AECOM

Ex Situ Cold Recycled Bound Material (CRBM)

Updates to DMRB CD 226
Stage 1.1.1 - Establishing acceptance criteria

National Highways

Project reference: T0054 - Pavement Call-Off Support 2021-2024
Project number: 60658793

06 July 2022

Delivering a better world

Quality information

Prepared by	Checked by	Verified by	Approved by
Joe Poulsom Principal Pavement Engineer	Martyn Jones Associate	Jessica Tuck Technical Director	Ramesh Perera Technical Director

Revision History

Revision	Revision date	Details	Authorized	Name	Position
V0.1	01.06.2022	Draft	Yes	Martyn Jones	Associate
V1.0	06.07.2022	First issue	Yes	Ramesh Perera	Technical Director

Distribution List

# Hard Copies	PDF Required	Association / Company Name

Prepared for:

National Highways

Prepared by:

Joe Poulsom
Principal Pavement Engineer
M: 07799 099802
E: Joe.Poulsom@aecom.com

AECOM Limited
12 Regan Way
Chetwynd Business Park
Nottingham NG9 6RZ
United Kingdom

T: +44 (115) 907 7000
aecom.com

Table of Contents

Figures

Tables

1. Introduction

National Highways has commissioned the Arup AECOM consortium to recommend updates to their requirement and advice documents (RADs) in relation to ex situ manufactured cold recycled bound material (CRBM) that is currently designed in accordance with DMRB CD 226 and specified in accordance with MCHW Clause 948.

CRBM is a generic term used to describe materials that comprise aggregates and binder that are processed at ambient temperatures to produce a bound material. CRBM can be produced in situ by pulverisation and mixing with added binder (also known as stabilisation), or ex situ at a dedicated fixed or mobile plant following transportation of the component materials to that plant. Aggregate within CRBM is typically predominantly reclaimed asphalt; however, any aggregate conforming to BS EN 13043 can be used. Filler aggregate, typically fly ash, is often added to CRBM to increase the proportion of fines within the mixture.

The binder used in CRBM can be hydraulic binder or a combination of bituminous binder and hydraulic binder. To enable bituminous binders to adequately coat the aggregate at ambient temperatures, the bituminous binder is typically foamed bitumen or bitumen emulsion.

CRBM is classified depending on the type of binder used as outlined in Table 1.

Table 1. CRBM terminology

Terminology	Binder type
Quick visco-elastic (QVE)	Bituminous binder with cement
Slow visco-elastic (SVE)	Bituminous binder with hydraulic binder excluding cement
Quick hydraulic (QH)	Cement
Slow hydraulic (SH)	Hydraulic binder excluding cement

For the purposes of pavement design, CRBM is further classified by design stiffness as outlined in Table 2. CRBM Class B1 and Class B2 are typically used when in situ stabilisation is undertaken.

Table 2. CRBM classification by stiffness

CRBM Classification	Design stiffness (MPa)	Minimum mean ITSM** from manufactured specimens (MPa)
Class B1	1900	1900
Class B2	2500	2500
Class B3	3100	3100
Class B4	N/A*	4700

* There are no approved design curves for CRBM Class B4
** Indirect Tensile Stiffness Modulus (ITSM)

Current design requirements for ex situ CRBM are contained within the Design Manual for Roads and Bridges (DMRB) CD 226 ‘Design for new pavement construction’, which refers to TRL 611 for the CRBM design curves. Product and installation requirements for CRBM are currently contained within Clause 948 of the Specification for Highway Works (SHW).

Currently, DMRB CD 226 imposes restrictions on the use of CRBM to limit the use of CRBM to sites with a design traffic of 30 million standard axles (msa) or less. This was on the basis of a lack of evidence of in situ performance of the CRBM beyond 25 msa as outlined in TRL 611, which states ‘… *the road trials on which the design guidance contained in this report was formed carried a maximum traffic of 25 msa; therefore designs for heavily traffic roads* [>30 msa] *are based upon extrapolations of existing knowledge and they should therefore be treated with caution’*. Consequentially, the use of CRBM on sites with a design traffic greater than 30 msa requires a ‘departure from standard’ application.

