Repair Materials & Methods at O’Hare Airport

CEAT Brownbag Seminar Series
Friday, September 21, 2012
David A. Lange
Daniel I. Castaneda
Outline of Project

• Airfield site visit
• Review of literature and industry practices
• Grad-level class project at UIUC
• Lab and field trials of repairs

• Concrete repair guide tailored for O’Hare
Challenges at O’Hare

• Repairs on airfield must be fast!
  – Overnight repairs

• High water table → pumping & freeze/thaw
  – HMA susceptible to stripping/raveling

• Budgeting
  – Widespread damage, opt for affordable (repeating) repairs
  – Localized damage, opt for “higher-end” repairs
Photos of Repairs at O’Hare
Alpha and Bravo Taxiways

- Water table near surface; heavy aircraft pumps water through
  - Poor agg base drainage
  - Poor under-drainage to Lake O’Hare
Alpha and Bravo Taxiways

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- Corner cracking, joint spalling, longitudinal cracking
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  - Poor agg base drainage
  - Poor under-drainage to Lake O’Hare
- Corner cracking, joint spalling, longitudinal cracking
- Poor compaction around utility conduits & underdrainage
- Rigidity around exposed utilities required
Hotel and Tango Taxiways

- Damage on Hotel less widespread; opt for upgrade (costlier material)
Hotel and Tango Taxiways

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- “Arrests” cracks
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- Differential movement & load transfer (spalling)
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- Maintenance began shortly after construction on Tango
- Design/construction problems?
Hotel and Tango Taxiways

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- Design/construction problems?
  - Slip form paving on Delta
Hotel and Tango Taxiways

- Maintenance began shortly after construction on Tango
- Design/construction problems?
  - Slip form paving on Delta
  - Joint spacing on alley btw H & G
Literature and industry practices

• “Understand failure to understand repair”
  – Material failures $\rightarrow$ material repairs
    • Environmental/exposure conditions
  – Structural failures $\rightarrow$ structural repairs
    • Loading and design
• Material repair of a structural failure is a band-aid; repairs can fail
What are **structural failures?** (1/2)

- **Asphalt Pavement**
  - Fatigue/alligator cracking (weak interface, poor base)
  - Longitudinal (poor joint construction)
  - Edge cracks (poor water drainage)
  - Joint/reflection cracks
  - Slippage cracks (poor tack/bond w/ sub-course)
  - Potholes (poor drainage, vehicle traffic)
  - Rutting (thin pavement sections)
  - Upheaval (swelling of sub-base)
What are structural failures? (2/2)

- Concrete Pavements
  - Spalling (high stresses, incompressible debris in joints)
  - Faulting (water pumping, misalignment at joint)
  - Pumping (dowel, poor load-transfer)
  - Punchout (erosion of sub/base)
  - Corner breaks (pavement thickness, support, poor dowel)
  - Linear cracking (loading, thermal curling, moisture stress, loss of support)
  - Blowup (insufficient joint spacing/expansion)
What are material failures?

• Asphalt Pavement
  – Block/reflective cracking (temp shrinkage)
  – Long/transverse cracking (temp shrinkage)
  – Rutting (improper binder, compaction, moisture)
  – Shoving (excess binder, fine/round aggregate)
  – Raveling/stripping (temp at placement, compaction, moisture)

• Concrete Pavement
  – D-cracking (freeze-thaw or infiltration at joints/edges)
  – Shrinkage cracking/crazing (poor curing)
  – ASR (excess alkali + reactive/ siliceous aggregate)
  – Popouts (moisture expansive aggregate)
Some failures can be avoided…

…with more careful construction practices!

– Spalling: re/moving slip-form early
– Plastic shrinkage: time of casting (night/day)
– Crazing: improper curing
– Tack coat: improve bond between courses

…with more careful maintenance practices!

– Edge cracking: remove vegetation, water drainage
– Spalling: removing incompressible debris, seal early
TOO LATE! We have failures. Now what?

