Use of Steel Slag as a Geotechnical Material: Research and Implementation

Monica Prezzi and Irem Zeynep Yildirim

Industrial Materials Use in Sustainable Pavement Systems: State-of-the-Practice

GOAL: Find new, innovative uses for BOF and EAF steel slag in geotechnical applications

Publications

- Yildirim, I. Z. (2009). "Experimental Study Of The Use of Steel Slag as a Geotechnical Material." Ph.D. Thesis, Purdue University.

Recyclable Materials

- BOF and EAF steel slag
- Tires/tire shreds
- Fly ash, bottom ash and ash mixtures
- Foundry sand
- Crushed glass
- Cement kiln dust
- Concrete materials from building demolition
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**Introduction**

- Technical considerations
  - Mechanical behavior
  - Specific characteristics of each material (lightweight/combustibility/volume instability/insulation properties)
  - Construction techniques
  - Quality control
  - Quality assurance
  - Long term behavior
  - Environmental impact

**Sizing**

- Coarse (2.5" - 8")
  - 64-203 mm
- Intermediate (5/8" - 2.5")
  - 16-64 mm
- Fine (Minus 5/8")
  - 0-16 mm

**Motivation**

- Almost no use for finer gradation steel slag
- Problems related to volumetric instability
- Problems related to disposal (stockpiling and land filling)

Limited research on the use of steel slag as a geotechnical material

1. Determine the geotechnical properties of BOF and EAF slag
2. Develop a methodology to deal with the volumetric instability problems
3. Design mixtures suitable for geotechnical engineering applications

**Testing Materials**

- BOF slag
  - Mittal Steel, Indiana Harbour Works Plant
  - (Integrated mill with BF and BOF processing, BOF slag is processed by Multiserv)

- Batch-1 Fresh BOF slag
- Batch-2 Fresh BOF slag
- Batch-2 Aged BOF slag (aging=1 year)
- Batch-3 Aged BOF slag (aging=1 year)
Testing Materials

- **EAF(L) slag**
  Nucor Steel, Whitesville Mill
  (Mini Mill with EAF and LF processes, EAF(L) slag processed by Levy Co.)

- Batch-1 Fresh EAF(L) slag
- Batch-2 Fresh EAF(L) slag
- Batch-2 Aged EAF(L) slag (aging=1 month)

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**Experimental Program**

<table>
<thead>
<tr>
<th>Experimental Program for BOF and EAF(L) Slag Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Index Properties</strong></td>
</tr>
<tr>
<td><strong>Mineralogy</strong> and Morphology</td>
</tr>
<tr>
<td><strong>Mechanical Behavior</strong></td>
</tr>
<tr>
<td><strong>Swelling Potential</strong></td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
</tr>
</tbody>
</table>

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**Grain-Size Distribution**

- **Sieve Analyses of BOF Slag Samples**
  (ASTM D422-63)
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Grain-Size Distribution of Batch-1 Fresh BOF slag

Sieve Analyses of EAF(L) Slag Samples

Grain-Size Distribution of Batch-1 Fresh EAF(L) slag

Specific Gravity of BOF and EAF (L) Slag

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Sample ID</th>
<th>Sample ID</th>
<th>Sample ID</th>
<th>Sample ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch-1 Fresh BOF slag</td>
<td>Batch-1 Fresh EAF(L) slag</td>
<td>Batch-1 Fresh BOF slag</td>
<td>Batch-1 Fresh EAF(L) slag</td>
<td>Batch-1 Fresh BOF slag</td>
</tr>
<tr>
<td>3.29</td>
<td>2.73</td>
<td>3.34</td>
<td>3.34</td>
<td>3.34</td>
</tr>
<tr>
<td>Batch-2 Fresh BOF slag</td>
<td>Batch-2 Fresh EAF(L) slag</td>
<td>Batch-2 Fresh BOF slag</td>
<td>Batch-2 Fresh EAF(L) slag</td>
<td>Batch-2 Fresh BOF slag</td>
</tr>
<tr>
<td>3.34</td>
<td>3.34</td>
<td>3.34</td>
<td>3.34</td>
<td>3.34</td>
</tr>
<tr>
<td>Batch-3 Aged BOF slag</td>
<td>Batch-3 Aged EAF(L) slag</td>
<td>Batch-3 Aged BOF slag</td>
<td>Batch-3 Aged EAF(L) slag</td>
<td>Batch-3 Aged BOF slag</td>
</tr>
<tr>
<td>3.32</td>
<td>3.34</td>
<td>3.32</td>
<td>3.34</td>
<td>3.34</td>
</tr>
</tbody>
</table>

