TS Interim Amendment No 44

TRANSPORT SCOTLAND
STANDARDS BRANCH
TS INTERIM AMENDMENT N° 44: INTRODUCTION OF SIMPLIFIED DESIGN METHOD FOR CRACK SEAT AND OVERLAY (CSO)

SUMMARY
This Interim Amendment provides guidance on a simplified new approach to Crack Seat and Overlay (CSO) technique intended for use on the trunk road network in Scotland.

1. BACKGROUND

Issues relating to flexible composite road pavements over the years have produced maintenance problems, use of the Crack and Seat process has been used. This simplified process is being introduced following research and trials on the trunk road network.

2. ACTION

Subject to the Overseeing Organisation approval the method described will be used for trunk road network operations where flexible composite pavements are subject to Crack and Seat methodology.

3. IMPLEMENTATION

This Transport Scotland TSIA is for immediate implementation. Transport Scotland managers should circulate this Interim Amendment to Operating Companies and works project contractors.

4. FURTHER INFORMATION

If you have any questions regarding the use or content of this TSIA, contact Dougie Millar - Transport Scotland, Standards Branch, Tel 0141 272 7274 e-mail Dougie.Millar@transportscotland.gsi.gov.uk

Simplified Design Method for the Crack, Seat and Overlay Method – Notes for Guidance

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1 Introduction

In the 1970s the use of Flexible Composite road construction became popular on the Scottish trunk road network. The pavements were constructed with a hydraulically bound base (previously known as a lean mix concrete) overlaid with asphalt. Experience has shown that rutting and cracking, in Fully Flexible pavements, can be dealt with quite effectively using traditional maintenance techniques. However, this is not the case for reflection cracking in Flexible Composite pavements as these cracks result from discontinuities in the lower hydraulically bound material (HBM) base.

Research undertaken by TRL for Transport Scotland has shown that the Crack, Seat and Overlay (CSO) treatment is a sustainable and economic solution to the problem of reflection cracking in Flexible Composite pavements. At present, however, the existing design method for the CSO treatment is very time consuming and is not suited to quick design alterations.

This guidance describes a new simplified design method that has been developed for Flexible Composite pavements. The new approach requires estimates of future traffic, thickness of the HBM layer and foundation stiffness, derived from the Falling Weight Deflectometer (FWD).

We are grateful to Scotland Transerv and Mouchell who assisted TRL with early trials of the design method and development of this Guidance.

1.1 CSO Guide

The CSO guidance has been developed using historical data collected from sites on the UK Motorway and Trunk Road networks and refers to relevant parts of the Manual of Contract Documents for Highway Works (MCHW).

1.2 Scope and definitions

The guide gives summary descriptions of:

- Flexible Composite construction;
- Reflection cracking;
- CSO process;
- Pavement assessment for CSO treatment;
- CSO Design;
- The crack and seat process; and
- Overlay design.

Surfacing: Asphalt layers overlying the Hydraulically Bound Material (HBM) base, normally consisting of a surface course and a binder course.

Flexible Composite: A pavement consisting of asphalt surface and binder courses over an HBM base. In Scotland these bases typically comprise a lean mix concrete that ranges in thickness between 120mm and 200mm.

Foundation stiffness: the composite stiffness of all unbound materials beneath the HBM base, derived from Falling Weight Deflectometer measurements using the HA Modulus back analysis programme (Texas Transportation Institute 2000).

Threshold stiffness: The stiffness of cracked and seated HBM for which the design thickness of asphalt overlay has been calculated.

2 Simplified Design Guidance for the Crack, Seat and Overlay Method – Notes for Guidance (NG)

NG 2.1 Flexible Composite construction

Road pavements having a variety of flexible (asphalt), rigid (concrete/HBM) and combinations of these material types have been designed and built in the UK over the last fifty years. Typically pavement designs were developed through the empirical observation of road performance and then, from around 1984, with the publication of TRRL report LR1132 (Powell et al 1974) the designs were enhanced and extended with analytical procedures.

For example, the third edition of Road Note 29 (Road Research Laboratory, 1970) was design guidance developed from the performance of trial sections of road that provided information on both materials and methods of construction. Road Note 29 included pavements with bound layers comprising rolled asphalt surfacings with a lean concrete/HBM base layer. These pavements, known as a flexible composite construction, currently comprise around 20% of the trunk road network in Scotland and typically have thicknesses as shown in Figure 2.1.

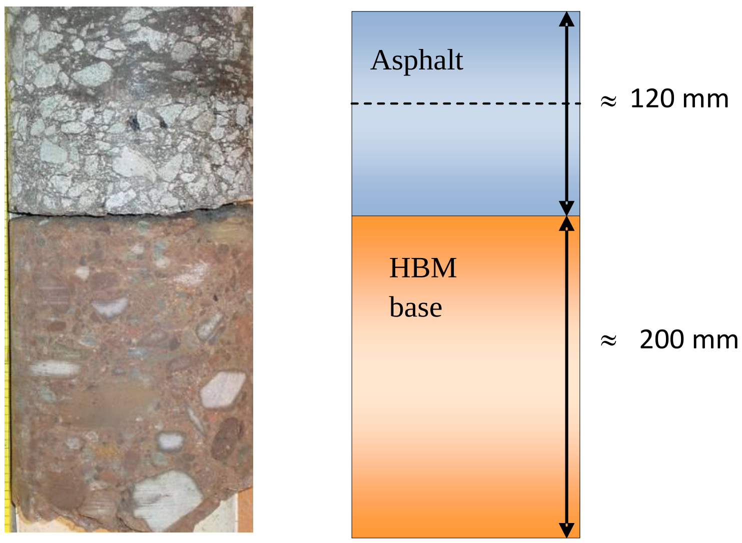


Figure 2.1: Typical bound construction of flexible composite pavement

Road Note 29 recommended a design life of 20 years, which from the traffic forecasts of the 1970s typically required a new pavement to carry a cumulative number of standard axles corresponding to around 10msa. Some of these designs have been known to carry up to 10 times their original design life, implying significant conservatism in the design process.

