Airport Pavements: Reflection on 20 Years of Design, Material and Construction Innovations

Dr. Jeffery Roesler, P.E.
Professor & Associate Head
Department of Civil & Environmental Engineering
University of Illinois Urbana-Champaign

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Acknowledgments

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& O’Hare Modernization Program
Presentation Outline (1/2)

• PAVEMENT DESIGN
  • A/C traffic characteristics
  • Methodology
  • Transfer functions
  • Design features (Joints, foundation layers, etc.)
  • Rehabilitation phase

• CONSTRUCTION MATERIALS
  • Concrete mixtures
    • Durability
    • Fiber Reinforced Concrete
  • Asphalt Material
    • Mix design method and binders
  • Recycled materials: RCA, RAP/RAS, etc.
Presentation Outline (2/2)

• CONSTRUCTION
  • Equipment Technology
  • Construction quality and productivity

• SUSTAINABILITY & LIFE CYCLE ASSESSMENT (LCA)
  • Tool to quantify environmental impact

• NON-DESTRUCTIVE TESTING & EVALUATION INNOVATIONS

• EMERGING SOLUTIONS – What’s coming?
• FUTURE CHALLENGES – What’s next?
U.S. Airport Facts

• Over 18,000 airports in the US
  • 537 airports with air carrier service (6700 aircraft)
  • 6 billion aircraft miles travelled/year
  • 800 million passengers annually
  • 608 billion passenger-miles/year
  • 7 million tons of freight annually (US values)

• 80% airport pavement condition is good versus 61% for highway pavements

• 80% on-time arrival

Bureau of transportation statistics (2017)
Chicago O’Hare Modernization Plan (OMP)

- 2004-present
- $8 billion program (Phase I)
  - 35 miles of runways, taxiways
  - $1.7 \times 10^6$ m\(^3\) of PCC
  - Asphalt Base/ Perm Subbase
  - Asphalt shoulders
  - $22 \times 10^6$ m\(^3\) of earthwork
- Modern, parallel runway configuration
- Massive earthmoving, construction, hydraulic, environmental impact challenges
Pavement Design Evolution & Innovations
Aircraft Characteristic Changes

✓ A/C dimensions

• Gear geometry:
  • B777 – Tridem; Combo gears A380-800 tandem/tridem

• A/C Loadings:

• Wheel Load
  • B777-300 (1995) - 57,000 lb versus A350-900 (2017) – 70,000 lb

• Higher tire pressures
Airfield Pavement Design Evolution

• Federal Aviation Administration
  • AC 150/5320-6C (1978)
  • AC 150/5320-6D & AC 150/5320-16 (1995)
  • LEDFAA (1995) – B-777 design software
  • FAARFIELD (2009) – design software release
  • AC 150/5320-6E (2009)
  • AC 150/5320-6F (2016)
  • FAARFIELD v.141 (2017)

• Continuous movement toward more fully M-E Design
FAA Pavement Design Developments (1978): 40 years ago

• Equivalent Aircraft Concept
  • Multiple Wheel Gear Analysis

• Aircraft Wander (Pass to Coverage Ratio)
  • Hosang (1975) – normal distribution of a/c traffic

• Plate Load Tests
  • Composite k-value

• Rigid Pavements use Westergaard edge stress
  • Concrete Fatigue vs. Aircraft Coverage

• CBR method for flexible pavements
  • Protection of subgrade

- CBR-based design

\[
t = \alpha \sqrt{\frac{P}{8.1 \cdot CBR} - \frac{A}{\pi}}
\]

\[
\alpha = 0.15 + 0.23 \log_{10} C
\]
BOEING: B-777-XXX
LEDFAA (1995) Features

• Tridem gear design (B777)
• Layered Elastic Analysis (JULEA)
  • interior stress
• Cumulative Damage Analysis
• Wander Paths
• New subgrade strain model
• New Concrete Fatigue Equation

$$SCI = \frac{DF - 0.2967 - (0.3881 + 0.000039 \times SCI) \log C}{0.002269}$$

SCI = structural condition index, DF = design factor, C = coverages

• Traditional charts - AC 150/5320-6D (1995)
  • Non-tridem gears
FAARFIELD (2009)

• Rigid / Flexible Design
• 3D-Finite Element Analysis (single gear)
  • NIKE3D
• Introduced LEAF program
• NAPTF Full-scale testing
  • Flexible/rigid
  • Tridem & tandem gears
• New Subgrade Strain equation
FAARFIELD Pavement Design (March 2017)

- FAARFIELD v. 1.41 software
- 3D Finite element analysis (Rigid)
  - Concrete Fatigue
- LEAF – layered elastic program (Flexible)
  - Asphalt fatigue and subgrade strain

- Advisory Circular - AC 150/5320-6F (Nov. 2016)
  - Design background and requirements
3-D FEM Response for a Six-Wheel Gear – Stress ($\sigma_{yy}$)

Free-edge loading of slab with width and length of 30ft and 25% assumed load transfer.