Average specific gravity of the BOF slag samples

Average specific gravity of the EAF(L) slag samples
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Chemical Composition

<table>
<thead>
<tr>
<th></th>
<th>BOF slag</th>
<th>EAF(L) slag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxide Composition by %</td>
<td>Oxide Composition by %</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>39.40</td>
<td>47.52</td>
</tr>
<tr>
<td>FeO</td>
<td>30.23</td>
<td>22.59</td>
</tr>
<tr>
<td>SiO₂</td>
<td>11.97</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>9.69</td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>2.74</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>L.O.I</td>
<td>1.80</td>
<td>6.20</td>
</tr>
</tbody>
</table>

* Loss on ignition

Morphological Properties of BOF slag

- Fresh and aged gravel-size BOF slag particles
  - Subrounded to subangular bulky particles with distinct asperities
  - Rough surface texture
  - Agglomerates in aged BOF slag

Morphological Properties of EAF(L) slag

- Fresh EAF(L) slag:
  - Subrounded to subangular bulky particles with distinct asperities
- Gravel-size particles from B-1 Fresh EAF(L) slag
- Gravel-size particles from B-2 Fresh EAF(L) slag

Triaxial Test Results - BOF Slag (aged)

- Effective Confining Stress
- Relative Compaction
- Peak Friction Angle
- Critical State Friction Angle

<table>
<thead>
<tr>
<th>σ'c (kPa)</th>
<th>R</th>
<th>φ'</th>
<th>ψ'</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>89%</td>
<td>47.3°</td>
<td>-41.3°</td>
</tr>
<tr>
<td>110</td>
<td>91%</td>
<td>45.2°</td>
<td>-39.6°</td>
</tr>
<tr>
<td>200</td>
<td>92%</td>
<td>43.5°</td>
<td>-40.2°</td>
</tr>
</tbody>
</table>
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Swelling Tests

- Steel slag samples were prepared at their optimum moisture content.
- Samples were compacted to 97-100% relative compaction in CBR molds (Diameter=6in).
- A steel mesh was placed in each container to give access to water from the bottom of the samples.
- Surcharge weight = ~2.5 kPa.
- Samples were soaked in water and swelling was monitored for ~17 months.

Long-Term Swelling of BOF Slag

- The swelling rates for the Batch-1 Fresh BOF slag:
  - 0-7 months: 0.69x10^-2 %/day
  - 7-10 months: 1.08x10^-2 %/day
  - 10-13 months: 3.22x10^-1 %/day
  - 13-17 months: 1.73x10^-1 %/day
- Max. swelling strain of 3.5%.
- Batch-2 Fresh and Batch-2 Aged BOF slag samples:
- Max. swelling strains of 0.6% and 0.5%.
- Batch-3 Aged BOF slag samples:
  - Max. swelling strains of 1.2-1.3%.
- Use of fresh BOF slag with fine gradation is detrimental.
- Aging alone is not sufficient to suppress swelling of the BOF slag samples tested.
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### Long-Term Swelling of EAF(L) Slag

- **Batch-2 Fresh EAF(L) slag**:
  - Initial 10 days: 0.008%/day
  - 10 days to 17 months: 1.80x10^-3%/day
  - Max. swelling strain: 0.98%
- **Batch-2 Aged EAF(L) slag**:
  - Initial 10 days: 0.01%/day
  - 10 days to 17 months: 1.55x10^-3%/day
  - Max. swelling strain: 0.83%
- No stabilization was observed after 17 months of monitoring.
- Aging of the EAF(L) slag sample for one month reduced slightly the swelling rate.
- Aging alone was not sufficient to suppress the swelling of the EAF(L) slag samples tested.

