COLD IN-SITU RECYCLING USING HYDRAULIC BINDERS TO TRL 611
IT’S NOT NEW!

London Borough of Wandsworth, 1953
FABGM core taken in 2007, 10 years after recycling in 1997.

FABGM is a hydraulically bound mixture [HBM] where the main binder constituent is coal fly ash known as PFA in the UK.

In this case the fly ash content was 12% and was activated using 3% lime. Note that the activation could also have been carried out using cement.
COLD INSITU HBM RECYCLING TO TRL 611 - AGENDA

- Design documents
- Thickness design to TRL 611
- HD26/06 input
- Site investigation
- Aggregate grading
- BSEN14227
- Specification
- Cubes or cylinders for strength testing?
- Use of slow setting & hardening binders
- Immediate traffickability & IBI test
COLD INSITU RECYCLING

THICKNESS DESIGN DOCUMENTS

• TRL 386: Design guide and spec for .......... cold insitu recycling. 1999 [N.B. Just cement and insitu recycling]

• TRL 611: A guide to the use and spec of cold recycled materials ...... 2004 [N.B. broadened to include exsitu & lime, fly ash & slag]

• TRL 615: Development of a more versatile approach to flexible and flexible composite pavement design. 2004 [TRL 615 is the design reference for TRL 611]

• HD26/06: Pavement design for trunk roads – paragraph 2.14
PART 3

HD 26/06

PAVEMENT DESIGN

SUMMARY

This Standard provides the details of permitted materials and of thickness for the construction of pavements for new trunk roads. This revision updates the previous Standard and also introduces different permitted designs that relate to the strength of the available foundation.

INSTRUCTIONS FOR USE


2. Remove HD 26/01 from Volume 7, Section 2 which is superseded by this Standard and archive as appropriate.

3. Insert HD 26/06 into Volume 7, Section 2.

4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.
**Examples of Hydraulic Bound Base Materials**

<table>
<thead>
<tr>
<th>HBM Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Rock Coarse Aggregate: (with coefficient of thermal expansion &lt;10 x 10^-6 per °C)</td>
<td>CBGM B – C8/10 (or T3)</td>
<td>CBGM B – C12/15 (or T4)</td>
<td>CBGM B – C16/20 (or T5)</td>
<td>CBGM B – C16/20 (or T5)</td>
</tr>
<tr>
<td>Gravel Coarse Aggregate: (with coefficient of thermal expansion ≥10 x 10^-6 per °C)</td>
<td>CBGM B – C8/10 (or T3)</td>
<td>CBGM B – C12/15 (or T4)</td>
<td>CBGM B – C16/20 (or T5)</td>
<td>CBGM B – C16/20 (or T5)</td>
</tr>
</tbody>
</table>

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</tr>
</tbody>
</table>

**Notes:**
- HBM: Hydraulic Bound Base
- CVB: Coarse Aggregate Base
- FABM: Fine Aggregate Base
Design Example 1

Subgrade Surface Modulus for design estimated as 40MPa (approximately 3.5% CBR); the following Restricted Design options exist:

- **Foundation Class 1** (Specification Series 600 materials; Figure 3.1):
  - 465 rounded up to 470 mm
- **Foundation Class 2** (CBGM A or B, C3/4 Figure 3.1):
  - 305 rounded up to 310 mm
- **Foundation Class 3** (Types 1, 2, 3 or Category B subbase on capping; Figure 3.2):
  - 290mm subbase + 230mm capping
- **Foundation Class 3** (CBGM A or B C6/10; Figure 3.1):
  - 305 rounded up to 310 mm

![Graph showing design options]

**FIGURE 3.1 Restricted Design Options – Subbase or Capping only**
Development of a more versatile approach to flexible and flexible composite pavement design

by M Nunn

TRL Report TRL615
A guide to the use and specification of cold recycled materials for the maintenance of road pavements

by D Merrill, M Nunn and I Carswell

TRL Report TRL611
HBM Pavement Design

(TRL 611 & 615)

Foundation Class 1 (50MPa)
Foundation Classes: TRL 615 -> TRL 611

Capping
- Class 1 = 50MPa

Type 1
- Class 2 = 100MPa

BOUND
- Class 3 = 200MPa

BOUND
- Class 4 = 400MPa
Foundation Classes: TRL 611

TRL 611 – section 5.4

- Class 2 foundation will be formed of a substantial thickness of well-graded, sound granular material (say Type 1) with a thickness suitable for the sub-grade strength.
- Class 1 foundation will be formed of poorer quality granular material (say 6F capping) or the granular layer is thin for the strength of sub-grade.
- Class 3 foundations represent stabilised foundations in good condition.
- Class 4 foundations – as Class 3 – but formed of coarse granular material suitably thick and strong.
Foundation Class 1 (50MPa)

