Evaluation of PCC Long-Term Durability Using Intermediate Sized Gravels to Optimize Mix Gradations

Final Report for MLR-00-03

April 2010

Highway Division
Evaluation of PCC Long-Term Durability
Using Intermediate Sized Gravels
to Optimize Mix Gradations

Final Report
for
MLR-00-03

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Highway Division
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8. ABSTRACT  
With the implementation of the 2000 Q-MC specification, an incentive is provided to produce an optimized gradation to improve placement characteristics. Also, specifications for slip-formed barrier rail have changed to require an optimized gradation. Generally, these optimized gradations have been achieved by blending an intermediate aggregate with the coarse and fine aggregate. The demand for this intermediate aggregate has been satisfied by using crushed limestone chips developed from the crushing of the parent concrete stone. The availability, cost, and physical limitations of crushed limestone chips can be a concern. 

A viable option in addressing these concerns is the use of gravel as the intermediate aggregate. Unfortunately, gravels of Class 3I durability are limited to a small geographic area in Mississippi river sands north of the Rock River. Class 3 or Class 2 durability gravels are more widely available across the state. The durability classification of gravels is based on the amount and quality of the carbonate fraction of the material. At present, no service histories or research exists to assess the impact of using Class 3 or 2 durability gravels would have on the long-term durability of Portland cement concrete (PCC) pavement requiring Class 3I aggregate.  

9. KEY WORDS  
optimized gradation, Shilstone gradation, Portland cement concrete, intermediate aggregate, pea gravel  

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Introduction and Objective

With the implementation of the 2000 Q-MC specification, an incentive is provided to produce an optimized gradation to improve placement characteristics. Also, specifications for slip-formed barrier rail have changed to require an optimized gradation. Generally, these optimized gradations have been achieved by blending an intermediate aggregate with the coarse and fine aggregate. The demand for this intermediate aggregate has been satisfied by using crushed limestone chips developed from the crushing of the parent concrete stone. The availability, cost, and physical limitations of crushed limestone chips can be a concern.

A viable option in addressing these concerns is the use of gravel as the intermediate aggregate. Unfortunately, gravels of Class 3I durability are limited to a small geographic area in Mississippi river sands north of the Rock River. Class 3 or Class 2 durability gravels are more widely available across the state. The durability classification of gravels is based on the amount and quality of the carbonate fraction of the material. At present, no service histories or research exists to assess the impact of using Class 3 or 2 durability gravels would have on the long-term durability of Portland cement concrete (PCC) pavement requiring Class 3I aggregate.

Materials and Mix Design

The mix design was developed in accordance with SS-01034 Quality Management Concrete. The mix design utilized well graded aggregates following the Shilstone\(^1\) principles. The materials used are shown in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Source</th>
<th>Specific Gravity</th>
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<tr>
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<td>Holcim Mason City I/II</td>
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<td>Fly Ash</td>
<td>Ottumwa Class C</td>
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<tr>
<td>Water w/c = 0.40</td>
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<td>Fine Aggregate</td>
<td>Cordova, IL AIL520</td>
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<tr>
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<tr>
<td>Intermediate Aggregate</td>
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<td>WR Grace Daravair 1400</td>
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<td>Water Reducing Admixture</td>
<td>WR Grace WRDA-82</td>
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</table>

Each mix had a target air content of 7 percent and target water to cementitious (w/cm) ratio of 0.40. The average production gradations for each pea-gravel source and the crushed limestone chips were compiled from producer records. Optimized gradation designs for each source were developed using the Shilstone technique to target an approximate coarseness factor of 60 percent and workability factor of 32 percent. The optimum percentage for each intermediate source was determined. The maximum percentage of intermediate aggregate used to achieve an optimized gradation for an individual source was used as the intermediate aggregate percentage for all mixes with an increase of 5 percent. The relative percent of aggregates used for each mix was 43 percent coarse, 19 percent intermediate, and 38 percent fine aggregate.

The coarse aggregate used is a high quality pure calcium carbonate source. In the investigation, the high quality limestone chip was used as the control to compare with eight pea gravel sources as the intermediate aggregate. The durability classification of gravels is based on the amount
and quality of the carbonate fraction of the material. The sources of intermediate aggregate used, including the percentage of carbonate fraction, are shown in Table 2.