### Steel Slag Mixtures

#### Materials used in Steel Slag Mixtures:
- **Class-C fly ash**
  - Nipsco Company, IN
- **Ground rubber 10/20 (0.85-2mm range)**
  - Rubber Mulch Products, IN

#### Strength gain characteristics

- EAF(L) slag + Class-C fly ash mixtures
- BOF slag + Class-C fly ash mixtures

#### Swelling behavior

- EAF(L) slag + Class-C fly ash mixtures
- BOF slag + Class-C fly ash mixtures
- BOF slag + ground rubber mixtures

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### Experimental Program

**EXPERIMENTAL PROGRAM FOR STEEL SLAG MIXTURES**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Tested Mixtures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compaction Characteristics</td>
<td>EAF(L) slag + 5% Class-C fly ash</td>
</tr>
<tr>
<td></td>
<td>EAF(L) slag + 10% Class-C fly ash</td>
</tr>
<tr>
<td>Strength Gain Characteristics</td>
<td>EAF(L) slag + 5% Class-C fly ash</td>
</tr>
<tr>
<td>(UC tests)</td>
<td>EAF(L) slag + 10% Class-C fly ash</td>
</tr>
<tr>
<td></td>
<td>EAF(L) slag + 15% Class-C fly ash</td>
</tr>
<tr>
<td>Strength Gain Characteristics</td>
<td>BOF slag + 5% Class-C fly ash</td>
</tr>
<tr>
<td>(UC tests)</td>
<td>BOF slag + 10% Class-C fly ash</td>
</tr>
<tr>
<td></td>
<td>BOF slag + 15% Class-C fly ash</td>
</tr>
<tr>
<td>Swelling Behavior (Long-Term CBR Swelling Tests)</td>
<td>Fresh BOF slag + 10% Class-C fly ash</td>
</tr>
<tr>
<td></td>
<td>Fresh BOF slag + 15% Class-C fly ash</td>
</tr>
<tr>
<td></td>
<td>Fresh BOF slag + 10% ground rubber</td>
</tr>
<tr>
<td></td>
<td>Aged BOF slag + 10% ground rubber</td>
</tr>
</tbody>
</table>
Compaction Characteristics of EAF(L) Slag and Class-C Fly Ash Mixtures

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>W (%)</th>
<th>(Y_{max} ) (%)</th>
<th>(Y_{opt} ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch-2 Fresh EAF(L) slag</td>
<td>11</td>
<td>2040</td>
<td>127</td>
</tr>
<tr>
<td>Batch-2 Fresh EAF(L) slag + 5% fly ash</td>
<td>10</td>
<td>1992</td>
<td>128</td>
</tr>
<tr>
<td>Batch-2 Fresh EAF(L) slag + 20% fly ash</td>
<td>10</td>
<td>2019</td>
<td>128</td>
</tr>
</tbody>
</table>

Unconfined Compression Tests

- Dry mixtures were prepared with mixing steel slag and Class-C fly ash
- The EAF(L) slag and Class-C fly ash mixtures were compacted at ~10% moisture content with standard proctor energy
- Batch-2 Fresh EAF(L) slag + 5% Class-C fly ash (by weight)
- Batch-2 Fresh EAF(L) slag + 10% Class-C fly ash (by weight)
- Batch-2 Fresh EAF(L) slag + 20% Class-C fly ash (by weight)
- The BOF slag and Class-C fly ash mixtures were compacted at ~7% moisture content with standard proctor energy
- Batch-3 Aged BOF slag + 5% Class-C fly ash (by weight)
- Batch-3 Aged BOF slag + 10% Class-C fly ash (by weight)

Intact UC samples of Batch-1 Fresh and Batch-3 Aged BOF slag could not be recovered from the molds
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### UC Test Results for EAF(L) Slag and Class-C Fly Ash Mixtures

