Summary

- Introduction
- UCPRC research focus areas
- Lessons learned
  - Project design
  - Mix design
  - Construction
- Conclusions
Introduction

- FDR-FA introduced to California in 2000
- International research focus
- California research focus
  - Thick, severely cracked AC
    - “Evolved roads"
  - Road must be open to traffic by dark
  - Mix design limited to ITS test
  - No contractor experience
- First pilot project built in 2001
Summary

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UCPRC Research Focus

- Recycling/sustainability strategic initiative
- Phase 1: FDR-NS and FDR-FA study
  - Literature review
  - Mechanistic sensitivity analysis
  - Field performance assessment
  - Limited accelerated pavement testing
  - Laboratory study
  - Preliminary guidelines and specifications
- Phase 2: FDR-PC and FDR-EE
  - As for Phase 1 (comprehensive dry and wet APT)
  - ME performance models
  - Single guideline for FDR in California
Summary

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Project Design

- Lessons learned on project design
  - All projects must be designed
  - Check variability along project length
    - FWD, GPR, cores, DCP, etc.
    - Understand reasons for earlier failures
Subgrade Stiffness - FWD

Zone A: >45MPa, no improvement necessary
Zone B: 25MPa - 45MPa, improvement required before recycling
Zone C: <25MPa, detailed study and improvement before recycling
Layer Thickness Assessment

![Graph showing layer thickness assessment with zones and digouts marked.](image)

- **Zone A**: >45MPa, no improvement necessary
- **Zone B**: 25MPa - 45MPa, improvement required before recycling
- **Zone C**: <25MPa, detailed study and improvement before recycling
**Project Design**

- Lessons learned on project design
  - All projects must be designed
  - Check variability along project length
    - FWD, GPR, cores, DCP, etc.
    - Understand reasons for earlier failures
  - Drainage and land use
Drainage and Land Use
Drainage and Land Use
Drainage and Land Use

Dry

Wet
Drainage and Land Use

![Graph showing the relationship between stiffness (MPa) and distance (feet) for dry and wet side drains.](image-url)

- **Dry side drain**
- **Wet side drain**
Drainage and Land Use

EFA (MPa)

Rice field

Drainage and Land Use
Summary

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Mix Design

- California mix design based on a comprehensive laboratory test program
  - >4,000 specimens, 8 tons of RAP, ~100 buckets of asphalt binder
Mix Design

- Lessons learned on binders
  - Highly variable in California, depending on crude source(s)
  - Anti-foamants are used (residual effect)
  - Softer binders have best foam characteristics
  - Foamability requirements should be linked to likely pavement temperature during construction
  - Use a consistent procedure for determining half life
Mix Design

- Lessons learned on aggregate
  - Keep lab aggregate temperature above 20°C (68°F)
  - Keep fines content (passing 0.075mm [#200]) at 5 to 12%
    - Moisture sensitive if more than 15%
    - Binder content usually increases with higher fines content
  - Marginal aggregates can break down under multiple recycler passes
Mix Design

- Lessons learned on laboratory test methods
  - Focus on addressing field issues:
    - Know laboratory testing capability
      - ITS test ok with replicates
    - Check traffic management during/after construction
      - Same-day opening to traffic can dictate active filler content
    - Separate asphalt and asphalt-plus-active filler tests
      - Understand influence/role of each
    - Do soaked and unsoaked tests
    - Use soaked test result (not TSR) for mix design
    - Learn from the fracture faces
  - Typical mix in CA = 3% FA + 1.5% cement
Summary

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- Conclusions
Construction - Benchmark
Construction

- Lessons learned on construction
  - Pre-pulverization
  - Equipment issues
  - Training / supervision
Construction

- Lessons learned on construction
  - Pre-pulverization
  - Equipment issues
  - Training / supervision
  - Cement/active filler spreading
Construction – Cement Spreading
Construction

- Lessons learned on construction
  - Pre-pulverization
  - Equipment issues
  - Training / supervision
  - Cement/active filler spreading
  - Temperatures
Construction

- Lessons learned on construction
  - Pre-pulverization
  - Equipment issues
  - Training / supervision
  - Cement/active filler spreading
  - Temperatures
  - Compaction moisture
Construction - Compaction Water
Construction

- Lessons learned on construction
  - Pre-pulverization
  - Equipment issues
  - Training / supervision
  - Cement/active filler spreading
  - Temperatures
  - Compaction moisture
  - Compaction
Construction - Compaction
Construction