In addition, whilst Clause 948 includes end-product minimum mean stiffness requirements for Class B1 to Class B4 materials, the permitted mixture classification for ex situ CRBM is limited by CD 226 to Class B3. As noted above, Class B1 and Class B2 are typically only used for in situ stabilisation. The design stiffness (and hence design curve) for Class B3 in TRL 611 assumes equivalence to an HRA 40/60 mixture (3100 MPa). CRBM Class B4 was introduced since the publication of TRL 611. Class B4 has a higher end-product minimum mean stiffness requirement than Class B3; therefore, 'departure from standard' applications have been submitted for the use of Class B4 using a higher assumed design stiffness than Class B3 in order to reduce the overall construction thickness.

1.1 Scope

In order to reduce the number of 'departure from standard' applications and support decarbonisation, National Highways has commissioned the Arup AECOM consortium to:

- Establish a new maximum permitted design traffic (msa) for ex situ CRBM QVE Class B3 and Class B4.
- Develop design curves for ex situ CRBM QVE Class B4 to accompany the design charts in TRL 611 for QVE Class B3.
- Introduce a minimum asphalt overlay thickness for ex situ CRBM QVE Class B3 and Class B4. CD 226 currently requires a minimum thickness of bituminous surface course of 20 mm; and TRL 611 a minimum total asphalt surfacing thickness (including binder course) of 50 mm for designs up to 10 msa, and 70 mm for designs up to 30 msa.

The scope of the current task is limited to:

- Ex situ CRBM QVE Class B3 and Class B4, as other CRBM types have had limited use on the SRN and have different performance characteristics.
- Informing the new design curves and new maximum permitted design traffic based on the in situ performance of existing CRBM sites which have been constructed more than 10 years ago. An initial desk-based study will be undertaken using available data sources (typically network level survey data) or new condition data that could be collected at traffic speed. This is on safety grounds; however, should the findings from the desk-based study identify that there is insufficient or inconclusive information to inform an update, then non-traffic speed surveys may need to be arranged (under traffic management) in order to close knowledge gaps.

1.2 Work stages and approach

The task has been split into work stages including hold points at regular intervals to present findings and agree the next steps with National Highways. This is in consideration of the project scope, which comprises an initial desk-based study using (i) published literature – that may have limitations; and (ii) network level (traffic speed) survey data - the potential inconclusive nature of this data may support a need to undertake slow and/or static surveys to close any key knowledge gaps.

The proposed approach is to develop outline designs using a design protocol based on precedent which would act as the baseline designs which could be accepted subject to the condition of existing ex situ CRBM sites being as expected, or deviated from in the event of condition being poorer than expected for an equivalent design utilising bituminous bound mixtures. The key activities in each work stage are outlined below:

- Work Stage 1.1.1
  - Identify acceptance criteria for implementing updates based on condition of existing CRBM sites.
  - Develop outline designs to be implemented subject to acceptance criteria being met.
- Work Stage 1.1.2
  - Desk-based study to review in situ performance of existing relevant CRBM sites against acceptance criteria.
  - Evaluate implications of desk-based study on outline designs, then accept outline designs, propose amendments to outline designs, or propose additional information gathering as appropriate.

- Work Stage 1.1.3
  - Subject to findings from Work Stage 1.1.2, additional surveys to close knowledge gaps.
- Work Stage 1.2
  - Updating RADs.

The proposed work stages and activities and hold points in each work stage are detailed in Figure 1. This interim technical note presents the output from Work Stage 1.1.1.

