Applications of Lightweight Foamed Concrete Fill in Sioux City, Iowa

Presented By:
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Iowa Section
Presentation Outline

1. Project Background
2. Existing Condition
3. Subsurface Information
4. Design Methodology
5. Construction Recommendations and Issues
Project Background
Project Background

- Located in Sioux City, Iowa
- Existing I-29: 4 lane facility with 2 lanes in each direction.
- Final configuration: 3 lanes in each direction.
- Site constraints:
  - Adjacent to Big Sioux and Missouri River on the west and railroad, loess bluffs on east
  - City owned bike path
  - DOT is responsible for stability of the roadway as well as the City owned bike path
Project Background

• Design proposed: MSE walls along the west edge to accommodate additional lanes.
  – 2 MSE walls, each about 2000 feet long and about 22 feet high (exposed face) with relocated bike trail at the front of the walls.

• Original roadway composed of miscellaneous fill and widened section is predominantly sand.

• Evidence of slope instability along the bluffs as well as along the area adjacent to the river.
Project Background
Project Background

• Evidence of slope instability was observed during site visit in 2009.
• Existing trail had 2H: 1V foreslope and was constructed as a RSS.
• Majority of roadway and trail constructed in 1960s by filling in the Big Sioux River.
Existing Conditions
Subsurface Information

• Subsurface exploration: 59 borings
• Sampling: SPT, Shelby tubes and bag samples.
• Drilled primarily along wall alignments with a few at the east side of I-29
Subsurface Information

- **Sandy Silt/Clay (Fill)**
  - 2.5 to 14 ft thick
  - Misc. fill (wood, rock)
  - 5 to 50+bpf

- **Sand/Silt (alluvium)**
  - 8.5 to 50+ ft
  - 7 to 20 bpf

- **Stiff/Very Stiff Silty Clay**
  - 10 to 45 ft
  - 15 to 35 bpf

- **V. Dense P. G. Sand**
  - 18 to 50 bpf

- **Groundwater varies per Big Sioux River levels. (3ft to 26 ft from river bottom)**

### Table 2: Recommended Design Parameters

<table>
<thead>
<tr>
<th>Layer</th>
<th>UW (pcf)</th>
<th>Strength Type</th>
<th>c (psf)</th>
<th>φ (deg)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embankment Fill and Soil Type 1</td>
<td>120</td>
<td>Mohr-Coulomb</td>
<td>600</td>
<td>12</td>
<td>Iowa DOT guidelines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drained</td>
<td>600</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Soil Type 2</td>
<td>120</td>
<td>Cohesionless</td>
<td>-</td>
<td>30</td>
<td>Conservative value.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drained</td>
<td>-</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Soil Type 3</td>
<td>120</td>
<td>Undrained</td>
<td>600</td>
<td>-</td>
<td>Conservative value, assumed to increase at a rate of 20 psf/ft to a maximum value of 1200 psf, drained values from CU test in nearby borings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drained</td>
<td>250</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Soil Type 4</td>
<td>125</td>
<td>Cohesionless</td>
<td>-</td>
<td>37</td>
<td>Very Dense Sand, Conservative value assumed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drained</td>
<td>-</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

Regular MSE backfill values: UW = 125pcf, infinite strength in reinforced zone and φ = 32 degrees for granular backfill in temporary excavation.

LWFC design values: UW = 40psf, infinite strength in entire fill area comprising reinforced zone and temporary excavation.
Design Methodology

• Use of light Weight Fill Material Either due to Settlement Concern or Stability Concern or both Concerns

• Primary concern was to avoid causing slope failure in trail as result of additional fill for roadway.

• Analyses compared regular MSE Backfill and LFCF
  – Portion of wall adjacent to Big Sioux also compared with SPL in place of MSE.

• Decision was made to use lightweight fill to minimize the additional driving force.
Design Methodology

MSE Wall Criteria: FHWA-NHI-00-043

- Sliding: \[ FS \geq 1.5 \]
- Eccentricity, \( e \), at base: \[ \leq \frac{B_{MSE}}{6} \]
- Bearing Capacity: \[ FS \geq 2.5 \]

Additionally a FS of 2.0 or greater was used analyze the wall against overturning failure. The minimum width of the wall was limited to 8 feet with 4 feet embedment in accordance with IowaDOT guidelines.

\[ FS \geq 1.3 \] for slope stability (Iowa DOT)
Lightweight Foamed Concrete Fill (LFCF)

- LFCF is essentially a cement-sand grout with foaming agent causing a higher void content, i.e. foamed concrete.