- Lessons learned on construction
  - Pre-pulverization
  - Equipment issues
  - Training / supervision
  - Cement/active filler spreading
  - Temperatures
  - Compaction moisture
  - Compaction
  - Quality control
Construction - Quality Control
Summary

- Introduction
- UCPRC research focus areas
- Lessons learned on:
  - Project design
  - Mix design
  - Construction
- Conclusions
Conclusions

- FDR is an excellent rehabilitation strategy (state, county and city)
- Projects can go wrong, but the FDR approach is not usually to blame
- Important to capture learning in guidance documents, specifications, and training
Thank you!
FDR in Texas: Lessons Learned from FDR projects on Expansive Clays

Tom Scullion
Texas A&M Transportation Institute

Critical Issues

1. Handling Project variability
2. Problems on expansive soils
3. Early opening of FDR projects in Energy Sector
Critical Steps in the FDR process

1. Assembling Background Information
2. NDT Evaluation and Section Breakdown
3. Verifying Pavement Structure and Sampling
4. Laboratory Mix Design - Stabilizer Selection
5. Pavement Thickness Design
6. Special Considerations in final design
   1. Expansive High PI Soils
   2. Ensuring Surface bonding
   3. Microcracking
   4. Early Traffic
   5. Sulfates
   6. Cold Weather
7. Construction Quality Assurance
8. Feedback - addressing Performance problems
Assembling Background Information
Using the Web Soil Survey

- Press the green “start WSS” button
- Define the Area of Interest (AOI)
- Use Soil Map for soil series information
- Use the Soil Data Explorer for use limitations and soil properties (such as plasticity index or sulfate content)
  - Maps are generated and can be printed or saved
### Summary by Map Unit — La Salle County, Texas (TX283)

<table>
<thead>
<tr>
<th>Map unit symbol</th>
<th>Map unit name</th>
<th>Rating (percent)</th>
<th>Acres in AOI</th>
<th>Percent of AOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BZB</td>
<td>Brystal very fine sandy loam, gently undulating</td>
<td>11.0</td>
<td>124.5</td>
<td>3.1%</td>
</tr>
<tr>
<td>CBG</td>
<td>Calvo very fine sandy loam, gently undulating</td>
<td>9.8</td>
<td>67.5</td>
<td>1.7%</td>
</tr>
<tr>
<td>CDB</td>
<td>Chacon clay loam, gently undulating</td>
<td>27.6</td>
<td>16.7</td>
<td>0.4%</td>
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<tr>
<td>CEB</td>
<td>Charco-Altica complex, nearly level</td>
<td>20.9</td>
<td>9.6</td>
<td>0.2%</td>
</tr>
<tr>
<td>Ch</td>
<td>Cochina clay, occasionally flooded</td>
<td>36.5</td>
<td>417.3</td>
<td>10.5%</td>
</tr>
<tr>
<td>CUA</td>
<td>Cotulla clay, nearly level</td>
<td>37.5</td>
<td>1,623.1</td>
<td>40.0%</td>
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<tr>
<td>DLC</td>
<td>Dilley fine sandy loam, gently undulating</td>
<td>7.3</td>
<td>80.3</td>
<td>2.0%</td>
</tr>
<tr>
<td>LAB</td>
<td>Lasalle clay, gently undulating</td>
<td>37.5</td>
<td>103.9</td>
<td>2.6%</td>
</tr>
<tr>
<td>MCC</td>
<td>Maverick clay, gently undulating</td>
<td>31.6</td>
<td>616.9</td>
<td>15.5%</td>
</tr>
<tr>
<td>MGC</td>
<td>Moglia clay loam, gently undulating</td>
<td>25.8</td>
<td>41.6</td>
<td>1.0%</td>
</tr>
<tr>
<td>Pt</td>
<td>Poteet very fine sandy loam, occasionally flooded</td>
<td>6.1</td>
<td>21.6</td>
<td>0.5%</td>
</tr>
<tr>
<td>W</td>
<td>Water</td>
<td>8.8</td>
<td>8.8</td>
<td>0.2%</td>
</tr>
<tr>
<td>WCB</td>
<td>Webb very fine sandy loam, gently undulating</td>
<td>13.2</td>
<td>492.4</td>
<td>12.4%</td>
</tr>
<tr>
<td>ZVB</td>
<td>Zavo sandy clay loam, gently undulating</td>
<td>19.3</td>
<td>345.0</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

**Totals for Area of Interest**

|                | 3,969.3 | 100.0% |

---

**Section 1**

- High PI clay soils at east of SH 97
NDT Evaluation and Section Breakdown

• GPR
  – Estimate structure and thickness variability
  – Identify section breaks
  – Choose sample locations