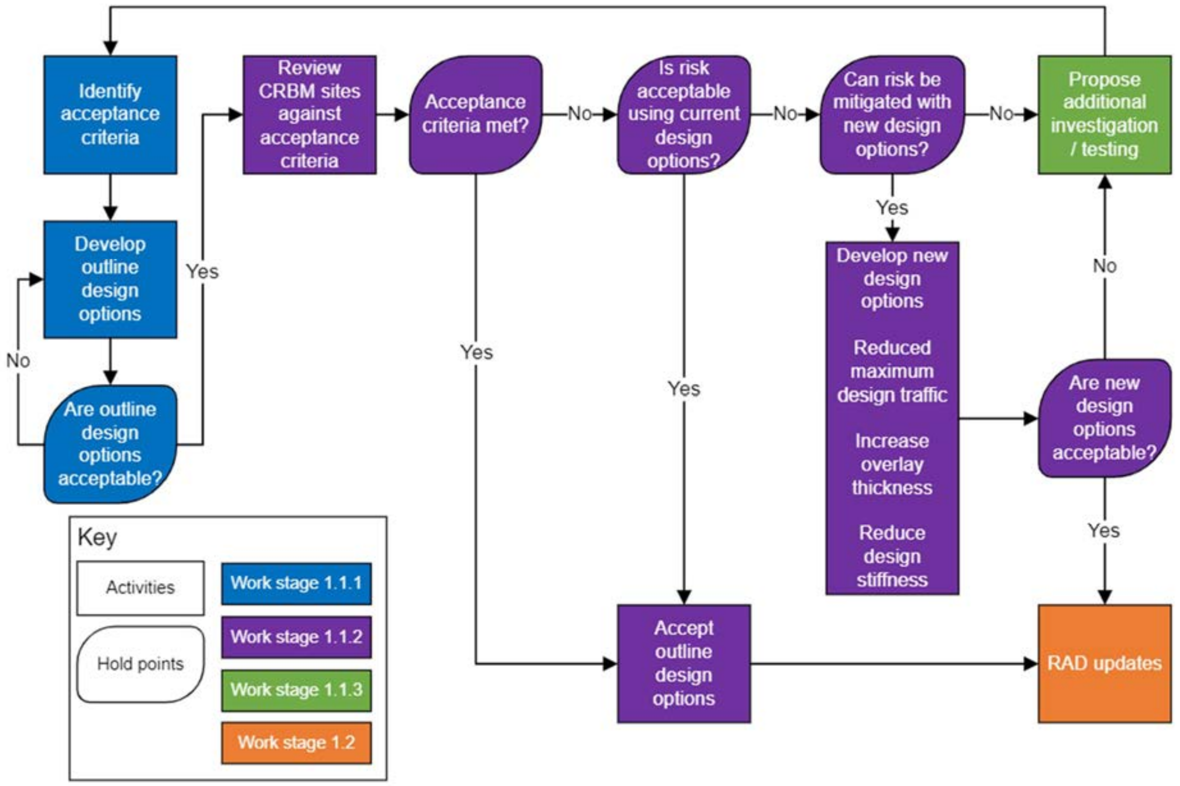

Figure 1 Work stages

2. Outline design approach

This section presents the proposed outline designs and design basis for QVE CRBM for a design traffic exceeding 30 msa which may be incorporated into National Highways RADs subject to the in situ performance of relevant CRBM sites being identified as acceptable. The purpose of presenting a baseline approach prior to reviewing information is to enable potential streamlining of the task subject to acceptance criteria being met.

2.1 Background

Pavement thickness design with QVE CRBM in the UK is undertaken using the same methodology as flexible pavement design, i.e. using linear elastic, multi-layer analysis, to calculate the traffic-induced strains at critical locations in the pavement, considering the design traffic, foundation stiffness and pavement material properties (i.e. Poisson's ratio and design stiffness specific to each layer).