• Identify the mechanism of failure. Then select repair material & technique.
• The BIG questions:
  – How do we intelligently select materials?
  – Do costlier repair materials equate to better performance?
  – Are there niche applications for high-performance or low-cost materials?
Repair Material Selection Process

1. Owner Requirements
2. Service Conditions
3. Causes of Deterioration
4. Application Conditions

- Determine project objectives
- Determine material properties needed to meet project objectives
- Identify materials or systems which will produce the required properties

[ICRI No. 03733]
Examples

ICRI No. 03733 & ACI 546.3R extensively enumerate many performance requirements & desirable material properties.
<table>
<thead>
<tr>
<th>Service Conditions</th>
<th>Performance Requirements</th>
<th>Undesirable Response</th>
<th>Desirable Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Ambient temperature changes</td>
<td>Cracking in repair material due to thermal contraction stresses</td>
<td>Thermal coefficient similar to that of substrate</td>
</tr>
<tr>
<td></td>
<td>Temperature changes within repair material at early ages</td>
<td>Spalling due to thermal expansion stresses in substrate</td>
<td>Low exotherm during cure</td>
</tr>
<tr>
<td></td>
<td>Atmospheric gases and chemical contact</td>
<td>Deformation due to thermal expansion from high exotherm</td>
<td>Low permeability; no cracks</td>
</tr>
<tr>
<td></td>
<td>Moisture conditions, saturation; freezing and thawing</td>
<td>Cracking due to thermal contraction stresses in repair material</td>
<td>Resistance to freezing and thawing</td>
</tr>
<tr>
<td></td>
<td>Moisture conditions</td>
<td>Corrosion of reinforcing steel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disintegration of cement matrix</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cracking due to drying shrinkage stresses</td>
<td>Very low drying shrinkage; low permeability</td>
<td></td>
</tr>
<tr>
<td>Service Conditions</td>
<td>Performance Requirements</td>
<td>Undesirable Response</td>
<td>Desirable Properties</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------</td>
<td>----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Structural Properties</td>
<td>Bond to substrate</td>
<td>Loss of bond, delamination, detachment of repair from substrate</td>
<td>Tensile bond</td>
</tr>
<tr>
<td>Load carrying as intended by the engineer</td>
<td>Does not carry load as anticipated, overstressing either the substrate or repair material</td>
<td>Modulus of elasticity similar to substrate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carries loads initially, but over time, the repair relaxes under creep deformation</td>
<td>Very low compressive creep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drying shrinkage causes material to lose volume, reducing its ability to carry compressive loads</td>
<td>Very low drying shrinkage</td>
<td></td>
</tr>
<tr>
<td>Dynamic Loading</td>
<td>Vehicle wheels</td>
<td>Abrasion damage to surface</td>
<td>High compressive strength; high abrasion resistance</td>
</tr>
<tr>
<td></td>
<td>Edge spalling at joints</td>
<td>High compressive, tensile, and bond strengths; tensile anchorage into substrate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delamination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact</td>
<td>Spalling</td>
<td>High tensile and impact strengths, internal tensile reinforcement; high compressive strength</td>
<td></td>
</tr>
</tbody>
</table>

[ICRI No. 03733]
Desirable properties in general

<table>
<thead>
<tr>
<th>Property</th>
<th>Relation between Repair and Substrate Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrinkage strain</td>
<td>$R &lt; S$</td>
</tr>
<tr>
<td>Creep (repair in compression)</td>
<td>$R &lt; S$</td>
</tr>
<tr>
<td>Creep (repair in tension)</td>
<td>$R &gt; S$ (e.g. epoxies in cracks)</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>$R = S$</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>$R = S$</td>
</tr>
<tr>
<td>Strength</td>
<td>$R &gt; S$ (slightly)</td>
</tr>
<tr>
<td>Porosity and resistivity</td>
<td>$R = S$</td>
</tr>
</tbody>
</table>

Also desire fast setting time and high flow-ability!
How to determine properties? (1/2)

• Bond strength
  – Direct tensile (ACI 503R)
  – Direct shear (Michigan DOT Shear Bond)
  – Slant shear (ASTM C882, C1042, AASHTO T237)

• Dimensional behavior
  – Drying shrinkage (ASTM C157)
  – Coefficient of thermal expansion (CRD-C39, ASTM C531)
  – Modulus of elasticity (ASTM C469)
  – Creep (ASTM C512, C1181)
  – Restrained shrinkage (ASTM C1581, AASHTO PP34-99)
How to determine properties? (2/2)

