Soil Cement Roads
Richland County MT

20th Annual NRRA Pavement Conference
St. Paul, MN
February 18th, 2016

Russell Huotari, Richland Co Public Works Director
Steve Monlux, USFS Retired
LVR Consultants, LLC
stevemonlux@gmail.com
William Vischer, USFS Retired

For Current Report, Google “soil cement montana”
Presentation Topics

• The Problem:
• Structural Design Options
• Performance Measurements
• Life Cycle Cost Comparisons
• Soil Cement Construction & Repair
• Conclusions & Recommendations
The Problem

• Heavy Truck Traffic on Weak Soil Roads
  – 50,000 ESAL’s per well (development, fracking, crude and produced water haul)
• Truck ADT & Weight Unknown
• Over 100 miles of oil field arterials
• Limited Budget
• Limited Rock Resources
Richland Co Road Network & Resource Impacts

Oil Development, Wheat, Gravel Roads

Missouri River

Richland County Border

Population Center, Beet Farms, Gravel Resources

56 mi

Yellowstone River

Montana

North Dakota
Approach to Problem

• Staff a Group to develop options
• Design structural sections
  – Subgrade strengths
  – Truck traffic
  – Available materials
• Build trial sections that have low initial cost
  – Falling Weight Deflectometer (FWD) Test (Montana Non-Destructive Test Unit)
  – Back calculate ESAL life, develop thickness design process (William Vischer, USFS Retired)
  – Develop repair options for problems that develop
Weak Soils (CBR of 1 to 3 typical)

5” Asphalt, + 8” Base (15 yrs old) 3” Scoria, old gravel base (after 3 months)
Weak Clay/Silt Subgrade Soils

Thin gravel layers mix with subgrade

Gravel

Gravel with Fabric & Geogrid

Standard Pavement Design

Gravel with Fabric

Fabric

Geogrid

Hot Mix

Crushed Gravel

Subgrade

Gravel $ Too High
Asphalt & Aggregate Designs ~ 2006 to 2014

Standard Hot Mix Designs

Structural Layers

2006 ($1 M/mi)
- 5” Hot Mix
- 8” Crushed Gravel Base

Subgrade Soil

2009
- Double BST
- Gravel Base – 8” Thick (2009)
- 10” Thick (2010)

~ Subgrade Soil

Thin BST on Base Designs

Structural Layer (4” Lift of gravel stabilized with BASE 1)

2009

~ Subgrade Soil

Double BST

2009

~ Subgrade Soil

2006 ($1 M/mi)
- 5” Hot Mix
- 8” Crushed Gravel Base

Subgrade Soil

2009
- Double BST
- Gravel Base – 8” Thick (2009)
- 10” Thick (2010)

~ Subgrade Soil

2009

~ Subgrade Soil

2014 ($3 M/mi +)
- 7” Hot Mix
- 8” Crushed Gravel Base
- 17” Pit Run Gravel

Fabric
2010 Designs

BST over 10” Gravel Base

$400,000/mile

Water infiltration to Clay Subgrade is close to structural support area

Edge cracking & break off mtc. problems

BST over 8” Soil Cement

$250,000 /mile

Harder support from soil cement reduces damage from large rock punctures

Flatter wider shoulder is less of a hazard

Wide impermeable shoulder keeps surface water further away from critical structure support area.
What is Soil Cement?

Cement-Based Pavement Materials

- Roller-Compacted Concrete
- Pervious Concrete
- Conventional Concrete
- FAA Econocrete P-306
- Full-Depth Reclamation
- Cement-Modified Soil
- Cement-Treated Base
- Flowable Fill

Cement Content vs. Water Content

- FAA Cement-Treated Base/Subbase P-301 & P-304
- No Wearing Course Required
- Wearing Course Required

2/29/2016

Copyright Monlux/Vischer 2016
Concerns with Clay Soil Cement

- Life
- Low cost driving surface
- Repair methods for semi-rigid layer
- Accurate thickness design process
- Clay pulverization
- Deep layer compaction
- Curing in windy climate
Soil Cement Designs – Typical Sections

