BSM Stabilisation (Mix) Design

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SARF Course on BSMs

KZN DoT

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Life is full of surprises...

Try to keep them to a minimum
Primary Design Objectives

• Load spreading
  – Resilient Modulus (Mr)
• Rut resistance
  – Shear Strength
• Flexibility
  – Displacement at Ultimate Strength
• Durability
  – Moisture resistance
Early South African pavements

Key pavement considerations

40mm HMA SURFACING

CEMENT STABILISED BASE

Selected subgrade layer

REFLECTIVE CRACKING
The South African “inverted” pavement

The Concept

40mm HMA SURFACING

CRUSHED STONE BASE

CEMENT STABILISED SUBBASE

Selected subgrade layer

CRACK PREVENTION LAYER

HIGHER COMPACTION

HIGHER Mr

WATER!!!!
The South African “upside-down” pavement

Distress Mode?

Unbound
Permanent deformation (shear/ruts)

Bound
Fatigue (cracking)

Durability??

The Upgrade

40mm HMA SURFACING

BITUMEN STABILISED BASE

CEMENT STABILISED SUBBASE

Selected subgrade layer
Factors influencing mix selection

- Temperature
- Traffic
- Moisture
- Binders
- Support
- Aggregates
Traffic vs Classes of BSM

- BSM1
- BSM2
- BSM3

> 6 MESA
- High shear strength
- Crushed stone or RAP

1 to 6 MESA
- Mod shear strength
- Graded nat gravel, RAP

< 1 MESA
- Soil gravel or sand
AGGREGATES/COMPACTION
BSM Grading requirements (1)

Emulsion slightly coarser than foam
BSM Aggregate requirements (2)

<table>
<thead>
<tr>
<th>Emulsion</th>
<th>Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI &lt; 7%</td>
<td>PI &lt; 10%</td>
</tr>
<tr>
<td>$P_{0.075} &gt; 2%$</td>
<td>$P_{0.075} &gt; 4%$</td>
</tr>
<tr>
<td>Reclaimed asphalt RA + (15 to 25% Crusher dust)</td>
<td></td>
</tr>
<tr>
<td>Triaxial tests at representative temperature (especially <strong>hot</strong> regions)</td>
<td></td>
</tr>
</tbody>
</table>
BSM: RAP Influence

Bitumen Stabilised
Non-continuously bound

<table>
<thead>
<tr>
<th></th>
<th>RAP: Recovered pen</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td></td>
</tr>
<tr>
<td>&lt;5%</td>
<td>RAP: Recovered BC(%)</td>
</tr>
<tr>
<td>&lt;2%</td>
<td>Emulsion Residual BC</td>
</tr>
<tr>
<td>No</td>
<td>Rejuvenating Agent</td>
</tr>
<tr>
<td>TG2/Wirtgen</td>
<td>Mix Design</td>
</tr>
</tbody>
</table>
Vibratory Compaction Hammer

To prepare specimens

Kelfkens, U Steil

Rear View of Frame
Influence of Tamping Foot

Effect of Tamping Foot at 80% OMC and 20Kg Surcharge

Layer 1  Layer 2  Layer 3  Layer 4  Layer 5

Time (Sec)
## Compaction time (vibratory)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>ITS</td>
<td>ITS</td>
<td>Triaxial</td>
</tr>
<tr>
<td>Foot φ</td>
<td>100mm</td>
<td>150mm</td>
<td>150mm</td>
</tr>
<tr>
<td>Height</td>
<td>65mm</td>
<td>95mm</td>
<td>125mm</td>
</tr>
<tr>
<td>Layers</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Surchg</td>
<td>5 kg</td>
<td>10 kg</td>
<td>10 kg</td>
</tr>
<tr>
<td>Foam</td>
<td>10 sec</td>
<td>25 sec</td>
<td>25 sec</td>
</tr>
<tr>
<td>Emuls</td>
<td>10 sec</td>
<td>15 sec</td>
<td>15 sec</td>
</tr>
</tbody>
</table>
Quality Assessment: Foamed bitumen
Bitumen Emulsion