Courtesy: FAA
Rigid pavement failure model in FAARFIELD

\[
\frac{DF}{F_c} = \left[ \frac{F_s'bd}{\left(1 - \frac{SCI}{100}\right)(d-b) + F_s'b} \right] \times \log C + \left[ \frac{\left(1 - \frac{SCI}{100}\right)(ad-bc) + F_s'bc}{\left(1 - \frac{SCI}{100}\right)(d-b) + F_s'b} \right]
\]

\(DF\) = design factor, defined as the ratio of concrete strength \(R\) to tensile stress

\(C\) = coverages

\(SCI\) = structural condition index, defined as a subset of the pavement condition index (PCI) excluding all non-load related distresses from the computation

\(a, b, c, d\) = calibrated performance parameters

\(F_s'\) = compensation factor for high quality and stabilized base

\(F_c\) = calibration factor
Flexible Pavement Transfer Functions: *Asphalt Fatigue*

- Asphalt Fatigue Ratio Dissipated Energy Change (RDEC)

\[
N_f = 0.4801 PV^{-0.9007}
\]

\[
PV = 44.422 \varepsilon_h^{5.140} S^{2.993} VP^{1.850} GP^{-0.4063}
\]

- PV = estimated value of RDEC plateau value
- S = AC flexural stiffness, psi
- \( \varepsilon_h \) = horizontal strain at bottom of AC layer
- VP and GP = volumetric and gradation parameter

*FAA 2016 (after Shen & Carpenter-2007)*
Flexible Pavement Transfer Function: *Subgrade Strain*

- Subgrade Strain Criteria
  - \( C = \text{coverages to failure} \)
  - \( \varepsilon_v = \text{vertical compressive strain at top of subgrade} \)

\[
\log_{10}(C) = \left( \frac{1}{-0.1638 + 185.19 \times \varepsilon_v} \right)^{0.60586}
\]

when \( C > 1000 \text{ coverages} \); and

\[
C = \left( \frac{0.004141}{\varepsilon_v} \right)^{5.1}
\]

when \( C \leq 1000 \text{ coverages} \)

*FAA (2016)*
Airport Pavement Rehabilitation Options

Flexible Pavements
• AC Overlays of existing AC or PCC
• Rubblization of PCC w/ AC overlay
• Reconstruction w/ AC
• Full-Depth Reclamation (FDR)

Concrete Pavements
• Full-depth slab repair
• Reconstruction w/ Concrete
• Concrete Overlays (Unbonded)
Design: Rubblization with AC overlay

- Rubblization procedures have been successfully utilized for highway concrete pavement rehabilitation for >20 years (see M. Thompson)

- Procedures have been adapted for airfield concrete

  Airfield Implementation
  Airfield Asphalt Pavement Technology Program (AAPTP) 04-01
  “Development of Guidelines for Rubblization”
  Final Report by Asphalt Institute
  May (2008)
COLES CO. AIRPORT
CHARLESTON-MATTOON, IL

Existing Pavement Section
14in. Jointed Concrete Pavement
7in. Asphalt Stablized Base

Runway Length: 6500 FEET
Built in 1970s

REHAB: SUMMER 2015

RUBBLIZED Concrete + MILL + AC O/L (Min. 4 IN.)
Guillotine Breaker
Multi-Head Breaker
**Chicago ORD - Taxiway A&B**
*(2014-present)*

**EXISTING SECTION**

22 INCHES - Jointed Concrete Pavement  
(Dowel & tie bars)  
Steel Mesh in most slabs ~5 to 6 inch deep

6-INCH ASPHALT BASE  
6-INCH GRANULAR SUBBASE

*Prof. Thompson*
Hypothetical: Rubblization and AC O/L at ORD

• Preliminary design calcs from FAARFIELD (2015)
  • Rubblize PCC, mill 5 in. and construct a 5 in. HMA
  • CBR range from 3 – 5
  • Evaluated for different aircraft

• Use multiple machines to minimize closure time (MHBs – Mills- Pavers)
### FAARFIELD (2015) Results

