UK Flexible Pavement Design Method

Postgraduate Studies
Highways Engineering

Prepared By:

Dr Taher M. Ahmed

Department of Civil Engineering

University of Anbar

Syllabus of:
Advanced Pavement Design

5. UK Flexible Pavement Design Method **........ (2.5 weeks)**

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5.1. Preface

- The UK pavement design methodology is a semi-analytical methodology based on the methodology suggested in 1970 (RRL 1970).
- Then reviewed two times:, one in 1987 based on the 20-year research work by TRRL and the second one in 2006 based on a TRL research study .

5.2. The design Criteria

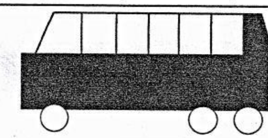
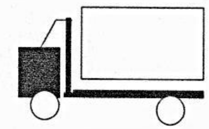
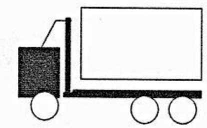
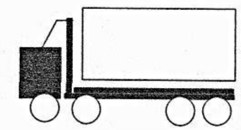
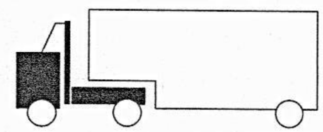
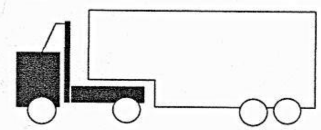
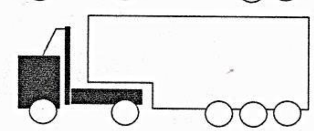
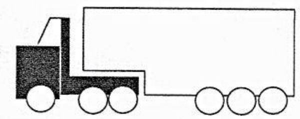
1. **Foundation design**: the deflection of the foundation surface and the minimum thickness of the upper foundation layer. Where, the foundation is distinguished into four different classes of materials, known as foundation classes. The thickness of the foundation depends on the subgrade CBR or subgrade stiffness modulus.

2. **Pavement design**: the strain of the asphalt layer and the stress of the hydraulically bound layer. The pavement structure consists of upper and lower layers. The upper layers are asphalt layers and the lower (base) layers are either asphalt layers or hydraulic bound layers. **The thickness of the pavement structure depends on the foundation classes and the traffic volum**e

5.3. Determination of design traffic

- The design traffic is the commercial vehicle loading over the design period expressed as the number of equivalent standard (80 kN) axles (ESA80-kN).
- The design traffic is calculated using the **commercial vehicle flow, vehicle wear factors (*Load Equivalency Factor (LEF)*) and traffic growth.**
- A commercial vehicle (cv) is defined as that having a gross weight of **more than 3.5 tones**. Lighter vehicles are not taken into consideration since the structural wear caused is considered negligible.
- Commercial vehicles are classified into eight classes and three categories, as shown in Table 5.1.

Table 5.1. Classes of commercial vehicles and wear factors per commercial vehicle category

Class no.	Commercial vehicle (CV)	Schematic representation of CVs	Category	Wear factors: Maintenance W_M	Wear factors: New W_N
1	Buses and coaches		PSV[a]	2.6	3.9
2	2-Axle rigid		OGV1[b]	0.4	0.6
3	3-Axle rigid			2.3	3.4
4	4-Axle rigid		OGV2[b]	3.0	4.6
5	3-Axle articulated			1.7	2.5
6	4-Axle articulated				
7	5-Axle articulated			2.9	4.4
8	6 (or more)-Axle articulated			3.7	5.6
		OGV1 + PSV		0.6	1.0
		OGV2		3.0	4.4

Source: Adapted from Highways Agency, *Design Manual for Roads and Bridges (DMRB), Vol. 7: Pavement design and maintenance*, Section 2, Part 1, HD 24/06: Traffic assessment, Department for Transport. London: Highways Agency, 2006b (© Highways Agency).

[a] PSV, public service vehicle.
[b] OGV, other goods vehicles.

5.3. Determination of design traffic

•The pavement structural wear caused by a class of commercial vehicle is expressed by its *wear factor* (*W*) Table 5.1 (Fourth power law).

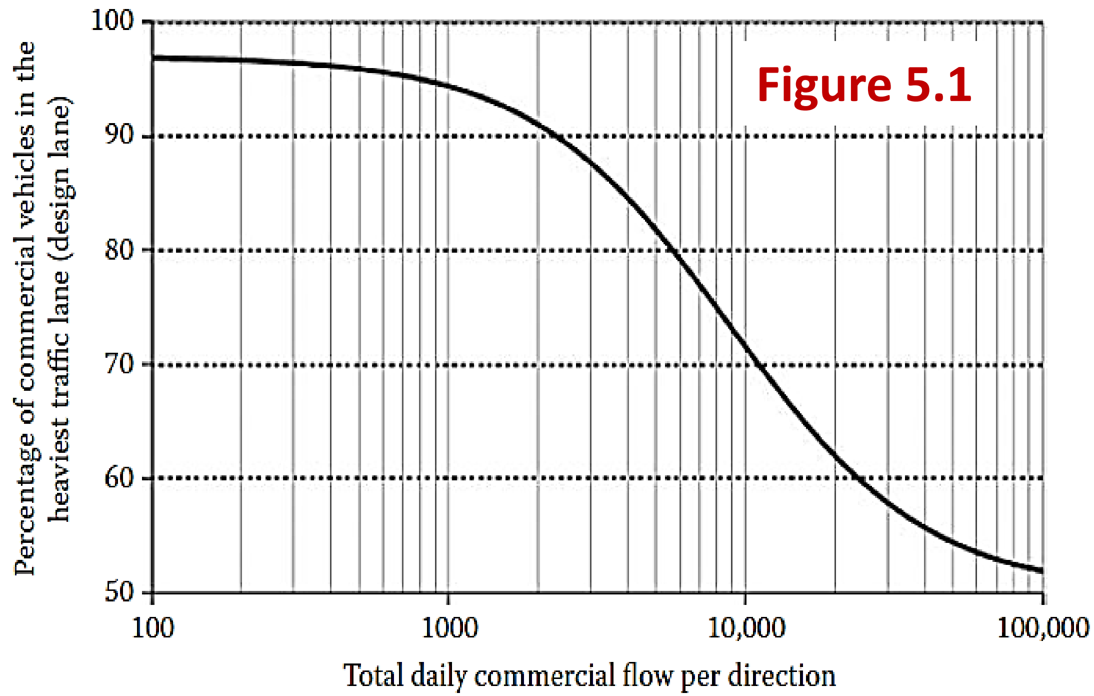
•The *traffic growth* is expressed by the growth factor (*G*), which is a function of the design period and the annual traffic percentage increase. The *design traffic* (*T*) is the sum of the future cumulative flow, in terms of million standard axles (msa), of each commercial vehicle class, *Ti*, that is,