• Durability
  – Permeability (AASHTO T259, T227, ASTM C1202)
  – Water vapor transmission (ASTM E96)
  – Freeze/thaw resistance (ASTM C666)
  – Scaling resistance (ASTM C672)
  – Sulfate resistance (ASTM C1012)
  – ASR resistance (ASTM C227, C289, C295)
  – Abrasion resistance (ASTM C418, C779, C944, C1138)

• Mechanical
  – Tensile strength (ASTM C190, C496)
  – Flexural strength (ASTM C78, C348, C42)
  – Compressive strength (ASTM C109, C39, C42)
How to determine properties? (2/2)

- **Durability**
  - Permeability (AASHTO T259, T227, ASTM C1202)
  - Water vapor transmission (ASTM E96)
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- **Mechanical**
  - Tensile strength (ASTM C190, C496)
  - Flexural strength (ASTM C78, C348, C42)
  - Compressive strength (ASTM C109, C39, C42)

Table 2.1 in ACI 546.3R more expansive in available tests!
Grad Course Project at UIUC

• *Infrastructure Repair* class at UIUC
  – Bond strength project
  – ASTM C882 *Bond Strength of Epoxy-Resin Systems Used With Concrete by Slant Shear*
Grad Course Project at UIUC

• Repair Materials:
  – Akona Instant Water Stop
  – Speccrete Speccoplug 1 Minute
  – Quikrete Quick-Setting Cement
  – Speccopatch-RS
  – Type M Lime Mortar
  – SikaBond Construction Adhesive
  – Loctite Metal/GC
  – Loctite Marine
  – Gorilla Super Glue
  – Asphalt (HMA, WMA, CMA)
  – Epoxy Mortar (sand replacement)
  – Set 45

• Surface Treatments:
  – Sandblasting
  – Chisel
  – Detergent scrubbing
  – Muriatic acid etching
  – Saw-cutting & grooving
Grad Course Project at UIUC

### Student Group A

<table>
<thead>
<tr>
<th>Repair Material</th>
<th>Slab Shear Strength (lbf/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aloma Inst. Watr Stop</td>
<td>299</td>
</tr>
<tr>
<td>Quikrete Quick Setting Cement</td>
<td>50</td>
</tr>
<tr>
<td>Specocon Specoplug 1 Minute Set Hydraulic Cement</td>
<td>379</td>
</tr>
</tbody>
</table>

### Student Group B

<table>
<thead>
<tr>
<th>Repair Material</th>
<th>Slab Shear Strength (lbf/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specopatch RS</td>
<td>740</td>
</tr>
<tr>
<td>Type M Lime Mortar (masonry mortar)</td>
<td>170</td>
</tr>
<tr>
<td>SkidBan Construction Adhesive</td>
<td>362</td>
</tr>
</tbody>
</table>

### Student Group C

<table>
<thead>
<tr>
<th>Repair Material</th>
<th>Slab Shear Strength (lbf/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast-in-place concrete</td>
<td>293</td>
</tr>
<tr>
<td>Loctite Steel/Concrete by Henkel Corporation</td>
<td>502</td>
</tr>
<tr>
<td>Loctite Marine by Henkel Corporation</td>
<td>396</td>
</tr>
<tr>
<td>Loctite</td>
<td>59</td>
</tr>
</tbody>
</table>

### Student Group D

<table>
<thead>
<tr>
<th>Repair Material</th>
<th>Slab Shear Strength (lbf/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaN</td>
<td>42</td>
</tr>
<tr>
<td>NaN</td>
<td>20</td>
</tr>
<tr>
<td>NaN</td>
<td>20</td>
</tr>
</tbody>
</table>

### Student Group E & F

<table>
<thead>
<tr>
<th>Repair Material</th>
<th>Slab Shear Strength (lbf/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy w/ coated sand</td>
<td>295</td>
</tr>
<tr>
<td>Epoxy w/ coated sand</td>
<td>195</td>
</tr>
<tr>
<td>Epoxy w/ coated sand</td>
<td>895</td>
</tr>
</tbody>
</table>