#### Annual Departure Data (20-year Design Life) for B737s

<table>
<thead>
<tr>
<th>AC</th>
<th>MTOW (kips)</th>
<th>Tire Pressure (psi)</th>
<th>CBR</th>
<th>CDF</th>
<th># Departures</th>
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<tbody>
<tr>
<td>B737-700</td>
<td>155</td>
<td>197</td>
<td>3</td>
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<td>16,500</td>
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<tr>
<td></td>
<td></td>
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<td>4</td>
<td>0.73</td>
<td>100,000/137,000*</td>
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<td></td>
<td></td>
<td></td>
<td>5</td>
<td>0.13</td>
<td>100,000/769,000*</td>
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<tr>
<td>B737-800</td>
<td>175</td>
<td>204</td>
<td>3</td>
<td>1</td>
<td>3,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>25,500</td>
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<tr>
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<td></td>
<td></td>
<td>5</td>
<td>0.71</td>
<td>100,000/141,000*</td>
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<tr>
<td>B737-900</td>
<td>175</td>
<td>197</td>
<td>3</td>
<td>1</td>
<td>3,000</td>
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<td></td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>25,500</td>
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<td></td>
<td></td>
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<td>100,000/141,000*</td>
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<tr>
<td>B737-900ER</td>
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<td>220</td>
<td>3</td>
<td>1</td>
<td>1,050</td>
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<td>4</td>
<td>1</td>
<td>8,800</td>
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<td>5</td>
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<td>48,000</td>
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*For a CDF = 1

#### Annual Departure Data (20-year Design Life) for Airbus

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<th>AC</th>
<th>MTOW (kips)</th>
<th>Tire Pressure (psi)</th>
<th>CBR</th>
<th>CDF</th>
<th># Departures</th>
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<tbody>
<tr>
<td>A319-opt</td>
<td>151</td>
<td>200</td>
<td>3</td>
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<td></td>
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<td>4</td>
<td>0.33</td>
<td>100,000/303,000*</td>
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<td>5</td>
<td>0.06</td>
<td>100,000/1.7E6</td>
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<td>A320-200 Twin</td>
<td>163</td>
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<td>1</td>
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<td>4</td>
<td>0.96</td>
<td>100,000/104,000*</td>
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<td></td>
<td>5</td>
<td>0.17</td>
<td>100,000/588,000*</td>
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<tr>
<td>A321-200 std</td>
<td>197</td>
<td>212</td>
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<td>1</td>
<td>825</td>
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#### Annual Departure Data (20-year Design Life) For a Group 4 Aircraft

<table>
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<th>AC</th>
<th>MTOW (kips)</th>
<th>Tire Pressure (psi)</th>
<th>CBR</th>
<th>CDF</th>
<th># Departures</th>
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<tr>
<td>757-300</td>
<td>274</td>
<td>200</td>
<td>3</td>
<td>1</td>
<td>285</td>
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<td>4</td>
<td>1</td>
<td>2,450</td>
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<td>5</td>
<td>1</td>
<td>18,000</td>
</tr>
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</table>
FAARFIELD (2015) Results, cont’d

### Annual Departure Data (20-year Design Life) for Some Large Aircraft

<table>
<thead>
<tr>
<th>AC</th>
<th>MTOW (kips)</th>
<th>Tire Pressure (psi)</th>
<th>CBR</th>
<th>CDF</th>
<th># Departures</th>
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</thead>
<tbody>
<tr>
<td>B747-400B</td>
<td>877</td>
<td>200</td>
<td>3</td>
<td>1</td>
<td>20</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>105</td>
</tr>
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<td></td>
<td>5</td>
<td>1</td>
<td>425</td>
</tr>
<tr>
<td>B767-300</td>
<td>361</td>
<td>182</td>
<td>3</td>
<td>1</td>
<td>125</td>
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<td></td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>800</td>
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<td>5</td>
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<td>6500</td>
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<tr>
<td>B777-200</td>
<td>547</td>
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<td>4</td>
<td>1</td>
<td>165</td>
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<td>5</td>
<td>1</td>
<td>1200</td>
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<tr>
<td>A340-300</td>
<td>608</td>
<td>206/158*</td>
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<td>1</td>
<td>52</td>
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<td></td>
<td>4</td>
<td>1</td>
<td>235</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1</td>
<td>1,350</td>
</tr>
</tbody>
</table>

*Belly gear

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eprintln.is
Precast Concrete Slabs
(Super-Slab™)

Fort Miller Group
Success for Precast Slabs on Highway System

Tappan Zee, 2001

NYS 1-495

NJ I-295, 2008

Minnesota TH62

Virginia I-66 Ramp
I-55/I-294 Toll Highway (Chicago)

August 22, 2013
Precast Slab Advantages

• Improved durability/quality from controlled environment (shrinkage, uniformity, etc.)