- Cumulative traffic (msa)
- Bound base (mm)
- Asphalt (mm)
- Foundation Class 1 (50MPa)

- 150mm
- 255mm
- 20msa
<table>
<thead>
<tr>
<th>ROAD TYPE CATEGORY</th>
<th>TRAFFIC (msa*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>30 – 80</td>
</tr>
<tr>
<td>1</td>
<td>10 – 30</td>
</tr>
<tr>
<td>2</td>
<td>2.5 – 10</td>
</tr>
<tr>
<td>3</td>
<td>0.5 – 2.5</td>
</tr>
<tr>
<td>4</td>
<td>0 – 0.5</td>
</tr>
</tbody>
</table>

* Millions of standard axles
### TRL 611 Table 7.4: Thickness of HBM of strength ‘H5’ as combined structural course and foundation (mm)

<table>
<thead>
<tr>
<th>Sub-grade CBR (%)</th>
<th>Type 3 road (0.5 – 2.5 msa)</th>
<th>Type 4 road (&lt; 0.5 msa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface dressing</td>
<td>40mm asphalt</td>
</tr>
<tr>
<td>2 – 4</td>
<td>280</td>
<td>240</td>
</tr>
<tr>
<td>5 – 7</td>
<td>260</td>
<td>220</td>
</tr>
<tr>
<td>8 – 14</td>
<td>240</td>
<td>200</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>220</td>
<td>180</td>
</tr>
</tbody>
</table>

Note: This table is identical to Table 6 in TRL 386, except for strength.
<table>
<thead>
<tr>
<th>HAUC Road Type</th>
<th>TRL 386</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 3: 0.5 - 2.5 msa</td>
<td>$R_c$ of 7 MPa @ 7 days</td>
</tr>
<tr>
<td>Cat 4: 0 - 0.5 msa</td>
<td>$R_c$ of 4.5 MPa @ 7 days</td>
</tr>
<tr>
<td>HAUC Road Type</td>
<td>TRL 386</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
</tr>
<tr>
<td>Cat 3: 0.5 - 2.5 msa</td>
<td>$R_c$ of 7 MPa @ 7 days</td>
</tr>
<tr>
<td>Cat 4: 0 - 0.5 msa</td>
<td>$R_c$ of 4.5 MPa @ 7 days</td>
</tr>
</tbody>
</table>
### TRL 611: Adjustment from ‘H’ to Rc strength classes

<table>
<thead>
<tr>
<th>HBM strength class IN TRL 611</th>
<th>Equivalent Rc class (approx suggestion using TRL 615)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Circa C3/4 to C4/5</td>
</tr>
<tr>
<td>H2</td>
<td>Circa C4/5 to C5/6</td>
</tr>
<tr>
<td>H3</td>
<td>Circa C5/6 to C6/8</td>
</tr>
<tr>
<td>H4</td>
<td>Circa C6/8 to C8/10</td>
</tr>
<tr>
<td>H5</td>
<td>C8/10</td>
</tr>
</tbody>
</table>
• For trunk roads up to 30 msa, it may be advantageous to use cold recycled materials and a design guide is available as part of TRL611 (2004).
• These designs may also be suitable for non-trunk roads including those with design traffic less than 1 msa.
• For roads carrying less than 2.5 msa, using cement as the primary binder, the adjustments contained in Table 7.5 of TRL611 have been reviewed.
• Experience indicates that such adjustment is unnecessary and that HBM based on the use of cement with H2 strength classification can be safely used for Type 4 roads and H3 for Type 3 roads.
<table>
<thead>
<tr>
<th>Road Type</th>
<th>TRL 386</th>
<th>TRL 611</th>
<th>HD26/06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 3: 0.5 - 2.5 msa</td>
<td>7 @ 7 days</td>
<td>H5 at 28 days</td>
<td>H3 at 28 days</td>
</tr>
<tr>
<td>Cat 4: 0 - 0.5 msa</td>
<td>4.5 @ 7 days</td>
<td>H5 at 28 days</td>
<td>H2 at 28 days</td>
</tr>
</tbody>
</table>
### CBM/HBM CUBE STRENGTH REQUIREMENTS (MPa)