Although providing good support to the asphalt surfacing, the HBM base tends to crack due to thermal stresses and these discontinuities induce cracking in the asphalt surfacing (reflection cracking). Cost-effective sustainable maintenance of these pavements is often difficult, with treatments ranging from crack sealing, strengthening and partial reconstruction all being used with varying degrees of success. However, none of these treatments address the issue of continued thermally induced stresses from the HBM, and therefore the reappearance of reflective cracking in the asphalt surfacing.

Even though the cost-effectiveness of construction and maintenance techniques has always been recognised as being important, the need for sustainable construction and maintenance has not. This has however become more important in the past decade. In terms of sustainability practices for the construction industry, the conservation of materials and energy are particularly important considerations. CSO offers obvious benefits through maximising the reuse of in-situ materials and minimising the amount of new (hot mix) materials needed. In addition, long-life designs, i.e. > 80 msa, can be considered where appropriate.

While the CSO method is a cost effective and sustainable approach treatment, design and site quality control have been relatively time-consuming and expensive to apply, needing specialist knowledge of the application of linear elastic theory. The need for a more streamlined design approach was recognised and this guide provides the background to the CSO process and instruction on its use.

NG 2.2 Reflection cracking

Hydraulically bound materials (HBM) contain large amounts of water when they are placed to facilitate both chemical curing and compaction. As the water is lost through evaporation and chemical processes, the volume of material reduces, often leading to regular, mainly transverse, shrinkage cracks. Subsequent surface initiated cracking in the asphalt surfacing often follows as a result of the thermal expansion and contraction of the cracks in the underlying HBM base layer. With time these cracks commonly propagate to the full depth of the asphalt layer, resulting in ravelling at the crack impairing ride quality and subsequent ingress of water into the sub-base. Without timely maintenance, further deterioration caused by environmental effects and trafficking can cause further localised failures.

Figure 2.2: Reflection cracking on the A9

Figure 2.2 shows reflection cracking on a section of the A9 at around 8-10m spacing, and Figure 2.3, the development of a pothole from a transverse reflective crack.

Figure 2.3: Reflection cracking on the A9 near Ballinluig

NG 2.3 CSO process

The CSO process can be divided into three main parts:

- Assessment of the pavement to identify whether it will be suitable for CSO and to obtain detailed information to enable design to be carried out.
- Overlay design to determine an overlay thickness and a threshold stiffness.
- Quality control in the field to monitor the cracked and seated stiffness and adjust overlay thicknesses as appropriate.

Details of the three parts are given below and a complete description of the Crack, Seat and Overlay process is provided in Appendix A.

NG 2.4 Assessment

The first step in the design process is to determine whether a flexible composite pavement is suitable for a crack and seat treatment.

The essential characteristics of a suitable pavement will be:

- a strong HBM base;
- a regular pattern of full-depth transverse cracks with a spacing generally greater than 6m;
- an adequate foundation, and
- minimal lengths of longitudinal cracking, i.e. infrequent, one or two incidences.

The evaluation process used to determine whether CSO is likely to be a suitable technique is given in Figure 2.4.