The magnitude of strain relates to the number of heavy 40 kN 'standard axle' vehicle wheel load applications that can be carried before failure of the CRBM base material by fatigue cracking (i.e. Fatigue Life); and a Fatigue Life Shift Factor (K) is applied to this relationship based on site monitoring of in service CRBM pavements to account for e.g. non uniform design stiffness. If the calculated lives of CRBM pavements are shown to be consistently different to that observed in service, then the design stiffness and/or the K factor can be adjusted in the analysis.

The design criteria limits the horizontal strain at the bottom of the QVE CRBM (or bituminous bound base course) with load repetitions (i.e. the design traffic). With increased design traffic, an increased material thickness and/or enhanced materials properties (to permit an increase in design stiffness) are required to limit horizontal strain to acceptable limits and prevent the occurrence of fatigue cracking throughout the design life.

As outlined in Section 1, the use of CRBM on the SRN is currently limited to sites with a design traffic of 30 msa or less without a 'departure from standard' application. This is based on the lack of evidence of in situ performance of the CRBM beyond 25 msa at the time of the publication of TRL 611 (2004), which forms the basis of the pavement design in CD 226 (2021).

It is noted that, with increasing cumulative design traffic, beyond around 20 msa, only a relatively small increase in pavement thickness is required to achieve a significantly increased design life up to 80 msa. Beyond that, the pavement thickness does not need to be increased to accommodate additional load repetitions. Known as long-life pavements, flexible pavements with a design life beyond 80 msa are considered to be constructed such that the pavement thickness and properties are sufficient to limit horizontal strain to a level whereby repeated loading would not result in fatigue cracking or structural deformation in the base layer. Subject to non-deterioration of the substrate, deterioration of long-life pavements is assumed to be limited to the surface layers only.

Beyond 80 msa, the material properties of the bound layers are much more critical to achieving pavement performance as an over-estimate of the design stiffness may result in a pavement that deteriorates at a much accelerated rate. The design stiffness is the minimum expected long term stiffness taking into account any assumed age hardening, degradation, and (in the case of the lower pavement layers) confinement.

2.2 Design stiffness

The in situ long term design stiffness for a bituminous bound material (including QVE CRBM), to be used within a linear elastic, multi-layer pavement thickness design analysis, is typically related to the indirect tensile stiffness modulus (ITSM) (laboratory test) of the material. The material sample used for ITSM testing is either artificially conditioned (for a period of 28 days at a temperature of 40 ±2 °C) or cored from the site, to be representative of in-service performance, but with a need to factor this laboratory derived stiffness to account for in situ factors such as confinement from the surrounding pavement layers and longer loading times. For asphalt concrete (AC dense 40/60), the design stiffness is assumed to be approximately 130% of the laboratory ITSM.

It is important to note that the in-service stiffness changes during the design life of a QVE CRBM [1], whilst a 'conventional' bituminous bound mixture (i.e. conforming to BS EN 13108) typically exhibits a fairly consistent stiffness (albeit with some potential for age hardening due to binder oxidation that can result in an increase in the in-service stiffness with time) before fatigue cracking results in a rapid stiffness decrease at the end of its design life. In contrast, the QVE CRBM typically exhibits a variable initial stiffness (depending on the cement additive) and then a steady decrease in the in-service stiffness with time. To account for this variable stiffness for a QVE CRBM, when a single design stiffness is used in the pavement thickness design analysis it is important to calibrate the calculated design life (to failure by fatigue cracking) with observed performance in situ.

As outlined in Section 1, the precedent set in TRL 611 is that the design stiffness used for QVE CRBM is equivalent to the material's end-product criteria, an assumed 360-day in-service stiffness, which is the minimum mean ITSM of manufactured specimens subject to accelerated curing, herein referred to as 'end-product ITSM'. This is a 1:1 design stiffness ratio is more conservative than the above indicated 1:1.3 ratio for a bituminous bound mixture.