#### Summary of the UC strength of EAF(L) slag Mixtures

<table>
<thead>
<tr>
<th>Unconfined compressive strength of EAF(L) Slag and Class-C fly ash mixtures (MPa)</th>
<th>Curing time</th>
<th>1 day</th>
<th>2 day</th>
<th>4 day</th>
<th>7 day</th>
<th>14 day</th>
<th>30 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh EAF(L) slag + 5% Class-C fly ash</td>
<td>830</td>
<td>842</td>
<td>892</td>
<td>988</td>
<td>1021</td>
<td>1065</td>
<td></td>
</tr>
<tr>
<td>Fresh EAF(L) slag + 10% Class-C fly ash</td>
<td>1014</td>
<td>1054</td>
<td>1094</td>
<td>1190</td>
<td>1205</td>
<td>1235</td>
<td></td>
</tr>
<tr>
<td>Fresh EAF(L) slag + 20% Class-C fly ash</td>
<td>1672</td>
<td>1671</td>
<td>1624</td>
<td>1625</td>
<td>1731</td>
<td>1795</td>
<td></td>
</tr>
</tbody>
</table>

#### Time vs. unconfined compressive strength gain of EAF(L) slag and Class-C fly ash mixtures

<table>
<thead>
<tr>
<th>Mixtures</th>
<th>0 days</th>
<th>2 days</th>
<th>4 days</th>
<th>7 days</th>
<th>14 days</th>
<th>28 days</th>
<th>90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF(L) slag + 5% Class-C fly ash</td>
<td>405.9</td>
<td>452.9</td>
<td>510.5</td>
<td>568.5</td>
<td>626.5</td>
<td>684.5</td>
<td>742.5</td>
</tr>
<tr>
<td>EAF(L) slag + 10% Class-C fly ash</td>
<td>485.2</td>
<td>532.2</td>
<td>589.2</td>
<td>646.2</td>
<td>703.2</td>
<td>760.2</td>
<td>817.2</td>
</tr>
<tr>
<td>EAF(L) slag + 20% Class-C fly ash</td>
<td>564.5</td>
<td>611.5</td>
<td>668.5</td>
<td>725.5</td>
<td>782.5</td>
<td>839.5</td>
<td>896.5</td>
</tr>
</tbody>
</table>

### UC Test Results for EAF(L) Slag and Class-C Fly Ash Mixtures

#### UC Test Results - BOF Slag and Class-C Fly Ash Mixtures

<table>
<thead>
<tr>
<th>Curing time</th>
<th>1 day</th>
<th>2 day</th>
<th>4 day</th>
<th>7 day</th>
<th>14 day</th>
<th>30 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOF slag + 5% Class-C fly ash</td>
<td>932</td>
<td>988</td>
<td>1021</td>
<td>1065</td>
<td>1109</td>
<td>1153</td>
</tr>
<tr>
<td>BOF slag + 10% Class-C fly ash</td>
<td>1114</td>
<td>1160</td>
<td>1206</td>
<td>1252</td>
<td>1298</td>
<td>1344</td>
</tr>
<tr>
<td>BOF slag + 20% Class-C fly ash</td>
<td>1772</td>
<td>1822</td>
<td>1872</td>
<td>1922</td>
<td>1972</td>
<td>2022</td>
</tr>
</tbody>
</table>

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**UC Test Results - BOF Slag and Class-C Fly Ash Mixtures**

Summary of the UC strength of BOF(L) slag Mixtures

<table>
<thead>
<tr>
<th>Curing time</th>
<th>1 day</th>
<th>2 day</th>
<th>4 day</th>
<th>7 day</th>
<th>14 day</th>
<th>28 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOF slag + 5% Class-C fly ash</td>
<td>312</td>
<td>320</td>
<td>330</td>
<td>340</td>
<td>350</td>
<td>360</td>
</tr>
<tr>
<td>BOF slag + 10% Class-C fly ash</td>
<td>315</td>
<td>325</td>
<td>335</td>
<td>345</td>
<td>355</td>
<td>365</td>
</tr>
<tr>
<td>BOF slag + 15% Class-C fly ash</td>
<td>318</td>
<td>328</td>
<td>338</td>
<td>348</td>
<td>358</td>
<td>368</td>
</tr>
<tr>
<td>BOF slag + 20% Class-C fly ash</td>
<td>321</td>
<td>331</td>
<td>341</td>
<td>351</td>
<td>361</td>
<td>371</td>
</tr>
</tbody>
</table>

Time vs. unconfined compressive strength gain of BOF slag and Class-C fly ash mixtures

- BOF slag + 5% Class-C Fly ash
- BOF slag + 10% Class-C Fly ash
- BOF slag + 15% Class-C Fly ash
- BOF slag + 20% Class-C Fly ash