<table>
<thead>
<tr>
<th>Source</th>
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<th>Durability Class</th>
<th>District / County</th>
<th>% Carbonate</th>
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<tr>
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<td>4/Harrison</td>
<td>15</td>
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<tr>
<td>Anthon</td>
<td>A97522</td>
<td>3</td>
<td>3/Woodbury</td>
<td>30</td>
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<tr>
<td>Bellevue</td>
<td>A49526</td>
<td>31</td>
<td>6/Jackson</td>
<td>0</td>
</tr>
<tr>
<td>Turner</td>
<td>A49516</td>
<td>31</td>
<td>6/Jackson</td>
<td>0</td>
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<tr>
<td>Fort Dodge limestone</td>
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<td>31</td>
<td>1/Webster</td>
<td>100</td>
</tr>
</tbody>
</table>

Test Procedure

Two mixes were weighed, batched, and mixed according to ASSHTO T126 for each source. A 0.9 cubic foot batch was sufficient quantity to allow for air and slump tests as well as the fabrication of 6 durability beams. A total of 108 durability beams were tested.

One mix used washed intermediate aggregate while the second mix used salt soaked intermediate aggregate. Salt soaked aggregates were prepared by heating the aggregate to 230 °F for 12 hours. Next, 1000 grams of sodium chloride (NaCl) is dissolved in hot tap water. This salt solution is then poured over the hot aggregate until the aggregate is entirely immersed. The aggregate is soaked for 24 hours in the salt solution. Finally, the aggregate is removed from the salt solution and rinsed. The rinsed aggregate is dried to SSD condition for incorporation into the mix.

All beams were fabricated and tested according to ASTM 666 procedure B. In order to compare to previous freeze thaw durability testing, 89 days of moist room curing was conducted. Testing was terminated when either 300 freeze-thaw cycles were completed or until a relative dynamic modulus of elasticity of 60 percent was reached. After freeze thaw durability testing was terminated the beams were removed from the freezer and stored in the freezer room.

After the completion of durability testing, a sample was obtained from each set of beams. The samples were polished using a lapping wheel. The sections were examined using an optical microscope and SEM. Qualitative observations were made to determine if the intermediate aggregate exhibited any potential for increased deterioration.

ASTM C 666 Results

The results of the ASTM C 666 method B freeze thaw durability testing are found in Table 1. Graphical representation of the relative durability factor (DF) and percent growth are found in Figures 1 and 2. Individual beam test data are found in the Appendix.
Table 3 – ASTM C 666 Method B data

<table>
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<th>Source</th>
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<th>Durability Factor</th>
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</table>

Figure 1 – Average ASTM C 666 B durability factors salt and non-salt by source

Ft Dodge Coarse Agg Average Durability Factor for Salt and No Salt for Various Sources
Petrographic analysis

Since little difference was noted between the freeze thaw durability beams, sections from a sampling of the salt soaked aggregate beams were examined for petrographic analysis. Two Class 2 sources, two Class 3 source, and one Class 3I source examined to determine if any of the intermediate aggregates showed signs of distress. One sample was obtained from the middle of the beam and one near the edge of the beam. Polished sections were obtained from the beams and examined under an optical microscope. The optical images overall view are shown in Figures 3-12.

Figure 3 – Rockford optical images (no salt) - middle (l), edge (r)
Figure 4 – Rockford optical images (salt) - middle (l), edge (r)

Figure 5 – Army Post Road optical images (no salt) - middle (l), edge (r)

Figure 6 - Army Post Road optical images (salt) - middle (l), edge (r)
Figure 7 - Anthon optical images (salt) - middle (l), edge (r)

Figure 8 – Woodbine optical images (salt) - middle (l), edge (r)

Figure 9 - Bellevue optical images (no salt) - middle (l), edge (r)
Little deterioration was noted in any of the samples investigated. Salt was concentrated in a rim around a few aggregate particles, but no deterioration was noted. Pyrite, found in some samples, also exhibited little signs of deterioration.

Figure 11 – Salt concentrated around aggregate in Woodbine sample
Discussion

Based on ASTM C 666 freeze-thaw durability testing Method B, it appears that addition of pea gravel at 19 percent relative of total aggregate, does not drastically affect the durability rating, salt or non-salt, as compared to the control, regardless of the gravel durability classification. The percent growth increases slightly in the salt soak specimens, especially in those sources with higher amounts of carbonate fraction.