- Bitumen
- Emulsifiers, acid
- Hot water
- Heat
Oil in water emulsion (O/W)
Bitumen Emulsion Types

Global BSMs

Type

Emulsifier

pH

BITUMEN EMULSION

Cationic

Amines + HCl +ve

2 – 6 ACID

Anionic

Fatty Acids + NaOH -ve

10 -12 ALKALI

Non-Ionic

No charge

7 NEUTRAL

RSA BSMs
Factors influencing mix design

Oversimplified?
TEMPERATURE

MOISTURE
Curing Protocol TG2_{2009}

**CURING METHOD**

- **Level 1 Mix Design**
  - All BSMs: 72 hours at 40 °C, unsealed

- **Level 2 & 3 Mix Design**
  - BSM-foam: 20 hours at 30 °C unsealed, 48 hours at 40 °C sealed
  - BSM-emulsion: 26 hours at 30 °C unsealed, 48 hours at 40 °C sealed

- **“dry”**

- **“equilibrium”**
Curing Protocol (BSM lab)

Conditions

Simulated

“dry”
Constant mass @ 40°C

“wet”
Soak 24hrs @ 25°C

“equilibrium”
60% of OMC @ 40°C, seal
CURING: FIELD VALIDATION

PSPA

Mr (MPa)

EMC (%)

BASE PROPERTY

Time

?
Mr (field) versus cure

N7 PSPA Mr Analysis over 7 Months

- B1-B3
- B4-B6
- Poly. (B4-B6)
Mix Design (TG2, 2009)

PRELIMINARY STEPS
- Aggregate selection and blending
- Aggregate classification
- Pre-treatment

LEVEL 1 Mix Design
- Using Selected Aggregate Blend
- Consider Climate & Early Traffic

Treatment Type
- Foamed Bitumen
- Bitumen Emulsion

Expansion Ratio & Half-life
- Acceptable?

Aggregate-Emulsion Compatibility Acceptable?

Compaction & Cure
- Vibratory or Marshall
  - φ=100mm specimens
  - ITS dry and soak

Select bitumen type and content
Select filler type and content
Results acceptable?

LEVEL 2 MIX DESIGN
- Vibratory Compaction & Cure at Optimums
  - φ=150mm h=127mm
  - ITS equil and ITS soak

Optimise bitumen content
Check ITS results
Results acceptable?

LEVEL 3 MIX DESIGN
- Vibratory Compaction & Cure at Optimums
  - φ=150mm h=300mm
  - Triaxial (monotonic)
  - MIST (wet) triaxial

FINALISE MIX SELECTION
DETERMINE DEMAC AND CERTAINTY

Design Traffic < 3 MESA
- Done

Design Traffic < 6 MESA
- Done

Done

YES

NO
Mix Design (Wirtgen, 2012)
Testing the Material

Bitumen Stabilised Material
- Non-continuously bound

Asphalt
- Continuously bound

DIFFERENT BEHAVIOUR PATTERNS
BSM = non-continuously bound
Developing the Right Tools

UCS versus ITS

MR439  Zambia  Greece
Mix Design Approach (TG2, 2009)

- Preliminary tests
- Level 1
- Level 2
- Level 3

- Grading, MDD, OMC, Atterberg Limits (PI)
- 100mmø Marshall ITS
- Binder, Active filler
- 150mmø ITS for OBC
- > 3 MESA refine OBC
- 150mmø 300H Triaxial
- >6 MESA reliability
2013 BSM Stabilisation Design

Natural Material Character

Step 1
150mmφ

Grading

Moisture density (Mod)

Atterberg Limits (PI)

Typical Bitumen %

0% 1%Lime 1%Cem

ITS – select active filler

dry

wet

3 reps
## Typical Bitumen % for BSM-foam

<table>
<thead>
<tr>
<th>Fraction passing 0.075 mm sieve (%)</th>
<th>Foamed bitumen addition (% by mass of dry aggregate)</th>
<th>Typical type of material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fraction passing 4.75 mm sieve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 50%</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>&lt; 4</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4 – 7</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>7 – 10</td>
<td>2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>2.6</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Recycled asphalt (RA/RAP)