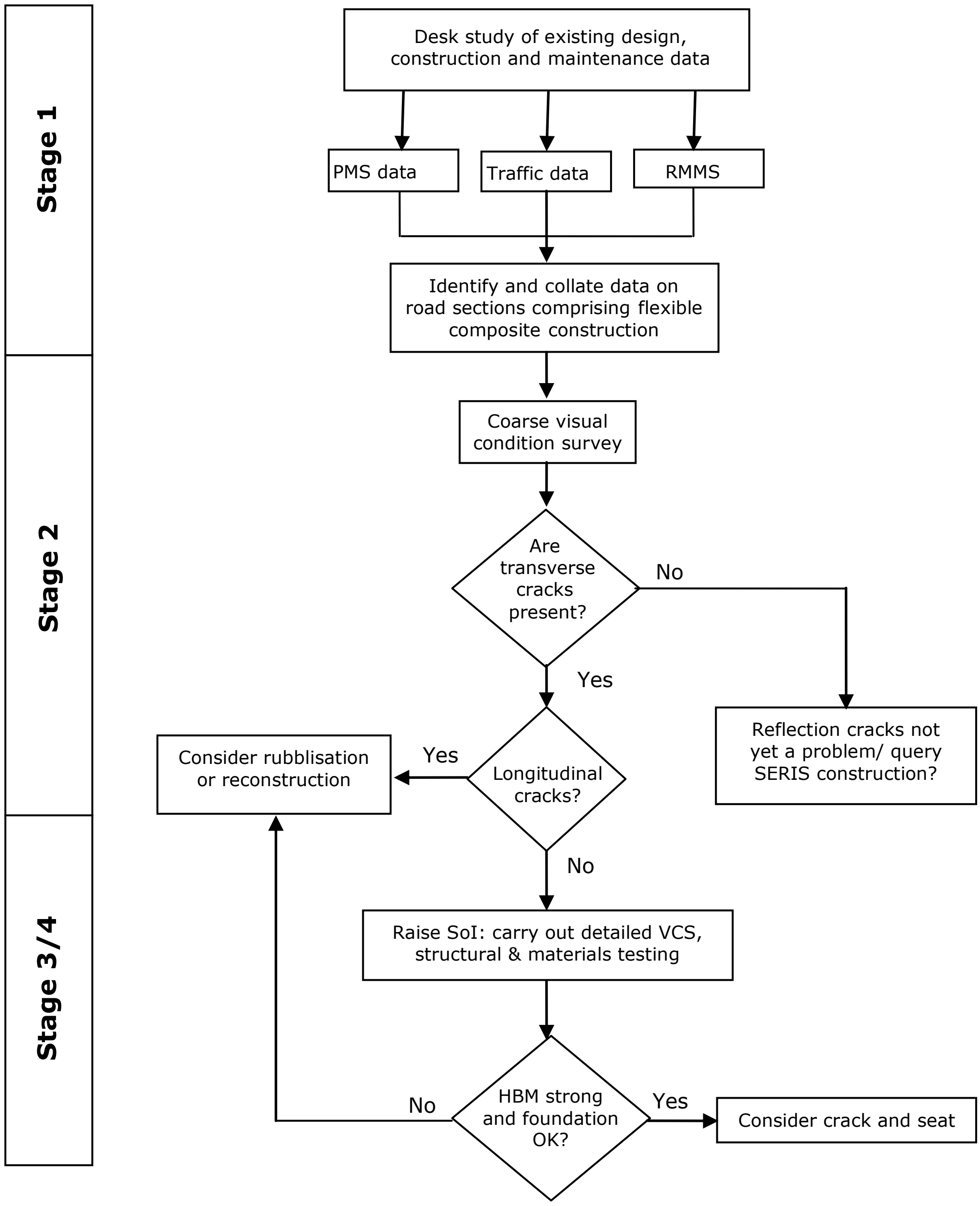


Figure 2.4 Road pavement evaluation for crack, seat and overlay treatment

NG 2.4.1 Assessment of maintenance needs

A more detailed explanation of the site investigation in Stage 3/4 (Flow chart in Figure 2.4) is given in Figure 2.5 (Coley and Carswell, 2006). Decision options are based on the type and severity of defects recorded during the detailed inspection and information collected as part of structural and material testing. The flow chart refers to major and minor defects and these are listed in Table 2.1. This chart can be used to investigate other possible treatments if the pavement is not suited to CSO.

Table 2.1: Major and minor defects

Major defects	**Minor defects**
Pumping	Asphalt cracking only
Longitudinal cracking	Fretting
Transverse cracking	Skid resistance (polishing)
Structural rutting	Surface rutting

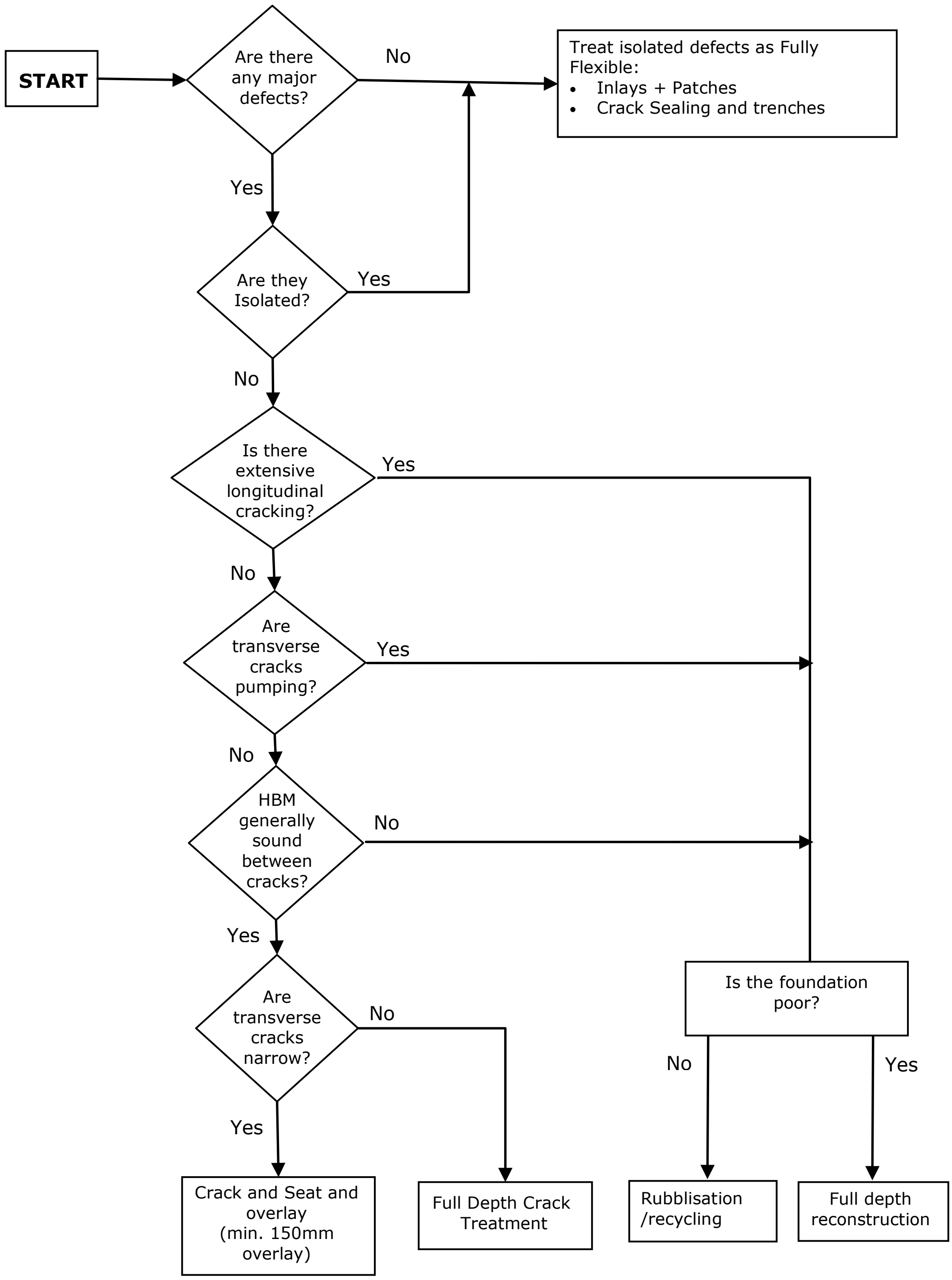


Figure 2.5: Treatment options for a flexible composite pavement

(From Coley & Carswell, 2006)

Once it has been confirmed that CSO is an appropriate treatment the design process can begin. This is described in NG 2.5.