$$T = \sum T_i = 365 \times F \times Y \times G \times W \times P \times 10^{-6} \quad \ldots\ldots 5.1$$

T_i in million standard axles.

Where:

Ti is the cumulative flow, in terms of million standard axles for commercial vehicle class *i*; *F* is the average annual daily flow of traffic for each traffic class at opening; *Y* is the design period (in years); *G* is the growth factor; *W* is the wear factor for each traffic class (W_N for new pavement design and W_M for maintenance design case), from Table 5.1; and *P* is the percentage of vehicles in the heaviest loaded lane, from Figure 5.1.



Note: The design period (life) is recommended to be taken as 40 years for heavy traffic; for less heavily trafficked sections or major maintenance schemes a 20 years.

5.4. Subgrade design CBR and surface stiffness modulus

- The design CBR of the subgrade is determined by executing CBR tests in the laboratory, over a range of conditions.
- It is not possible to collect material samples for laboratory assessment of CBR, the design CBR may be estimated from Table 5.2.
- The design CBR, for performance design, must be converted to subgrade surface modulus, *E*.

$$E = 17.6 \times CBR^{0.64} \quad \text{.............. 5.2}$$

Note: In AASHTO $M_r = E$

- where E is the subgrade surface stiffness modulus (MPa) and CBR is the California bearing ratio (% value) for fine soil material with laboratory CBR values ranging from 2% to 12%. For coarser materials, the plate bearing test may also be appropriate.

5.5. Foundation classes

The foundation consists of the sub-base layer and the capping layer (if used (Figure 5.2) and is constructed with unbound or hydraulically bound materials. Depending on the type of materials used, the methodology distinguished four foundation classes, on the basis of foundation surface modulus (Table 5.3).

Table 5.2 Estimation of equilibrium subgrade CBR Value

		CBR high water table						*CBR low water table*					
		Construction conditions						*Construction conditions*					
		Poor		*Average*		*Good*		*Poor*		*Average*		*Good*	
Soil	*PI*	*Thn*	*Thk*	*Thn*	*Thk*	*Thn*	*Thk*	*Thn*	*Thk*	*Thn*	*Thk*	*Thn*	*Thk*
Clay	70	1.5	2	2	2	2	2	1.5	2	2	2	2	2.5
	60	1.5	2	2	2	2	2.5	1.5	2	2	2	2	2.5
	50	1.5	2	2	2.5	2	2.5	2	2	2	2.5	2	2.5
	40	2	2.5	2.5	3	2.5	3	2.5	2.5	3	3	3	3.5
Silty clay	30	2.5	3.5	3	4	3.5	5	3	3.5	4	4	4	6
Sandy clay	20	2.5	4	4	5	4.5	7	3	4	5	6	6	8
	10	1.5	3.5	3	6	3.5	7	2.5	4	4.5	7	6	>8
Silt		1	1	1	1	2	2	1	1	2	2	2	2
Sand													
– Poorly graded								20					
– Well graded								40					
Sandy gravel													
– Well graded								60					

Source: Powell W.D. et al., *The Structural Design of Bituminous Roads*. TRRL Laboratory Report LR1132. Crowthorne, UK: Transport Research Laboratory, 1984.

Note: PI, plasticity index; Thn, thin pavement; Thk, thick pavement.

Table 5.3 Foundation classes according to Highways Agency (2009a) and materials to be used

Foundation class	*Materials*	*Foundation surface modulus (MPa)*
Class 1	Unbound selected granular material or stabilised granular material as per **Table 5.4**	≥50
Class 2	Unbound crushed, selective granular or with asphalt arisings material as per **Table 5.4[a] and 5.5** as well as bound materials such as CBGM A or B as per **Table 5.6** or soil cement achieving compressive strength of at least C3/4	≥100
Class 3	Cement-bound granular material CBGM A or B as per **Table 5.6** achieving compressive strength of at least C8/10	≥200
Class 4	Cement-bound granular material CBGM A or B as per **Table 5.6** achieving the required minimum foundation surface modulus	≥400

Source: Highways Agency, *Design Manual for Roads and Bridges (DMRB), Vol. 7: Pavement Design and Maintenance*, Section 5, Part 2, IAN 73/06 Revision 1: Design guidance for road pavement foundations, Department for Transport. London: Highways Agency, 2009a (© Highways Agency).

[a] Type II material is used only when the cumulative ESAL is $\leq 5 \times 10^6$.

Figure 5.2.