RA/Graded crushed stone/ Natural gravel/blends

Gravels/sands
## Typical Bitumen % BSM-emulsion

<table>
<thead>
<tr>
<th>Fraction passing 0.075 mm sieve (%)</th>
<th>Bitumen emulsion (Residual bitumen) addition (% by mass of dry aggregate)</th>
<th>Typical type of material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fraction passing 4.75 mm sieve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 50%</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>&lt; 4</td>
<td>3.3 (2.0)</td>
<td>3.3 (2.0)</td>
</tr>
<tr>
<td>4 – 7</td>
<td>3.7 (2.2)</td>
<td>4.0 (2.4)</td>
</tr>
<tr>
<td>7 – 10</td>
<td>4.0 (2.4)</td>
<td>4.7 (2.8)</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>4.3 (2.6)</td>
<td>5.3 (3.2)</td>
</tr>
</tbody>
</table>
2013 BSM Stabilisation Design

Natural Material Character

Step 1
150mmφ

Grading
Moisture density (Mod)
Atterberg Limits (PI)

Typical Bitumen %
0% 1%M %Cem

Step 2
150mmφ

ITS – select active filler

Selected active filler
-0.4% -0.2% 0% +0.2%

ITS – select bitumen %
<table>
<thead>
<tr>
<th>Recommended BSM classes based on ITS test results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parent material:</strong> Test result from Mix Design</td>
</tr>
<tr>
<td>RAP and GCS RAP/GCS blend RAP/GCS/gravel</td>
</tr>
<tr>
<td><strong>ITSDRY</strong> Both 100 mm and 150 mm Ø specimens</td>
</tr>
<tr>
<td><strong>ITSWET</strong> &amp; <strong>ITSSOAK</strong> Both 100 mm and 150 mm Ø specimens</td>
</tr>
<tr>
<td><strong>ITSEQUL</strong> 150 mm Ø specimens only</td>
</tr>
<tr>
<td><strong>Implied shear properties</strong></td>
</tr>
<tr>
<td>Cohesion</td>
</tr>
<tr>
<td>Angle of internal friction</td>
</tr>
<tr>
<td><strong>Implied parent material properties</strong></td>
</tr>
<tr>
<td>California Bearing Ratio (CBR)</td>
</tr>
<tr>
<td>Plasticity Index (PI)</td>
</tr>
</tbody>
</table>

Ref: (Wirtgen, 2012)
2013 BSM Stabilisation Design

Step 3
150mmφ
300mmH

Triaxial: Shear properties

Final mix selection
Reliable performance related properties
Flexibility?

Equilibrium

Wet

4 $\sigma_3$ x 2 reps = 8 specimens
1 $\sigma_3$ x 2 reps = 2 specimens
## Level 1 and 2 Classification

<table>
<thead>
<tr>
<th>Test</th>
<th>Dia $\phi$ mm</th>
<th>BSM1 (kPa)</th>
<th>BSM2 (kPa)</th>
<th>BSM3 (kPa)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{ITS}_{\text{dry}}$</td>
<td>100</td>
<td>$&gt;225$</td>
<td>175 to 225</td>
<td>125 to 175</td>
<td>Indicates OBC</td>
</tr>
<tr>
<td>$\text{ITS}_{\text{wet}}$</td>
<td>100</td>
<td>$&gt;100$</td>
<td>75 to 100</td>
<td>50 to 75</td>
<td>Indicates active filler type &amp; amt</td>
</tr>
<tr>
<td>TSR</td>
<td>100</td>
<td>Not applicable</td>
<td></td>
<td></td>
<td>Prob mat TSR $&lt; 50%$, $\text{ITS}_{\text{dry}} &gt; 400$ kPa</td>
</tr>
<tr>
<td>$\text{ITS}_{\text{equil}}$</td>
<td>150</td>
<td>$&gt;175$</td>
<td>135 to 175</td>
<td>95 to 135</td>
<td>OBC refined</td>
</tr>
<tr>
<td>$\text{ITS}_{\text{soaked}}$</td>
<td>150</td>
<td>$&gt;100$</td>
<td>75 to 100</td>
<td>50 to 75</td>
<td>Adjusted to $\text{ITS}_{\text{wet}}$</td>
</tr>
</tbody>
</table>
Critical Material Properties