Typically, approximately 10 to 12 percent pea gravel is needed to achieve a well graded Shilstone aggregate combination using a coarse aggregate meeting Gradation No. 3 and a sand meeting Gradation No. 1. This research was conducted at a much higher percentage that would typically be required. Since 19 percent pea gravel had relatively minimal influence on durability rating, using a lower percentage of pea gravel should have even lesser affect on durability.

Conclusions and Recommendations

Based on the findings of this report, the following recommendations:

- When Class 3I aggregate is required, utilize pea gravels from Class 2 or Class 3 sources as an intermediate aggregate, limited to 15% of the total aggregate.

- Develop specifications for pea gravel to limit amounts of deleterious materials.
Acknowledgement

The author would like to thank the following people for their help in this research:

Paul Hockett for procuring all the aggregate samples, Mike Coles, Leroy Lutjen, and Ken Kennedy in the Cement and Concrete section for casting and testing the specimens, and Bob Dawson, Geologist, for the petrography work.
References

1. Shilstone, J. Sr., "Concrete Mixture Optimization", Concrete International, June 1990
Appendix
## Figure 13 – Aggregate Gradations

### Coarse

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### Intermediate

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<td>1.7</td>
<td>1.4</td>
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<td>0.1</td>
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<td>Fort Dodge</td>
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<td>100.0</td>
<td>100.0</td>
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<td>74.0</td>
<td>7.6</td>
<td>1.7</td>
<td>1.5</td>
<td>1.2</td>
<td>1.0</td>
<td>0.7</td>
<td>0.3</td>
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<tr>
<td>Average</td>
<td></td>
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<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>86.0</td>
<td>11.0</td>
<td>2.1</td>
<td>1.7</td>
<td>1.4</td>
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<td>0.7</td>
<td>0.3</td>
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### Fine

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<th>Source</th>
<th>State ID</th>
<th>Specific Gravity</th>
<th>SSD 3&quot;</th>
<th>2 1/2&quot;</th>
<th>2&quot;</th>
<th>1 1/2&quot;</th>
<th>1&quot;</th>
<th>3/4&quot;</th>
<th>1/2&quot;</th>
<th>3/8&quot;</th>
<th>#4</th>
<th>#8</th>
<th>#16</th>
<th>#30</th>
<th>#50</th>
<th>#100</th>
<th>#200</th>
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<td>A43520</td>
<td>DWU</td>
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<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
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<td>100.0</td>
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<td>DWU</td>
<td>100.0</td>
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<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
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## Figure 14 – Mix Proportions

**GENERAL INFORMATION**

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<tr>
<th>Project:</th>
<th>Intermediate Agg.</th>
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<tbody>
<tr>
<td>Project Title:</td>
<td>#REF!</td>
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<tr>
<td>Mix Type:</td>
<td>QM-C</td>
</tr>
<tr>
<td>Mix Number:</td>
<td>fort dodge</td>
</tr>
<tr>
<td>Date:</td>
<td>09/21/00</td>
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**MATERIALS**

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<thead>
<tr>
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<th>Type/Class</th>
<th>SPG</th>
<th>Percent</th>
<th>Percent</th>
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<tbody>
<tr>
<td>CEMENT</td>
<td>Holnam</td>
<td>I/II</td>
<td>3.14</td>
<td></td>
</tr>
<tr>
<td>FLY ASH</td>
<td>Ottumwa</td>
<td>C</td>
<td>2.61</td>
<td>20.00</td>
</tr>
<tr>
<td>MINERAL ADMIXTURE</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SILICA FUME SLURRY</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
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<td>FINE AGGREGATE:</td>
<td>AIL520</td>
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<td>2.66</td>
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<td>AIR ENTRAINING AGENT</td>
<td>DARAVAIR 1400</td>
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<td>RETARDER:</td>
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<td></td>
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<td>WATER REDUCER:</td>
<td>WRDA-82</td>
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<tr>
<td>SUPER WATER REDUCER:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACCELERATOR:</td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>DESIGN W/C(+FLY ASH):</td>
<td>0.40</td>
<td></td>
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<td></td>
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<tr>
<td>DESIGN SLUMP:</td>
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<td></td>
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<tr>
<td>DESIGN AIR CONTENT:</td>
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**QUANTITIES (absolute volume method in SSD condition)**