If the precedent set by TRL 611 i.e. a 1:1 end-product ITSM to design stiffness ratio is followed for CRBM QVE B4, then a 4700 MPa design stiffness could be assumed; however, there are two current concerns:

- Inconsistencies between the in-service stiffness of CRBM QVE and the end-product ISTM compliance criteria, have been reported by Transport Scotland [2]. Two of three CRBM QVE B4 schemes (targeting a minimum mean ITSM 4700 MPa) on the M9 Jct 3-4 Hard Shoulder exhibited significantly lower in-service stiffness at one year (average 960 MPa, 1260 MPa), measured through the back analysis of FWD testing and confirmed by the ITSM from cores, although the third scheme had an in-service stiffness greater than the end-product ITSM compliance criteria.

There would be an impact on the actual pavement design life where the in-service stiffness value was less than the value used in design. This inconsistency in observed in situ stiffness may be related to inadequate curing conditions potentially linked to environmental factors. The inconsistency contrasts with AECOM experience [1] [3] and other reported literature on the in-service performance of CRBM [2] [4] [5].

- The basis of design for QVE CRBM in TRL 611 is the fundamental assumption that the material acts visco-elastically. The risk with permitting / implementing a higher stiffness CRBM is that this is only achieved by the addition of additional cement, and above a certain amount (likely > 2% CEM I addition) the material behaves differently, specifically it is brittle rather than flexible, it no longer acts visco-elastically and there is a higher risk of cracking.

  Materials that are not flexible will have reduced resistance to fatigue, and as a result may exhibit more cracking and have a lower in-service stiffness. Therefore, the implication of targeting a higher end-product ITSM that is ensured by additional cement rather than good mixture design, material processing and quality controls, may be a negative in-service impact. Indeed, CRBM sites that have exhibited transverse reflective cracking caused by excessive stiffness and brittlement through increased cement addition, effectively acting as HBMs, are present on the SRN.

As such, it may be appropriate to:

1. Implement a maximum design stiffness and in situ stiffness value to limit the risk of a high stiffness, brittle, material being produced as a result of increased cement addition. Limiting the maximum design and in situ stiffness to ensure high quality controls during mixture design, material processing and manufacture is preferred over limiting the cement content as this may limit uptake of other cement types.
2. Limit the design stiffness for QVE to 3100 MPa (as permitted for good quality QVE B3 at this time).

2.2.1 Design stiffness sensitivity

The sensitivity to design stiffness is illustrated by the design thickness required (or design life offered by) for different design stiffness values as shown in Table 3. As an example, at 80 msa, a lower design stiffness (equivalent to QVE B3) would require an up to 40 mm increase in design thickness for the equivalent design traffic, but importantly, an over-estimate of design stiffness (i.e. 3100 MPa equivalent to a QVE B3) could result in up to a 50% (i.e. 20 year) reduction in design life.

Table 3. Design thickness required by design traffic and design stiffness

	Design thickness (mm) for FC2 (CD 226)	
Design traffic (msa)	CRBM design stiffness 3100 MPa	Design stiffness 4700 MPa
30	350	310
40	360	320
50	370	335
80	400	360

The sensitivity is more severe below 30 msa, where the reduction in design life can be greater than 50% (12 msa vs. 30 msa for an equivalent thickness (310 mm) at 3100 MPa and 4700 MPa respectively). Therefore, considering current asphalt overlay requirements for CRBM within CD 226 (a minimum of 20 mm), should design curves for CRBM QVE B4 be developed using a 1:1 design stiffness to end-product ITSM ratio, it may be prudent restrict the usage of CRBM QVE B4 to sites that are greater than 30 msa only.

2.3 Design fatigue

Studies subsequent to the publication of TRL 611 (2004) have found that QVE CRBM is not unduly susceptible to fatigue, and have identified that the fatigue characteristics of QVE CRBM are different to bituminous bound mixtures. The occurrence of macro cracking, which traditionally is the point in time at which a rapid stiffness reduction occurs in bituminous bound mixtures, is delayed in QVE CRBM to when the material converges on approximately 70% of its initial stiffness rather than for 50% of its initial stiffness for bituminous bound mixtures [1].