NG 2.5 Design

NG 2.5.1 Simplified approach

The new simplified approach differs from the established CSO approach in the design stage only, where design matrices take the place of design curves developed using the output from linear elastic theory. In situ construction monitoring procedures remain the same (see MCHW Clause 716, Highways Agency et al 2009).

The new design method is based on a single failure criterion (fatigue) that limits the flexural stress or strain at the bottom of the bituminous bound layer. The critical stress or strain is calculated as the value induced by a standard wheel load (40KN over a circular patch of 0.151 m radius) and calculated using a linear elastic, multi-layer pavement model. This new approach is aligned with the HA's current CSO design approach for flexible pavements (including pavements previously known as flexible composite) which is based on TRL Report 615, (Nunn, 2004). For simplicity the design approach is based on a selection of appropriate threshold stiffnesses from matrices defined by foundation stiffness, HBM base thickness, asphalt thickness and traffic.

NG 2.5.2 Foundation assessment

Before any maintenance operations are carried out, i.e. prior to the removal of any asphalt, an assessment of the foundation must be undertaken. Foundation stiffness is characterised using back-calculated FWD stiffness obtained using the guidance given in DMRB Volume 7 HD 29/08 and HD30/08 (Highways Agency et al). The designer should divide the scheme into representative sections based on (inter alia) the strength of the foundation and construction characteristics. It is recommended that the 15th percentile FWD stiffness value be used as representative of the foundation condition. An example is shown in Figure 2.6.

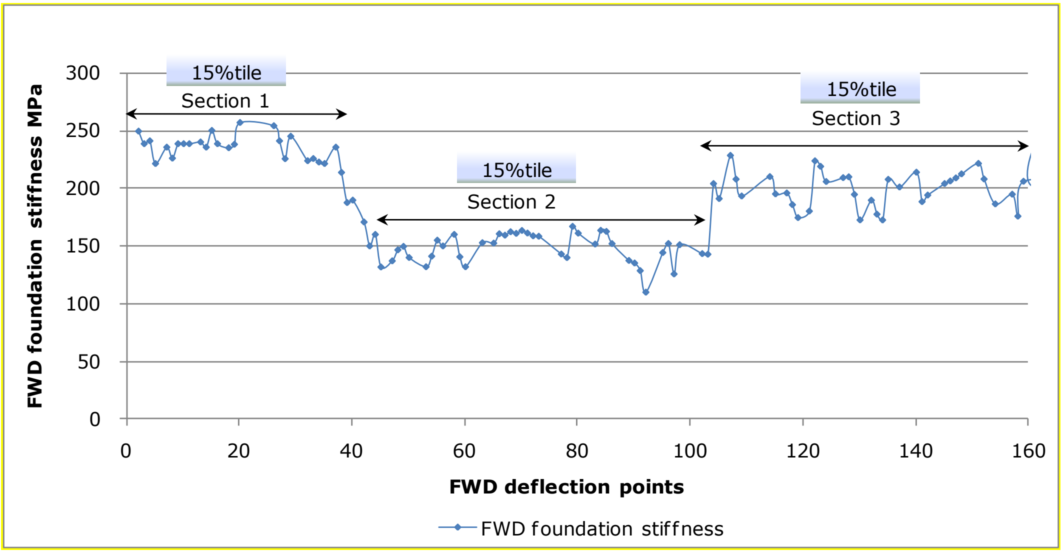


Figure 2.6: FWD foundation assessment-representative sections

NG 2.5.3 Design Parameters

Design parameters to encompass the range of expected conditions in Scotland have been selected following an assessment of designs carried out to date and expected traffic conditions in the future. Design inputs include: foundation category (defined by stiffness); design traffic (in million standard axles); HBM thickness; and asphalt overlay thickness. More detail of these properties is given below.

NG 2.5.3.1 Foundation category

For design purposes the pavement foundation has been divided into four groups based on FWD derived stiffnesses and which are compatible with HD26 of the Design Manual for Roads and Bridges, as given below:

- Good >200 MPa
- Average 101-150 MPa and 151-200 MPa
- Poor 50-100 MPa

NG 2.5.3.2 Traffic

Five classes of traffic to cover the range of traffic expected on the Scottish trunk road network have been selected for design:

- Group 1 <10 msa
- Group 2 11-20 msa
- Group 3 21-40 msa
- Group 4 41-80 msa
- Group 5 81-120 msa

NG 2.5.3.3 Hydraulically bound material

The thickness of the HBM has been divided into three groups:

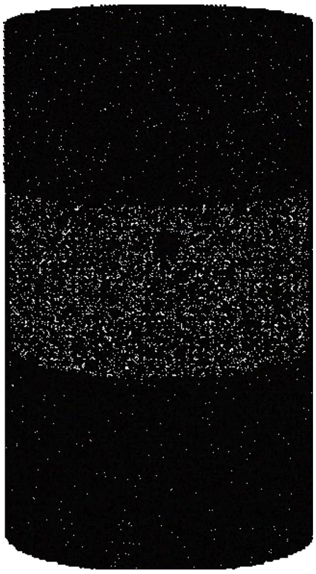
- Group 1 120-150 mm
- Group 2 151-200 mm
- Group 3 >200 mm

NG 2.5.3.4 Overlay materials and thickness

Two thicknesses of asphalt overlay are permitted:

- 150 = 30 mm Thin Surfacing + 120 mm EME2
- 170 = 30 mm Thin Surfacing + 140 mm EME2

The design parameters selected to calculate threshold stiffnesses are given in Table 2.2.