**Long-Term Swelling Tests on Steel Slag Mixtures**

- Dry mixtures were prepared by mixing steel slag and Class-C fly ash or ground rubber
- The samples were compacted in CBR molds assembled with dial gauges
- The steel slag samples were monitored for 9-15 months

**Long-term CBR swelling tests were performed on the following mixtures:**

- Batch-1 Fresh BOF slag + 10% Class-C fly ash (by weight)
- Batch-2 Fresh BOF slag + 20% Class-C fly ash (by weight)
- Batch-3 Fresh BOF slag + 30% Class-C fly ash (by weight)

**Results of long-term swelling tests for BOF slag and Class-C fly ash mixtures**

- Batch-1 Fresh BOF slag + 10% Class-C fly ash
- Batch-2 Fresh BOF slag + 20% Class-C fly ash
- Batch-3 Fresh BOF slag + 30% Class-C fly ash

**Results of long-term swelling tests for all BOF slag and Class-C fly ash mixtures**

- BOF slag + 5% Class-C fly ash
- BOF slag + 10% Class-C fly ash
- BOF slag + 15% Class-C fly ash
- BOF slag + 20% Class-C fly ash
Addition of 10% Class-C fly ash suppresses the swelling of both fresh and aged BOF slag samples significantly.

Addition of 10% Class-C fly ash is more effective in stabilizing the swelling of BOF slag than the addition of 10% ground rubber.

Addition of 5-10% Class-C fly ash suppresses the swelling of fresh EAF(L) slag almost completely.

Conclusions

- BOF and EAF(L) slag have superior frictional properties and densities than conventional soils.
- In the presence of water, fresh and aged BOF and EAF(L) slags increase in volume.
- Aging of BOF and EAF(L) slag is not sufficient to suppress swelling.
- BOF and EAF(L) slags do not show strong self-cementing properties.
- The UC strength of BOF and EAF(L) steel slag improved significantly with the addition of Class-C fly ash.
- Addition of 5-10% Class-C fly ash was effective in suppressing swelling of fresh EAF(L) slag.
- Addition of 10% Class-C fly ash was effective in suppressing swelling of fresh BOF slag.
- Both mixtures of BOF slag and Class-C fly ash and mixtures of EAF(L) slag and Class-C fly ash can be utilized effectively in geotechnical applications.
Steel Slag Implementation
I65 - Crown Point, Indiana
(Soil + 7% Steel Slag + 3% Class-C Fly Ash Mixture)

In Situ Soils

<table>
<thead>
<tr>
<th>UC samples</th>
<th>Relative Compaction (%)</th>
<th>Unconfined Compressive Strength (psi)</th>
<th>Strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW2Soil15</td>
<td>100</td>
<td>31.1</td>
<td>214.4</td>
</tr>
<tr>
<td>NW6Soil17</td>
<td>101</td>
<td>41.1</td>
<td>280.1</td>
</tr>
<tr>
<td>NW6Soil18</td>
<td>100</td>
<td>44.6</td>
<td>307.5</td>
</tr>
<tr>
<td>NW6Soil49</td>
<td>98</td>
<td>37.8</td>
<td>260.6</td>
</tr>
<tr>
<td>NW6Soil59</td>
<td>98</td>
<td>45.0</td>
<td>310.3</td>
</tr>
<tr>
<td>NW6Soil477</td>
<td>94</td>
<td>47.8</td>
<td>329.6</td>
</tr>
<tr>
<td>NW6Soil538</td>
<td>93</td>
<td>39.9</td>
<td>274.4</td>
</tr>
</tbody>
</table>

- Per AASHTO Soil Type: A-6 (Plasticity Index 12-13)
- Average UC strength = 275 kPa (40 psi)

Proctor Compaction Tests

- Optimum Water Content = ~15.5%
- Maximum Dry Unit Weight = 18 kN/m² (114.3pcf)
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Unconfined Compression Tests

- Unconfined Compression Strength of:
  - (Steel -7%, Fly ash - 3%)

<table>
<thead>
<tr>
<th>Mixture</th>
<th>(kPa)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil - 7% Steel Slag</td>
<td>766</td>
<td></td>
</tr>
<tr>
<td>+ 3% Fly Ash</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Swelling Tests

