Inverted Pavements
Southeastern Asphalt User/Producer Group
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What is an Inverted Pavement

- 2” to 3¼” HMA
- 6” to 8” Unbound Aggregate Base
  Compressed to 100% + Modified Proctor
- 6” to 10” Cement-Treated Base
  (≈ 4% cement)
- Prepared Subgrade

Inverted Pavement History

- Used successfully in South Africa since the 1970’s
- Traffic levels increase
  - US and Europe relied on thicker asphalt & increased concrete use
    - Not economically viable in South Africa
  - Investigated ways to improve roads by improving the aggregate base
    - Instituted strict gradation limits
    - Limited plasticity

Inverted Pavement History

- Wanted to improve/increase the density aggregate base
- Led to a cemented subbase being used as an “anvil” on which to compact the aggregate base
- Enables high level of compaction

Inverted Pavement History

- Soon discovered that this pavement
  - Could handle the highest traffic loads
  - Was impervious to water ingress
  - Performed well even when wet
- Decades of research have shown these pavements can be used on roads up to 50 to 100 million ESALs
Road (Pavement) Categories
South Africa

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Definition of the road categories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROAD CATEGORY</strong></td>
<td><strong>A</strong></td>
</tr>
<tr>
<td>Description</td>
<td>Major Interurban highways and major rural roads</td>
</tr>
<tr>
<td>Importance</td>
<td>Very important</td>
</tr>
<tr>
<td>Service level</td>
<td>Very high level</td>
</tr>
<tr>
<td>Risk</td>
<td>Very low</td>
</tr>
<tr>
<td>Approximate Design Traffic (kA)</td>
<td>50</td>
</tr>
<tr>
<td>Total Equivalent Traffic Loading (kA) (base)</td>
<td>3 - 40 x 10^6 over 25 years</td>
</tr>
</tbody>
</table>

**Typical Pavement Structural Designs**

### South Africa

**Table:**

<table>
<thead>
<tr>
<th>GRAVULAR BASES</th>
<th>MODERATE OR DRY REGIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESALS 3M 10M 30M 100M</td>
<td></td>
</tr>
</tbody>
</table>

ESALS 6” 10”

### Mechanics of Inverted Pavement Systems

\[ \sigma_0 = \sigma_1 + 2\sigma_3 \]

### Traditional Flexible Pavement System

- Successive stiffer layers from subgrade up
- Each layer "absorbs" the load as it's distributed to subgrade
- Traditional designs put unbound aggregate base on top of subgrade
- Built on the idea of protecting the layer below

### Inverted Pavement

- Changes the way we think about pavement
- Utilizes the stress dependency of graded aggregate base
Resilient Modulus Stress Dependency

- Granular Material is Stress Dependent: Higher Modulus with Increasing Stress State

What is Bulk Stress?

- Bulk stress ($\sigma$) represents the total stress condition at a given location in the pavement experiences
- It is higher closer to the surface

\[ \sigma = \sigma_1 + 2\sigma_3 \]

Stress Dependency

- Higher stresses in unbound aggregate base result in increased stiffness and strength
- Value of the base is best captured when it is placed near the surface where stresses are the greatest
- Inverted pavement moves base to the top where it performs more efficiently

Inverted Flexible Pavement

- 2” to 3½” HMA
- 6” to 10” Unbound Aggregate Base Compacted to 100% + Modified Proctor
- 6” to 10” Cement-Treated Base (≈ 4% cement)
- Prepared Subgrade

Isn't This Asphalt Too Thin?

- The South African protocol uses very thin asphalt layers

Recent Research

- Research at Georgia Tech on inverted systems
- Traditional pavement, asphalt acts like a beam
- Inverted pavement, thin asphalt performs like a membrane
**Beam versus Membrane**

- **Tension**
  - Stress [kPa] vs. Depth [m]
- **Compression**
  - CTB used as strong foundation
  - Anvil to compact aggregate base against

**Inverted Pavements**

- CTB used as strong foundation
  - Anvil to compact aggregate base against
- Aggregate base placed in the optimal position
  - Near the surface
  - High stress increases stiffness
- Thin asphalt protects the aggregate base
  - Acts like a membrane
  - Reduced tension