Click on above text for detail
Click [here](#) to advance
Student Group B

<table>
<thead>
<tr>
<th>Repair Material</th>
<th>none</th>
<th>acid etched (muriatic)</th>
<th>detergent scrubbed</th>
<th>saw-cut 1/8&quot; 1&quot;OC</th>
<th>saw-cut 1/8&quot; 1.5&quot; OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speccopatch-RS</td>
<td>741</td>
<td>1232</td>
<td>1139</td>
<td>1094</td>
<td>1088</td>
</tr>
<tr>
<td>Type M Lime Mortar (masonry mortar)</td>
<td>483</td>
<td>438</td>
<td>406</td>
<td>550</td>
<td>611</td>
</tr>
<tr>
<td>SikaBond Construction Adhesive</td>
<td>0</td>
<td>190</td>
<td>187</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Cold Mix Patches did not setup/bond after 2h refrigeration.
Preliminary insight based on class results

• Repair materials have wide-range of results
• Some materials see improved bond after surface treatment
• Moisture in substrate affects bond
• Asphalt and other materials can have very poor bond strength
Lab Trials of Repair Materials

• How do “industrial-grade” repair materials compare with “consumer-product” materials?

• Modified bond strength testing

• Drying shrinkage beam testing

• Key parameters:
  – Repair material selection
  – Dry versus moist substrates
  – Saw cut versus acid etched substrates
How was testing done?

- Revised ASTM C882
  - 4”x6” concrete cylinders (in lieu of 3”x6”)
  - Saw cut substrates (in lieu of casting half)
  - Re-join halves w/ thin repair layer (instead of “full-depth” repair/replacement)
  - Moist: moist-cure room 24h before testing, 10-15 minute air dry
  - Acid: surface immersed in diluted muriatic acid for 3-5 minutes
  - 1 and 3 day testing
OPC shrinkage range of ~520 to ~780 με

Really high!

Really low!
1 and 3 Day Compressive Strengths

Strength, $\sigma$ (psi)

- Flexpatch
- M3 Epoxy
- Pavemend SLQ
- Pavemend TR
- Set45 1.7L
- Set45 1.9L
- Special Patch
- Type III PC Mortar

Equation:

$$f'c \approx \left(\frac{MOR}{K}\right)^2$$
1 and 3 Day Compressive Strengths

![Graph showing compressive strength over days for various materials.](image)

\[ f'c \approx \left( \frac{E_c}{57,000} \right)^2 \]
Detail of Bond Tests

Moisture

Acid-Etching

Click on above graphs for detail
Click here to view moisture effect, e.g.
Click here to continue presentation
1 Day Dry to Moist Bond/Shear Strengths

- 1 Day Dry Shear Strength
- 1 Day Moist Shear Strength

Strength, τ (psi)

- Flexpatch
- M3 Epoxy
- Pavemend SLQ
- Pavemend TR
- Set45 1.7L
- Set45 1.9L
- Special Patch
- Type III PC Mortar

Click [here](#) to return
Click [here](#) to proceed
3 Day Dry to Moist Bond/Shear Strengths

Click [here](#) to return
Click [here](#) to proceed

<table>
<thead>
<tr>
<th>Material</th>
<th>3 Day Dry Shear Strength</th>
<th>3 Day Moist Shear Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexpatch</td>
<td>[2000]</td>
<td>[1000]</td>
</tr>
<tr>
<td>M3 Epoxy</td>
<td>[4000]</td>
<td>[2000]</td>
</tr>
<tr>
<td>Pavement SLQ</td>
<td>[1500]</td>
<td>[750]</td>
</tr>
<tr>
<td>Pavement TR</td>
<td>[2500]</td>
<td>[1250]</td>
</tr>
<tr>
<td>Set45 1.7L</td>
<td>[1500]</td>
<td>[750]</td>
</tr>
<tr>
<td>Set45 1.9L</td>
<td>[1500]</td>
<td>[750]</td>
</tr>
<tr>
<td>Special Patch</td>
<td>[1500]</td>
<td>[750]</td>
</tr>
<tr>
<td>Type III PC Mortar</td>
<td>[500]</td>
<td>[250]</td>
</tr>
</tbody>
</table>