• FWD
  – If structural problems suspected
  – Strength variability, subgrade stiffness
Example GPR Profile
Verifying Pavement Section and Sampling

- Use history and NDT to select locations
- Sampled by auger for layer thickness verification and for laboratory design
- Augur gradation similar to that under reclaimer
Lab Testing:

• Run PI, OMC, MDD, Sulfates,

• Strength design: Move to small samples to
  • Handle project variability
  • Vary add rock
  • Evaluate multiple stabilizers
Performance Problems with FDR Projects

- Edge Drying—clay
- Too little stabilizer
- Debonding
- Too Much stabilizer
- Poor Distribution
- Wrong Stabilizer
Expansive Clay
Longitudinal Cracking Problems
Causes of Longitudinal Cracking (Mid 1990’s survey)

- Cracks Originating in Subgrade where:
  - PI > 35
  - Trees near edge
  - Summer droughts
  - Stiff bases
  - Steep Side slopes
  - Lack of edge support
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

http://drought.unl.edu/dm
Proposed Typical Section showing Geogrid (mid 1990’s, Darlene Goehl)
FM 1915 – Reconstructed in 1997 Bryan District
USDA Service Soil Survey Map

All sections have 10” lime treated subbase (5% lime) and seal coat surface.
Fm1915 – 5 & 16 years after reconstruction

distances measured from Little river relief bridge

GEOGRID SECTION 1
0.65 MILES

GEOGRID SECTION 2,
2.2 miles
Fm1915 – 5 & 16 years after reconstruction

distances measured from Little river relief bridge

CONTROL SECTION,
1.3 miles

2001

CONTROL SECTION,
0.83 MILES

2001

2013

2013
TxDOT Design Approach
(Darlene Goehl Bryan District)

- Utilize the U.S.D.A maps to identify possible problem soils. Define testing locations based on this information.
  - This is in addition to the District’s standard one mile testing frequency.
- Perform soils tests to a depth of seven feet below the pavement.
  - This depth is based on the moisture fluctuation within the district.
- Define the limits of potential problem areas based on the soil testing.
- Analyze the FWD data, looking for areas of weak subgrade.
- Drive the project and look for existing problems and areas maintenance has already repaired.
- Combine all the information to define the limits of Geogrid reinforcement.
Repairing Energy Sector Roads with FDR.

FM 99 Corpus Christi District Summer 2014
Challenges Repairing Roads in the Energy Sector

• Thin weak pavements with often marginal materials
• Exceptionally heavy traffic operating 24/7 - many overloads
• No detours: roadway must be opened at end of work day
• Traditional approaches not working
FM 99  Combined Effort
• TxDOT Corpus Christi
• TTI
• Wirtgen Inc.

Up-front Testing and lab Design by TTI
Roadway widened 3 ft on either side
Add base 4 inches
Stabilize with 1.5% cement and 2.4% Foamed Asphalt
Final surface 2 CST

State of The Art Reclaimer provided by Wirtgen
Wirtgen supervised construction
Application of Cement/Foamed asphalt

11 Inch one pass 1.5% cement/2.4% asphalt

Final surface 2 CST

Traffic Allowed on section 1 hour after compaction
### FM 99 Open for Business

<table>
<thead>
<tr>
<th>FM 99 Section Cement/ Foam Asp section</th>
<th>Average Deflection @9000 lbs. (mils)</th>
<th>Backcalculated Base Modulus (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 weeks</td>
<td>10.0</td>
<td>495</td>
</tr>
<tr>
<td>6 weeks</td>
<td>10.1</td>
<td>433</td>
</tr>
</tbody>
</table>
Recommendations to Date from FM 99

- Foamed asphalt appears viable solution – holds up under early trafficking
- Treatment appears moisture resistant – section while under traffic received 4 in. of rain without damage before placing final surface
- Foam asphalt requires full engineering evaluation with upfront testing, sampling, and lab design
- More testing to arrive at design Modulus – after 2 weeks value of over 400 ksi found
Special Thanks to TxDOT Staff

Research and Technology Transfer Division, Austin

Darlene Goehl  Area Engineer Bryan District
Oscar Soliz  Area Engineer Corpus Christi District
Valente Olivarez Director of Construction Corpus
Long Term Performance of Full Depth Reclamation (FDR) with Expanded (Foamed) Asphalt in Cold Regions

Becca Lane, P.Eng.
Materials Engineering and Research Office
Ministry of Transportation Ontario, Canada
Outline

○ Introduction
○ Advantages of Full Depth Reclamation (FDR) with expanded (foamed) asphalt
○ Hwy 17, Wawa demonstration project
○ Long term performance
○ Other projects
○ Conclusions
Introduction


- This presentation focuses on the results of long term performance monitoring of that project and highlights the performance of subsequent projects.
Project Location is in a Cold Region!!