<table>
<thead>
<tr>
<th></th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Cast Density</td>
<td>480 kg/m³ (30 pcf)</td>
<td>580 kg/m³ (36 pcf)</td>
<td>670 kg/m³ (42 pcf)</td>
</tr>
<tr>
<td>Minimum Compressive Strength @ 28 days</td>
<td>280 kPa (41 psi)</td>
<td>550 kPa (80 psi)</td>
<td>830 kPa (120 psi)</td>
</tr>
<tr>
<td>Coefficient of Permeability (cm/sec) @ 13.8 kPa (2.0 psi)</td>
<td>$1 \times 10^{-5}$</td>
<td>$1 \times 10^{-5}$</td>
<td>$1 \times 10^{-6}$</td>
</tr>
<tr>
<td>Frost Heave per BRRL LR90 (250 hour exposure) 11.43 cm (4.5&quot;) high x 10.16 cm (4&quot;) diameter</td>
<td>&lt;1.25 cm (0.5&quot;)</td>
<td>&lt;1.25 cm (0.5&quot;)</td>
<td>&lt;1.25 cm (0.5&quot;)</td>
</tr>
</tbody>
</table>

ACI 213R-03

Guide for Structural Lightweight-Aggregate Concrete
Reported by ACI Committee 213
Geotechnical Design

• Slope Stability Analyses
  – Existing I-29 and bike path/trail
  – Stage 1 (Full excavation)
  – Final MSE wall\SPL wall section
  – Final MSE wall with LFCF backfill
### Geotechnical Design

**TABLE 3: RESULTS OF SLOPE STABILITY ANALYSES, WALL RW6302**

<table>
<thead>
<tr>
<th>Station</th>
<th>Existing</th>
<th>Stage 1</th>
<th>MSE wall</th>
<th>LWFC</th>
<th>H_{MSE}</th>
<th>B_{MSE}/H_{MSE}</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>circular</td>
<td>block</td>
<td>circular</td>
<td>block</td>
<td>circular</td>
<td>block</td>
<td></td>
</tr>
<tr>
<td>530202+50</td>
<td>0.7</td>
<td>1.9</td>
<td>0.7</td>
<td>3.1</td>
<td>0.7</td>
<td>2.0</td>
<td>7     ft min.  circular through trail FS</td>
</tr>
<tr>
<td>530205+50</td>
<td>0.9</td>
<td>1.6</td>
<td>0.9</td>
<td>2.1</td>
<td>0.9</td>
<td>1.6</td>
<td>10 ft min.  circular through trail FS</td>
</tr>
<tr>
<td>530208+50</td>
<td>0.7</td>
<td>2.9</td>
<td>0.8</td>
<td>2.2</td>
<td>0.8</td>
<td>2.2</td>
<td>9     ft min.  circular through trail FS</td>
</tr>
<tr>
<td>530211+50</td>
<td>0.8</td>
<td>1.3</td>
<td>0.7</td>
<td>1.4</td>
<td>0.7</td>
<td>1.1</td>
<td>14    ft min.  circular through trail FS, SF = 1.1 through MSE (block), 5ft embed, B/H=0.7, 4ft embedment works in LWFC.</td>
</tr>
<tr>
<td>530214+50</td>
<td>0.8</td>
<td>1.7</td>
<td>0.8</td>
<td>1.4</td>
<td>0.8</td>
<td>1.4</td>
<td>14    ft min.  circular through trail FS</td>
</tr>
<tr>
<td>530217+50</td>
<td>1.1</td>
<td>1.9</td>
<td>1.1</td>
<td>1.4</td>
<td>1.1</td>
<td>1.5</td>
<td>14    ft min.  circular through trail FS, sloughing poss. in excavation</td>
</tr>
<tr>
<td>530222+50</td>
<td>1.3</td>
<td>2.3</td>
<td>1.3</td>
<td>1.7</td>
<td>1.3</td>
<td>1.7</td>
<td>13    ft min.  circular through trail FS</td>
</tr>
</tbody>
</table>

**FS** = foreslope  
**SF** = factor of safety  
**LWFC** = lightweight foamed concrete  
**T** = trail

**Stage-1**
### Geotechnical Design

#### TABLE 6: RESULTS OF SLOPE STABILITY ANALYSES, WALL RW6310 (STA. 531000+20 TO STA. 531011+90 AND STA. 53017+25 TO STA. 531020+41.21)