• Rapid construction with little, to no cure time
  • Reduces cost of continuous closures (must be considered in economic analysis)

• Ability to place in differing weather conditions

• Can store panels for future use/rehab

• Longer life/less M&R than overlay while maintain existing elevations
Sample Airport Projects

• San Diego – 1970’s
• Calgary (Canada) - 1993
• St. Louis Lambert – early 2000’s
• New York LaGuardia - 2004
• Washington Dulles – 2001-2002
• USAF/USCOE ERDC Testing (2011-2012)
LaGuardia Taxiway Application

(Chen, 2004)
Dulles International Taxiway (2002)

• Replaced 6 slabs (25’x25’ (qty 4) and 20’x25’ (qty 2) w/depth of 15”)

• New slabs – (12.5’x25’ and 12.5’x20’ w/depth of 13”)
  • Heavily reinforced to account for reduced depth, soft subgrade and handling

Fort Miller System

(Thuma, 2015)
Precast Slab Limitations

• Higher cost than cast-in-place concrete
• Experienced contractor required!
• Panel size determines size of equipment
• Limited literature/experience in US for long term performance (> 15 yrs) especially on **Airports**
  • Japan has had great success for over 30 yrs
Other Airport Design Changes

• Maximum slab size: 20 ft (6.1 m)
• Load transfer (dowels), in practice, used in majority of contraction joints although not required
• Drainable/open-graded foundation layers frequently specified

• Top-down cracking & curling
Other Modes of Concrete Pavement Cracking

• Top-Down cracking observations from full-scale tests:
  • FAA’s NAPTF at Atlantic City (USA)
  • A-380 PEP tests at Toulouse (France)

• Certain combined load and slab geometry situations.

from Dr. Ed Guo (2006)
Top-Down Cracking at FAA NAPTF

- FAA’s NAPTF Tests (CC2 - MRG)

Tests and observed cracks in CC2 tests (Hayhoe and Garg, 2006)

- Tridem and tandem gear loading
Introduction and Motivation

FAA CC2 failure cracks (all sections)

(a) Test Item MRC
(b) Test Item MRG
(c) Test Item MRG
Airbus Full-Scale Tests

- A-380 Pavement Experimental Programme - Rigid Phase (France)

Tests and cracks in PEP (Fabre et al. 2005)
Finite Element Analysis: Full Aircraft (A-380)

- Full Aircraft traverses an inner slab

![Diagram showing load positions and simulated positions]

588 simulated positions

A-380
Top Stresses (critical top stress case)

Critical top tensile stresses induced at transverse joint in-between 2 TDTs

Normalized by $\sigma^{BOT} = 271$ psi
(FAA critical bottom tensile stress)

TDTs gear loading position
(compression under wheels)
Construction Material Innovations for Airfield Pavements
Recycled and Innovative Construction Materials

- Recycled Concrete Aggregates (RCA)
- Reclaimed Asphalt Pavement (RAP)
- Controlled Low Strength Materials (CLSM)

- Blended Cements (Type 1L,1S,1P)
  - Portland limestone cement (Type 1L)
- Fiber Reinforced Concrete (FRC)
  - Patch mixes
  - Isolation joints
  - Other
Concrete Mix Design Updates

• Flexural strength requirements
  • 4.2 to 4.9 MPa at 28 days
  • Fly ash replacement ≤ 30%
  • Slag ≤ 25%
    • Total SCM ≤ 55%

• Reasonable paste contents
  • cement ≥ 471 to 517 pcy (280 to 310 kg/m³)
  • 0.45 ≥ w/cm ≥ 0.38

• Durability...
Concrete Durability Cracking

• D-Cracking: durability factor $\geq 95$ using ASTM C666 procedure B
  • Freeze in air and thaw in water for 300 cycles
Alkali Silica Reaction

• Chemical reaction between alkali and hydroxide ions in pore solution and reactive silica in aggregate

• Reaction produces gel

• Gel adsorbs water and swells, causing expansion and cracking of aggregate
ASR Control: FAA P-501

• Coarse and/or fine aggregate w/ reactive silica + alkalis+water results in expansive gel

• Coarse and fine aggregate separately tested w/ ASTM C1260.
  • Innocuous if the expansion of test specimens ≤ 0.10% at 28 days

• Combined coarse and fine aggregate tested w/ ASTM C1567 ≤ 0.10% at 28 days

• Low alkali cements, innocuous aggregates, admixtures (Slag, Type F ash, Lithium)
ASR Evaluation - Mortar Bar Expansion

Figure 1. Expansion of mortars containing fly ash.