2010
Soil Cement, 8” to 12” thick
5% to 8% Cement

Designs modified after FWD testing in spring and fall

2011
Soil Cement, 10” thick, 8% Cement

2012-13
Soil Cement, 12” thick, 6% to 7% Cement
Soft Subgrade Designs

2011

Soil Stabilization, 12” thick, 10% Cement

CBR = 1

2012 & 2013

Soil Stabilization, 12” thick, 6% to 7% Cement
Soil Modification, 18” thick, 3% Cement

CBR = 1

Soft Spot Location
2011: (5%) Proof Rolling & DCP
2012: (15%) Intelligent Compaction Roller & DCP
2013: (15%) Ground Penetrating Radar & DCP
Long Term Strength of Soil Cement

Designs should assume $E_p$ will be reduced by 20% to 40% over time (Bill Vischer, Nov 2014)
Soil Cement Thickness Design (Bill Vischer)

**Thickness Design Outline:** Page one provides an example solution with a step by step process that uses graphs shown on page two and three. Page 4 is a blank form of page one that should help keep the process organized.

### Thickness Design Steps with an Example

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Design Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1:</strong></td>
<td>Assume a design traffic ESAL value.</td>
<td>ESAL: 1,000,000</td>
</tr>
<tr>
<td><strong>Step 2:</strong></td>
<td>Determine subgrade modulus. Use either a DCP and charts, or FWD &amp; DCP (preferred option) for the average deflection directly under a 6,000 lb load ($D_o$) from tests conducted in the Spring season. Use Graph 1 to determine Subgrade Mr from FWD maximum deflection, $D_o$.</td>
<td>Subgrade Mr, psi: 3000</td>
</tr>
<tr>
<td><strong>Step 3:</strong></td>
<td>Use Graph 2 to determine allowable subgrade strain for the design ESAL.</td>
<td>Max Subgrade Microstrain: 480</td>
</tr>
<tr>
<td><strong>Step 4:</strong></td>
<td>Use Graph 3 to determine maximum allowable stress ratio for the Soil Cement layer based on design traffic ESAL.</td>
<td>Max Stress Ratio: 0.60</td>
</tr>
<tr>
<td><strong>Step 5:</strong></td>
<td>Use Graph 4 and the maximum subgrade strain to identify options of soil cement layer thicknesses possible for the design Subgrade Mr. Thicknesses correlating for $E_{sc}$ between 100 and 200 are suggested.</td>
<td></td>
</tr>
<tr>
<td><strong>Step 6:</strong></td>
<td>Use Graph 5 to determine the minimum cement content for each acceptable design option.</td>
<td></td>
</tr>
<tr>
<td><strong>Step 7:</strong></td>
<td>Use Graph 6 to determine the maximum stress ratio to determine which options from Step 5 are acceptable.</td>
<td></td>
</tr>
<tr>
<td><strong>Step 8:</strong></td>
<td>Selecting the best option requires engineering judgment when consideration of the following criteria.</td>
<td></td>
</tr>
<tr>
<td><strong>Step 9:</strong></td>
<td>Recommendations:</td>
<td></td>
</tr>
<tr>
<td>Alternative A:</td>
<td>Pretreat all known weak areas with 3% cement to 18&quot; depth to raise the average subgrade Mr, followed by 12% treatment @ 8% Cement.</td>
<td></td>
</tr>
<tr>
<td>Alternative B:</td>
<td>Treat 12&quot; depth at 8% Cement and lower Design Traffic ESAL value from 1,000,000 to 750,000.</td>
<td></td>
</tr>
</tbody>
</table>

**Design Process will be field validated and refined 2016-17**

<table>
<thead>
<tr>
<th>Design Option</th>
<th>Thickness, inches</th>
<th>$E_{sc}$, psi</th>
<th>Subgrade Mr</th>
<th>Maximum One Layer depth equals 12&quot;. Two layers increase cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>&gt;100</td>
<td>OK at any $E_{sc}$</td>
<td>5.3</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>&gt;140</td>
<td>OK at any $E_{sc}$</td>
<td>6.8</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>&gt;170</td>
<td>OK at any $E_{sc}$</td>
<td>8.8</td>
</tr>
<tr>
<td>4</td>
<td>&lt;12 won't work</td>
<td>8&quot; won't work</td>
<td>No</td>
<td>8&quot; won't work</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Soil Cement Thickness Design (Con’t)

