Evolution of Concrete Pavements: Lessons Learned for Long Life Concrete Pavements

(Special thanks to Todd Hanson, Iowa DOT)

National Concrete Pavement Technology Center
Iowa’s Lunch–Hour Workshop
In cooperation with the Iowa DOT
and the Iowa Concrete Paving Association
1904 1st Concrete Street
LeMars, Iowa

- First Street (Eagle Street)
- 2nd oldest concrete street in America
- Fed up with dust when dry & mud when wet
- 1904-1968
- 6ft diagonal panels scored into 4” squares to prevent horse slipping

1950 Photo
LeMars, Iowa - Today
1904 1st Concrete Street
LeMars, Iowa

- Two lift construction
- 5” lean concrete base (sand, cement & gravel)
- 1 ½” surface had higher cement content
- Modeled similar to sidewalk construction
1909 - Eddyville Cemetery Rd

• Oldest Farm to Market Road in Iowa
• Top 10 Oldest in U.S.

• What was Unique?
  Transverse grooves set in pavement
  Citizens fed up with deep sand in dry weather

108 Years Old
1913 - Iowa Highway Commission
Forms

Several Short Projects (1/4 to 1.3 mile) 6”-7” thick

- Cerro Gordo
- Louisa
- Benton
- Dallas
- Muscatine (1914)

Muscatine 103 Years Old - 2011 Photo
1913 - Iowa FA-1 Cerro Gordo Co. (between Clear Lake and Mason City)

Specifications

Type A (Full depth) or Type B (two course)

1st penalty clause
- Divide into 50 ft blocks
- Count bags of cement
- If any 3 adjacent blocks 4% less or 7 1/2 % more, remove and replace the blocks

Texture 3-ply belt 10” wide

1 mile of pavement for a cost of $11,500 ($1.23 /SY)

104 Years Old
1918 – Seedling Mile

- Linn County
- Northwestern States Cement donated 3,000 barrels of cement
- Ford Paving Company bid of $3.15/yd²
- Highway Commission talked them down to $2.84/yd² due to change from Type B to Type A and changing from crushed limestone to Muscatine Gravel

99 Years Old
Part of Lincoln Highway
1918 – Seedling Mile

Linn Co. Rd E48 (W. Mount Vernon Road)
1921 US 20 - Woodbury County

What was Unique?
- Dry materials dumped into skip hoist
- Water lines laid out along grade

96 Years Old

skip hoist
• Curing Prior to 1930
• 1 day wet burlap cure for 24 hours
• Then 2” of wet sand or earth or 6” of straw
• After October 15, used calcium chloride in mix (rate of 2lb per bag of cement) and required wet burlap for 24 hours
• In 1930, sand or wet earth or straw required for 6 days, with opening to traffic in 7 days
1921 US 20 - Woodbury County

- 10” PCC
- Fine & Coarse Aggregate: Correctionville
- Cement: Marquette-Northwestern
- No Joints (1920-1925)

2017 photo

96 Years Old
1930 - Mitchell County

- Curing by Ponding
- 1925 specs: 2” min. ponding depth in lieu of earth cure
- 1948 specs: ½” min. ponding depth for 48 hours

87 Years Old
1930’s – 1950’s

• Paving slowed during the war era

• By the 1940s there were 5,000 miles placed. Today there are approximately 10,000 miles. A majority of these miles were paved in the 1950s – 1970s.

• 1956 Interstate Highway System

• As the need for paving grew, demands on earlier opening also increased
1958 – Interstate Paving

- 1958 to 1966 jointed mesh reinforced
- 76.5’ joint spacing
- Mesh reinforced
- Tandem pavers
  - Bottom lift placed
  - Place mesh
- Top layer placed by second paver
1976 - Delaware Avenue

- Polk County pavement (from 1st St. to 36th St, Ankeny)
- 7” PCC
- 7” Class A Roadstone Base
- PCI of 86 in 2014

41 Years Old
Iowa Concrete Paving Milestones

1900: Curing, Cement Grind, Slow & Longer Strength Gain
1910: Proper Jointing
1920: No Jointing
1930
1940: Air Entrainment, Slip Form Paver
1950: Interstate Highway System
1960: Aggregate Classification, Internal Curing
1970: Lower Water/cement Ratio
1980: Fly Ash, Dowels
1990: SCM
2000: Maturity Method
2010: Teritary Mixes
2020: The Future: Fibers, Internal Curing, PEM

- Aggregate Classification
- Internal Curing
- Air Entrainment
- Slip Form Paver
- Interstate Highway System
- Lower Water/cement Ratio
- Fly Ash
- Dowels
- SCM
- Maturity Method
- Teritary Mixes
- Fibers
- Internal Curing
- PEM
What has Changed?