Design parameters			
Thickness in mm		Poisson's ratio	Stiffness in MPa
Surface Course	30	0.35	3500
EME2	120 140	0.35	8000
HBM	120-150 151-200 >200	0.2	500 1500 2500
Foundation	-	0.4	<100 100-200 >200

Table 2.2: Summary of design parameters

NG 2.5.4 Application of design matrices

Threshold stiffnesses were calculated using the worst case scenarios for each cell in the matrices and hence provide a factor of safety, i.e. a combination of the lowest foundation stiffness, least HBM thickness and greatest cumulative traffic. Design values for a range of design situations are presented in the matrices given in Table 2.3.

Design traffic <10 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
664	603	549	>200
749	660	584	151-200
881	746	634	101-150
1129	900	722	<100
TS+EME2 thickness 150mm			

Design traffic <10 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
489	461	433	>200
561	513	467	151-200
676	592	517	101-150
898	739	606	<100
TS+EME2 thickness 170mm			

Design traffic 10-20 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
955	831	729	>200
1073	905	770	151-200
1254	1015	831	101-150
1585	1208	933	<100
TS+EME2 thickness 150mm			

Design traffic 10-20 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
736	659	592	>200
840	729	635	151-200
1005	835	697	101-150
1317	1028	806	<100
TS+EME2 thickness 170mm			

Design traffic 20-40 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
1375	1145	967	>200
1538	1241	1017	151-200
1785	1380	1088	101-150
2226	1622	1205	<100
TS+EME2 thickness 150mm			

Design traffic 20-40 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
1106	942	810	>200
1258	1037	863	151-200
1494	1178	940	101-150
1932	1430	1072	<100
TS+EME2 thickness 170mm			

Design traffic 40-80 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
1979	1576	1283	>200
2205	1701	1342	151-200
2540	1878	1424	101-150
3125	2177	1558	<100
TS+EME2 thickness 150mm			

Design traffic 40-80 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
1663	1346	1107	>200
1884	1474	1173	151-200
2220	1662	1267	101-150
2835	1990	1425	<100
TS+EME2 thickness 170mm			

Design traffic 80-120 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
2449	1901	1515	>200
2723	2045	1579	151-200
3122	2249	1668	101-150
3812	2586	1810	<100
TS+EME2 thickness 150mm			

Design traffic 80-120 msa			
HBM in mm			FWD Ef (MPa)
120-150	151-200	>200	
2111	1659	1330	>200
2386	1811	1404	151-200
2800	2032	1509	101-150
3547	2414	1683	<100
TS+EME2 thickness 170mm			

Table 2.3: Design Matrices

Ef = foundation stiffness

NG 2.5.4.1 Design examples

Table 2.4 provides design threshold stiffness examples for a number of combinations of foundation stiffness, design traffic, HBM thickness and an overlay thickness of 150 mm.

Foundation stiffness (MPa)	**Design Traffic** (msa)	**Thickness of HBM** (mm)	**Threshold stiffness** (MPa)
200	100	130 180	**2723** **2045**
180	15	130 180	**1073** **905**
101	100	130 180	**3122** **2249**
80	8	130 180	**1129** **900**

Table 2.4: Design examples

NB. When selecting threshold stiffness values, it is not intended that the designer should attempt to interpolate between values in the matrix. If the designer is in doubt to what value should be selected then the higher value should be chosen for design purposes.

NG 2.5.4.2 Worked example

Following a road pavement evaluation study (see Figure 2.4), a 1.6 km scheme was identified for CSO treatment. A coring and GPR survey showed that the HBM was reasonably consistent at a thickness of 200 mm. However, owing to the existing depth of asphalt and finished level restrictions, and the need to provide a 150 mm overlay, the remaining thickness after planning corresponded to 165 mm. Although the HBM thickness was in excess of this in some areas, 165 mm was adopted for design purposes.

The scheme traffic loading was estimated to be 91 msa over a 40 year design life.

An FWD survey was conducted prior to the removal of any asphalt and a plot of the foundation modulus is given in Figure 2.7. In the back-analysis model, the foundation is considered to comprise all the material below the HBM. It was observed that the foundation conditions varied along the length of the scheme and was therefore broken into three representative sections, viz, a, b and c. The 15th percentile values for sections a, b and c corresponded to 240 MPa, 143 MPa and 185 MPa respectively.

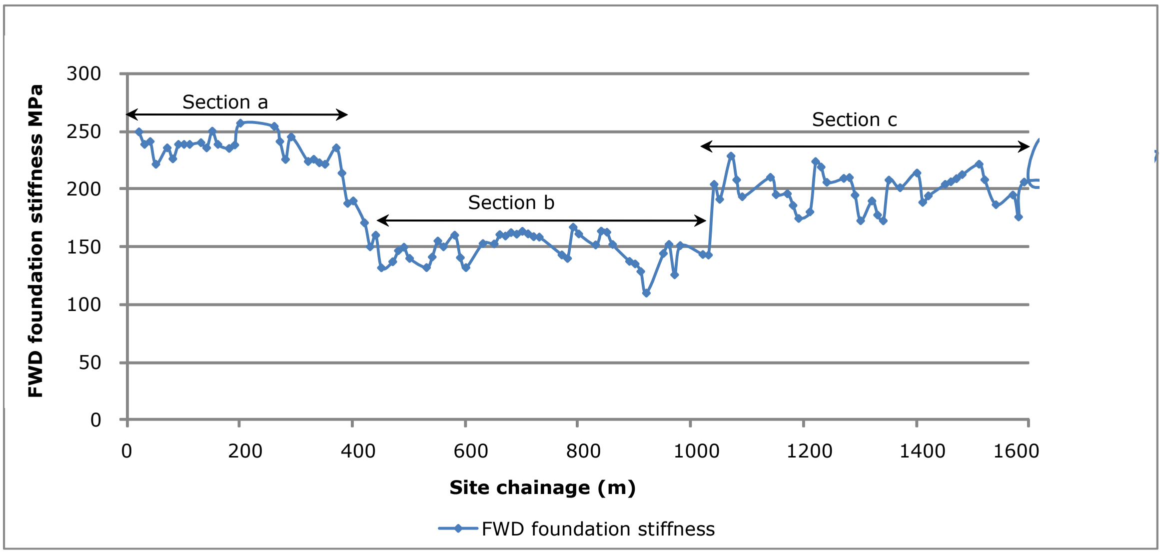


Figure 2.7: Foundation assessment

Table 2.5 shows the design threshold stiffness for the three sections a, b and c, and Figure 2.8 shows the matrix that was used to determine the design threshold values corresponding to the different combinations of foundation stiffness, design traffic, HBM thickness and an overlay thickness of 150mm.