2.4 Maximum design life

An over-estimation of design stiffness could lead to a reduction in design life. This reduction could be up to 20 years where the design traffic is 80 msa or less and the QVE B4 delivers a design stiffness of 3100 MPa, rather than 4700 MPa. Nevertheless, the pavement would still be expected to achieve a design life of 20 years. This reduced design life might be considered acceptable and the current proposal to limit QVE B4 to a design stiffness of 3100 MPa might be revisited subject to the findings from the desk-based study during Work Stage 1.1.2.

However, the implication of an over estimation in design stiffness for long-life pavements where the design traffic is greater than 80 msa (potentially up to 400 msa), the actual design life could be much lower due to the cumulative axle loading and potentially within the expected typical 12-16 year lifespan of the asphalt surfacing.

As such, in the absence of extensive evidence of in situ performance of pavements constructed with a CRBM base layer that constitute long life pavements, it is considered that a pragmatic maximum design traffic limit of 80 msa is established. However, it may be appropriate to reduce this value subject to the findings from the desk-based study during Work Stage 1.1.2.

2.5 Outline design options

The proposed outline design options for ex situ CRBM QVE B4 for design traffic up to 80 msa are presented in Table 4 assuming a design stiffness of 3100 MPa based on the nomographs in HD 26/06 for HRA 50 for CRBM QVE B4. Outline thicknesses based on a design stiffness of 4700 MPa (equivalent to AC 40/60) are provided for information as a representation of the maximum design stiffness that might be used subject to the findings during later work stages.

The design thicknesses have been developed on the basis of limiting horizontal strain at the bottom of the CRBM base layer, perceived practicable installation layer thicknesses for the asphalt and the CRBM layers and providing an element of risk mitigation, specifically by increasing the asphalt overlay thickness with increasing design traffic.

Table 4. Outline design thicknesses for CRBM QVE B4 for FC2 and FC3

CRBM Class	Foundation class	Design traffic (msa)	Asphalt thickness (mm)	CRBM thickness (mm)	Total bituminous bound thickness (mm)
QVE B4 (end-product ITSM 4700 MPa) equates to **Design stiffness 3100MPa**	FC2 (100 MPa)	30	110	235	345
		40	115	245	360
		50	120	250	370
		60	130	250	380
		70	135	255	390
		80	140	260	400
	FC3 (200 MPa)	30	110	215	325
		40	115	215	330
		50	120	215	335
		60	130	215	345
		70	135	215	350
		80	140	220	360
Design stiffness 4700 MPa*	FC2 (100 MPa)	30	110	200	310
		40	115	210	325
		50	120	215	335
		60	130	215	345
		70	135	215	350
		80	140	220	360

CRBM Class	Foundation class	Design traffic (msa)	Asphalt thickness (mm)	CRBM thickness (mm)	Total bituminous bound thickness (mm)
Design stiffness 4700 MPa*	FC3 (200 MPa)	30	110	170	280
		40	115	180	295
		50	120	180	300
		60	130	180	310
		70	135	180	315
		80	140	180	320

* At this stage of this project there is insufficient evidence from in situ pavements to support that QVE B4 will robustly deliver a long-term design stiffness of 4700 MPa.

The design assumptions and justification used to develop the outline design thicknesses presented in Table 4 are outlined in Table 5. The outline design thickness does not consider the potential additional structural contribution afforded by use of a binder course with a higher design stiffness than 3100 MPa. This provides an additional factor of safety with the design, but there may be scope for further refinement (thickness reduction) through analytical design at a later stage within this task.