Figure 1. Expansions produced by various sands.

Figure 2. Expansion of mortars containing slag.

Struble et al. (2008)
Superpave Binder Specification

- Penetration and Viscosity grading replaced by SUPERPAVE binder specification
- Adjustments for wheel load, tire pressure, rutting potential

<table>
<thead>
<tr>
<th>Aircraft Gross Weight</th>
<th>High Temperature Adjustment to Binder Grade</th>
</tr>
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<tbody>
<tr>
<td>≤ 12,500 lbs (5670 kg)</td>
<td>--</td>
</tr>
<tr>
<td>&lt; 100,000 lbs (45360 kg)</td>
<td>1 Grade</td>
</tr>
<tr>
<td>≥ 100,000 lbs (45360 kg)</td>
<td>2 Grade</td>
</tr>
</tbody>
</table>

Typically, rutting is not a problem on airport pavements. However, at airports with a history of stacking on end of runways and taxiway areas, rutting has occurred due to the slow speed of loading on the pavement. If there has been rutting on the project or it is anticipated that stacking may occur during the design life of the project, then the following grade bumping should be applied for the top 5 inches (125 mm) of paving in the end of runway and taxiway areas: for aircraft tire pressure between 100 and 200 psi (0.7 and 1.4 MPa), increase the high temperature one grade; for aircraft tire pressure greater than 200 psi (1.4 MPa), increase the high temperature two grades. The low temperature grade should remain the same.

### FAA P-401

<table>
<thead>
<tr>
<th>Performance Grade</th>
<th>PG 46</th>
<th>PG 52</th>
<th>PG 56</th>
<th>PG 64</th>
<th>PG 70</th>
<th>PG 76</th>
<th>PG 82</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average 7-day Melting Point Design, Temp. °C</td>
<td>&lt; 46</td>
<td>&gt; 52</td>
<td>&lt; 58</td>
<td>&lt; 64</td>
<td>&lt; 70</td>
<td>&lt; 76</td>
<td>&lt; 82</td>
</tr>
<tr>
<td>Min Melting Point Design, Temp. °C</td>
<td>-34</td>
<td>-40</td>
<td>-48</td>
<td>-56</td>
<td>-64</td>
<td>-72</td>
<td>-80</td>
</tr>
</tbody>
</table>

Flash Point Temp, I48, Min °C
Viscosity, ASTM D 4402, Min. 3 Pa.s, Test Temp. °C
Dynamic Shear, TP 5 Min, 1KPa G' at 10 rad/s, °C

Rutting Thin Film Oven Residue (T 240)
Min., Max., percent

Dynamic Shear, TP 5 Min, 2.39 Kpa G' at 10 rad/s, °C

Pressure Aging Vessel Residue (PP 1)
Min. Aging Temperature °C

Physic Softening

Crack Stiffness, TP 1 Determine the critical cracking temperature as described in PP 42
Direct Tensile, TP 3 Determine the critical cracking temperature as described in PP 42

FAA P-401
Materials: Superpave vs. Marshall

• Airport specifications (FAA P-401/403) now allow either Gyratory or Marshall
Asphalt Concrete Mix Design:

• Rutting/surface deformation potential (SMA mixes)
  • high tire pressures and heavily-loaded gear geometry
  • Bump binder grades

• Reclaimed Asphalt Pavement (RAP) ≤ 30%
  • Applied to shoulders (surface or intermediate layers)
  • 0-20% RAP no binder change; 20-30% RAP- soften binder
  • FAA P-401/403
Crushed Concrete (RCA): Base/Subbase Layer

- FAA P-219 Recycled Concrete Aggregate Base or Subbase Course
  - Most common use of RCA on airports

Nashville International Airport (2010)

- 70% of RCA is for base/subbase w/ 6% for PCC

Recycled Concrete Aggregate (RCA)

Fresh and hardened properties of concrete
- virgin and recycled coarse aggregate
- w/ and w/o structural fibers

- Effects of concrete drying shrinkage with recycled coarse aggregate

6.9 MPa = 1000 psi
Chicago O’Hare Airport Apron Test Sections

18 in. RCA Concrete

Permeable CTB

RCA = recycled concrete aggregate concrete
VAC = Virgin aggregate concrete
Chicago O’Hare Casting
Oct. 21, 2009

