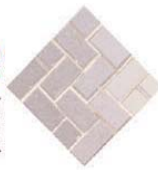


Structural Design of Concrete Block Pavements

(downloaded from <http://www.paving.org.uk>)

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Introduction:

This PDF download offers detailed guidance on structural design for various applications of concrete block paving. Generally, accepted design methods for concrete block pavements are based on the performance of asphalt pavements but using an equivalence factor to convert the surface to block paving. These methods can be considered as conservative, as research shows that interlock between the concrete blocks contributes to the structural performance of pavements.

Examples of uses of block paving

Thickness of Block mm	Typical application
50	Driveways, Patios, Pathways and Footways
60/65	Adopted highways and other roads <0.5 msa Cul-de-sacs, petrol forecourts, pedestrian areas subject to regular heavy traffic
80	Heavy duty pavements 0.5 to 12 msa
100	Very heavy duty pavements

Appropriate design methods for the pavement construction including sub-base, and where required, roadbase thicknesses are dependent upon traffic volumes, in millions of cumulative standard axles (msa):

- **up to 0.5 msa** - BS 7533-2: 2002, *Pavements constructed with clay, natural stone or concrete pavers, Part 2: Guide for the structural design of light duty pavements constructed of clay pavers or precast concrete paving blocks.*
- **0.5 to 12 msa** - 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.*
- **exceeding 12 msa** - Interpave publication: *The structural design of heavy duty pavements for ports and other industries* (which can be ordered on-line) or other appropriate design guides.

For aircraft pavements, the Civil Aviation Authority report: The use of pavers for aircraft pavements includes design methods for both new and overlay pavements derived from the specific loading characteristics of today's civil aircraft. The Ministry of Defence has also developed recommendations for concrete block pavements used by military aircraft. In addition to the above, design guidance for Overlay Resurfacing is also included in the PDF. Separate guidance is provided for the design of permeable pavements at www.paving.org.uk.

Light Duty Pavements:

The British Standard BS 7533-2 provides guidance on the design of lightly trafficked pavements for all paved areas subject to the usual road spectrum of axles loads up to 11 000 kg. This applies to areas trafficked by up to 0.5 msa which includes cul-de-sacs, driveways, car parks, precincts, lightly trafficked roads, private and industrial vehicle parks, estate roads and paved areas.

STEP 1

The bearing strength of the subgrade should be obtained as this determines the overall thickness of the sub-base. The strength of the subgrade is described as the 'California Bearing Ratio' (CBR). The CBR of the underlying materials may be provided by a site investigation report. If there is no report or the CBR has not been obtained then it may be estimated using the following table:

Estimated CBR values for British soils

Type of subgrade	Plasticity index	CBR per cent
heavy clay	70	2
	60	2
	50	2
	40	3
silty clay	30	4
sandy clay	20	5
	10	5
silt		1
poorly graded sand		20
well graded sand		40
well graded sandy gravel		60

The following information has been extracted and summarised from BS 7533: Part 2. For sub-base design, the subgrade strength can be estimated using simple field tests (after initial compaction of the trimmed ground) to give the sub-base thickness:

Identification of materials and CBR values using a simple field test

Rock or soil		Simple field test	CBR
Type	Condition		
Rock	Hard	Requires mechanical pick for excavation	Above 5%
Sand Gravel	Compact	50mm square peg hard to drive in 150mm	>5%
Clay Sandy clay	Stiff	Cannot be moulded by fingers Need pick for excavation	5%-2%
Clay Sandy clay	Firm	Can be moulded by fingers Need spade for excavation	5%-2%
Sand Silty clay Clayey sand	Loose	Dry lumps easily broken down 50mm square peg driven in easily	2%
Silt Sandy clay Silty clay Clay	Soft	Can easily be moulded by fingers	<2%
Silt Sandy clay Silty clay Clay	Very soft	Exudes between fingers when squeezed	Seek specialist advice
NOTE 1 This table is based on the principles in BS 8103-1.			
NOTE 2 The CBR of the rock or soil is significantly affected by moisture content			

For loose, soft and very soft materials comprising sand, silt and clay, specialist advice should be sought. The above guidance applies where the water table is 300 mm or more below formation level. Specialist advice should be sought where this is less, standing water is present or there are any doubts about the ground conditions. Any soft spots should be dug out and replaced with good fill or sub-base material and fully compacted. On sites where the CBR varies from place to place then the lowest recorded value should be used.