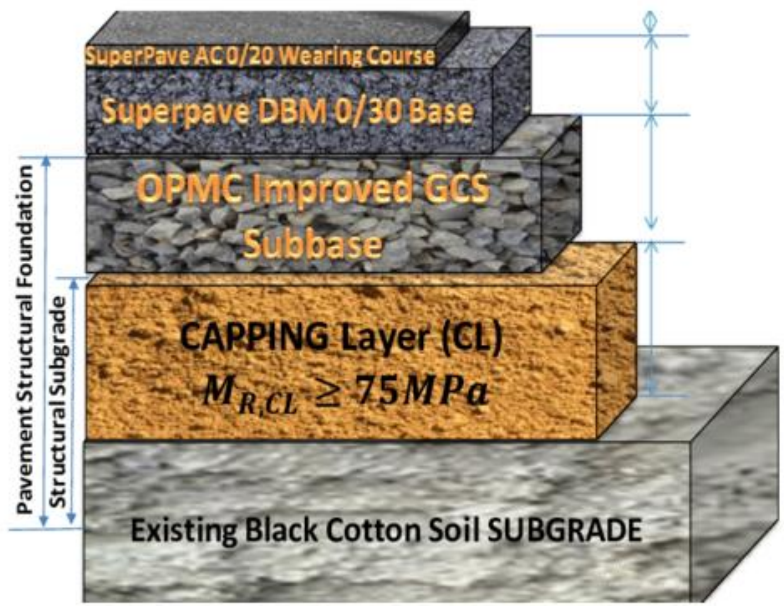


Table 5.4 Recommended mixture and grading requirements for normal graded and other unbound mixtures for base and sub-base

Unbound mix	*Type I (dense graded–all crushed)*			*Type II (selective granular material)*		
Designation	0/31.5			0/31		
Max. fines	UF_9			UF_{12}		
Oversize	OC_{85}			OC_{80}		
General category	G_A			G_E		
	Range	*SDV*	*Tolerance*	*Range*	*SDV*	*Tolerance*
Sieve (mm)	*% Passing, by mass*			*% Passing, by mass*		
40	100	—	—	100	NR	NR
31.5	85–99	—	—	80–99		
20	—	—	—	—		
16	55–85	63–77	±8	50–90		
10	—	—	—	—		
8	35–65	43–57	±8	30–75		
4	22–50	30–42	±8	15–60		
2	15–40	22–33	±7	—		
1	10–35	15–30	±5	0–35		
0.5	0–20	5–15	±5	—		
0.063	0–9	—	—	0–12		
	Difference between successive sieves					
	Sieve (between sieves)		*Permissible range (%)*	*Sieve (between sieves)*		*Permissible range (%)*
	—	—	—	20 mm	10 mm	7–30
	16 mm	8 mm	10–25	—	—	—
	—	—	—	10 mm	4 mm	7–30
	8 mm	4 mm	10–25	NR	NR	NR
	4 mm	2 mm	7–20	NR	NR	NR
	2 mm	1 mm	4–15	NR	NR	NR

Note: SDV = supplier-declared value grading range (S); Tolerance = permitted tolerance, from supplier-declared value.

Table 5.5 Mixture and grading requirements for open-graded unbound mixture and unbound mixtures with asphalt arisings (for base and sub-base)

Unbound mix	*Type III (open graded)*			*Type IV (with asphalt arisings)*		
Designation	0/40			0/31.5		
Max. fines	UF_5			UF_9		
Oversize	OC_{85}			OC_{75}		
General category	G_o			G_p		
	Range	*SDV*	*Tolerance*	*Range*	*SDV*	*Tolerance*
Sieve (mm)	*% Passing, by mass*			*% Passing, by mass*		
	100	—	—	—	—	—
63	—	—	—	100	—	—
40	80–99	—	—	—	—	—
31.5	—	—	—	75–99	—	—
20	50–78	58–70	±8	—	—	—
16	—	—	—	43–81	54–72	±15
10	31–60	39–51	±8	—	—	—
8	—	—	—	23–66	33–52	±15
4	18–46	26–38	±8	12–53	21–38	±15
2	10–35	17–28	±7	6–42	14–27	±13
1	6–26	11–21	±5	3–32	9–20	±10
0.5	0–20	5–15	±5	—	—	—
0.063	0–5	—	—	0–9	—	—
	Difference between successive sieves					
	Sieve (between sieves)		*Permissible range (%)*	*Sieve (between sieves)*		*Permissible range (%)*
	—	—	—	20 mm	10 mm	7–30
	20 mm	10 mm	10–25	—	—	—
	—	—	—	16 mm	10 mm	7–30
	10 mm	4 mm	10–25	NR	NR	NR
	8 mm	4 mm	—	NR	NR	NR
	4 mm	2 mm	7–20	NR	NR	NR
	2 mm	1 mm	4–15	NR	NR	NR

Source: Adapted from Highways Agency, *The Manual of Contract Documents for Highway Works (MCDHW), Volume 1: Specification for Highway Works, Series 800: Road pavements – Unbound, cement and other hydraulically bound mixtures*, London: Department for Transport, Highways Agency, 2009b (© Highways Agency).

Note: SDV = supplier-declared value grading range (S); Tolerance = permitted tolerance, from supplier-declared value.

Table 5.6 Minimum binder additions for HBM

Binder or binder constituent	*Application*	*Minimum addition by dry mass of mixture*	
		Mix-in-plant by mass batching (% by mass)	*Mix-in-place or mix-in-plant by vol. batching (% by mass)*
Cement	When used as the only binder	3%, 4%, 5%[a]	4%, 5%, 6%[a]
	When used with another binder	2%	3%
	When used as the only binder in soil treated by cement (SC)	3%	4%
Dry fly ash	When used with cement	4%	5%
	When used with lime	5%	6%
Wet (conditioned) fly ash	All applications	6%	8%
Fine granulated blast furnace slag	When used with cement	2%	3%
	When used with lime	3%	4%
Granulated blast furnace slag (GBS)	When used with lime	6%	8%
	When used with ASS (GBS + AAS ≥ 11%)	2.5%	3%
Air-cooled slag (ASS)	When used with GBS (ASS + GBS ≥ 11%)	2.5%	3%
Lime (quicklime or hydrated lime)	When used as the only binder in FABM 5	3%	4%
	When used with another binder	1.5%	2%
Hydrated road binder	All applications	3%	4%

Source: Highways Agency, *The Manual of Contract Documents for Highway Works (MCDHW), Volume 1: Specification for Highway Works, Series 800: Road pavements – Unbound, cement and other hydraulically bound mixtures*, London: Department for Transport, Highways Agency, 2009b (© Highways Agency).

