FAA Research on Pavement Design and Materials for New Generation Aircraft

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By: Navneet Garg, Ph.D.
NAPMRC Program Manager
Federal Aviation Administration (FAA)

Date: October 15, 2018
Outline

• **Introduction**

• **FAA’s Full-Scale APT Facilities**
  – NAPTF  National Airport Pavement Test Facility
  – NAPMRC  National Airport Pavement & Materials Research Center

• **Research at NAPTF**

• **Research at NAPMRC**

• **Field Instrumentation & Testing**
United States Airport System

- Over 600 million passenger enplanements annually at over 13,000 airports.
- 3,400 airports in the NPIAS (as of September 2014).

National Plan of Integrated Airport Systems (NPIAS)
Airport Funding Sources & Advisory Circulars

Sources of Airport Funding

- Passenger Facility Charges: 17%
- State and Local Contributions: 5%
- AIP Grants: 28%
- Airport Bonds: 50%

Source: GAO Report GAO-07-885 AIRPORT FINANCE Observations on Planned Airport Development and Funding Levels and the Administration's Proposed Changes in the Airport Improvement Program
FAA Airport Technology R&D Program

- Research conducted at the FAA William J. Hughes Technical Center, Atlantic City, NJ, USA.
- Sponsor: FAA Office of Airport Safety and Standards (AAS100), Washington, DC.
- Provide support for development of FAA pavement standards (Advisory Circulars).
1940’s through 1970’s

• 30 year period beginning in the 1940s.
• Testing performed by USACE.
• Tests involved full-scale aircraft loading on both flexible and rigid pavements, and overlays.
• Performance data obtained from these tests form the basis of rigid and flexible pavement design and evaluation models incorporated in both Federal Aviation Agency and Tri-Services manuals.
Design Charts – FAA AC 150/5320-6D

Figure 3-6 Flexible Pavement Design Curves, A-400 Model B4

Figure 3-7 Flexible Pavement Design Curves, B-747-100, SR, 200 B, C, F
Early 1990
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National Airport Pavement Test Facility (NAPTF)
- Located at the FAA’s William J. Hughes Technical Center in Atlantic City, NJ, USA.
- 75,000 lbs (335 kN) max. load per wheel.
- 2.5 to 5 mph (4 to 8 km/h) traffic test speed.
Current
Aircraft Tire Pressure Trends

<table>
<thead>
<tr>
<th>Aircraft (SWL-kg)</th>
<th>Old X Category Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>777-200 (19,500)</td>
<td>11.7</td>
</tr>
<tr>
<td>777-300ER (19,000)</td>
<td>11.7</td>
</tr>
<tr>
<td>A300-C4 (19,000)</td>
<td>11.9</td>
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<tr>
<td>737-200 (19,500)</td>
<td>12.4</td>
</tr>
<tr>
<td>737-700 (19,100)</td>
<td>12.5</td>
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<tr>
<td>A220-200 (18,000)</td>
<td>14.1</td>
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<tr>
<td>A340-600 (21,400)</td>
<td>14.4</td>
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<tr>
<td>747-400ER (24,200)</td>
<td>15.2</td>
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<tr>
<td>A380-800 (26,700)</td>
<td>15.0</td>
</tr>
<tr>
<td>A380-900F (28,100)</td>
<td>15.2</td>
</tr>
<tr>
<td>787-8 (25-26D)</td>
<td>15.2</td>
</tr>
<tr>
<td>747-8 (26-28D)</td>
<td>15.2</td>
</tr>
<tr>
<td>A350-900 Prelim(31-380)</td>
<td>16.6</td>
</tr>
</tbody>
</table>

New X Category Limit

Tire Pressure, bar

- 16.6
- 16.1
- 16.1
- 15.7
- 15.0
- 15.2
- 15.2
- 16.1
- 14.4
- 14.1
- 12.5
- 12.4
- 11.9
- 11.7

Federal Aviation Administration

FAA Research on Pavement Design and Materials for New Generation Aircraft

October 15, 2018
Heavy Vehicle Simulator – Airport (HVS-A)