Foundation stiffness (MPa)	**Design Traffic** (msa)	**Thickness of HBM** (mm)	**Threshold stiffness** (MPa)
(a) 240	91	165	**1901**
(b) 143	91	165	**2249**
(c) 185	91	165	**2045**

Table 2.5: Design threshold stiffnesses

Design traffic 80-120 msa			
HBM in mm			**FWD Ef (MPa)**
120 - 150	**151 - 200**	**> 200**	
2449	1901	1515	>200
2723	2045	1579	151-200
3122	2249	1668	101-150
3812	2586	1810	<100
TS+EME2 thickness 150 mm			

Figure 2.8: Design threshold matrix for 80-120 msa

NG 2.5.5 Use of design matrices during construction

Following cracking and seating a measure of the in-situ stiffness of the HBM is taken using FWD testing. If the measured stiffness, or the foundation stiffness, is significantly different to that used in the design, the design matrices should then be used to reassess the implications of any differences in terms of design traffic. Appropriate changes can then be made if required, such as consideration of future maintenance planning or by thickening the asphalt overlay, for instance.

NG 2.6 Cracking and Seating

The procedures used to crack and seat the HBM base need to conform to Clause 716, Volume 1 of the Manual of Contracts for Highway Works (MCHW). Thereafter, assessment of the stiffness of the cracked and seated HBM needs to be carried out in accordance with Clauses 717 and 719 of the Specification for Highway Works (SHW). Additional information on the CSO method is given in Annex A.

NG 2.7 EME2 Overlay

Transport Scotland has specified that EME2 is to be the overlay binder material to be used to overlay cracked and seated HBM layers. Appendix B provides information on the design of EME2, how it is specified, manufactured and placed in situ.

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Appendix A Crack Seat and Overlay Rationale

A.1 Crack Seat and Overlay Rationale

The philosophy underlying the crack and seat technique is to reduce the effective slab length between cracks in the cemented layer and to compact the cracked slabs into the foundation to obtain increased foundation stiffness prior to overlay. If the crack spacing in the cemented base is reduced, the horizontal strains resulting from thermal movements are distributed more evenly throughout the pavement and are therefore smaller and less likely to cause transverse cracks in the asphalt overlay. The overlay is required to seal the surface from water penetration and to provide an improved ride quality and meet the current safety and noise standards. The equipment used for crack cemented pavement layers uses a guillotine action which is a heavy, transversely mounted blade falling vertically under gravity as illustrated in Figure A.1.

Figure A.1 Standard guillotine breaker used for crack and seat

The cracking operation needs to create fine vertical cracks normally between 0.5m and 2.0m spacing. It is very important that these cracks are near vertical and fine, so as to maintain the good aggregate interlock needed for load transfer. The cracking operation needs to penetrate the full depth of the cemented layer to allow small thermal movements to take place but must not shatter the base of the cemented layer, which would reduce the effective thickness of the layer. The formation of longitudinal cracks also needs to be avoided as they can contribute to a reduction in load-spreading ability from the wheel paths.

For crack and seat it is necessary to adjust the settings of the guillotine for the local pavement and foundation condition. The force that the machine needs to apply to crack the pavement layer depends on the strength and the thickness of the cemented layer and the foundation support. After cracking, the crack pattern is inspected and cores are taken to ensure the pattern meets the requirements. The treated surface is then rolled with not less than six passes of a pneumatic tyred roller (PTR) ballasted to not less than 20 tonnes. This seating operation is carried out to minimise the occurrence of any voids under the slabs prior to application of the new asphalt overlay.

A.2 The Crack and Seat and Overlay (CSO) Method

To date CSO treatments have generally been used with Pavement Quality Concrete (PQC) and have been shown to be cost effective. Fewer pavements incorporating HBM layers have been cracked and seated as limited guidance was available as to define when these pavements are suitable for this process. Recently the CSO design method has been criticised for being unnecessarily complicated, considering that the resultant overlay thickness often only varies between 150 and 180mm. The existing methodology and the need for the more streamlined approach are described below.

A.2.1 Existing methodology

The current procedure for determining the overlay thickness for a cracked and seated concrete pavement is based on an analytical design procedure, described in Chapter 4 of HD26/06 (DMRB 7.2.3). At present, there are two main requirements in designing overlays for cracked and seated concrete pavements: to inhibit reflection cracking and to ensure the treated pavement can carry the anticipated future traffic loading.

Research, based on the performance of UK crack and seat trials monitored since the early 1990s, has shown that 150mm total overlay (surface plus binder/base course) is usually sufficient to inhibit reflection cracking and this is the current recommended minimum thickness of overlay for a cracked and seated concrete pavement. It is also particularly important that the overlay design ensures that the treated pavement can carry the anticipated future traffic loading. The crack and seat process has a weakening effect on the concrete pavement and the required overlay thickness needs to take this into account.

The current structural design guidance is based on the method reported in TRL's report LR1132 (Powell et al, 1984). This classic pavement design method uses a simplified multi-layer, linear-elastic model analysis to determine the two standard modes of failure caused by repeated loading of a standard 40kN wheel load (with radius 0.151m). The two modes of failure are fatigue cracking at the bottom of the asphalt overlay (tensile strain) and overstressing of the subgrade (vertical strain), resulting in permanent deformation.