STEP 2

The number of commercial vehicles using the area should be obtained. As a guide to typical applications and number of commercial vehicles per day (cv/d) the following table can be used.

Category	Maximum trafficking(msa)	cv/d	Typical applications
I	> 0.5		use BS 7533 -1
II	0.5	≥ 5 < 5	Adopted highways & other roads Car parks with occasional heavy traffic Footways overridden by vehicular traffic
IIIa		<1	Pedestrian areas with occasional vehicular traffic
IIIb		Nil	Car parks and footways
IV			Private drives, paths, patio

A typical design life of 20 years can be adopted for concrete block paving.

The volume of traffic to be carried by the pavement is expressed as 'standard axles'.

This theoretical figure is calculated by taking the number of commercial vehicles using the pavement during its design lifetime. Where channelised traffic in highways and roadways occurs, the traffic figure should be multiplied by 3. If the application of this factor results in a figure greater than 0.5 msa then BS 7533-1 should be used.

STEP 3

The construction thickness is determined based on the category of application and the CBR, and the thickness of each layer obtained from the following table.

Category	Sub-base thickness mm CBR					Roadbase mm	Laying Course mm	Paving thickness minimum mm
	≤2%	3%	4%	5%	≥6%			
II	400	350	250	150	150	125	30	60
IIIa	350	300	225	150	150	0	50	50
	250	150	100	100	0	70	30	50
IIIb	300	250	175	100	100	0	50	50
IV	200	150	125	100	0	0	50	50

A DESIGN EXAMPLE

A driveway is to be constructed overlying firm clay with an estimated CBR value between 2 and 5.

The category is IV and the construction thickness, using the lowest CBR value, is obtained from the above table, as follows:

Construction thicknesses -

Sub-base	200 mm
Laying Course	50 mm
Paving Blocks	50 mm

Heavy Duty Pavements

The procedure for the design of paving subject to highway loading conditions can be calculated from BS7533-1, on which the following guidance is based.

STEP 1

Establish the CBR of the subgrade. The saturated CBR value should be determined either by site investigation or, in the case of fine grained soils, from the plasticity index of the subgrade material. The degree of subgrade drainage must also be considered when deciding the appropriate CBR to be assumed.

Site investigation data should be analysed carefully and advice sought if in doubt. The equivalent equilibrium suction index CBR values may then be obtained from the following table, which is taken from BS7533-1.

Equilibrium suction index CBR

Type of soil	P I	High water table			Low water table		
		Construction conditions			Construction conditions		
		Poor	Average	Good	Poor	Average	Good
Heavy clay	70	1.5 to 2	2	2	1.5 to 2	2	2 to 2.5
	60	1.5 to 2	2	2 to 2.5	1.5 to 2	2	2 to 2.5
	50	1.5 to 2	2 to 2.5	2 to 2.5	2	2 to 2.5	2 to 2.5
	40	2 to 2.5	2.5 to 3	2.5 to 3	2.5	3	3 to 3.5
Silty clay	30	2.5 to 3.5	3 to 4	3.5 to 5	3 to 3.5	4	4 to 6
Sandy clay	20	2.5 to 4	4 to 5	4.5 to 7	3 to 4	5 to 6	6 to 8
	10	1.5 to 3.5	3 to 6	3.5 to 7	2.5 to 4	4.5 to 7	7 to >8
Silt	-	1	1	2	1	2	2
Poorly graded sand	-	20					
Well graded sand	-	40					
Sandy gravel	-	60					

The construction conditions referred to in the table above relate to the general conditions on site during the construction period. This factor has a significant effect on the assessment of the CBR value to be used. A high water table is one which is 300 mm or less below the formation level, while a low water table is 1 m or more below the formation level. 'Good' conditions are where the subgrade is protected promptly with an improvement layer or sub-base, while 'Poor' conditions are where little or no subgrade protection is provided.

The value used for the CBR should be based on the worst results obtained on site. If it is considered to be economical, a localised design can be introduced for the poorer areas or poor materials can be replaced.

STEP 2

Assess the number of commercial vehicles per day (cv/d) passing in each direction and determine the number of standard axles for the required design life from the following table.