<table>
<thead>
<tr>
<th>Road Type</th>
<th>TRL 386</th>
<th>TRL 611</th>
<th>HD26/06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 3 : 0.5-2.5 msa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 7 days</td>
<td>7</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>@ 28 days</td>
<td>@ 28 days</td>
<td>@ 28 days</td>
<td>@ 28 days</td>
</tr>
<tr>
<td>Cat 4: 0-0.5 msa</td>
<td>4.5</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>@ 7 days</td>
<td>@ 7 days</td>
<td>@ 28 days</td>
<td>@ 28 days</td>
</tr>
<tr>
<td>@ 28 days</td>
<td>@ 28 days</td>
<td>@ 28 days</td>
<td>@ 28 days</td>
</tr>
</tbody>
</table>
SITE INVESTIGATION TO TRL 611
TRL 611 Table 5.3
Guidance on site investigation

• Defines 3 pavement types
  – A designed pavement structure
  – Ditto but with reinstatements
  – Un-designed pavement structure

• Then provides guidance on each

• What follows here relates mainly to minor roads and thus ‘un-designed pavement structures’
SITE INVESTIGATION – purpose?

- To establish what’s wrong with the pavement
- traffic levels
- sub-grade nature & properties including strength
- nature and make-up of pavement – material types, thickness and width (edges are particularly important)
- obstructions – visible or otherwise
- drainage issues?
- to provide material for laboratory mixture design
SITE INVESTIGATION – TRL 611: Field requirements

• Trial pits/cores every 500m² thus every 100m on a 5m wide country lane or say 70m on an urban road.

• Should be biased to edges rather than centre.

• should be of a size to get sufficient material for characterizing sub-grade and pavement layers

• DCP to test sub-grade strength (guidance given)

• Pulverisation? [refer to later slide on mixture grading]
SITE INVESTIGATION – laboratory tests?

• Upper pavement materials – moisture content, gradings, plasticity.

• foundation (includes sub-grade) – ditto

• mixture design on material broken down to sub-28mm [refer to slide on mixture grading later]

• cubes or cylinders?

• Rc or RtE?
TRL 611 – Mixture design – mixture grading

• TRL 611 section 6 continued TRL 386 approach but modified the gradings from AGGREGATE to MIXTURE GRADINGS to thus include binder

• Why?
  – BSEN14227:2004 and 2013 revision
  – The frequent use of PFA (coal fly ash) to modify the grading, particularly for foamed bitumen work, but also & very beneficially for hydraulic treatment
BSEN 14227
-Covers hydraulically bound mixtures and treated soils as follows;

-1: CBGM (cement bound granular mixtures)-2013
-2: SBGM (slag-bound granular mixtures)-2013
-3: FABGM (fly ash bound granular mixtures)-2013
-5: ‘HRB’BGM (‘HRB’ bound granular mixtures)-2013
-10: Soil treated with cement - 2004
-11: Soil treated with lime - 2004
-12: Soil treated with slag - 2004
-13: Soil treated with HRB - 2004
-14: Soil treated with fly ash - 2004

Note 1: HRB denotes ‘hydraulic road binder’
Note 2: Parts 10 – 14 Intention to combine into one part - 15 – in 2014
Note 3: Parts 1, 2, 3 & 5 must use aggregate to BSEN 13242 ‘Aggs for unbound and HBM’,
Note 4: Parts 10 – 14 use the soil, not necessarily in-situ, but with a max size requirement
Note 5: There is a part 4: Fly ash for hydraulically bound mixtures
TRL 611 – Mixture design – grading

- TRL 386 defined 2 aggregate zones: A & B
- Zone A: 50mm down well-graded aggregate
- Zone B: a finer grading than Zone A – only permissible with proof of use

- TRL 611 defines 3 mixture zones; A, B & C
- Zone C is effectively the old TRL 386 zone A and is thus the main one for in-situ recycling
- Zone B is a finely graded mixture probably suitable for in-situ HBM work but not in-situ foamed bitumen work
- Zone A has been introduced for ex-situ work but is also suitable for in-situ work
CUBES OR CYLINDERS?
HBM with \( R_f = 1 \text{ MPa} \) (\( R_c = 6 \text{ MPa} \)) can be equivalent to:
HBM with \( R_f = 2.5 \text{ MPa} \) (\( R_c = 15 \text{ MPa} \))
How can this be so? Basically it depends on stiffness. Consider H7.
### 60 day properties (Katsakou & Kolias, 2007)