- Wheel loads - 10,000 (44.48 kN) to 100,000 lbs (444.8 kN).
- Pavement temperatures up to 150°F (67°C)
- Test speeds - 0.17 to 5 mph (0.27 to 8 kmph)
- Single and Dual-Wheel configuration.
- Single wheel - radial aircraft tire size 52x21.0R22
- Dual wheel assembly (B-737-800)
- Wander Width – 6 feet (1.83 m)
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Testing at NAPTF

- **CC1:**
  - 1999-2001
  - 6 flexible pavements, 3 rigid pavements
  - Low (CBR≈4), medium (CBR≈8), and high (CBR≈20) strength subgrade

- **CC3:**
  - 2002
  - 4 flexible pavements over low strength (CBR≈4) subgrade

- **CC2**
  - Test Strip and a free standing test slab
  - 2004
  - 3 rigid pavements over medium strength (CBR≈8) subgrade
  - Three different support conditions
Testing at NAPTF

- **CC2-OL:**
  - 2005
  - Rubblized CC2 pavements (after completion of CC2 Testing)
  - 5-inch thick HMA overlay

- **CC4:**
  - 2007 Phase-I
  - 2008 Phase-II
  - IPRF project (unbonded concrete overlays)

- **CC5**
  - Test strip
  - 2008
  - 4 flexible pavements over low strength (CBR≈4) subgrade
  - Effect of landing gear spacing on pavement performance
  - Effect of subbase quality on pavement performance.
Testing at NAPTF

• CC6
  – Investigate the relative effect of concrete strength on test item performance.
  – Investigate the effect of subbase material (cement stabilized vs. asphalt stabilized) on performance.
  – CC6 test items give 6 combinations of concrete strength and sub

• CC7
  – Develop Perpetual Pavements Design criterion for airport pavements.
  – Vertical strain threshold in the intermediate HMA layer to limit rutting.
  – Horizontal strain threshold in the HMA base layer to prevent bottom-up fatigue cracking.
  – Relationship between laboratory fatigue strain threshold and measured field HMA strains.
  – Study strain distribution in the HMA layer.
  – Verify/Refine/Modify fatigue model based on the ratio of dissipated energy change (RDEC)
  – Overload (South Side Pavements) - Determine allowable aircraft overload criteria for flexible pavement.
AC 150/5320-6F Airport Pavement Design and Evaluation

- Issued Nov. 10, 2016.
  - Replaces AC 150/5320-6E.
  - Incorporates FAARFIELD 1.42 software program.
- General reorganization of contents.
- Download at: https://www.faa.gov/airports/resources/recent_advisory_circulars/
FAARFIELD – What Is It?

Federal Aviation Administration
Rigid and Flexible Iterative Elastic Layered Design

- **FAARFIELD** is the standard FAA airport pavement thickness design program.
- **FAARFIELD** design procedure for:
  - Flexible
  - Rigid
  - Overlay
- **Current version is FAARFIELD 1.42 (posted 18 Sep 2017)**
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October 15, 2018
Structural Models in FAARFIELD

- Both layered elastic (LEAF) and 3D-FEM (NIKE3D) are used in FAARFIELD.
- Flexible pavement design
  - LEAF is used for all structural computations.
- Rigid pavement design
  - LEAF is used to generate a preliminary thickness.
  - Final iterations are done using a 3D finite element model (3D-FEM).
PANDA-AP – Research Grant with Texas A&M University

Standalone PANDA-AP:
- Considers failure mechanisms in each pavement layer
- Can be used as a \textit{supplement} to FAARFIELD for refined analysis
- Allows for the definition of different gear configurations, loading type, and pavement structure
- User-friendly and customized for airfield pavements
- Will be free to public and independent of commercial FE software, such as Abaqus and Ansys
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Research at NAPMRC

EVALUATION OF NEW ASPHALT TECHNOLOGIES FOR AIRFIELD PAVEMENTS
- Warm Mix Asphalt, Stone Matrix Asphalt, Polymer Modified Binders,
  RAP Mixes, Full-Depth Rehabilitation