• Tri-axial test to determine:
  – Shear parameters (C & $\phi$)
  – Resilient modulus ($M_r$)
  – Permanent deformation behaviour
Triaxial Testing
Effect of using BSM

- Shear stress: \( \tau \)
- Normal stress: \( \sigma \)
- Higher Cohesion
- Effect of Binder
- Cohesion: \( C \)
- Friction angle: \( \phi \)
## Typical target binder contents

<table>
<thead>
<tr>
<th>Typical Binder Cont. (%)</th>
<th>&gt;75% RAP + Cr Dust</th>
<th>Granular GM &gt; 2</th>
<th>Granular GM &lt; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2%</td>
<td>2%</td>
<td>2.5%</td>
<td>3%</td>
</tr>
</tbody>
</table>
Shear properties (monotonic triaxial at 25°C)

Cohesion $C$

Friction Angle $\phi$

Ebels
Simple triaxial trials - with latex membrane as confining tube
New “Simple triaxial”
Research Triaxial Test RTT versus Simple Triaxial Test STT

BSM Crushed Hornfels with 3.3% Emulsion

$\sigma_3 = 50$ kPa and 1% Cement

$\sigma_3 = 200$ kPa and 0% Cem
## BSM Classification into Shear Properties

<table>
<thead>
<tr>
<th>Equivalent BSM Class</th>
<th>Angle of Internal Friction (º)</th>
<th>Cohesion (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM 1</td>
<td>&gt; 40</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>BSM 2</td>
<td>30 to 40</td>
<td>100 – 250</td>
</tr>
<tr>
<td>BSM 3</td>
<td>&lt; 30</td>
<td>50 – 100</td>
</tr>
</tbody>
</table>
MOISTURE DAMAGE
Durability of BSMs: Improved Tests
- Untreated Material Properties
- Moisture sensitivity tests

Moisture Induction Sensitivity Test MIST
MIST saturation time

- Foam +1% Lime
- Foam +1% Cement

Degree of saturation (%) vs. Pulsing time (sec)
Effect of moisture

Shear stress $\tau$

Cohesion $C$

Lower Cohesion

Normal stress $\sigma$

Friction angle $\phi$

Effect of Moisture

Lower Cohesion
Retained Cohesion (Twagira)

![Graph showing retained cohesion percentages for different tested BSMs (BSM 1, BSM 2, BSM 3). The graph includes bars for each BSM category, with Q+ 0C, Q+ 1C, Q+ 1L, H+ 0C, H+ 1C, and H+ 1L.]
## BSM Classification into Moisture Resistance

<table>
<thead>
<tr>
<th>Equivalent BSM Class</th>
<th>Retained Cohesion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM 1</td>
<td>&gt; 75</td>
</tr>
<tr>
<td>BSM 2</td>
<td>60 – 75</td>
</tr>
<tr>
<td>BSM 3</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Unsuitable</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>
Dissipated Energy

BSM+2%cem

BSM+1%cem

W = 0.5 σε

Stress (kPa)

Strain
ITS displacement measures
(from Mix Design)

ITS wet (All)

Active Filler Content (%)

Vertical Displacement at ITSmax (mm)
Triaxial data from Mix Design

Can refine by separating data based on $\sigma_3$
So we need quality from structural design
Conclusions

- Understanding of material behaviour of BSMs has increased significantly
- Active filler versus bitumen content is very important
- More advanced test methods (triaxial)
- Mix Design is linked to Structural Design method for BSMs
Thank you

Questions??