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<tr>
<th>Volume</th>
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<th>Weight</th>
<th>Weight</th>
<th>Weight</th>
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<tr>
<td></td>
<td>Batch Size</td>
<td>Batch Size</td>
<td>Batch Size</td>
<td>Batch Size</td>
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<tr>
<td></td>
<td>1.0 yd³</td>
<td>1.0 ft³</td>
<td>1.0 ft³</td>
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<td>0.0846</td>
<td>X</td>
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<tr>
<td>FLY ASH:</td>
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<td>0.0255</td>
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<td>2.61</td>
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<td>0.0000</td>
<td></td>
<td></td>
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<tr>
<td>SILICA FUME SLURRY:</td>
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<td>0.0000</td>
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<td></td>
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<tr>
<td>WATER:</td>
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<td>0.2956</td>
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**Summation**

<table>
<thead>
<tr>
<th>Paste Content</th>
<th>Mortar Content (abs vol)</th>
<th>Mortar Content (% pass)</th>
</tr>
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<tbody>
<tr>
<td>27.0000</td>
<td>1.0000</td>
<td>143.2</td>
</tr>
<tr>
<td>3887</td>
<td>128.9</td>
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**CHEMICAL ADMIXTURES**

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<tr>
<th>Rate</th>
<th>Rate</th>
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</thead>
<tbody>
<tr>
<td>Rate</td>
<td>Batch Size</td>
<td>Batch Size</td>
</tr>
<tr>
<td>oz/100 lbs cementitious</td>
<td>1.0 yd³</td>
<td>1.0 ft³</td>
</tr>
<tr>
<td>AIR ENTRAINING AGENT:</td>
<td>0.8</td>
<td>20.73</td>
</tr>
<tr>
<td>RETARDER:</td>
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<tr>
<td>WATER REDUCER:</td>
<td>3.5</td>
<td>20.73</td>
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<tr>
<td>SUPER WATER REDUCER:</td>
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<tr>
<td>ACCELERATOR:</td>
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</table>
Figure 15 – Coarseness and Workability Factors

1 Workability Factor VS Coarseness Factor for Combined Aggregate
Figure 16 – Combined Percent Passing Gradations 0.45 Power Curve

Combined Aggregate Gradation Power 45

Percent Passing

Sieve Size

#200
#100
#50
#30
#16
#8
3/8"
1/2"
3/4"
1"
1 1/2"
2"
2 1/2"
3"
# Figure 17 – ASTM C 666 B Individual Beam Test Results

<table>
<thead>
<tr>
<th></th>
<th>Rockford</th>
<th>Ames</th>
<th>Army Post</th>
<th>Harlan</th>
<th>Woodbine/Clarks</th>
<th>Bellevue</th>
<th>Turner</th>
<th>Fort Dodge</th>
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<tbody>
<tr>
<td>Beam 1</td>
<td>0.0034</td>
<td>0.0047</td>
<td>0.0021</td>
<td>0.0047</td>
<td>0.0017</td>
<td>0.0029</td>
<td>0.0013</td>
<td>0.0017</td>
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<td>Beam 2</td>
<td>0.0036</td>
<td>0.0029</td>
<td>0.0033</td>
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<td>0.0023</td>
<td>0.0027</td>
<td>0.0018</td>
<td>0.0020</td>
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<tr>
<td>Beam 3</td>
<td>0.0022</td>
<td>0.0040</td>
<td>0.0030</td>
<td>0.0050</td>
<td>0.0021</td>
<td>0.0018</td>
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<tr>
<td>Avg.</td>
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<td>0.0039</td>
<td>0.0028</td>
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<td>0.0020</td>
<td>0.0025</td>
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</table>

# Figure 18 – Rockford freeze thaw beams Rockford (no salt)

# Figure 19 – Rockford freeze thaw beams (salt)
Figure 20 – Ames South freeze thaw beams (no salt)

Figure 21 – Ames South freeze thaw beams (salt)

Figure 22 – Army Post Road freeze thaw beams (no salt)

Figure 23 – Army Post Road freeze thaw beams (salt)
Figure 24 – Harlan freeze thaw beams (no salt)

Figure 25 – Harlan freeze thaw beams (salt)

Figure 26 – Woodbine-McCann freeze thaw beams (no salt)

Figure 27 – Woodbine-McCann freeze thaw beams (salt)
Figure 28 – Anthon freeze thaw beams (no salt)

Figure 29 – Anthon freeze thaw beams (salt)

Figure 30 – Bellevue freeze thaw beams (no salt)

Figure 31 – Bellevue freeze thaw beams (salt)