[a] The percentages refer to mixtures with maximum nominal size aggregate >8 to 31.5 mm, 2 to 8 mm and <2 mm, respectively.

5.5.2. Foundation design

The thickness determination of the foundation, per foundation class, is carried out by two alternative design approaches:

5.5.2.1. The restricted foundation design.

- The designers are conservative, making allowances for uncertainty in material performance and in layer thickness. Hence, restricted foundation design is intended for use on schemes of limited extent. The test required to be carried out for achieving required specifications are limited to the following:

1. CBR value at the top of the exposed subgrade, immediately prior to placement of the overlying foundation layers,
2. material density and the actual thickness for each stage of foundation construction.
3. compliance with the relevant material specification

- The determination of the foundation thickness in the case of **restricted design** is carried out with the use of design charts shown on **Figures 5.4. to 5.5** where the total foundation layer thickness is determined.

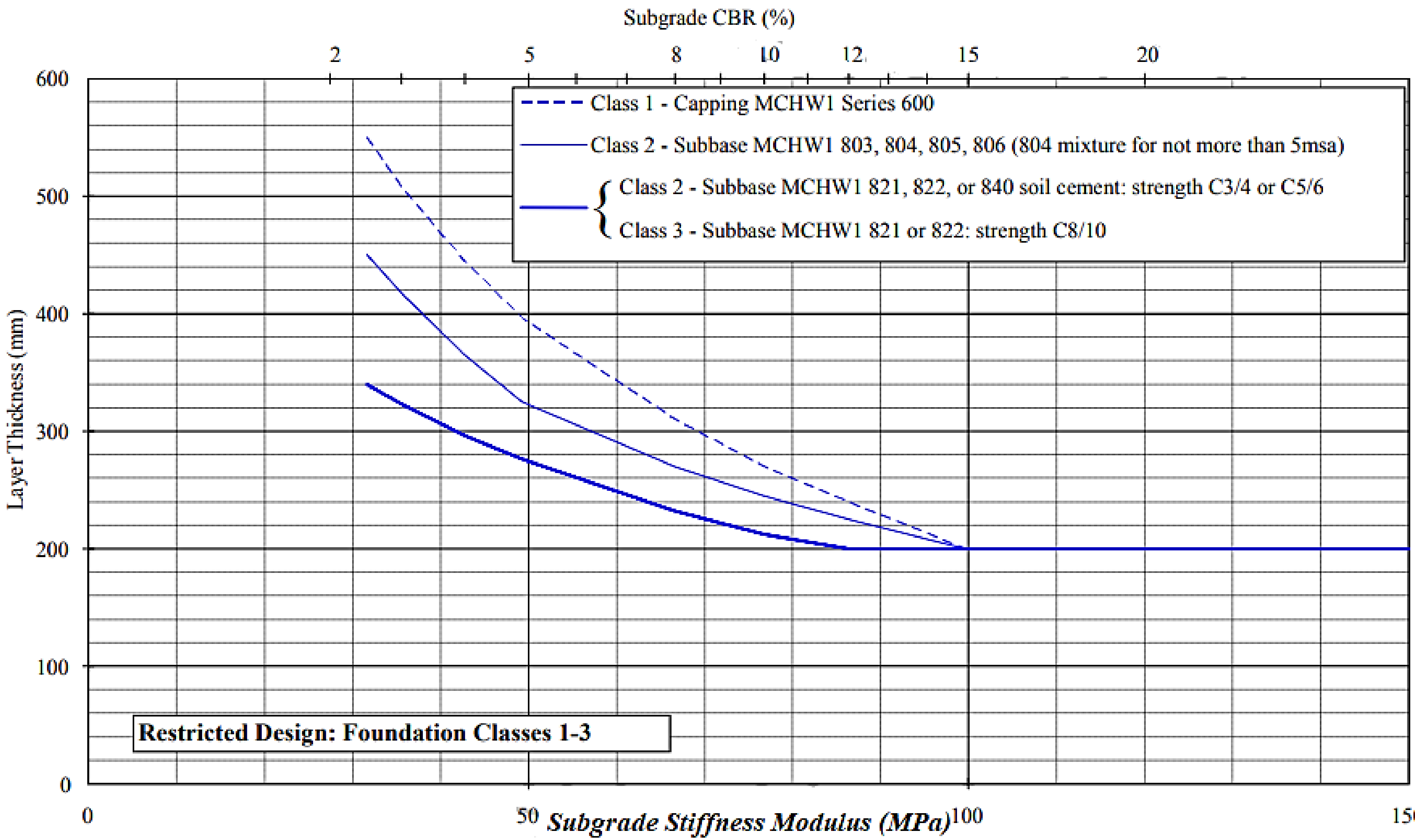


Figure 5.4. **Restricted Design Options – Subbase or Capping only**

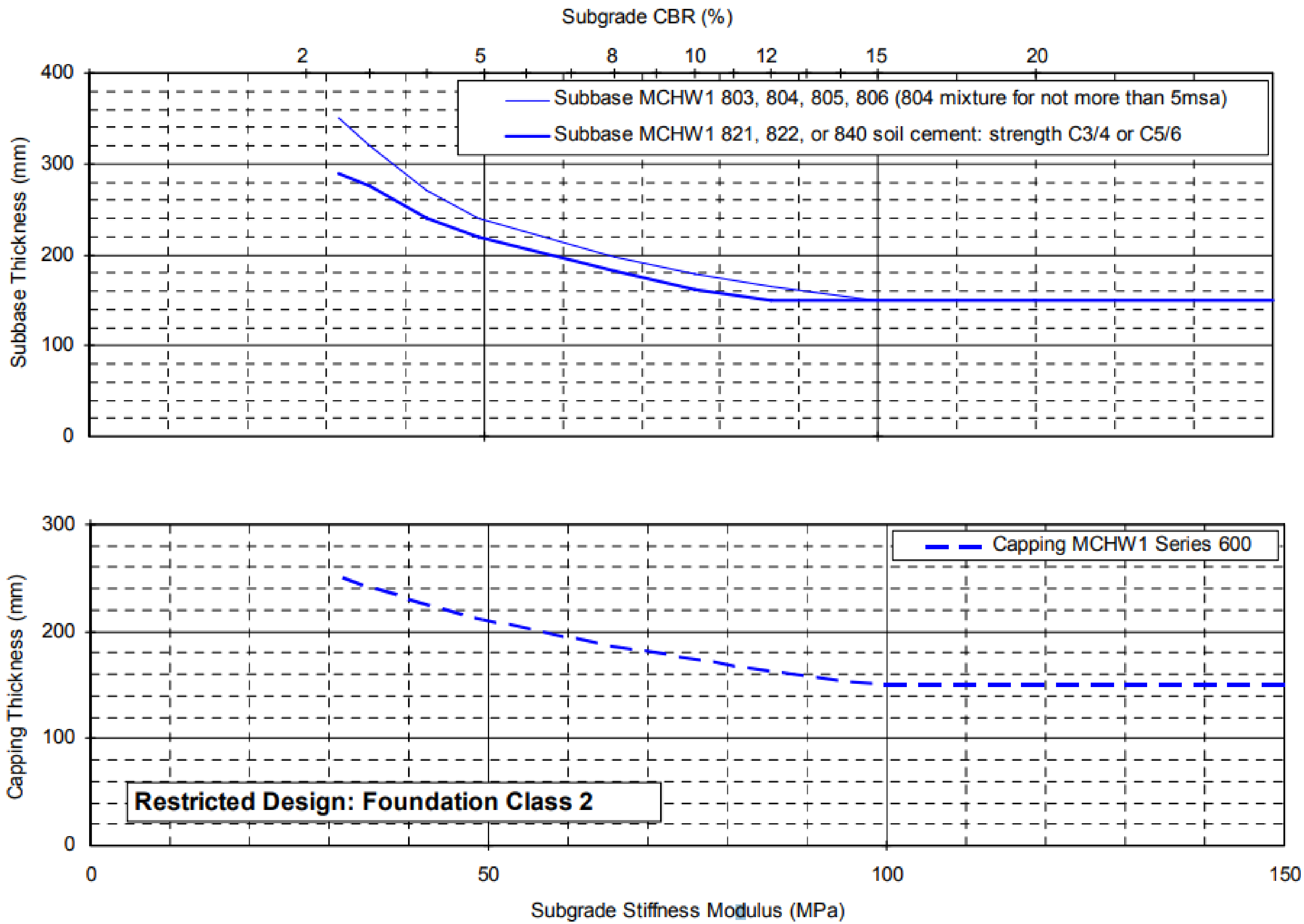


Figure 5.5. Restricted Design Options – Class 2 Subbase on Capping

Note: MCHW1 is the Manual of Contract Documents for Highway Works

Note:

1. Table 5.7 gives the unadjusted mean foundation surface modulus and the minimum foundation surface modulus values, for each foundation class and for different categories of material
2. The methodology also imposes maximum permissible layer stiffness values for each foundation class, regardless of the foundation design method employed. This is to minimise the risk of selecting very thin or very stiff foundation layers at lower subgrade CBR values. The maximum permissible layer stiffnesses to be used are as follows: 100 MPa for class 1, 350 MPa for class 2, 1000 MPa for class 3 and 3500 MPa for class 4.

Fast-setting: bound mixtures that achieve more than 50 per cent of their specified compressive strength class after 28 days curing at 20 degrees C.