- Highway 17 within the boundaries of Lake Superior Provincial Park.
- Project length 22.5 km
Typical winter…
Why use Expanded Asphalt Stabilization (EAS)?

- Need to conserve natural resources
  - No aggregate extraction within park boundaries
  - EAS pulverizes and reuses existing materials, uses asphalt stabilization to strengthen the granular base, and saves a lift of hot mix asphalt

- In place process reduces transportation of materials
  - Trucking, energy and emissions reduced

- Previous challenging experience in the local area with CIR
  - Moisture-related concerns in cool, damp, foggy microclimate – difficult to cure and remove moisture from CIR mat
Pavement Design

- In-place full depth reclamation (FDR) of the existing HMA and granular base to a depth of 200 mm
  - 50:50 blend, max size 26.5 mm

- Stabilize reclaimed material by adding 2.8-3.0% expanded (foamed) asphalt:
  - In this process, a small amount of cold water is added to hot asphalt cement causing it to rapidly expand (foam). The foamed asphalt is uniformly mixed into the reclaimed materials.

- Grading/placing and compacting

- 80 mm HMA overlay placed following a minimum 2 day curing period
Crossfall correction
Long Term Performance
ARAN Monitoring

- To monitor pavement performance, MTO carried out annual ARAN testing:
  - Roughness (IRI) and rutting surveys
  - Visual distress data collection (DMI)
    - IRI & DMI used to calculate Pavement Condition Index (PCI)
IRI Comparison of Expanded Asphalt Various Mixes 2002-2013

- Avg IRI Entire Hwy
- Avg IRI Mix 1
- Avg IRI Mix 2
- Avg IRI Mix 3
Summary of Long Term Performance (Hwy 17, Wawa)

- Results of ARAN surveys carried out in the years following construction found that the pavement has remained smooth (IRI<1) and in excellent condition (PCI>85) after 10 years in service.
- The three different mix designs, two with corrective aggregate and one without, performed similarly over the 10 year period.
- A control section of FDR with 80 mm HMA overlay started off with similar performance but deteriorated at a much faster rate.
International Roughness Index (IRI) Comparison of 3 Treatments on Hwy 17 near Wawa, Ontario
Pavement Condition Index (PCI) Comparison of 3 Treatments on Hwy 17 near Wawa, Ontario
IRI Performance of 100 Full Depth Reclamation Contracts

The chart shows the IRI (International Roughness Index) performance of 100 full depth reclamation contracts over a period of 10 years. The IRI values range from 0.95 to 1.49, with a steady increase as the age of the contracts increases from 1 year to 10 years.
10 Year International Roughness Index (IRI) Comparison of FDR performance curve to FDR with EA (Wawa)
Pavement Condition Index (PCI) Comparison of FDR performance curve to FDR with EA (Wawa)
Results also indicate that the EAS with a two lift HMA overlay rehabilitation strategy performed better than adjacent CIR and FDR projects.

Performance of the Hwy 17, Wawa EAS project was compared to the ministry’s established IRI and PCI performance curves for FDR with HMA overlay:

- the FDR with EAS is outperforming the average FDR project both in terms of roughness (IRI) and pavement condition (PCI).
10 Other Projects

- MTO’s first FDR with Expanded Asphalt project was in 2001 and more than 10 projects have been carried out since.
Introduction of “Paver Laid” EAS
Introduction of “Compacting Paver”

2003
Addition of Lime

2004
Some issues with over-asphalting
Experiment with Widenings
10 Year International Roughness Index (IRI) Comparison of FDR performance curve to FDR with EA (10 contracts) to FDR with EA (Wawa)
Pavement Condition Index (PCI) Comparison of FDR performance curve to FDR with EA (10 contracts) to FDR with EA (Wawa)
Conclusions

- FDR with expanded (foamed) asphalt stabilization has been shown to provide an acceptable in-place recycling rehabilitation strategy that conserves natural resources and provides an economic alternative to conventional FDR with HMA overlay, particularly in areas where aggregates are in short supply.
Thank you!

