In Situ Measurement of Density and Strength/Stiffness of HMA Mixtures

Zhong Wu
Louisiana Transportation Research Center

Louisiana Asphalt Technology Conference
February 23-24, 2005
Shreveport, LA
Outline

- Objectives
- Scope
- Field Testing
- Laboratory Testing
- Discussion of Results
- Conclusions
Objectives

* Evaluate the variability of Air Voids of Plant Produced Mixtures
* Compare different methods of air void measurements
* Characterize SGC samples and field cores
* Assess the in-situ test measurements
Scope

- Four rehabilitation Projects
  - I-10 Egan
    » 25.0 mm Superpave Binder Course
    » 12.5 mm Superpave Wearing Course
  - I-10 Vinton
    » SMA mixture
  - US190
    » 25.0 mm Superpave Base Course
    » 25.0 mm Superpave Binder Course
  - LA964
    » 19 mm Type 8 Wearing Course
Experimental Design

- **Field Evaluation**
  - In-situ Density
    - PQI Model 301
  - FWD
  - LFWD
  - PSPA

- **Laboratory Evaluation**
  - Density
    - Conventional, Vacuum Sealing
  - Mechanistic Properties
    - Indirect tensile strength
    - Indirect tensile resilient modulus
    - Frequency sweep at constant height
Mobile Laboratory

- Test section
  - Collect sufficient loose mixtures from the paver
  - Mixture composition analysis
  - Compacted Samples
    » Air voids
    » Mechanistic tests
Laboratory Density Measurement

- Cores and SGC samples
- Conventional (Saturated Surface Dry) Method
  - AASHTO T166
- Vacuum Sealing Method
  - CoreLok
  - ASTM D 6752
Laboratory Mechanistic Tests

- **Indirect Tensile Strength Test**
  - 25°C
  - Each test section:
    » One Core and SGC sample
  - Analysis: ITS

- **Indirect Tensile Resilient Modulus Test**
  - 5°C, 25°C, and 40°C
  - Each test section:
    » One Core and SGC sample
  - Analysis: ITMr

- **FSCH**
  - AASHTO TP 7
  - 48°C and 60°C
  - Each test section:
    » One Core and SGC sample
  - Analysis: G* and δ
Field Test Section Layout

- Density
  - 5 tests per point
  - 15 point
  - 75 test results

PQI model 301
TransTech System, Inc.
Field Test Section Layout (contd..)

- FWD & LFWD
  - 15 points

FWD
Dynatest 800 model

LFWD - PRIMA 100 model
Carl Bro Company, Denmark
Field Test Section Layout (contd..)

Portable Seismic Pavement Analyzer (PSPA)

- PSPA
  - 15 points

PSPA-D
Geomedia Research & Development Inc.
- Cores
  - 3: 6” diameter
  - 2: 4” diameter
Results of Methods of Air Voids Measurements
Typical Variation of Air Voids Measurement

I. Conventional Method (AASHTO T-166)

- 25mm Superpave (Egan BC)
  - Test Section
  - S1: 3.6
  - S2: 4.2
  - S3: 5.9
  - S4: 5.4
  - S5: 7.0
  - S6: 7.1
  - Avg: 5.5

- 12.5mm Superpave (Egan WC)
  - Test Section
  - S1: 6.7
  - S2: 4.6
  - S3: 8.0
  - S4: 7.4
  - S5: 5.5
  - S6: 6.2
  - Avg: 6.4
Typical Variation of Air Voids Measurement (Contd.)

II. Vacuum Sealing Method (CoreLok)
Typical Variation of Air Voids Measurement (Contd..)

III. Pavement Quality Indicator (PQI)

Egan BC - 25 mm Superpave

<table>
<thead>
<tr>
<th>Test Section</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egan BC-25 mm Superpave</td>
<td>3.4</td>
<td>4.8</td>
<td>5.6</td>
<td>5.7</td>
<td>6.9</td>
<td>9.1</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Egan WC - 12.5 mm Superpave

<table>
<thead>
<tr>
<th>Test Section</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egan WC-12.5 mm Superpave</td>
<td>6.1</td>
<td>5.3</td>
<td>7.9</td>
<td>6.5</td>
<td>4.5</td>
<td>6.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Comparison of Average Air Voids

Mix Type

- Egan BC
- Egan WC
- Vinton SMA
- US190 Base
- US190 BC
- LA964 WC

Air Voids (%)

- AASHTO T166
- CoreLok
- PQI

5.5, 6.4, 7.5, 6.4, 5.9, 6.7, 7.9, 7.4, 9.3, 9.0, 9.5, 10.0
Relationship of Air Voids Test Methods (Conventional vs CoreLok)