Slow-setting: bound mixtures that achieve 50 per cent or less of their specified strength class after 28 days curing at 20 degrees C.

Table 5.7 Top of foundation surface modulus requirements

		Surface modulus (MPa)			
		Foundation class			
		1	*2*	*3*	*4*
Long Term in Service Surface Modulus		≥50	≥100	≥200	≥400
Mean foundation surface modulus	Unbound mixture types	40[a]	80[b]	[c]	[c]
	Fast-setting mixture types	50[a]	100	300	600
	Slow-setting mixture types	40[a]	80	150	300
Minimum foundation surface modulus	Unbound mixture types	25[a]	50[b]	[c]	[c]
	Fast-setting mixture types	25[a]	50	150	300
	Slow-setting mixture types	25[a]	50	75	150

Source: Highways Agency, *Design Manual for Roads and Bridges (DMRB), Vol. 7: Pavement Design and Maintenance*, Section 5, Part 2, IAN 73/06 Revision 1: Design guidance for road pavement foundations, Department for Transport. London: Highways Agency, 2009a (© Highways Agency).

[a] Only permitted on trunk roads including motorways that are designed for not more than 20 msa.
[b] Not permitted for pavements designed for 80 msa or above.
[c] Unbound materials are unlikely to achieve the requirements for Classes 3 and 4.

5.5.2.2. The *performance foundation design* approach

- This method offers greater flexibility to the designer, since a wide range of resources, incorporating natural, secondary and recycled materials, may be utilized. Additionally, the mechanical properties of the materials used are utilized more efficiently and the performance foundation design provides some assurance that the material performance assumptions made at the design stage are being, or are likely to be, achieved.
- It is required to carry out an in situ test for subgrade and foundation acceptance to achieve that the obtained CBR value must be equal to, or greater than, the design CBR which is performed using a dynamic cone penetrometer or the plate bearing test.
- Design charts to determine the foundation thickness in case a performance foundation design are developed based on the characteristics of materials (physical and mechanical properties).