There are four main variables in the design method:

- Existing pavement construction details (material and layer thicknesses, including subgrade CBR)
- Design traffic
- Asphalt overlay material and thickness
- Stiffness of the cracked and seated concrete

The first two variables are known for each scheme and are determined from in situ pavement testing and the use of existing equations to calculate stiffness values, past traffic data and predicted traffic growth. The third and fourth variables are the main outputs required from the design process. The fourth variable is important from a structural viewpoint as the required thickness of the overlay will depend on the load-spreading ability of the existing pavement structure after the crack and seat treatment. At the design stage, the stiffness modulus of the pavement after it is cracked and seated is not known as it depends on many factors including sub-base type, concrete strength, and crack spacing.

A.2.2 Analysis of stress and strain

The overlay design process requires an analysis program that uses a simplified multi-layer linear elastic model, e.g. BISAR (Shell 1998), PADAL (Tam and Brown, 1989) or WESLEA (Van Cauwelaert et al, 1989). Each overlay thickness and material type requires a separate run of the analysis program to calculate critical stresses and strains in the pavement for a range of traffic loading. Each run provides a value for the expected life of the pavement.

To facilitate the above process, typical values for the stiffness modulus of a cracked and seated concrete pavement (for various pavement types) have been determined from a TRL database of previous CSO schemes. These 'seed values' are the 5th percentile modulus values, which means that 95% of values have been above this seed value hence, for typical pavements, they should represent a 5% failure threshold.

Once an overlay design is selected, the above process is repeated (using the same model) to determine a minimum effective stiffness threshold that needs to be achieved by the cracked and seated concrete in order to achieve the required design life. The pavement construction data is input along with the design overlay thickness, the stiffness value for the chosen overlay base material, and at least three values for the cracked and seated concrete stiffness modulus. Each concrete stiffness value requires a separate run of the analysis program and the output will then determine the minimum expected pavement life for each of these designs.

A.2.3 Validation

The construction of a CSO scheme incorporates a design validation stage where detailed FWD testing and back-analysis is used on site to identify locations where the cracked concrete does not meet the effective stiffness threshold. Any such areas are then inspected, and retested if required. If the areas of low effective stiffness are also seen to be visually defective, they are normally excavated and replaced with a full-depth asphalt construction.

A.2.4 Weaknesses of present Method

The present linear elastic analytical design approach is site specific and onerous for relatively simple design situations with few variables. In addition the existing design methodology is heavily dependent on accurate knowledge of the thicknesses and elastic stiffnesses of the underlying unbound foundation materials. Robust values for these parameters are hard to determine from the limited amount of data usually available from pavement investigations, and there is a significant risk that designs may be unreliable where variability in foundation condition/construction material type exists. The current design method does not make use of foundation properties derived from FWD measurements on the in-service pavement.

The design validation stage (during construction) uses back-analysis of FWD data to determine the stiffness of the cracked and seated concrete. The theory underlying this approach assumes that the material tested is homogeneous, which is not truly valid after cracking and seating. The derived parameter is therefore termed an "effective" stiffness and the presence of the induced cracks introduces a degree of uncertainty into the results. To date vertical subgrade strain has usually been found to be the critical parameter during design but has not been found to be the case in practice. This is probably due to the weakest subgrade strength measure often being chosen subjectively and used for design, which is often not representative of the majority of the pavement. This introduces a significant degree of conservatism into the design and can result in excessive amounts of reconstruction.

APPENDIX B EME2 for Overlays to Cracked and Seated Cemented Bases

B.1 Introduction

EME is a base/binder course material with a high content of hard bitumen and low air voids content designed to combine good mechanical performance with impermeability and durability. It has been in widespread use in France for around 20 years. The mixture is designed to be workable and durable and to have high elastic stiffness, high deformation resistance and good fatigue resistance.

EME base material is defined in the French standard NFP 98-140 (AFNOR, 1999). This gives minimum requirements on the hardness, angularity and cleanliness of aggregates and for acceptable grades of binder. The designer is free to select an appropriate binder that provides the properties required to satisfy end performance criteria for the mixture. EME is designed to satisfy criteria determined using laboratory tests developed by LCPC to measure the properties of laboratory compacted specimens in respect of compactability, water sensitivity, deformation resistance, stiffness and fatigue.

The material is laid as a binder course and base in lifts of 60 mm to 150 mm thick using 0/10 mm, 0/14 mm and 0/20 mm gradings. The superior structural properties of the high modulus material justify thickness reductions of 25 to 40% in French road designs compared to 'grave bitume' (AFNOR, NF P 98-138, 1999).

There are two grades of EME in the French specifications, EME Class 1 and EME Class 2 with the Class 2 material having a significantly higher binder content, as defined by the richness modulus

Determination of binder richness modulus involves calculating the specific surface area of the aggregate grading of the mix separated on particular sieves. It will be necessary to carry out a particle size analysis of the combined aggregate (or the individual fractions) including the 6.3 mm, 0.315 mm and 0.080 mm sieves, despite the fact that some of these are not part of the sieve set adopted for use in European Standards for aggregates and asphalt.

The binder richness modulus, K, is derived from the following formula:

$$B_{PPC} = K.\sqrt[5]{\Sigma}.a$$

Where:

B_{PPC} = the mass of soluble binder expressed as a percentage of the total dry mass of aggregate, including filler. (Note that this is different from the conventional UK expression of binder content B_M, which is as a percentage by mass of the total mix. $B_{PPC} = B_M \times 100/100 - B_M$)

Σ = specific surface area of aggregate given by,

$$\Sigma = 0.25G + 2.3S + 12s + 135f$$

G = proportion* by mass of aggregate over 6.3 mm,
S = proportion* by mass of aggregate between 6.3 mm and 0.315 mm,
s = proportion* by mass of aggregate between 0.315 and 0.080 mm,
f = proportion* by mass of aggregate smaller than 0.080 mm,
a = $2.65/\rho_g$ which is a correction coefficient taking into account the density of aggregate (ρ_g) if this differs from 2.65 mg/m^3.