Conversion of commercial vehicles per day (cv/d) to number of standard axles in millions of axles (msa)

Volume of traffic cv/d	Cumulative traffic			
	20 years design life		40 years design life	
	zero growth	2% growth	zero growth	2% growth
30	0.2	0.3	0.4	0.6
120	0.8	1	2	3
2504	2	3	6	9
500	6	8	15*	22*
1000	16*	22*	*	*

This table applies to normal pavements on which commercial vehicles constitute less than 50% of the flow. In other cases, guidance should be sought from TRL1132**. If necessary these values must be modified to take account of the appropriate factors for traffic speed and channelisation. Where the speed of the traffic over the pavement is expected to exceed 30 mph the number of standard axles should be multiplied by a factor of two. When vehicle track width and traffic lane width are virtually the same the channelising effect should be taken into account by applying a factor of three to the number of standard axles (this condition is rarely met in normal highways). These factors may need to be applied cumulatively in exceptional circumstances.

Particular care should be taken in the selection of the laying course material to be used for areas subjected to loading by heavy channelised traffic, particularly in areas of high rainfall. The minimum block thickness for roads carrying averages of more than 5 commercial vehicles per day should be 80 mm. In cases of lesser flows the block thickness may be 50 mm.

Notes:

* Volumes exceed the scope of BS 7533: Part 1

** TRL1132 - 1984. The Structural Design of Bituminous Roads.

STEP 3

Use the following table to determine the thickness of the improvement layer and sub-base, or sub-base alone. The thicknesses are dependent upon the subgrade CBR value and trafficking. Using the combination of improvement layer with sub-base or sub-base only may result in a pavement design of equivalent structural performance.

	Foundation option	<2%	>2% - <3%	>3% - <4%	>4% - <5%	>5% - <10%	>10% - <15%	>15% - <30%
Untrafficked	Sub-base/improvement layer	150/150	150/150	Sub-base alone				
	Sub-base		170	150	150	150	150	150
Up to 4 dwellings 2000m ² or 100 sa	Sub-base/improvement layer	150/210	150/180	150/150	Sub-base alone			
	Sub-base		250	190	160	150	150	150
Up to 20 dwellings or 200 sa	Sub-base/improvement layer	150/370	150/250	150/170	150/160	150/150	150/150	150/0
	Sub-base		310	240	210	180	150	150
Up to 50 dwellings 5000m ² commercial or 500 sa	Sub-base/improvement layer	150/470	150/340	150/250	150/220	150/200	150/150	150/0
	Sub-base		350	270	230	200	160	150
Up to 80 dwellings 8000m ² or commercial or 1000 sa	Sub-base/improvement layer	150/600	150/450	150/350	150/300	150/250	150/180	150/0
	Sub-base		400	310	270	225	180	150
large development 5000m ²	Sub-base/improvement layer	200/600	200/450	150/450	150/350	150/300	150/250	150/150
	Sub-base		450	350	310	270	240	225

The number of standard axles in the table is based on traffic during the construction phase, i.e. those designed to impose directly on to the sub base during the construction period.

Sub base materials should be Type 1 granular materials as in the Specification for Highway Works. The use of Type 2 or inferior materials may lead to the pavement construction becoming excessively sensitive to moisture changes and water movements. Any soft or poorly compacted materials must be removed from the subgrade.

If the subgrade materials are susceptible to frost attack, the total pavement thickness of sub base, laying course sand and concrete blocks must not be less than 450 mm. The nominal compacted laying course thickness over a sub base of granular material should be 50 mm. When a bound roadbase is provided a thinner laying course may be used but in no place should the compacted thickness of sand laying material be less than 30 mm.

STEP 4

The thickness of roadbase required can be ascertained from the number of standard axles using the pavement in its design life and the type of roadbase employed from the following table:

Structural design for roadbase and surfacing

Design in millions of standard axles	Roadbase thickness (mm) CBM3	Dense bitumen macadam roadbase (mm)	Laying course thickness (mm)	block thickness (mm)
0.5 to 1.5	130	130	30	50, 60, 65 or 80
>1.5 to 4	130	130	30	80
>4 to 8	180	155	30	80
>8 to 12	230	170	30	80

For pavements with msa's in the range of >1.5 to 8, it is permissible to reduce the blocks thickness if the road base thickness is increased to compensate. The following table gives guidance on the increase in road base necessary.