Strength, $\tau$ (psi)
1 Day Moist to Acid-Moist Bond/Shear Strengths

Click here to return
Click here to proceed
1 Day Acid-Dry to Acid-Moist Bond/Shear Strengths

Click here to return
Click here to proceed

Legend:
- 1 Day Dry Acid Shear Strength
- 1 Day Moist Acid Shear Strength

- Flexpatch
- M3 Epoxy
- Pavemend SLQ
- Pavemend TR
- Set45 1.7L
- Set45 1.9L
- Special Patch
- Type III PC Mortar

Strength, $\tau$ (psi)
### Summary of Bond Tests

<table>
<thead>
<tr>
<th>Materials</th>
<th>Saw-Cutting Moist Substrate</th>
<th>Does Acid-Etching improve bond?</th>
<th>Acid-Etching Moist Substrate</th>
<th>If already moist, does acid-etching help?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexpatch</td>
<td>-53%</td>
<td>7%</td>
<td>-70%</td>
<td>-31%</td>
</tr>
<tr>
<td>M3 Epoxy</td>
<td>-74%</td>
<td>-33%</td>
<td>-95%</td>
<td>-87%</td>
</tr>
<tr>
<td>Pavemend SLQ</td>
<td>3%</td>
<td>26%</td>
<td>-60%</td>
<td>-51%</td>
</tr>
<tr>
<td>Pavemend TR</td>
<td>-50%</td>
<td>-8%</td>
<td>-53%</td>
<td>-14%</td>
</tr>
<tr>
<td>Set45 1.7L</td>
<td>-38%</td>
<td>74%</td>
<td>-52%</td>
<td>33%</td>
</tr>
<tr>
<td>Set45 1.9L</td>
<td>-67%</td>
<td>-10%</td>
<td>-56%</td>
<td>21%</td>
</tr>
<tr>
<td>Special Patch</td>
<td>-25%</td>
<td>12%</td>
<td>-50%</td>
<td>-25%</td>
</tr>
<tr>
<td>Type III PC Mortar</td>
<td>66%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Good >0%
- Poor ~ 15%
- Bad <15%

- Even “optimal” materials are susceptible to poor performance due to moisture in substrate
- Acid-etching is not useful for every material interface…
Insight from Lab Tests

- Some materials are designed to expand (fill small holes), but detrimental in “large” repairs
- Strength may not govern… flexure, compliance
- Moisture diminishes bond... Material specific!
- Some materials have high standard deviation…
  - Fast set materials difficult to reproduce (results will vary based on speed of placement, temp, RH, etc).
How sensitive is a repair material to installation? Difficult to replicate “lab” results in the “field”
Summary

• O’Hare has wide range of failures – structural and material
• Identify performance requirements and desirable properties
• Lab work of materials that meet those properties
  – Strength offers “insight” into MOR, $E_c$
  – Bond offers insight to field application:
    • Moisture, surface preparation, temperature, “timing” of placement
  – Shrinkage $\rightarrow$ dimensional stability with substrate
Acknowledgements

• Funding by O’Hare Modernization Program partnership with Center for Excellence for Airport Technology
• Several repair materials donated by Rossi Contractors and Ceratech (Pavemend)
• Research assistants Paul Papazis and Sarah Klarich
Reading List

• Diagnosis of deterioration in concrete structures by the Concrete Society
• ACI 201.1 R-0 Guide for Conducting a Visual Inspection of Concrete in Service
• ACI 224 R-01 Control of Cracking in Concrete Structures
• ACI 364.1 R-07 Guide for Evaluation of Concrete Structure before Rehabilitation
• ACI 503 R93 Use of Epoxy Compounds with Concrete
• ACI 503.5 R-92 Guide for the Selection of Polymer Adhesives with Concrete
• ACI 546.3 R-06 Guide for the Selection of Materials for the Repair of Concrete
• ICRI No. 03372 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays
• ICRI No. 03733 Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces
• ACI E706 RAP Bulletin 7 Field Guide to Concrete Repair Applications: Spall Repair of Horizontal Concrete Surfaces