PROBLEM: Lack of Guidance/Standards/Specifications
- Lack of Performance Data

Laboratory Performance Evaluation
- Evaluate:
  - Rutting
  - Fatigue
  - Moisture Susceptibility
  - Durability
  - Low Temperature Cracking

Full-Scale APT NAPMRC
- Full-Scale APT:
  - Rutting
  - Fatigue
  - Tire Pressure Effects
  - WMA
  - RAP/RAS
  - Full Depth Reclamation

Field Performance Evaluation
- Field Projects:
  - Lab Evaluation of Field Mixes
  - Construction Evaluation
  - Evaluate:
    - Mix Design
    - Production, Construction
  - Support from AAS-100, ADO

Compare to P-401 HMA
TEST CYCLE (TC) AT NAPMRC

Objectives, Pavement Construction, Sensors

NDT & Pavement Characterization

Posttraffic Testing

Full-Scale APT, Pavement Evaluation
Test Cycle 1 (TC1) Objectives

- Compare Warm Mix Asphalt (WMA) performance with P401 Hot Mix Asphalt (HMA) performance (rutting);
- Effect of tire pressure on pavement rutting;
- Effect of polymer modified binder (PMA) on pavement rutting;
- Effect of temperature on pavement rutting.
HVS-A
Results

• Compare Warm Mix Asphalt (WMA) performance with P401 Hot Mix Asphalt (HMA) performance (rutting);
  
  Comparable Performance in rutting.
  
  Cracking performance need to be evaluated (TC2)

• Effect of tire pressure on pavement rutting;
  
  Significant effects on mixes with unmodified binders.
  
  Insignificant effects on mixes with PMA.

• Effect of polymer modified binder (PMA) on pavement rutting;
  
  Improves rutting performance significantly.

• Effect of temperature on pavement rutting.
  
  Rutting performance of HMA/WMA is more sensitive to temperature than tire pressure.
## TC1 Posttraffic Tests

### Loose Mix with Two Replicates

<table>
<thead>
<tr>
<th>Test Priority</th>
<th>Scheduling Priority</th>
<th>Test Objective</th>
<th>Test Type</th>
<th>Number of Reported Tests</th>
<th>Standard Specification</th>
<th>Performing Organization</th>
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<tbody>
<tr>
<td>Primary</td>
<td>1</td>
<td>Quality Assurance</td>
<td>Bulk Specific Gravity, $G_{mb}$</td>
<td>All of prepared specimens</td>
<td>AASHTO T166</td>
<td>FAA Materials Lab</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Theoretical Maximum Specific Gravity, $G_{mm}$</td>
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<td>2</td>
<td>8</td>
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<td></td>
<td>2</td>
<td>Rutting Potential</td>
<td>Asphalt Pavement Analyzer</td>
<td>4</td>
<td>2</td>
<td>8</td>
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<tr>
<td></td>
<td></td>
<td>Indirect Tension (IDT- High Temp.)</td>
<td>4</td>
<td>2</td>
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<td>ASTM D7369</td>
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<tr>
<td></td>
<td>3</td>
<td>Stiffness Characterization</td>
<td>Conventional Dynamic Modulus</td>
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<td></td>
<td></td>
<td>Flow Number</td>
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<td>2</td>
<td>8</td>
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<tr>
<td></td>
<td>5</td>
<td>Fracture Energy</td>
<td>Disk-Shape Compact Tension</td>
<td>4</td>
<td>2</td>
<td>8</td>
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<tr>
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<td>6</td>
<td>Rutting Potential</td>
<td>Hamburg Wheel</td>
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<td>8</td>
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<tr>
<td></td>
<td>7</td>
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<td>IDT Dynamic Modulus</td>
<td>4</td>
<td>2</td>
<td>8</td>
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<tr>
<td></td>
<td>8</td>
<td>Fatigue Performance</td>
<td>Semi-Circular Bend (Intermediate Temp)</td>
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<td>2</td>
<td>8</td>
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</tbody>
</table>