- Volumetric Swell, ε (%)

Ramp Prior to Stabilization

- Truck used for uniformly spreading the slag-fly ash mixture on the subgrade

Spreading the Slag-Fly Ash Mixture

- Spreading the slag-fly ash mixture on the subgrade
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Mixing

- Mixing the Slag-Fly Ash Mixture with in-situ soil
- Mixing and checking moisture content using nuclear gauge

Compaction

- Compacting with sheepsfoot roller and smooth-wheeled drum roller

Subgrade

- Subgrade after compaction
Quality Control – Nuclear Gauge Density Tests

<table>
<thead>
<tr>
<th>Station</th>
<th>Wt Unit Weight</th>
<th>Moisture Content</th>
<th>Dry Unit Weight</th>
<th>Density Computation</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 - 0.5 ft</td>
<td>26.83 (132.6)</td>
<td>12.4</td>
<td>18.84 (118)</td>
<td>102.6</td>
</tr>
<tr>
<td>300 - 3 ft</td>
<td>24.33 (91.8)</td>
<td>11.9</td>
<td>10.64 (122.7)</td>
<td>109.4</td>
</tr>
<tr>
<td>300 - 6 ft</td>
<td>21.55 (137)</td>
<td>14.4</td>
<td>10.62 (121.3)</td>
<td>109.3</td>
</tr>
<tr>
<td>300 - 9 ft</td>
<td>21.27 (135.4)</td>
<td>15.9</td>
<td>18.66 (118.6)</td>
<td>193.3</td>
</tr>
<tr>
<td>300 - 10 ft</td>
<td>21.08 (138)</td>
<td>12.3</td>
<td>19.28 (122.7)</td>
<td>191.7</td>
</tr>
</tbody>
</table>

Quality Control – Dynamic Cone Penetration Tests

Quality Control – Dynamic Cone Penetration Tests

Pavement Work

<table>
<thead>
<tr>
<th>Station</th>
<th>DCP (NDCP)</th>
<th>for a penetration of 0 to 150 mm (0 to 6 inch) (modified after Kim et al. 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 - 0.5 ft</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>300 - 3 ft</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>300 - 6 ft</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>300 - 9 ft</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>300 - 10 ft</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>300 - 15 ft</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>300 - 20 ft</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>300 - 30 ft</td>
<td>46</td>
<td>48</td>
</tr>
</tbody>
</table>

Pavement Work

<table>
<thead>
<tr>
<th>Station</th>
<th>Placement of reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 - 15 ft</td>
<td>Placement of reinforcement</td>
</tr>
</tbody>
</table>

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Preparation for Concrete Placement

- Layout of the new ramp
- Spraying the machines with form oil to prevent the concrete from sticking to the metal

Concrete Placement

- Transferring the concrete from the trucks to the ramp; concrete later placed by the vibrating machine

Concrete Placement

- Placement of concrete: before and after the initial leveling by the vibratory equipment

Concrete Work

- Leveling the concrete
Concrete Work

- Tinned concrete surface

Finishing Concrete Work

- Coating concrete surface with 1600-white, water-based, wax-based concrete curing compound

Acknowledgments

- Nayyar Zia Siddiki (INDOT)
- Barry Partridge (INDOT)
- John Yzenas (Edward C. Levy Co)
- Multiserv Co.
- Hobi Kim (Fugro Consultants)
- Helen H. Santoso
- Meera Vasudevan

Thanks!
Main Mineral Phases

- Portlandite
- Dolomite
- Calcite
- Pentahydrate
- Magnesite

Minor and probable phases include:

- Lime CaO
- Malenterite
- Larnite
- Periclase
- Wollastonite

X-ray Diffraction Data

- B-1 Fresh BOF slag
- B-3 Aged BOF slag
- B-2 Fresh EAF slag

B-1 Fresh and B-2 Fresh EAF slag
- Very crystalline structure
- Well-defined overlapping peaks with very high intensities

B-3 Aged BOF slag
- Very crystalline structure
- Well-defined overlapping peaks

B-1 Fresh and B-3 Aged BOF slag
- Defined overlapping peaks

X-ray Diffraction Analysis

Use of Steel Slag as a Geotechnical Material: Research and Implementation

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