Permeable CTB
Field Visit
Fibers for Airfield Concrete Pavement

• Steel / Synthetic
• Micro- and Macro-fibers
• Provides many different functions
MACRO-Fiber Reinforcement: Concrete Pavement Benefits:

• *Increase* in *structural capacity* of slab
• Maintain crack/joint widths
• Tie *longitudinal*/transverse contraction joints
• Reduce deterioration rates after initial cracking
• Moderate joint spacing extension

➢ Fibers are less economical for thicker slabs
Flexural Beam Test (ASTM C 1609-07)

\[ \text{MOR} = \frac{P_L}{bd^2} \]

\[ f_{150}^{150} = \frac{P_{150} L}{bd^2} \]

\[ f_{150}^{150} = \text{residual strength} \]

\( P_1 = \text{peak load} \)

\( L = \text{span} \)

\( B = \text{width} \)

\( d = \text{thickness} \)

concrete modulus of rupture (MOR)
Flexural Beam Results
150x150x550mm

\[
\text{MOR} = \frac{PL}{bd^2}
\]

[Graph showing stress vs. beam deflection with various fiber types and plain concrete.]
FRC Application to Airports

- Full-depth patches same thickness
  - Greater slab load capacity
- Post-tensioned section
- Moderate extension of joint spacing (6.1m to 7.6m)
- Bonded concrete overlay
- Isolation joint alternative

- 2-lift paving option
  - (virgin PCC) / (PCC w/ RCA & fibers)
Two-Lift Solution w/ RCA Concrete

- Optimize thickness of RAC.

3 in. PCC

13 in. RCA w/ fibers

6 in. DGAC

6 in. ATPB

Treated Soil

Sawn Joint 4 in.

Cast Fresh: Sequentially
Isolation Joint Design

- Joints used in areas where there is differential lateral/longitudinal slab movement expected
- Commonly employed at the intersections of taxiways and runways and aprons

*FAA 2009*
Project Objectives

• Does the Type A-1 (reinforced) isolation joint design perform adequately under live aircraft loading?
• Does a novel, fiber reinforced isolation joint design perform adequately under live aircraft loading?
Field Instrumentation at ORD

- Four strain gauge trees located on opposite sides of the isolation joint
Field Instrumentation & Evaluation
Materials: Patching

• Patch Material Compatibility
• Material volume change is a major problem for durable repairs.
• Rapid repair and patching materials with low shrinkage potential.
Pavement Construction Innovations
Airfield Construction

- AC overlay Staged Construction – continuous nighttime paving & opening for service each day
  - Mill and AC inlay or AC overlay
- Precast Slabs – demonstration projects
- 50ft (15m) Wide Paving
- Joint Details – improvements
  - Elimination of Keyed Joints for longitudinal shear transfer
  - Rational doweling and joint spacing selections
- Full-depth repair preferred over reconstruction
Innovations for Concrete Paving
Stringless Paver – controls horizontal/vertical position

GPS Receiver

GPS Controller and Laser Height Gages

Laser Sensor

High Resolution Laser

Tech Center
Hamilton County (IL) – Bonded Concrete Overlay of Asphalt
27cm CRCP Overlay (I-57/I-64)  
Stringless Paving (2011-2013)
Airfield Pavement: Life Cycle Assessment

• Used to quantify sustainability
• LCA-AIR (2015) tool developed at University of Illinois
  • Chicago O’Hare case study
  • LCA-AIR fills need
• Chicago Department Aviation:
  • Great for landside operations
  • Limited for airside
  • Doesn’t address life cycle impacts
LCA-AIR System Boundaries

Kulikowski et al. 2016
LCA-Air Framework

Kulikowski et al. 2016

Impact by Phase - PCC

<table>
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<th>Impact category</th>
<th>Unit</th>
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<tr>
<td>Ozone depletion</td>
<td>kg CFC-11 eq</td>
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<tr>
<td>Global warming potential</td>
<td>kg CO2 eq</td>
</tr>
<tr>
<td>Smog</td>
<td>kg O3 eq</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO2 eq</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg N eq</td>
</tr>
<tr>
<td>Carcinogens</td>
<td>CTUh</td>
</tr>
<tr>
<td>Non carcinogens</td>
<td>CTUh</td>
</tr>
<tr>
<td>Respiratory effects</td>
<td>kg PM2.5 eq</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td>CTUe</td>
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<tr>
<td>Fossil fuel depletion</td>
<td>MJ surplus</td>
</tr>
<tr>
<td>Primary energy consumption</td>
<td>TJ</td>
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(renewable – non-renewable)
Innovations in Non-Destructive Assessment