* *The proportions of aggregate must be expressed as decimal fractions of the total mass (eg, if there is 38% of the mass passing 6.3 mm and retained on 0.315 mm then S would be 0.38)*

A 0/20 mm EME was selected for trials and subsequent use in the UK as this size was considered to be the most economical, particularly in terms of aggregate usage and best suited to UK practice. The richer Class 2 material was chosen with the aim of producing an extremely durable high performance material for use on long-life heavily trafficked roads. In France there is extensive use of 0/10 mm and 0/14 mm in both EME, and BBME (Bitumineux Beton Module Eleve), which is a similar binder course material.

B.2 Current specification

The current specification for EME2 is given in Clause 930 of the Manual of Contract Documents for Highway Works (MCHW) and is summarised below.

MCHW Clause 930 (08/08) EME2 Base and Binder Course Asphalt Concrete

1 (08/08) EME2 base and binder course asphalt concrete shall conform to BS EN 13108-1 (BSi, 2006), the detailed requirements of BSI PD 6691 Annex B (for the selected mixture, the requirements of this Clause and those specified in Appendix 7/1.

The mixture designation shall be one of the following:

(i) AC 10 EME2 bin/base 10/20 des.

(ii) AC 10 EME2 bin/base 15/25 des.

(iii) AC 14 EME2 bin/base 10/20 des.

(iv) AC 14 EME2 bin/base 15/25 des.

(v) AC 20 EME2 bin/base 10/20 des.

(vi) AC 20 EME2 bin/base 15/25 des.

2 (08/08). The binder shall be Hard Paving Grade Bitumen in accordance with BS EN 13924 (2011) and the requirements specified in Tables 9/4, 9/5 and 9/6.

3 (08/08). EME2 mixtures, otherwise conforming to BS EN 13108-1 (BSi, 2008) and the detailed requirements of BSI PD 6691 Annex B (BSi, 2010), but using alternative paving grade bitumens or polymer modified paving grade bitumens, shall not be used without prior approval by the Overseeing Organisation.

B.3 Design Methodology

The EME design method essentially follows the French approach, and aims to produce a very stable mixture that requires heavy compaction equipment to densify the material to a level where it does not compact further under traffic.

Initially several different aggregate gradings with a single binder content are normally investigated for acceptable workability using the gyratory shear compactor test (PCG test - Presse à Cisaillement Giratoire test). This test simulates the action of compaction plant on-site and enables the voids content obtained on-site with a heavy, pneumatic-tyre roller to be estimated.

The PCG test is used to determine a composition to achieve a minimum performance in terms of this test rather than an optimum composition. EME Class 2 must achieve a voids content of 6 percent or less and BBME Class 3 must achieve a voids content of 5% or less in the PCG test. If a low voids content can be achieved easily the material is likely to lack internal stability as measured in the LCPC rutting test. Material that is to be placed as a thinner layer is designed to be more workable. For example, the recommended laying thickness of BBME with a 0/10 mm aggregate is 60 to 70 mm and this material has to achieve its target density in fewer gyrations in the PCG test.

When a grading has been found that satisfies the PCG design criterion, the binder content, or binder richness modulus defined above is recalculated for the grading selected using a formula which takes into account the specific surface area and the density of the aggregate. The sensitivity of the mixture to stripping by water is then checked by carrying out unconfined compression tests (Duriez test) on two sets of cylindrical samples, one set after conditioning in water. If the ratio of the results after and before conditioning is above a certain value, the material is deemed to be acceptable.

Material is then prepared in the LCPC pneumatic-tyre slab compaction apparatus from which test samples can be cut for performance testing. If the samples in each of these tests do not achieve the performance criteria specified in Table B-1 changes are made to the composition and the design tests repeated until a satisfactory mixture is obtained.

Table B.1 Design Criteria using LCPC Performance Tests

Test	EME Class 2	BBME Class 3
PCG test 0/10 mm 0/14 mm 0/20 mm	≤6% air voids, after 80 gyrations 100 gyrations 120 gyrations	4 to 9% air voids, after 60 gyrations 80 gyrations (and, ≥11% after 10 gyrations)
Duriez test (after and before immersion ratio)	≥0.75	≥0.80
Rutting test (60˚C, 30,000 cycles on 100mm slab)	≤8%	≤5%
Complex modulus test (15˚C, 10 Hz)	≥14 GPa	≥12 GPa
Fatigue test (10˚C, 25 Hz - tensile micro-strain for 10^6cycles)	≥130	≥100
Binder richness modulus 0/10 mm 0/14 mm 0/20 mm	 3.4 3.4 3.4	 3.5 3.3 -

B.4 Manufacture, laying and compaction

Whenever new mixture constituents are used a laboratory design exercise must be carried out to determine an appropriate mixture formulation. If the mixture has been used before, the testing required can be restricted to the PCG test and the Duriez test to verify the formulation.

Mixing and laying EME is no different to conventional materials, provided the temperatures are maintained at the appropriate level.

Laying thicknesses for the different aggregate gradings of EME (0/10 mm, 0/14 mm and 0/20 mm) are respectively 60 to 100 mm, 70 to 120 mm and 100 to 150 mm, and for BBME (0/10 mm and 0/14 mm) the recommended laying thicknesses are 60 to 70 mm and 70 to 90 mm respectively. The requirements for laying are that the surface on which the high stiffness material is to be laid should be clean and tack coated at the rate of 250 grams of residual bitumen per m^2. The air voids in the permanent works must be less than 6% for EME Class 2 and in the range 4% to 9% for all classes of BBME.

B.5 Construction Joints: Asphaltic Layers

Best practice is, wherever possible all asphaltic layers shall be laid and compacted without 'cold' longitudinal joints. Echelon paving is the preferred method but where joints are required for construction reasons they shall be side compacted (chamfered joints) and chamfered face painted with bitumen.

B.6 Loop detectors Installation

If loop detectors are to be installed they shall be located in the binder course.