asphalt or block paving, although ignored in the calculation, is assumed to compensate for the edge/corner loading conditions that will occur at cracks and which will produce greater stresses than the interior loading condition that is the basis of this design approach
- P = maximum wheel load
- s = tensile strength and is taken as
  0.7 MPa for HBM compressive strength categories C5/6 or C6/8
  1 MPa for C8/10 or C9/12
  1.5 MPa for C12/15 or C12/16
- E_1 (HBM modulus of elasticity) = 15,000 MPa (assumes the use of CBGM 'B' / SBM B1–2 / FABM 1 / HRBBM 1)
- E_2 (foundation modulus of elasticity) = 10 x CBR in MPa

ANNEX B: Specification framework for HBM for heavy-duty paved areas

For ease of use, the design table in the main text is reproduced here but with the HBM thickness recommendations removed and replaced with the specification recommendations, which are in accordance with the BS ENs for HBM and the SHW 800 series.

Table B1: Specification with relevant SHW clause numbers

	1	2	3	4	5	6	7
		Maximum wheel load (tonnes)					
A		Up to 5	Up to 5	> 5 to 10	> 5 to 10	> 10 to 20	> 20 to 40
Surfacing layer guidance (Note 1)							
B	Thickness of asphalt surfacing	80 mm	80 mm	100 mm (possibly 80 mm)	100 mm (possibly 80 mm)	100 mm	100 mm
C	Concrete block paving	80 mm block on 30 mm bedding sand layer					
Base layer guidance							
D	HBM strength class (MPa) (Notes 2 & 4)	C8/10 or C9/12	C5/6 or C6/8	C8/10 or C9/12	C5/6 or C6/8	C8/10 or C9/12	C12/15 or C12/16
E	HBM specification for subgrade design CBR ≥ 15% (typically sandy gravel subgrade)	HBM specification options; (Note the 1st strength class in each column above relates to CBGM and the 2nd to SBM, FABM and HRBBM) 1. CBGM B to clause 822 of the SHW. 2. SBM B1–2, FABM 1 & HRBBM 1 to clause 830 of the SHW. 3. In all cases refer to Note 2 for strength testing. 4. Where HBM is formed using mix-in-place stabilisation (Note 3), construction shall be to clause 816 of the SHW.					
F	HBM specification for subgrade design CBR 8% – 14% (typically a sandy subgrade)						
G	HBM specification for subgrade design CBR less than 8%	Depending on subgrade strength and type, at least 250 mm to possibly 750 mm depth of subbase/capping/subgrade treatment, frost resistant in the case of columns 2 & 3, will be necessary between the subgrade and the HBM and the design based on row F.					

Notes

1. *The surfacing or first course of surfacing should be laid as soon as possible to provide a weather-proof seal. Asphalt will normally be laid in two courses of, say, a 30 or 40 mm thin surface course on a 50, 60 or 70 mm binder course. Where fuel and oil resistance is required, consideration should be given to using grouted macadam as the surface course or substituting the whole of the asphalt surfacing with 80 mm thick concrete blocks (size 100 x 200 mm) on a 30 mm sand laying course.*
2. *The strength classes shown are compatible with the European standards for cement bound granular mixtures (BS EN 14227–1), other hydraulically bound mixtures (BS EN 14227–2, 3 & 5) and series 800 of the SHW. Strengths shall be assessed at 28 days using sealed curing at 20°C for mixtures employing at least 3% CEM I cement by dry mass. For mixtures based on fly ash or ggbs (or GBS) containing less than 3% CEM I cement by dry mass, or activated by lime, 28 day testing shall also be used but after sealed curing at 40°C. In all cases, the specified strength shall mean the minimum based on the average of five specimens every 1000 m^2 with no individual result less than 70% of the minimum average requirement.*
3. *Subject to the achievement of the specified density for the layer, mix-in-place construction shall only be permitted:*
   - *For columns 2 and 3, provided the required depth is constructed in one lift.*
   - *For columns 4 to 7 inclusive, for the first lift only of multi-lift work.*

   In the case of the latter, the recommended HBM thickness in the table shall be increased by 50 mm. Whatever the method of construction for multi-lift work, the lift under construction shall be placed and compacted before setting and drying out takes place in the underlying lift. It is also advised that the minimum depth of lift for mix-in-place work shall be 200 mm and for mix-in-plant work 150 mm except that the first lift of multi-lift work shall be not less than 200 mm irrespective of the method of construction.
4. *Stabiliser proportions shall comply with Table 8/10 in the SHW.*

ANNEX C: Example of the use of the design and specification framework

Requirement

10 tonne maximum wheel load on a sand subgrade. Target strength class C5/6 & C6/8.

Options

Surfacing
100 mm two-course asphalt.

HBM thickness
440 mm.

HBM types and strength
CBGM B C5/6 to SHW clause 822 or
SBM B1–2, FABM 1 or HRBBM 1 C6/8 to SHW clause 830.

Example constructions

- Mix-in-plant only:
  440 mm constructed in two equal lifts of 220 mm to SHW clause 814.
- Mix-in-plant only (bearing in mind 200 mm minimum depth for first lift):
  440 mm constructed as 240 mm on 200 mm, both lifts to SHW clause 814.
- Mix-in-plant only (bearing in mind 150 mm minimum lift thickness and 200 mm minimum for first lift):
  500 mm constructed in two lifts of 150 mm on 200 mm first lift, all to SHW clause 814.
- Mix-in-place followed by mix-in-plant (thus overall depth increased by 50 mm):
  490 mm constructed as 270 mm to SHW clause 816 followed by 220 mm to SHW clause 814.
- Mix-in-place followed by mix-in-plant (thus overall depth increased by 50 mm):
  500 mm constructed as 200 mm to SHW clause 816 followed by two equal lifts of 150 mm to SHW clause 814.

Strength testing
Testing shall be carried out at 28 days using sealed curing at 20°C for CBGM B. For SBM B1–2, FABM 1 or HRBBM 1, strength shall be measured at 28 days using 40°C sealed curing. In all cases, the specified strength shall mean the minimum based on the average of five specimens every 1000 m^2 with no individual result less than 70% of the minimum average requirement.

Construction
For multi-lift work, the lift under construction shall be placed and compacted before setting and drying-out takes place in the underlying lift.

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– Part 4: *Fly ash for hydraulically bound mixtures.*
– Part 5: *Hydraulic road binder bound mixtures (HRBBM).*
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– Part 11: *Soil treated by lime (SL).*
– Part 12: *Soil treated by slag (SS).*
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BP/28
First published 2007

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