• Laser scanning, 2D/3D camera, Mobile LiDAR, Drones
  • Rapid assessment of distresses and other assets on airport
  • Panel by panel PCI
2D/3D Laser Scanning

- Multiple companies
- Utilizes laser and 3D cameras to capture data
- Crack detection to 1 mm
- Automatic Distress Analyzer
  - Calcs geometry of cracking
  - Generates a map of locations
- Creates a virtual pavement surface
- Operates day or night
- Data file can be imported into MicroPaver

(Wang, 2007)
NDT&E – con’t

• Robotic Total Station w/ Laser Scanning - Topographic
• Fast FWD... Will we have Fast HWD?
• GPR
  • Pavement layers and thickness
  • Presence of dowels, mesh, tie bars and depth
  • Find Drainage Pipes
  • Asphalt Density Measurements
Chicago O’Hare: Taxiway A/B Pavement Survey (2015) - GPR

- Along Taxiway A/B center slab, edge slab, shoulder, apron slab.
- 400MHz and 900MHz antennas were used

Al-Qadi et al.
Taxiway A Center Slab: GPR Data

Steel Mesh depth ranges from 5.5in to 7in.
Taxiway A Center Slab: Survey Path

No mesh

6.5"

15"

15"

6.5"

15"
Clogged pipe: No. 2, 4 and 12.
Example: $G_{mb}$ Prediction of Lane III Using ALL Model

Al-Qadi et al.

![GPR Survey](image)

![Raw GPR Data](image)

---

**Bulk Specific Gravity**

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<tr>
<th>Sec. 1</th>
<th>Sec. 2</th>
<th>Sec. 3</th>
<th>Sec. 4</th>
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**Dielectric Constant**

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<th>Sec. 4</th>
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Using the core from Sec. 1 to find $\varepsilon_s = 6.1$
Asphalt Mixture Density Prediction

Principle: The bulk dielectric constant of a mixture is a function of the dielectric and volumetric properties of its components.

Density Prediction Model - ALL (Al-Qadi, Lahouar, and Leng)

Model:

\[
G_{mb} = \frac{\varepsilon_{AC} - \varepsilon_b}{3\varepsilon_{AC} - 2.3\varepsilon_b} - \frac{1 - \varepsilon_b}{1 - 2.3\varepsilon_b + 2\varepsilon_{AC}}
\]

\[
\frac{\varepsilon_s - \varepsilon_b}{\varepsilon_s - 2.3\varepsilon_b + 2\varepsilon_{AC}} \left(1 - \frac{P_b}{G_{se}}\right) - \frac{1 - \varepsilon_b}{1 - 2.3\varepsilon_b + 2\varepsilon_{AC}} \left(\frac{1}{G_{mm}}\right)
\]

- \(\varepsilon_{AC}\): dielectric constant of asphalt mixture
- \(\varepsilon_b\): dielectric constant of binder
- \(\varepsilon_s\): dielectric constant of aggregate
- \(P_b\): binder content
- \(G_{se}\): effective specific gravity of aggregate
- \(G_{mm}\): maximum specific gravity of mixture
Ultrasonic Shear Wave Tomography (MIRA)

Evaluation of Ultrasonic Techniques on Concrete Structures

September 2013

Prepared by:
Dwight Clayton – ORNL
Cyrus Smith – ORNL
Christopher C. Ferraro – Lynch and Ferraro Engineering, Inc.
Jordan Nelson – Lynch and Ferraro Engineering, Inc.
Lev Khazanovich – University of Minnesota
Kyle Hoenig – University of Minnesota
Satish Chintakunta – Engineering & Software Consultants Inc.
John Popovic – University of Illinois – Urbana-Champaign
Hajin Choi – University of Illinois – Urbana-Champaign
Suyun Ham – University of Illinois – Urbana-Champaign

Reflections at reinforcements

Reflection at pavement thickness interface

Cracking

Honeycomb

(b)

Honeycomb

(b)

Multi-sensor array ultrasonic imaging

S-wave arrays. Dry point contact transducers at 50 kHz. 90 (45) A scans in 350 ms, data acquisition, transfer and processing in < 2 sec

(Source: Krause et al. at BAM 2009)
MIRA Test on RCC pavement: poor consolidation and/or cold joint
Magnetic Imaging Technology

THICKNESS

DOWEL BARS
MIT Scan2 Dowelled Joint Results

- Typical Joint
- Basket Opened
- Anchoring Issue
- Missing Dowels
Emerging Solutions for Airfield Pavements
Asphalt Material Technology

• Warm Mix Asphalt (WMA)
  • Test section at Boston airport with RAP
  • Asphalt-treated permeable base (ATPB), binder course and shoulders for Taxiway ZS at O’Hare (2011).