- $y = 1.19x$, $R^2 = 0.82$
- $y = 1.06x$, $R^2 = 0.97$
- $y = 1.06x$, $R^2 = 0.98$

Air voids of Conventional method (%) vs Air voids of CoreLok method (%) for 25mm, 19mm, and 12.5mm
Relationship of Air Voids Test Methods
(PQI vs. Conventional / CoreLok)

$y = 0.55x + 3.28$
$R^2 = 0.27$

$y = 0.50x + 3.63$
$R^2 = 0.16$

Air Voids, %
Air Voids (PQI), %

0 2 4 6 8 10 12 14
0 2 4 6 8 10 12 14

Conventional
Corelok

$y = 0.50x + 3.63$
$R^2 = 0.16$

$y = 0.55x + 3.28$
$R^2 = 0.27$
Variation of ITS, ITMr, and G*
Typical Variation of ITS

I 10 Egan Binder Course (25 mm Superpave)

- **SGC**
  - Mean = 196psi
  - STD = 25psi
  - CV = 13%

- **Core**
  - Mean = 179psi
  - STD = 25psi
  - CV = 14%
Typical Variation of ITS (Contd..)

I 10 Egan Wearing Course (12.5mm Superpave)

- **SGC**
  - Mean = 188psi
  - STD = 18psi
  - CV = 9%

- **Core**
  - Mean = 157psi
  - STD = 17psi
  - CV = 11%
Average ITS Results (25 °C)
ITS(SGC) vs ITS (Core)

\[ y = 1.06x + 7.54 \]

\[ R^2 = 0.32 \]
Variation of ITMr - I 10 Egan
12.5 mm Mixture - 5°C

SGC
- Mean = 713 ksi
- STD = 72 ksi
- CV = 10%

Core
- Mean = 754 ksi
- STD = 63 ksi
- CV = 8%
**Variation of ITMr – I 10 Egan**

**12.5 mm Mixture – 25°C**

---

**SGC**

- Mean = 411ksi
- STD = 41ksi
- CV = 10%

**Core**

- Mean = 428ksi
- STD = 32ksi
- CV = 8%
Variation of ITMr – I 10 Egan
12.5 mm Mixture – 40°C

SGC
- Mean = 208 ksi
- STD = 27 ksi
- CV = 13%

Core
- Mean = 202 ksi
- STD = 16 ksi
- CV = 8%
Average IT Mr Results (5 °C)

IT Mr, ksi

- Egan BC
- Egan WC
- Vinton(SMA)
- 190 Base
- 190 BC
- 964 WC

Legend:
- SGC
- Core
Average IT Mr Results (25 °C)

- **IT Mr, ksi**
  - SGC
  - Core

- **Locations**:
  - Egan BC
  - Egan WC
  - Vinton(SMA)
  - 190 Base
  - 190 BC
  - 964 WC
Average IT Mr Results (40 °C)

IT Mr, ksi

SGC  Core

Egan BC  Egan WC  Vinton(SMA)  190 Base  190 BC  964 WC
ITMr of All Mixtures (5°C, 25°C, and 40°C) (SGC vs. Core)

\[ y = 0.963x \]

\[ R^2 = 0.85 \]
ITMr of All Mixtures (5°C) (SGC vs. Core)

\[ y = 0.6686x + 180.59 \]

\[ R^2 = 0.3616 \]
$y = 1.154x - 69.527$

$R^2 = 0.4732$
ITMr of All Mixtures (40°C) (SGC vs. Core)

\[ y = 0.8665x + 41.863 \]

\[ R^2 = 0.2814 \]
Typical Variation of $G^*$
I 10 Egan 12.5 mm Mixture – 48 C

- **SGC**
  - Mean = 25992 psi
  - SD = 3604 psi
  - CV = 14 %

- **Core**
  - Mean = 14758 psi
  - SD = 1310 psi
  - CV = 9 %
Typical Variation of G*  
I 10 Egan 12.5 mm Mixture – 60 C

SGC
- Mean = 10082 psi
- STD = 2243 psi
- CV = 22%

Core
- Mean = 5366 psi
- STD = 949 psi
- CV = 18%
Average FSCH Test Results at 48 °C

![Graph showing G*(10Hz), psi for different materials: Egan WC, Egan BC, SMA, US190 Base, US190 BC, LA964 WC. The graph compares G* data for SGC and Core.]
Average FSCH Test Results at 60 °C