Alternative design for roadbase and surfacing

Design in millions of standard axles	Roadbase thickness (mm) CBM3	Dense bitumen macadam roadbase (mm)	Laying course thickness (mm)	block thickness (mm)
>1.5 to 4	150	150	30	60
>1.5 to 4	145	145	30	65
>4 to 8	195	170	30	65

If the traffic is channelised or speeds exceed 30 mph, then the minimum construction corresponds to 0.5 to 4 msa. The materials used in the roadbase should be as specified in Clauses 906 or 1038 of the Specification for Highway Works. Other materials may be substituted and guidance may be found in BS7533 -1.

A DESIGN EXAMPLE

A housing development of 50 dwellings will be served by an access road, which will be trafficked by 120 commercial vehicles per day. The traffic is estimated to grow at 2% over 20 years. The road sub-base will be used for site access and the CBR of the subgrade value is between 4 and 5%. The speed limit for the road is 50 kph but traffic is channelised.

Step 1	Subgrade CBR 5% and sub-base used for site access for 50 dwellings Gives a subgrade improvement layer of 220 mm and sub-base layer 150 mm OR a sub-base layer of 230 mm
Step 2	Traffic volume 120 per day 2% growth, 20year design life = 1 msa.
Step 3	Channelised traffic, so use factor of 3. Therefore msa = 3
Step 4	As traffic is in the range >1.5 to 4 msa, the roadbase is 130 mm thick using either CBM3 or dense bitumen macadam

Construction thicknesses -

Improvement layer	220 mm
Sub-base type 1	150 mm
Paving Blocks Roadbase CBM 3 or Dense bitumen roadbase	50 mm
Laying course	30 mm
Paving Blocks	80 mm

Ports and Other Very Heavy Duty Pavements

The Third Edition of the Interpave and British Ports Association *The structural design of heavy duty pavements for ports and other industries* can be used to design pavements surfaced with block paving. It was published in 1996 and, for the first time, a radically new way of analysing pavements is incorporated in the design method, which includes pavement design charts based on finite element analysis. This has allowed design to be based on the concept of Equivalent Single Load. Also, it has allowed the design of the whole pavement to be separated into design of the base and design of the foundation. In making this separation, no accuracy is lost and the design exercise has been greatly simplified, such that only one chart is now required for design.

The resulting pavement should remain serviceable throughout its life. During the last 10 years, a good deal of experience has been gained in the use of Material Conversion Factors or Material Equivalence Factors so that they can now be used as a means of effectively swapping one material for another during the design process. This means that when a design has been produced using the chart, the designer can generate alternative design solutions using different materials and so investigate a full range of solutions.

The Third Edition of the Interpave and British Ports Association *The structural design of heavy duty pavements for ports and other industries* can be ordered on-line at www.paving.org.uk.

Pavements for Aircraft

Where concrete block paving is used by aircraft, design should follow the recommendations of the Civil Aviation Authority or Ministry of Defence on the use of pavers for aircraft pavements.

Pavement Overlays

In the Component Overlay Design Method given in BS 7533: Part 1, the condition of each course in an existing pavement is expressed as an equivalent thickness of a standard material. This allows the current condition of dilapidated materials to be assessed numerically. The standard material chosen is dense bitumen macadam (see Clause 903 of the Department of Transport Specification for Highway Works).

Once each type of material within the pavement is identified, a Material Conversion Factor (MCF) is assigned to that material. The true thickness of each course in the pavement is then multiplied by the appropriate MCF to obtain the equivalent thickness of dense bitumen macadam.

In order to account for any degradation which may have taken place in each course of the pavement since construction, the equivalent thickness of each course is multiplied by two factors which account for the less than perfect condition of the material in the pavement. These two condition factors are CF1, to be applied to take account of cracking and spalling of the pavement materials, and CF2, to account for rutting and settlement. If the deterioration of the surface of the roadbase is a result of failure in the sub-base, the subgrade improvement layer or the subgrade, it may not be possible to overlay the existing pavement.

Once the existing pavement has been transformed into an equivalent thickness of dense bitumen macadam, a pavement is designed in accordance with the new pavement design method and that theoretical pavement is then transformed into an equivalent thickness of dense bitumen macadam using the material conversion factors. By comparing the equivalent thickness of dense bitumen macadam in the existing pavement with the equivalent thickness of dense bitumen macadam required for the new pavement, a determination can be made as to whether the provision of a concrete block paving overlay will provide a satisfactory engineering solution. It may be that an additional course of material will have to be provided beneath the concrete block paving in order to bring the overlaid pavement to a satisfactory structural condition (see BS 7533: Part 1 for full details).