Table 5. Basis of outline design for ex situ CRBM > 30 msa

Criteria	Outline design assumption	Justification
Design methodology	Multi-layer, linear elastic analysis	Precedent from TRL 611. QVE CRBM performs like a visco-elastic material.
Foundation class	FC2 and FC3 only	FC1 not appropriate for > 30 msa Additional risk if CRBM were used in combination with FC4
Design traffic	30 to 80 msa	Designs < 30 msa are already established. Risk mitigation (see Section 2.3)
Minimum nominal asphalt overlay thickness	Min. 110 mm asphalt	Risk mitigation including limiting the ingress of water into the CRBM layer
Number of asphalt overlay layers	Up to two layers of asphalt (up to 140 mm) comprising 100 mm binder course and 40 mm surface course	Additional risk mitigation with increasing design traffic. Three layers of asphalt may be uneconomical. 50 mm asphalt surfacing may be uneconomical and offers limited additional structural contribution.
Binder course type	AC 40/60 Dense or better	Stiffness contribution Deformation resistance
Number of CRBM layers	Up to two layers of CRBM (max. approx. 260 mm)	Literature suggests that CRBM may be installed up to 150 mm thick in one layer. The installation of three layers of CRBM may be uneconomical and introduce weaknesses at layer interfaces.
CRBM design stiffness	QVE B4 – 3100 MPa	Equivalence between end-product ITSM and design stiffness as per TRL 611 using the over-arching assumption that pavements designed using the TRL 611 design curve for CRBM QVE B3 complying with Clause 948 (i.e. achieving 3100 MPa ITSM) are durable up to 30 msa; and increased reassurance that CRBM QVE B4 complying with Clause 948 (i.e. achieving 4700 MPa ITSM) will remain durable up to 80 msa.
Fatigue Life Shift Factor (K)	1	Precedent from TRL 611, i.e. same critical strain versus fatigue relationship used for CRBM as for a ‘conventional’ bituminous bound mixture.

3. Proposed acceptance criteria

In order to establish whether the outline design approach presented in Section 2 is appropriate, a performance analysis of existing CRBM sites on the SRN has been proposed to validate the performance of sites constructed following the methodology outlined in TRL 611 or precursor methodologies i.e. TRL 386.

Various data sources may be available against which this performance analysis can be undertaken. However, as outlined in Section 1.1, the scope for Work Stage 1 of this task is limited to a desk-based study using published literature and data collected from network level (traffic speed) surveys. On this basis, the proposed acceptance criteria for the outline design approach presented in Section 2 is based on the utilisation of network level (or traffic speed) survey data only. This survey data is classified as 'essential information' in order to support the acceptance of the outline design approach. This approach may carry additional technical risk versus an extensive intrusive testing regime; however, the outline designs presented in Section 2 have been developed in consideration that the design options may be accepted on the basis of network level survey data alone, specifically the minimum 110 mm asphalt overlay thickness.

This data may be supplemented by any additional survey data, intrusive or otherwise, that may have been collected that is available from stakeholders such as the supply chain and National Highways Operations Directorate (OD). Based on the potential lack of availability, this information has been classified in this instance as 'desirable information'; however, should this information be available, subject to its completeness and alignment with other information, it may be used to inform the outline design approach.

As outlined in Section 1.1, should the findings from this desktop study be inconclusive/insufficient to allow acceptance of the proposed design approach, then intrusive surveys may be procured for selected sites to supplement the current findings at a later work stage in this task.

3.1 Essential information

As outlined in the project scope, the new maximum permitted design traffic for ex situ CRBM should be informed on the basis of in situ performance of sites which have been constructed more than 10 years ago. This is to ensure that only sites which exhibit long term performance are considered in the performance analysis.

In addition, it is important that the sites assessed are representative of the outline design approach considering the asphalt overlay thickness and the CRBM type. As such, Table 6 presents the proposed criteria for sites to be reviewed.