G*(10Hz), psi
Complex Shear Modulus (G*$_{10\text{Hz}}$) (SGC vs. Core)

\[ y = 1.46x \]

\[ R^2 = 0.76 \]
Variation of Field Measurements
**Light Falling Weight Deflectometer (LFWD)**

- 10-kg drop weight onto loading plate
- The center deflection ($\delta_c$)

\[
E_{LFWD} = \frac{K(1 - \nu^2)Pr}{\delta_c}
\]

Where: $K = 2$ for flexible plate and or $K = \pi/2$ for rigid. 
P is the applied load, $r$ is the plate radius.
• Dynatest Model 800
• 7 Sensors
• Three indicators
  - d1
  - d1-d6
  - d7
Portable Seismic Pavement Analyzer (PSPA)

- Ultrasonic Surface Wave method to determine the surface layer modulus
  - One source producing surface wave
  - Two sensors measuring wave propagation time/velocity
Typical Variation of FWD Results
I 10 Egan 25 mm Binder Course
Variation of LFWD Results – I 10 Egan
25 mm Mixture

Test Section

LFWD Deformation Modulus (ksi)

S1    S2    S3    S4    S5    S6

LWP  CL  RWP

Variation of LFWD Results –– I 10 Egan
25 mm Mixture
Variation of PSPA Modulus

PSPA Modulus (ksi)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Modulus (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US190 Base-2</td>
<td>CV=12%</td>
</tr>
<tr>
<td>US190 Base-3</td>
<td>CV=19%</td>
</tr>
<tr>
<td>US190 BC-1</td>
<td>CV=16%</td>
</tr>
<tr>
<td>US190 BC-2</td>
<td>CV=21%</td>
</tr>
<tr>
<td>LA964 WC-1</td>
<td>CV=18%</td>
</tr>
<tr>
<td>LA964 WC-2</td>
<td>CV=19%</td>
</tr>
</tbody>
</table>
**Relationship Between FWD and LFWD – d1**

*(200 mm loading plate)*

\[
y = -1.79x + 571.82
\]

\[
R^2 = 0.79
\]
Relationship Between FWD and LFWD - d7 (200 mm loading plate)

\[ y = -0.17x + 89.4 \]

\[ R^2 = 0.32 \]
Relationship Between FWD and LFWD – d1-d6
(200 mm loading plate)

$y = -1.38x + 397.3$

$R^2 = 0.80$
Variation of $E_{(LFWD)}$ with PQI

Air voids

$R^2 = 0.3016$
PSPA Modulus vs PQI Air Voids

\[ y = -63.195x + 2139.6 \]

\[ R^2 = 0.1045 \]
Conclusions

Air Voids

- Binder course mixtures had the highest air voids variation as measured by all three methods, followed by the wearing course and SMA mixtures.
- CoreLok air voids variation were slightly higher than the conventional methods.
- Strong correlation between air voids measured using Conventional and CoreLok methods.
- Correlations between PQI measured air voids and other two methods (CoreLok and AASHTO T-166) are fair.
**Conclusions**

**Mechanistic Tests**

- Binder course mixtures had the highest ITS & G* variations followed by the wearing course and SMA mixtures.
- Cores showed better correlations to air voids than SGC samples.
- Cores and SGC samples showed similar variations in ITS, G*.
- The ITS and G* of SGC samples were higher than cores.
- Good correlation was observed between the G* of the cores and SGC samples.
Conclusions
Mechanistic Tests

- Good correlations were observed between $E_{LFWD}$ and FWD deflections d1 and d1-d6
- LFWD test may be used as an alternative to FWD testing in pavement structure evaluation
Thank You!
<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Modulus (25°C) (ksi)</th>
<th>CV(%)</th>
<th>Mid depth temp (°C)</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>US190</td>
<td>base2</td>
<td>1637</td>
<td>12</td>
<td>28.6</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>base3</td>
<td>1501</td>
<td>19</td>
<td>32.6</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>BC1</td>
<td>1761</td>
<td>16</td>
<td>21.3</td>
<td>282</td>
</tr>
<tr>
<td></td>
<td>BC2</td>
<td>1795</td>
<td>21</td>
<td>35.3</td>
<td>377</td>
</tr>
<tr>
<td>LA964</td>
<td>WC1</td>
<td>1563</td>
<td>18</td>
<td>27.6</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>WC2</td>
<td>1533</td>
<td>19</td>
<td>29.1</td>
<td>291</td>
</tr>
</tbody>
</table>
PSPA Modulus vs LFWD Modulus

![Graph showing the relationship between PSPA Modulus and LFWD Modulus.](image)