Becca Lane, P. Eng.
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Ministry of Transportation Ontario
Tel: 416-235-3512

email: Becca.Lane@ontario.ca
Lessons Learned from Using FDR on Virginia DOT Highways

Brian Diefenderfer, PhD, PE
Overview

• Agency methods to begin using FDR
  – Specifications
  – Guidelines

• Research to extend use of FDR
  – Long-term performance monitoring
  – Instrumented pavements
  – Laboratory testing
Pavement Recycling

• A set of cost-effective and environmentally sensitive techniques for pavement rehab

• Benefits
  – 30 to 50 percent cost savings
  – 50 percent less greenhouse gases emitted
  – Fix deterioration causes rather than symptoms

• Used by VDOT
  – Full-depth reclamation, cold in-place recycling, cold central-plant recycling
Full-Depth Reclamation

• Mechanical stabilization
  – Additional aggregate or RAP

• Asphalt stabilization
  – Foamed asphalt
  – Emulsified asphalt

• Chemical stabilization
  – Cement
  – Lime
  – Fly ash (type C or F)
  – Cement / lime kiln dust
VDOT Pavement Recycling History

• Pre-2008
  – Regional focus, no monitoring

• 2008-2011
  – 8 projects, 2-year FDR study
  – I-81 project
  – NCAT test sections constructed

• 2012-today
  – Specs and usage guidelines
  – NCAT test sections continuation
Specifications

• Experience requirement
• Quality control plan
  – Corrective action list
• Acceptance requirements
  – Field density
  – Stability / indirect tensile / compressive strength
  – Gradation
  – Depth
  – Stabilizing agent dosage

Maximum!
Specifications

• Mix design
• Recycling equipment
  – Roller weights, etc.
• Test strip construction
• Weather limitations
Guidelines

• Length of project
• Distress rating
• Maintenance history
• Overlay thickness requirements
  – Generally meet SN calculations
  – 2-course overlay on interstate
  – May specify thickness for given traffic levels
• Directives / carrots
  – First consideration for greater than 4 inches?
  – Dedicated pot of funding
I-81

• 23,000 AADT
• 28% trucks
• 7.2 lane miles
• Constructed 2011
### I-81

<table>
<thead>
<tr>
<th>Material</th>
<th>Right Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-inch New AC</td>
<td></td>
</tr>
<tr>
<td>8-inch CCPR</td>
<td></td>
</tr>
<tr>
<td>12-inch FDR</td>
<td></td>
</tr>
<tr>
<td>Subgrade</td>
<td></td>
</tr>
<tr>
<td>6-inch New AC</td>
<td></td>
</tr>
<tr>
<td>6-inch CCPR</td>
<td></td>
</tr>
</tbody>
</table>

**Right Lane**
Using What We Learned – I-81

• Recycling performs well on a high volume road

• Summer 2014 (4 years), excellent performance
  – ~ 7 million ESALs in the right lane
  – Rutting less than 0.1 inches
  – Ride quality range = 45-55 inches/mile

• Layer coefficients from this project (lab & field)
  – FDR + CCPR ~ 0.37
  – CCPR range = 0.36 to 0.44
  – CIR range = 0.35 to 0.39
NCAT

- 10 million ESALs applied in 2 years
- Constructed 2012
Using What We Learned - NCAT

• Recycling performs well on a high volume road
• No cracking at 11.5+ million ESALs
• Ride quality steady
• Rutting < 0.25 inch

• Is FDR section perpetual?
  – Presence of stabilized base reduced strain by 80% for same overlay thickness
  – Will a recycled layer behave the same as an AC material at low strain levels?
NCAT

• 17 inches manipulated
  – Layer 1 = 12.5% recycled
  – Layer 2 = 30% recycled
  – Layer 3 = 100% recycled
  – Layer 4 = 100% recycled

• Entire cross section
  – 80% recycled

• Perpetual section for reconstruction?

S12

4-inch AC
5-inch CCPR
8-inch FDR
Subgrade
NCHRP 9-51

- **Material Properties for CIR and FDR for Pavement Design**

- Cores from 24 projects

- Partners
  - Univ of Maryland
  - Virginia DOT
  - Wirtgen
  - Colas Solutions
NCHRP 9-51

![Graph showing the relationship between dynamic modulus (MPa) and reduced frequency (Hz) for different materials with and without chemical additives at higher and lower temperatures.](image-url)
Summary

• FDR can be a successful part of a high-truck volume pavement

• FDR provides a significant stiffening effect
  – Perpetual performance?
    • If what we know about asphalt pavements is transferable, “yes”