5.5.2.3. Cases where subgrade CBR is low (CBR < 2.5%)

- When the subgrade has a CBR value less than 2.5%, its bearing capacity is considered unsuitable to support a pavement foundation. In these cases, the subgrade must be permanently improved. This can be done by removing 0.5 to 1.0 m by a suitable materials or using lime or similar for cohesive soil or using Geosynthetic material.
- In all cases the new design subgrade CBR is assumed to be equal to 2.5%.

5.5.3. Flexible pavement design

- **Flexible pavement structure consists of all layers above foundation.**

✓ The upper layers of the flexible pavement are bound in bitumen. In this case, the pavement is called flexible pavement with asphalt base.

✓ lower (base) layers are bound in either bitumen or hydraulic binder. it is called flexible pavement with HBM (hydraulically bound mixture) base.

✓ The designer may choose from a range of asphalt mixtures for asphalt base and binder course, all with graded bitumen, and a range of HBMs, having a 28-day compressive cube strength ranging from **10 to 20 MPa**.

5.5.3.1. Asphalt base and binder course material

There are four different types of dense asphalts mixtures (HMA):

(a) dense bitumen macadam (DBM125),

(b) hot rolled asphalt (HRA50),

(c) heavy duty macadam (HDM50) or dense bitumen macadam (DBM50)

(d) enrobe a module eleve (EME2) (high stiffness modulus) (French mix).

5.5.3.2. HBMs for base layer

The types of HBM permitted to be used are distinguished into four categories, from A to D, on the basis of their strength

Note: C8/10 = (cylinder compressive strength 8 MPa / cube compressive strength 10 MPa)

Table 5.8 Categories of hydraulic bound mixtures (HBM)

HBM category	*A*	*B*	*C*	*D*
Crushed rock coarse aggregate[a]	—	CBGM B-C8/10 SBM B1-C9/12 FABM1-C9/12	CBGM B-C12/15 SBM B1-C12/16 FABM1-C12/16	CBGM B-C16/20 SBM B1-C15/20 FABM1-C15/20
Gravel coarse aggregate[b]	CBGM B-C8/10 SBM B1-C9/12 FABM1-C9/12	CBGM B-C12/15 SBM B1-C12/16 FABM1-C12/16	CBGM B-C16/20 SBM B1-C15/20 FABM1-C15/20	—

Source: Highways Agency, *Design Manual for Roads and Bridges (DMRB), Vol. 7: Pavement design and maintenance*, Section 2, Part 3, HD 26/06: Pavement design, Department for Transport. London: Highways Agency, 2006a (© Highways Agency).

[a] With coefficient of thermal expansion $<10 \times 10^{-6}$ per degree Celsius (typically limestone).

[b] With coefficient of thermal expansion $\geq 10 \times 10^{-6}$ per degree Celsius.

cement-bound granular mixtures (CBGMs), Slag bound mixtures SBM, fly ash bound mixtures (FABM)

5.5.3.3. Surface course material

- ✓ In all new construction or major maintenance works, the Highways Agency proposes the use of thin surface course system or thin surfacing.
- ✓ The typical thickness of the thin surfacing is 25 to 50 mm and is made of asphalt concrete for very thin layer, almost the asphalt must be modified with polymer or fibre additive.
- ✓ Hot Rolled Asphalt HRA, Pores Asphalt PA, Dense Bitumen Macadam DBM

5.5.4. Determination of flexible pavement thickness

UK highway agency developed a nomograph that can be to determine the thickness of pavement structure as shown in Figure 5.6.

5.5.4.1. Determination of flexible pavement with asphalt base

- The total thickness of the flexible pavement structure, comprising the surface course, binder course and base, is obtained from the right-hand portion of the nomograph shown in Figure 5.6. It depends on the type of base material.
- Thus, by knowing the cumulative number of ESAL, the foundation class and the type of asphalt to be used in the base and binder course, the total asphalt thickness is determined (see Figure 5.6., right-hand portion).