<table>
<thead>
<tr>
<th>Station</th>
<th>Existing</th>
<th>Stage 1</th>
<th>MSE wall</th>
<th>LWFC</th>
<th>H&lt;sub&gt;MSE&lt;/sub&gt;</th>
<th>B&lt;sub&gt;MSE&lt;/sub&gt;/H&lt;sub&gt;MSE&lt;/sub&gt;</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>531001+00</td>
<td>0.8</td>
<td>1.6</td>
<td>0.8</td>
<td>1.8</td>
<td>0.8</td>
<td>1.6</td>
<td>circular through trail FS</td>
</tr>
<tr>
<td>531004+00</td>
<td>1.1</td>
<td>1.4</td>
<td>1.1</td>
<td>1.6</td>
<td>1.1</td>
<td>1.4</td>
<td>circular through trail FS, 0.7H for LWFC</td>
</tr>
<tr>
<td>531007+00</td>
<td>0.8</td>
<td>0.8(T)/1.2</td>
<td>0.8</td>
<td>1.6</td>
<td>0.8</td>
<td>1.2</td>
<td>circular through trail FS, 0.7H for LWFC, 5ft embedment for MSE, SF =1.2 for asbuilt and MSE (block)</td>
</tr>
<tr>
<td>531010+00</td>
<td>1.0</td>
<td>1.4</td>
<td>1.0</td>
<td>1.6</td>
<td>1.0</td>
<td>1.4</td>
<td>circular through trail FS, 0.7H for LWFC, 5ft embedment for MSE</td>
</tr>
<tr>
<td>531019+00</td>
<td>2.0</td>
<td>1.8</td>
<td>2.1</td>
<td>2.5</td>
<td>1.8</td>
<td>1.7</td>
<td>0.7H for LWFC</td>
</tr>
</tbody>
</table>

#### TABLE 9: RESULTS OF SLOPE STABILITY ANALYSES, WALL RW6310 (STA. 531011+60 TO STA. 53017+25)

<table>
<thead>
<tr>
<th>Station</th>
<th>Existing</th>
<th>Stage 1</th>
<th>SPL Wall</th>
<th>LWFC</th>
<th>H&lt;sub&gt;MSE&lt;/sub&gt;</th>
<th>B&lt;sub&gt;MSE&lt;/sub&gt;/H&lt;sub&gt;MSE&lt;/sub&gt;</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>531014+00</td>
<td>0.9</td>
<td>1.5</td>
<td>0.6 (slough)</td>
<td>1.1</td>
<td>0.9</td>
<td>1.3</td>
<td>flood impacted wall, 0.7H for LWFC, circular through trail FS, SPL wall has 20ft embedment</td>
</tr>
<tr>
<td>531017+00</td>
<td>0.8</td>
<td>1.1(T)</td>
<td>0.8</td>
<td>1.3</td>
<td>0.8</td>
<td>1.6</td>
<td>flood impacted wall, 0.7H for LWFC, circular through trail FS, SPL wall has 20ft embedment</td>
</tr>
</tbody>
</table>

FS = foreshore  
SF = factor of safety  
LWFC = lightweight foamed concrete  
T = trail
Geotechnical Design
Geotechnical Design
Geotechnical Design

• External Stability Analyses
  – 4 feet minimum embedment
  – For portion of wall likely to be submerged, used 70pcf LFCF up to 3 ft above 100 year flood level
  – design considered buoyancy
# Geotechnical Design

## TABLE 5: COST COMPARISON SUMMARY FOR WALL 5302

<table>
<thead>
<tr>
<th>Type of Backfill</th>
<th>Quantity</th>
<th>Rate</th>
<th>Total Cost</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional MSE backfill</td>
<td>19,655 sf</td>
<td>$75/sf</td>
<td>$1,474,125</td>
<td>Rate from Council Bluffs, Segment 1 wall, includes panels, reinforced zone and temporary excavation backfill</td>
</tr>
<tr>
<td>LWFC</td>
<td>13,746 cy</td>
<td>$110/cy</td>
<td>$1,512,060</td>
<td>Rate for 40pcf LWFC is $80/cy, includes HDPE liner. Quantity assumes B/H =0.8 with 1:1 temporary excavation. Cost includes $25/sf for panels with reinforcing straps.</td>
</tr>
</tbody>
</table>