**Material Specifications**

### Aggregate Base

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>G1 Basis</th>
<th>TDOT Grading D</th>
<th>NC DOT ABC</th>
<th>GDOT GAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5 (1.5&quot;)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>95-100</td>
</tr>
<tr>
<td>25 (1&quot;)</td>
<td>84-94</td>
<td>85-100</td>
<td>75-97</td>
<td></td>
</tr>
<tr>
<td>19 (3/4&quot;)</td>
<td>72-88</td>
<td>60-95</td>
<td>60-90</td>
<td></td>
</tr>
<tr>
<td>12.5 (1/2&quot;)</td>
<td>65-75</td>
<td>55-80</td>
<td>55-80</td>
<td></td>
</tr>
<tr>
<td>9.5 (3/8&quot;)</td>
<td>50-80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.75 (3/16&quot;)</td>
<td>30-55</td>
<td>30-65</td>
<td>30-55</td>
<td></td>
</tr>
<tr>
<td>2.00 (1/8&quot;)</td>
<td>21-40</td>
<td>20-40</td>
<td>20-45</td>
<td>25-45</td>
</tr>
<tr>
<td>1.18 (7/32&quot;)</td>
<td>11-24</td>
<td>9-18</td>
<td>9-18</td>
<td>14-30</td>
</tr>
<tr>
<td>0.875 (1/4&quot;)</td>
<td>4-12</td>
<td>4-12</td>
<td>4-12</td>
<td>4-11</td>
</tr>
</tbody>
</table>

**Aggregate Base**

- Plasticity Index < 4
- Unweathered crushed stone

**Cement Treated Base**

- Strength: 200 to 400 psi
- Can use the same aggregate base or lower quality stone
  - Fine aggregate such as screenings
- 4% cement
Asphalt Surfacing

- South Africa uses both gap graded and well graded
- Both modified and unmodified binders
- Georgia Tech research indicates more flexible mixes with unmodified binders may be better
  - 4.75 mm mixes may be ideal

Inverted Pavements in the U.S.

Morgan County Quarry Haul Road (GA)

- Constructed in 2003
- Still performing well

2001 NSSGA Capstone Award

- Blue Circle (Lafarge, Martin Marietta) Morgan County, GA quarry haul road constructed in 2001.
  - December 2007 evaluation showed no rutting or cracking present.
  - Approximately 900,000 ESALs at that time

LaGrange Bypass, GA

- Constructed in 2009

Luck Stone, Bull Run Quarry, VA

- Constructed in 2011
  - FHWA participating
    - Installed pressure and strain gauges
  - Still gathering data
I-25 in Northern New Mexico

- Interstate 25, Raton, NM
- 54+ inches of snow per year
- Constructed in 2012

3" HMA
8" Aggregate Base
10" Cement-Treated Base

Louisiana DOT Stone Interlayer Pavements

- Louisiana DOTD Field Evaluation Project 97 constructed in 1991
  - Inverted: 3.5" HMA / 4" crushed limestone / 6" of soil cement base
  - Control: 3.5" HMA / 8.5" soil cement base
  - 10 year evaluation showed almost 50 percent reduction in cracking versus typical flexible section
- Accelerated pavement testing
  - Stone interlayer (inverted) pavement carried over four times the ESALs of the conventional pavement lane before failure.
- Louisiana DOTD adopted stone interlayer base course (inverted) design as a standard option.

Inverted Pavement Performance

Vulcan Materials

- Planned for 2015
- Road relocation in a Charlotte, NC Quarry

3" NCDOT S9.5 mm
6" NCDOT Aggregate Base
8" NCDOT Cement Treated Aggregate Base

Cost Comparisons

- Georgia quarry haul road (2001)
  - 22% savings compared to typical structure
- Georgia DOT LaGrange Bypass
  - Estimated life cycle cost analysis (LCCA) savings of $131k per lane mile
- Virginia DOT Highway 569 Relocation near Bull Run
  - 20 to 30% estimated savings

Inverted Pavement Key Points

- Uses thin-lift asphalt surface
  - Allows for "mill and fill" surface maintenance
- Less cracking and improved fatigue life due to lower tensile stresses at bottom of the asphalt layer
- 6" - 8" optimal thickness for unbound base to maintain increased bulk stress state condition
- Low cement content on cement treated base (~4 percent)
- Cement treated base can be made of cost-effective materials
Inverted Pavement Performance
South Africa

- “The Economic Benefits of HVS Development Work on G1 Base Pavements,” July 2005
  - Pavements with high quality Crushed Stone bases are capable of accommodating traffic demands of up to 50 million standard axles. [1.8” asphalt]
  - “The optimum thickness for a G1 base layer on a cemented subbase is 150 mm [6”].”
  - “If a pavement with a Crushed Stone base is maintained with resurfacings at appropriate intervals, the pavement can provide service for an indefinite time.”
  - “The high quality, high density Crushed Stone (G1), placed on a thick cemented subbase (200 mm [8”] or more), showed the least permanent deformation under loading and was also the least sensitive to moisture.”

Inverted Pavement Summary

- Inverted Pavements consist of
  - Thin HMA layer
  - Base
  - Cement Treated Base
  - Subgrade
- Nothing new, just changing the order from a typical flexible system
- Layers placed in their optimal position to perform
- Potential cost savings compared to traditional pavements

Questions...