- 13 Pavements
- Constructed from 1909-2006
- Studied Air Content & Permeability

<table>
<thead>
<tr>
<th>County</th>
<th>Year</th>
<th>Location</th>
<th>Fine Agg</th>
<th>Coarse Agg</th>
<th>Cement</th>
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<tbody>
<tr>
<td>Mahaska</td>
<td>1909</td>
<td>Eddyville Cemetery Rd</td>
<td>Eddyville</td>
<td>Eddyville Gravel</td>
<td>n/a</td>
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<tr>
<td>Woodbury</td>
<td>1921</td>
<td>Old 20 E of Sioux City</td>
<td>Correctionville</td>
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<td>Marquette Northwestern</td>
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<td>1929</td>
<td>Old 63 S of Ottumwa</td>
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<td>Dewey Stone</td>
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<td>Monona</td>
<td>1938</td>
<td>IA 175 MP 8.7 to 14.4</td>
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<td>Correctionville Gravel</td>
<td>Ash Grove</td>
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<td>Pocahontas</td>
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<td>IA 15 MP 0 to 5.5</td>
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<td>Hawkeye</td>
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<td>1955</td>
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<td>Sprague</td>
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<td>Northwestern Penn Dixie</td>
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<td>Clemons</td>
<td>Ferguson Stone</td>
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<td>Stutz</td>
<td>Moberly Mine</td>
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<td>1980</td>
<td>IA 17 MP 21.6 to 32.7</td>
<td>Christensen</td>
<td>Stutz Gravel</td>
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<td>Christensen</td>
<td>Ames Mine</td>
<td>Ash Grove 15% C fly ash</td>
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<td>1997</td>
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<td>Ivanhoe</td>
<td>Bowser Stone</td>
<td>Holcim IS(35) 10% C fly ash</td>
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<td>US 151</td>
<td>Anamosa</td>
<td>Stone City</td>
<td>Lafarge I(20) 20% C fly ash</td>
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<td>Fremont</td>
<td>2006</td>
<td>IA 2</td>
<td>Oreapolis #8</td>
<td>Weeping Water</td>
<td>Ash Grove IP(25) 20% C fly ash</td>
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</table>
What has Changed?
Cement Chemistry

Cement chemistry has changed over the years, but we have the same or better results.
What has Changed? - Air

Air Entrained Concrete Specifications

1952 3-5%
1956 4-6%
1960 5-7%
1995 6-8% (increase to account for loss through paver)
2000 5-7.5%

2017 6-10% (on grade prior to paver)
  5.5- 7.5% (non-slip form paver)
What has Changed? - Air

Air Content of Pavement Cores

Iowa DOT Report
MLR-05-02, March 2007

13 project sample size

Air Entrained after 1952

Year

%Air Concrete

What has Changed? - Permeability

RCP - AASHTO T 277

13 project sample size

1952
Air Entrained

1994
Ternary

2000
Well Graded

Iowa DOT Report MLR-05-02, March 2007

Low permeability is more important than air (based on older pavements)
What has Changed? – Not the mix
Current Class C-4 & Class C-SUD

Class C-4 Mix
- Cement: 0.118
- Water: 0.159
- Air: 0.06
- Fine Aggr.: 0.331
- Coarse Aggr.: 0.332

Class C-SUD Mix
- Cement: 0.106
- Water: 0.133
- Air: 0.06
- Fine Aggr.: 0.315
- Coarse Aggr.: 0.386
Results of Iowa DOT (MLR-05-02) Report

- The air content for projects placed prior to the requirement for air entrainment in 1952 is less than 3%.
- Air contents increased as specification limits increased.
- The indicated permeability of older pavements is very low.
- The permeability of pavements utilizing a Shilstone type gradation and supplementary cementitious materials, such as slag and fly ash, can reduce indicated permeability to the level of older pavements.
What has Changed?

Pavement Section

Uniform depth until 1926

Thickened edge 1926-1957

18’ wide until mid-1930’s

20’ wide until 1948

22’ wide until 1959

Expansion joint with load transfer every 80’ to 120’
What has Changed?
Deicing Practices

- Salts were common in the 1950s
- Brine became common in late 1990s

Source: Iowa DOT
Deicers - Impact on Joints

• The formation of Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide (CH) are the two principal ingredients that mesh into a solid mass forming concrete pavement.