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Graded limestone</td>
<td>20</td>
<td>1.6</td>
<td>1.4</td>
<td>3.3</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Asphalt planings</td>
<td>7</td>
<td>0.8</td>
<td>0.6</td>
<td>2.7</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

What is the better material?
**Example comparison using TRL 611 derived Rf and actual Rf**

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Es</th>
<th>⇒ Ed</th>
<th>Rc</th>
<th>⇒ Rf</th>
<th>H class from TRL611 using Rf derived from Rc</th>
<th>Rf actual</th>
<th>H class from TRL611 using actual Rf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graded limestone</td>
<td>28 *</td>
<td>34</td>
<td>20 *</td>
<td>2.2</td>
<td>H7</td>
<td>3.3*</td>
<td>H8</td>
</tr>
<tr>
<td>Asphalt planings</td>
<td>5*</td>
<td>13</td>
<td>7*</td>
<td>0.8</td>
<td>H3</td>
<td>2.7*</td>
<td>H9</td>
</tr>
</tbody>
</table>

**TRL611:**

- Ed = 8.4 + 0.93Es
- $R_f = 0.11R_c$

* 60 day properties (katsakou & Kolias, 2007)
Katsakou & Kolias 2007

\[ R_f = R_c \left[ 0.0015 \text{ (planings \%age)} + 0.1293 \right] \]

<table>
<thead>
<tr>
<th>(R_c)</th>
<th>(R_f) (TRL611 - %age planings irrelevant)</th>
<th>(R_f) (0% planings)</th>
<th>(R_f) (50% planings)</th>
<th>(R_f) (100% planings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.55</td>
<td>0.65</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>10</td>
<td>1.1</td>
<td>1.3</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td>15</td>
<td>1.6</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
TRL611: Specification for in-situ recycling – A3.2 - Quality plan

- Sourcing of additional aggregates & other constituents
- Declaration of constituents and the job-standard mixture
- Construction procedures and control
- Inspection (including plant calibrations) and test schedules
- Demonstration of performance properties (mixture design validation from laboratory testing)
TRL611: Specification for *in-situ* recycling – Table A3.2: Minimum binder constituent proportions by % wt

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cement</th>
<th>lime</th>
<th>Fly ash</th>
<th>ggbs</th>
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<tbody>
<tr>
<td>QH</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>QH</td>
<td>3</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>QH</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>SH</td>
<td>-</td>
<td>3</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>SH</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>6</td>
</tr>
</tbody>
</table>
### TRL 611: Specification for in-situ recycling: Table A3.4: Setting times

<table>
<thead>
<tr>
<th>Family</th>
<th>Example setting time under normal temperature conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>QH</td>
<td>2 hours</td>
</tr>
<tr>
<td>SH</td>
<td>24 hours</td>
</tr>
</tbody>
</table>
ILLUSTRATIVE STRENGTH DEVELOPMENT OF HBM AT 20°C

[Chart showing the strength development of CBM, SBM, and FABM over different days.]

CBM
SBM
FABM

[Days]

HRBBM?
The essential characteristic of HBM without cement

HBM without cement have a *favourable* slow set and strength development that gives more time for construction and produces a more advantageous cracking scenario with the benefit of either less surfacing (TRL611&615) or better in-service performance. Such HBM are recommended.

The short term performance of such HBM is not a function of strength as with CBM but instead a function of the immediate internal cohesion and friction within the mixture. Hence with granular mixtures which have no cohesion and which rely solely on internal friction for initial stability, the mixture grading and proportion of crushed material are important and easily achievable for early performance.
IMMEDIATE BEARING INDEX (IBI) TEST FOR HBM

- If aggregate is not crushed or the percentage of ‘crushed’ is less than 50% say or the material is poorly graded, then the IBI test should be carried out.
- The IBI test is an immediate CBR test without surcharge (BS EN 13286-47).
- It is a measure of the ability of a mixture to withstand immediate trafficking with minimal and inconsequential distress.
- For HBM recycling, ideally IBI > 50.
TRL611: Specification for in-situ recycling – A3.8 – trafficking trial*

• when required by the quality plan

• shall use materials and plant for main works

• the trial area shall be left to cure for 24 hrs, or other declared time, then subject to controlled trafficking

• the trafficking shall be HGV with axle configuration and loading typical of what the layer may be subject to during construction

• the number of passes shall equate to the amount of construction traffic or a default traffic level of 100 standard axles

• the measure rutting shall be less than 10mm or that declared.

* JK note: use of a PTR?
THANK YOU FOR LISTENING