Table 6. Proposed criteria for sites to be reviewed

Parameter	Criteria
Installation date	> 10 years
Cumulative traffic	≥ 15 msa (20-year design life) ≥ 30 msa (40-year design life)
Asphalt overlay thickness (mm)	< 150 mm
CRBM type	QVE B3 or B4 only
Foundation condition	N/A – info only

Table 7 outlines the proposed criteria for the network level survey data collected during the desktop study. The proposed acceptance criteria are based on the pavements constructed with CBRM base layers constituting 'technically simple schemes' against the maintenance assessment criteria outlined in CS 230. Any sections of pavement which have been subject to extensive maintenance will be summarised but then excluded from any analysis of condition. It is anticipated that the cumulative traffic to 'failure' (i.e. condition category 4) could be extrapolated for some of the parameters depending on the amount of data available and the spread across the cumulative traffic range.

Table 7. Proposed acceptance criteria from network level survey data

Parameter	Acceptance criteria
Maintenance history	Aligned with average (to be determined during desktop study)
TSD	NSC Category 1 or 2 (CS 230)
Rutting	TRACS rut depth < 11 mm (CS 230)
eLPV	eLPV Category 1 or 2 (CS 230)
Visual condition	Free from crazing and longitudinal cracks (some transverse cracking is anticipated due to high stiffness CRBM produced in 2000s [2] [3]).

3.2 Desirable additional information

The following additional information will be reviewed subject to availability to ascertain the in situ performance of the CRBM and validate or otherwise the design assumptions surrounding in situ stiffness and fatigue properties:

- Core visible condition integrity, in situ material sample for ITSM and ITFT testing in the laboratory
- Back analysed pavement (combined surfacing and CRBM base) layer stiffness from FWD

Where available, stiffness values from sites are expected to be within an order of magnitude of the design assumptions.

4. Options in the event of not meeting the proposed acceptance criteria

Various options are available to revise the outline design approach in the event of not meeting the proposed acceptance criteria. The options will be based on the deviation from the proposed acceptance criteria and the perceived risk associated with the outline design approach. Subject to the desk-based study identifying significant deterioration in the CRBM, options include:

- Not permitting CRBM for design traffic > 30 msa.
- Not introducing design charts for QVE CRBM B4.

Subject to additional risk mitigation being the agreed way forward, options include:

- Increasing the minimum asphalt overlay thickness. This would provide additional waterproofing properties and structural contribution from the asphalt layer which has assumed improved stiffness and fatigue properties.
- Increasing the total bituminous bound thickness through a revised design stiffness assumption. This would result in a lower strain at the bottom of the CRBM layer assuming equivalent in situ material properties*.

However, an increase in maximum overlay thickness and/or total bituminous bound thickness may result in:

- Reduced viability of CRBM designs. Where the asphalt overlay thickness exceeds 150 mm (the typical limit for two layer construction), the use of CRBM may become unviable. A CRBM course thickness above approximately 280 mm may result in the CRBM becoming unviable due to the need to three layer construction beyond this thickness.

Note *: There is the possibility of exceeding the proposed acceptability criteria. If there is sufficient evidence from in situ pavements to support that QVE B4 will robustly deliver a long-term design stiffness of 4700 MPa then the design thickness would reduce by up to around 40 mm as shown in Table 3.

5. Bibliography

[1] H. Lacalle Jiménez, “AIRFIELD PAVEMENT DESIGN WITH COLD RECYCLED MATERIALS,” University of Nottingham, Nottingham, 2017.

[2] Atkins Jacobs JV, “Task 1-583 Subtask 3.3 - Technical Demonstration of Solutions Cold Recycling,” Atkins Jacobs JV, 2020.

[3] AECOM, “A21 Sevenoaks (Southbound) Pavement Investigation,” AECOM, St Albans, 2014.

[4] TRL, “TRL 611 A guide to the use and specification of cold recycled materials for the maintenance of road pavements,” TRL, Crowthorne, 2004.

[5] N. Thom, “Foamix Road Trials and Design Considerations,” Viridis, 2002.