• Magnesium and calcium chloride will react with CH with water at between 32°F and 122°F, depending on the salt concentration.
Deicers - Impact on Joints

• This reaction results in the formation of calcium oxychloride which results in flaking (expansion) of the hardened paste causing significant damage particularly in joints.

• Oxychloride expansion can be 3 times greater than freeze-thaw expansion.

• The use of SCM’s (fly ash, slag, and silica fume) has shown to reduce the formation of calcium oxychlorides.
What has Changed? Aggregates

• Aggregate quality very critical in performance of concrete durability

• 1930s pit run gravel was predominant

• Then, limestone and dolomite sources were mined

• Durability of these carbonate aggregates largely dependent on pore system
  • D-cracking
  • Deicer attack

• Aggregate is now tested to ensure long term performance
What has Changed?

Aggregates

• 1967 study of D-cracking pavements

• Significant cracking after 5-10 years for certain aggregates (calcitic limestone, calcitic dolomite, dolomitic limestone)

• Led to Durability classification in 1971

• Pore system studied by Iowa DOT Office of Materials (shale, clay, tripolitic chert)

• D-cracking is related to pore size

• Led to Iowa Pore Index Test (in use since 1978)
What is Essential for Long Life Concrete Pavements?
Summary
What is Essential for Long Life?
Low Permeability

Proper Materials
Proper Design
Proper Construction
What is Essential?
Materials – Aggregate Durability

Durability Classification – IM T203

Class 2 – produce no deterioration of pavements in non-interstate roads after 15 years & only min. deterioration after 20 years (pore index >20)

Class 3 – produce no deterioration of pavements in non-interstate roads after 20 years & less than 5% deterioration of the joints after 25 years (pore index >25)

Class 3i – produce no deterioration of pavements on interstate roads after 30 years & less than 5% deterioration of the joints after 35 years (pore index >30)
What is Essential?
Materials – Low Permeability

Use SCMs to tie up CH

\[
\text{Cement} + \text{Water} = \text{C-S-H}
\]

\[
\text{SCM} + \text{Water} + \text{CH} = \text{more C-S-H}
\]
What is Essential?
Materials – Air Entrainment

Proper air void system
Spacing ≤ 0.008 in.

I.M. 318 (Air Content)
I.M. 327 (Sampling)
What is Essential? Proper Design

- Pavement Designer is now available!
- Web-based pavement design application
- Developed by ACPA, NRMCA and PCA
What is Essential? Proper Design

www.pavementdesigner.org
What is Essential?
Design – Drainage

Shadowing - Potential sign of saturation

Joint deterioration – Can be caused by backer rod
What is Essential? Design – Drainage

• Water is coming to our pavement from several sources
• We need to control this water so pavement is not saturated
What is Essential?
Design – Drainage

• Used when soil is reasonably stable & not excessively wet.
• Provides a **working platform** during construction
• Provides **uniformity** as a support layer
• Serves as a **drainage system** to help drain surface water away from the pavement to a subdrain or ditch
• Provides a cutoff layer from subsurface moisture (and risk for pumping)
What is Essential?
Construction – Use Proper Air

Check air after paver to determine loss

Air Content (on grade before consolidation)
  • Slip form (8.0% +/- 2.0%)
  • Non slip form (7% +/- 1.5%)

• Adjust the mix when:
  • Slip form Air < 7% or > 9%
  • Non slip form Air <6% or > 8%

(on grade before consolidation)

(Ch. 9.6 Iowa DOT Field Inspection Manual)
What is Essential?
Construction – Proper Cure

Curing

• Start early
• Application rate = 0.067 gal per SY
• Apply within 30 min.
• When it dries, it dies

Poor

Good
What is Essential?
Construction – Proper Sawing

- Road Standard PV-101 (IDOT & SUDAS) defines all joints
- Check saw depth and width daily
- Inadequate depths may lead to cracking
- Check saw blade wear
Summary
What is Essential for Long Life?

Materials
- Low Permeability (Use SCMs)
- Aggregate Durability
- Air Entrainment

Design
- Thickness
- Drainage

Construction
- Proper Air
- Proper Curing
- Proper Sawing
THANK YOU!

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www.cptechcenter.org