## TABLE 11: COST COMPARISON SUMMARY FOR WALL 5310

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Type of Backfill</th>
<th>Quantity</th>
<th>Rate</th>
<th>Total Cost</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined MSE wall with conventional backfill and SPL wall</td>
<td>Regular MSE backfill</td>
<td>12,585 sf</td>
<td>$75/sf</td>
<td>$943,875</td>
<td>Rate from Council Bluffs, Segment 1 wall, includes panels, reinforced zone and temporary excavation backfill</td>
</tr>
<tr>
<td></td>
<td>SPL wall</td>
<td>11,280 sf</td>
<td>$145/sf</td>
<td>1,635,600</td>
<td>Rate is national average, includes cost of final CIP facing @ approx. $500/cy</td>
</tr>
<tr>
<td></td>
<td>Total cost</td>
<td></td>
<td></td>
<td>$2,579,475</td>
<td>Approx. $99/sf</td>
</tr>
<tr>
<td>LWFC</td>
<td>LWFC</td>
<td>23,484 cy</td>
<td>$110/cy</td>
<td>$2,583,240</td>
<td>Rate for 40pcf LWFC is $80/cy, includes HDPE liner. Quantity assumes B/H =0.8 with 1:1 temporary excavation. Cost includes $25/sf for panels with reinforcing straps.</td>
</tr>
</tbody>
</table>
MSE Wall With LFCF Typical Sections

**Typical Section with LFC**

- Scale: None

**Typical Section for Suggested Construction Procedures for LFCF**

- Scale: None
CIP Wall-For Trail

- 630 feet long
- Max. Height: approx. 15 ft
- Constructed in front of the MSE wall to protect the MSE wall from flood debris impacts
- Bottom of wall at bottom of MSE wall below expected scour level
Trail Reconstruction
Construction Recommendations

• Reinforcing straps placed at each lift interval. Minimum width 10ft per Iowa DOT guidelines.
• Staggered lifts were recommended to avoid forming vertical cold joints.
• Geomembrane was placed at top of fill and below the pavement system to aid in drainage as well as prevent icing.
• Scarification was recommended between each successive lifts.
• Recommended construction sequence was to build the trail before wall was completed to full height and to excavate in stages.
Wall Construction

- Project let: March 2010
- Bid Prices:
  - LFCF: 73,043cy @ $41.60/cy
  - Wall panels, straps: 73,943sft @ $21.75/sft
- Construction Start: September 2010
- Road Opened to Traffic: December 2011
Wall Construction

Leveling Pad and Dewatering
Excavation

Subdrain placement
Wall Construction

Ready for LFCF Placement

LFCF Plant
Wall Construction

Fill Placement  Ready for Next Lift
Wall Construction

Steps to prevent vertical joints

Curing Concrete
Wall Construction

Construction through Winter 2010
Wall Construction

CIP Wall Footing

CIP Wall Construction
Wall Construction

Final Lift

Placing Geomembrane
Wall Construction

CIP wall and MSE Wall Complete

Wall with Barrier Open to Traffic
Construction Issues

- Grading contractor excavated both walls to full depth with 2:1 slope.
- Construction traffic was allowed on the top of the excavated surface, this caused some slope failure.
- Improper fill placement
- Improper formwork support (LFCF spill)
- Walls were constructed to full height without bike path being constructed.
- 2011 Flooding
Construction Issues

Wall excavation and seepage flooding

Excavation not to correct width
Construction Issues

Flooded excavation

Slope failure in backslope excavation
Construction Issues

Improper Fill placement
Construction Issues

LFCF Spill Entering Big Sioux (~ 5 cy)

LFCF in Big Sioux Downstream of Spill
Construction Issues

2011 Flooding
Construction Issues
Construction Issues
Instrumentation

• Slope inclinometers: installed in March and April 2012 along the trail and on the east side.
• Last available reading was May 2013.
• Movement stabilized at 0.5 inches, considered acceptable.
• No issues of slope instability have been reported.
Instrumentation
LFCF can Float and Crack!
LFCF can Float and Crack!
LFCF can Float and Crack!
Acknowledgements

- Iowa DOT
  - Soils Design
  - Office of Design
  - Sioux City RCE
- GSI
- REICO
THANK YOU!!

• Questions?