Graph 1. Subgrade Mr vs Max Deflections
(From CR 351 Tests on Subgrade)

Graph 2. Subgrade Strain VS ESALS

Graph 3. Stress Ratio vs ESALs

Graph 4. Soil Cement ($E_{sc}$) VS Subgrade Strain

Graph 5. Soil Cement ($E_{sc}$) VS Soil Cement Stress Ratio

Graph 6. Soil Cement ($E_{sc}$) VS Cement Content

$y = 0.0208e^{0.038t}$
$R^2 = 0.9995$
## Estimated Annual Cost Comparisons

<table>
<thead>
<tr>
<th>Road Design Option</th>
<th>Average Estimated Life from FWD Data</th>
<th>Approximate Cost per Mile (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ESAL Life</td>
<td>Years (b)</td>
</tr>
<tr>
<td>Road Surface</td>
<td>Support Structure</td>
<td></td>
</tr>
<tr>
<td>5&quot; Hot Mix</td>
<td>8&quot; Base</td>
<td>1,150,000</td>
</tr>
<tr>
<td>Double BST</td>
<td>10&quot; Base</td>
<td>100,000</td>
</tr>
<tr>
<td>Double BST</td>
<td>12&quot; Soil Cement</td>
<td>500,000</td>
</tr>
<tr>
<td>Double BST</td>
<td>3&quot; Gravel on 12&quot; Soil Cement</td>
<td>2,000,000</td>
</tr>
<tr>
<td>4&quot; Treated Gravel</td>
<td>12&quot; Soil Cement</td>
<td>2,000,000</td>
</tr>
</tbody>
</table>

(a) Costs are very project specific
(b) Based on 200 trucks/day, 50,000/yr (150,000 ESAL/yr)
(c) Classic case of under designed structural section for the selected ESAL/year traffic
(d) Primarily gravel replacement - WAG

Consider other issues with the Soil Cement option
Soil Cement Construction

- Road Preparation
- Cement Spreading
- Mixing Cement & Water
- Compaction
- Final Shaping & Compaction
- Curing & Surface Construction
1. Rebuild Crown

2. Blade up shoulder & center line berm

3. Rip Surface to control cement flow

4. Spread cement
Mixing, Compaction & Finishing

- Water to Hydrate Cement
- Reclaimer to pulverize soil and mix soil, water & cement
- Pad Foot Roller for Compaction
- Blade Rebuilds Crown
- Spread Cement
- 25 Ton Rubber Roller for Finish
Uneven Moisture/Compaction

Problem solved in 2013 by mix chamber cleaning after each cement spread
Clay Pulverization Problems

Pulverization increased by: slower ground speed, multiple passes, higher drum speeds, and closing mix chamber doors.
Double Chip Seal (2011-12)

First Seal on Soil Cement

Second Seal on top of First Seal
## Surfacing on Soil Cement

<table>
<thead>
<tr>
<th>Year</th>
<th>Double BST</th>
<th>BST on 3” Gravel</th>
<th>3” HMA on 3” Base</th>
<th>4” Treated Gravel (Bentonite &amp; CaCl₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1.75</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2011</td>
<td>24</td>
<td>0.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2012</td>
<td>12</td>
<td>0</td>
<td>0.4</td>
<td>12</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
<td>4.8</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Build $</th>
<th>Low</th>
<th>Moderate</th>
<th>Highest</th>
<th>Moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Est. Mtc. $</td>
<td>Moderate</td>
<td>Low</td>
<td>Lowest</td>
<td>Moderate (Blading, Chloride, Rock)</td>
</tr>
<tr>
<td>Estimated Life Cycle $</td>
<td>Moderate</td>
<td>Low?</td>
<td>Low?</td>
<td>Moderate?</td>
</tr>
</tbody>
</table>
Treated Gravel Surfacing (1 yr. old)