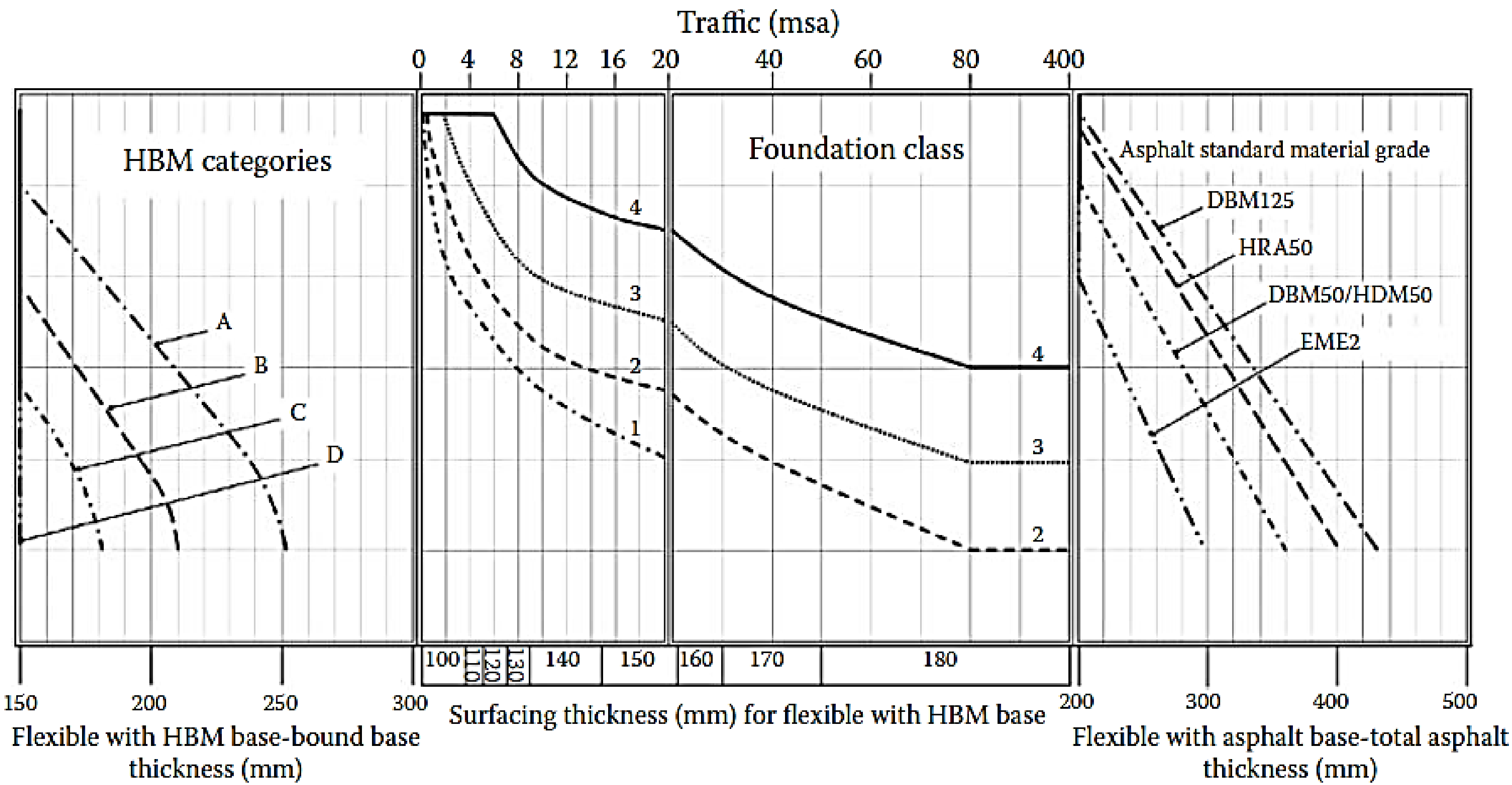


Figure 5.6. Nomograph for determining the design thickness for flexible pavements

5.5.4.2. Determination of flexible pavement with HBM base

- In a composite pavement structure, the upper layer part is from asphalt and the lower part is from HBMs. The thickness of the HBM layer, also called **hydraulically bound base layer**, depends on the type and strength of the mixture and is determined using the left portion of the nomograph shown in Figure 5.6.
- The thickness of the overlying asphalt layer is determined by the bottom axis in the central portion of the same nomograph, knowing the cumulative traffic over the design period expressed in million standard axles.

Note:

UK highway agency developed a new nomograph in the last version of pavement design 2021. The nomograph has been simplified more to reduced the number of asphalt mixes from four to two mixes only as shown in Figure 5.7.