### Field Cores with Two Replicates

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<th>Test Priority</th>
<th>Scheduling Priority</th>
<th>Test Objective</th>
<th>Test Type</th>
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<th>Standard Specification</th>
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<tbody>
<tr>
<td>Primary</td>
<td>1</td>
<td>Quality Assurance</td>
<td>Bulk Specific Gravity, $G_{mb}$</td>
<td>All of prepared specimens</td>
<td>AASHTO T166</td>
<td>FAA Materials Lab</td>
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<td>2</td>
<td>Rutting Potential</td>
<td>Asphalt Pavement Analyzer</td>
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<td>Indirect Tension (IDT- High Temp.)</td>
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<td>4</td>
<td>Fracture Energy</td>
<td>Disk-Shape Compact Tension</td>
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<td>Hamburg Wheel</td>
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<td>Stiffness</td>
<td>IDT Dynamic Modulus</td>
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<td>Fatigue Performance</td>
<td>Semi-Circular Bend (Intermediate Temp)</td>
<td>6</td>
<td>2</td>
<td>12</td>
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</table>
## TC1: APA Test Results

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Mix Type</th>
<th>Hose Pressure/ # of Passes</th>
<th>100/8000</th>
<th>250/4000</th>
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<tbody>
<tr>
<td>Lab Compacted</td>
<td></td>
<td></td>
<td>Average</td>
<td>Std Dev</td>
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<tr>
<td></td>
<td>H64-22</td>
<td>3.2</td>
<td>0.2</td>
<td>6.8</td>
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<tr>
<td></td>
<td>W64-22</td>
<td>4.4</td>
<td>0.5</td>
<td>8.9</td>
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<tr>
<td></td>
<td>H76-22</td>
<td>1.9</td>
<td>0.6</td>
<td>2.1</td>
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<tr>
<td></td>
<td>W76-22</td>
<td>2.0</td>
<td>0.2</td>
<td>4.5</td>
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<td>Field Cores</td>
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<td>L1(W76-22)</td>
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<td>4.4</td>
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<td>L2(W64-22)</td>
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<td>L4(H64-22)</td>
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<td>7.2</td>
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<td>L5(W76-22)</td>
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<td>0.8</td>
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<tr>
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<td>L6(H76-22)</td>
<td>4.3</td>
<td>0.2</td>
<td>5.1</td>
</tr>
</tbody>
</table>
TC1: APA Test Results

APA Test Results (All Mixes)
Comparison of Rutting at Hose Pressures of 100-psi and 254-psi

- y = 1.8788x
- R² = 0.8861

FAA PROPOSED CRITERION
Relationship between HVS-A & APA Results

\[ y = 17317x^{-2.08} \]
\[ R^2 = 0.7245 \]
TC1: High Temperature IDT Test Results

**Conditioning:**
Approximately 4-5hrs @ 104ºF (40ºC)

**Rate of Loading:**
2.0 in./min (50mm/min)

**High Temperature Indirect Tensile Strength Test**

\[ IDT = \frac{2P}{\pi dt} \]

- Load, \( P \)
- Thickness, \( t \)
- Diameter, \( d \)
Relationship between HVS-A & IDT Results

Relationship between HVS-A and IDT Test Results

\[ y = 0.0195x^{0.268} \]

\[ R^2 = 0.8301 \]
Relationship between IDT & APA Results

![Graph showing the relationship between High Temperature IDT and APA Test Results](image)

\[ y = 729.75x^{1.24} \]

\[ R^2 = 0.79 \]
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Field Instrumentation and Testing

• MAIN OBJECTIVE
  – better understanding of long-term pavement behavior in the field under varied climatic and operating conditions, and
  – improved characterization of paving materials.

Improved pavement design and evaluation tools will conserve airport development funds and reduce the downtime of airfield pavements for construction and maintenance activities.
Shoving/slippage is showing up at many airports
Newark
LaGuardia
Houston
Kahului Maui
Amsterdam
Australia
Newark Strain Gage Installation Location

High-Speed Taxiway N of Newark Liberty International Airport
HMA Delamination and Slippage at EWR Airport

2013-07-10

2013-07-18

2014-07-07
Navneet Garg, Ph.D.
Program Manager, Airport Pavement R&D Section
Airport Technology R&D Branch
Navneet.Garg@faa.gov
(609)485-4483
http://www.airporttech.tc.faa.gov