Treated Gravel (3% Bentonite, 1.5% Calcium Chloride)

Bentonite reduces chloride leaching, chloride reduces Bentonite dusting
Soil Cement Quality Assurance

QA Costs depend on Contractor, site conditions, weather, etc

• Cement application rate
• Pulverization
• Depth of mixing
• Moisture content during mixing
• Compaction
• Surface finish crown and profile
• Curing
Extent of Soil Cement Structural Repairs

<table>
<thead>
<tr>
<th></th>
<th>2011 (24 miles)</th>
<th>2012 &amp; 13 (30 Miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Surface Area, SY</td>
<td>394,240 SY</td>
<td>492,800 SY</td>
</tr>
<tr>
<td>Total Repair Surface Area</td>
<td>9,878 SY</td>
<td>1,418 SY</td>
</tr>
<tr>
<td>% of Total work (1)</td>
<td>2.5 %</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

(1) Note that the relative amounts of truck traffic are unknown

Repairs for 2012 & 2013 work is less because
- Better control of cement flow/content
- Better control of pulverization and moisture content
- Increased design thickness – 10” vs. 12”
- Soft Spot Treatment ~ more treated (15% vs 5% of road area), deeper treatment (12” vs. 18”)

2/29/2016

Copyright Monlux/Vischer 2016
Problems with 2011 Work

Otta Seal Bleeding

Compression Failures

QA/QC – Soil Pulverization & Cement Uniformity

Low cement content on 5 ft shoulder

Note: Repair patch of 5” Hot mix & 15” Base rutted after 6 months

12 inch stabilization depth inadequate for very soft subgrade

Soil cement compression failure due to excessive flexure
BST “Pick-up” Problems (2011)
(caused by stopping vehicles on bleeding BST)

Problem Area  Solution: Spray patch, UPM or Omega Mix patch

Cold UPM Patch Material
Road 321 BST Shoving/Tearing (2011)

Repair Methods:
No Depression Area:
Remove BST & fabric, new BST full width

Depression Area: Re-soil cement, 3” Gravel & BST Full width
Damage by 200 Ton Oil Rig Movement (2011)

Re soil cement or cover with 3” gravel & BST full width

Lt Lane 2 day cure

Rt Lane 5 day cure
Pot Hole at Soil Cement Transverse Joint (2011)
(Caused by low cement content)

1 yr. Fix? (UPM Type cold mix patch)
Long Term Fix (Re-mix with Portland Cement, add 3” Base & BST)
Depressed/Rutted Areas (2011) (Caused by low cement content)

Full Depth Reclamation with additional Portland Cement

Use Pick Axe to determine FDR area
Repair Options for Structural Problems

Depressions caused by low cement content
- Full Depth & Width Reclamation with more cement, gravel base and BST

Compression Failures from Flexure
- Reinforce with 4” Gravel Base & BST
Proposed Strategy for Improving Unpaved Arterial Roads

• Year 1: Cement stabilize soft spot areas on gravel roads
  – 18 inch treatment depth
  – 3 inch gravel surfacing

• Year 2: After all soft spots stabilized
  – Cement stabilize 12 inch depths,
  – Add 3 inch base
  – Double chip seal or 3 inch hot mix asphalt

• Re-stabilize any failed areas with at least 5% more cement
Conclusions/Recommendations

Costs: Soil Cement cost effective where:
Rock costs are high,
Soils are suitable,
Road widths are marginal

Design thicknesses based on truck traffic, subgrade strength, etc.
Conclusions/Recommendations

• Construction and Maintenance
  Google: “Soil Cement – Montana”

• Other Resources
  Wirtgen Cold Recycling Technology Manual

  TRB – “Recommended Practice for Stabilization of Subgrade Soils and Base Materials”

  Soil Stabilization for Pavements UFC 3-250-11 (TM 5-822) Transportation Research Board publications

Thank You!

Questions or Comments?