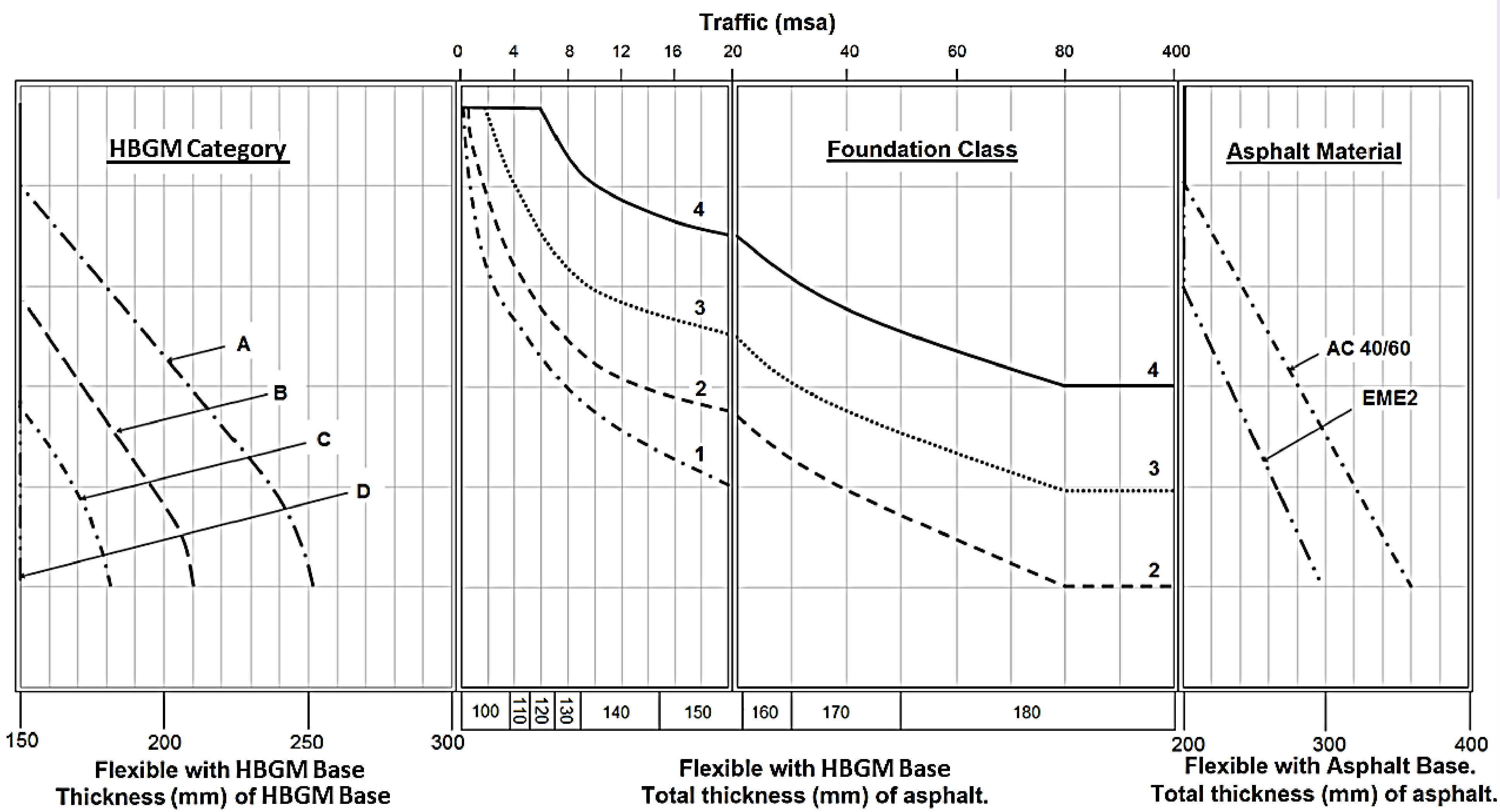


Figure 5.7. Nomograph for determining the design thickness for flexible pavements

Example (A): flexible pavement with an HBGM base.

Design factors:

1) design traffic = 60 msa;

2) foundation stiffness class 2.

Using Figure 5.8. and with HBGM category C base material:

Total asphalt thickness of 180 mm asphalt (surface course, binder course and base), over 180 mm HBGM Category C (rounded up to the nearest 5 mm).

Example (B): flexible pavement with an asphalt base.

Design factors:

1) design traffic >80 msa (that is, 'long life' pavement);

2) foundation stiffness class 3.

Using Figure 5.8. and with AC 40/60 selected as the binder and base material:

Total asphalt thickness of 320 mm (surface course, AC 40/60 binder course and AC 40/60 base).

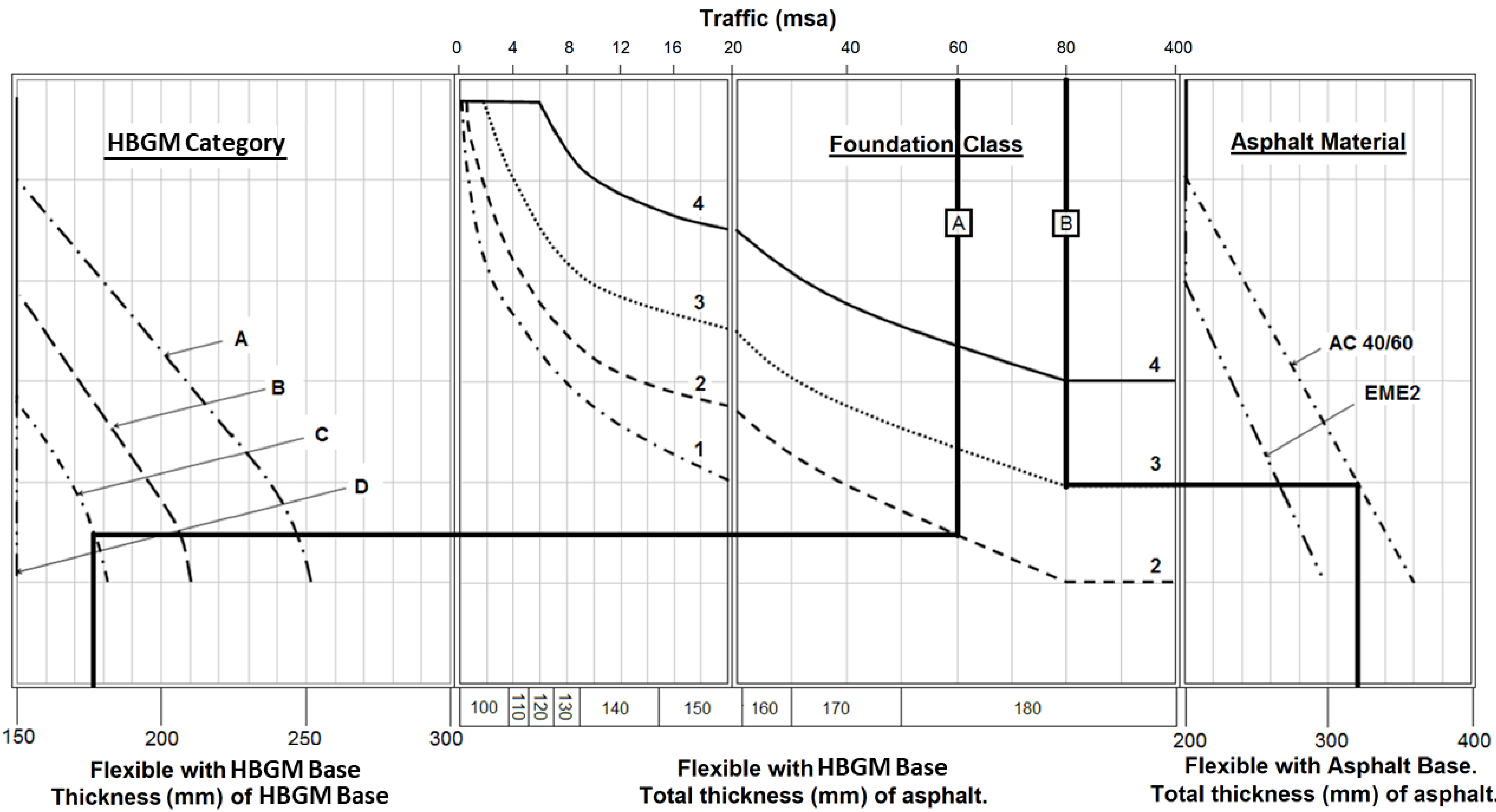


Figure 5.8. Nomograph for determining the design thickness for flexible pavements

End of Ch5.