• Recycled Asphalt Shingles (RAS)
  • Binder course on Chicago O’Hare shoulder

• FAA Tech Center will be testing some WMA/RAP mixtures soon (N. Garg, 2017)
Foam concrete: Cellular ceramic material

- Unique material with **engineered** properties:
  1. high void content: 50 to 90%
  2. low specific density: 0.2 to 0.8
  3. void size: 100-500 μm
  4. low strength: 20-300 psi
  5. high strain capacity under compression

Engineering applications:

1. light-weight isolation wall
2. sound/thermal barrier
3. **engineering material arresting system (EMAS)**

---

EMAS
http://www.tagesanzeiger.ch
Controlled Low-Strength Material with Recycled Aggregates

- Flowable, self-compacting fill
- Compressive strength <2 MPa for excavation but < 8.6 MPa
- Allows use of *non-standard materials (recycled; high FA)*
- Robust mix designs are available
- Flow primarily related to paste volume
- Subsidence is a function of w/cm with secondary relations to paste volume and cement content
- Strength primarily controlled by cement content
- RFA (Recycled Fine Aggregates) generally performs better than virgin aggregate for CLSM
Concrete w/ Fractionated, Reclaimed Asphalt Pavement

Compressive Strength (psi) vs Concrete Age (days)

- 0%
- 20%
- 35%
- 50%

6.9 MPa = 1000 psi
Illinois Tollway Concrete w/ FRAP

• First pavement in Illinois containing a portion of RAP as coarse aggregate (2010)
• Mix contained 35% FRAP, 20% fly ash, and FRAP had 15% agglomerated particles
• 9” concrete pavement topped with 3” WMA (I-94 Composite Pav’t)
• I-90 used 20% FRAP in two-lift concrete (8.5” bottom lift & 3.5” surface concrete)
Concrete with Internal Curing (IC)

• FLWA = Fine Lightweight Aggregates
  • Generally passing 3/8” (9.5 mm) sieve

• Source could be shale, slate, clay, or BFS
  • Man-made: Expanded Shale (Haydite)
  • Absorption: 14.6%
  • SSD SG: 1.63
  • OD SG: 1.43

• LWA provide additional reservoir of water to replenish pore water lost due to hydration and evaporation thus provide “internal curing

• Directly addresses the self-dessication issue
Better Internal Curing w/ Fine Lightweight Aggregates

Predicted Benefits:
• Better curing
• Improved surface properties
• Increased degree of hydration
• Less curling
FLWA to Standard Concrete Mixture (w/c 0.42) – “Unrestrained Curling”
Real-Time Smoothness

• What is it?
  • An integrated system of profile data collection sensors and processing software that provides real-time profile feedback to the contractor.
Real-Time Smoothness

• Background 2010 and 2011
• SHRP2 R06E
  • Evaluation of GOMACO GSI and Ames Engineering RTP
  • Georgia, Arkansas, Texas, Michigan and New York
Real-Time Smoothness - Laser

- Laser enabled smoothness measurement system monitors profile and calculates smoothness indices directly behind the paver.
- Calculates and displays profile as concrete is placed
- Instantly calculates and displays Profile Index (PI) and International Roughness Index (IRI)
- Locates areas of localized roughness and must grind locations
Real-Time Smoothness - Ultrasonic

The GSI includes: GSI computer assembly, real-time graphic display, media storage card, two sonic sensors, slope sensor, distance counter wheel assembly, and cables.
Intelligent Compaction (IC)

- Modern compactors with a measurement system and feedback control
- Maps compaction process w/ GPS
- IC technology allows for instantaneous corrections in the compaction process
- IC rollers can locate and map areas of weakness or nonuniformity
Intelligent Compaction Technology
Future Challenges for Airfield Pavements

• Much has changed in optimizing construction and rehabilitation
  • Construction under operations – staged, closures, etc.
• Reflective cracking – not resolved but still a lot of research and trials underway with new solutions.
• Increased pressure to use recycled or by-product materials
• Heavier loads and tire pressures expected to continue
Future Challenges, con’t

• Geosynthetics
• ACN/PCN
• 40 year pavement design
  • Need longer service lives slabs but cracking won’t necessarily by main issue
  • Flexible vs. Rigid design strategies
• Pavement Smoothness enhancement
• Performance Specifications for new & recycled materials for pavement layers
Questions/ Comments