Research Objectives

- 6 test cells exposed to varying degrees of early loading by two levels of axle weight (39,000 lbs and 9,000 lbs).
- Performance concerns due to early loading:
  - Cracking/Fatigue Damage
  - Durability
  - Dowel looseness
- To evaluate effects of early loading on the long-term performance of concrete pavement, the following information was collected for Cells 124-624: concrete maturity, concrete dynamic strains, concrete strains caused by environment, warp and curl measurements, concrete strength and durability (freeze-thaw), non-destructive testing (MIRA), international roughness index measurement, falling weight deflectometer testing, and petrographic data.

Primary Loading Scheme for Early Loading

- 6" PCC
- 6" Agg Base
- 1" Dowels
- 15'L x 12'W joints
- 2017 Const.
Concrete Age:
- 3 hrs.
- 5-3/4 hrs.
- 8-1/3 hrs.
- 10-1/2 hrs.
- No Load

Cell x24 Early Loading Sequence

<table>
<thead>
<tr>
<th>Maturity (Deg-Hr)</th>
<th>Flexural (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>12</td>
</tr>
<tr>
<td>200</td>
<td>196</td>
</tr>
<tr>
<td>300</td>
<td>267</td>
</tr>
<tr>
<td>400</td>
<td>318</td>
</tr>
</tbody>
</table>

Loads applied to lanes:
- 1st Load on Cell 124 (forward and back)
- 1st Load on Cell 224, 2nd load on Cell 124
- 1st Load on Cell 324, 2nd load on Cell 224, 3rd load on Cell 124
- 1st Load on Cell 424, 2nd load on Cell 324, 3rd load on Cell 224, 4th load on Cell 124

Starting Day 2, 5 passes per day for first week

MnROAD Maturity Curve

Hours | TTF
--- | ---
3.0 | 100
5.75 | 200
8.33 | 300
10.5 | 400

Compressive and Flexural Strength of Concrete

- Compressive Strength of Concrete: $y = 176.51 \ln(x) - 739.35 \quad R^2 = 0.9671$
- Flexural Strength: $y = 1086.98 \ln(x) - 5515 \quad R^2 = 0.9952$

Log. (Compressive Strength of Concrete)
MnROAD Test Cells Being Loaded

- [https://www.youtube.com/watch?v=A7n-CaONlwU&ab_channel=NRRA](https://www.youtube.com/watch?v=A7n-CaONlwU&ab_channel=NRRA)

Future Joint
Microcracking and Carbonation in Cores

- Cores were taken in the wheel path and between wheel paths
- Cell 424 had a 1-inch deep microcrack, not attributed to early loading since it first loading was at 318 psi flexural
- Research shows most common length of microcracking in cores (Stutzman, 1999)
  - 0.4 to 0.8 inches (10 to 20 mm)
- Carbonation was negligible to 0.07 inches (2 mm) where no microcracking was present
- Carbonation was 0.24 inches (6 mm) to 0.51 inches (13 mm) deep along subvertical cracks
- Early age trafficking of Cells 124 and 424 did not cause top concrete surface damage or long-term durability problems

<table>
<thead>
<tr>
<th>Cell</th>
<th>Wheel path microcracking</th>
<th>Between wheel paths microcracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>0.16 in (4 mm)</td>
<td>0.28 in (7 mm)</td>
</tr>
<tr>
<td>424</td>
<td>0.2 in (5 mm)</td>
<td>0.51 in (13 mm)</td>
</tr>
<tr>
<td>524 (No early loading)</td>
<td>0.43 inches (11 mm)</td>
<td>0.43 inches (11 mm)</td>
</tr>
</tbody>
</table>

Dowel Looseness

- Opening pavements too early to live traffic may be risky because of the possible excessive bearing stresses under dowels that develop due to the application of wheel loads at early ages. These stresses can lead to damage in the concrete surrounding the dowels that is not apparent at the surface yet compromises the load-transfer efficiency of all joints containing compromised dowels.

- However, a laboratory study of this phenomenon found little evidence of failure in the “compression zone” of paste surround the dowel after early age loading (Crovetti and Khazanovich, 2005). Nevertheless, the application of early-opening-to-traffic should emphasize the proper design and construction of joints to ensure adequate joint performance.
Ride Quality

- Early loading on Cells 124-424 did not produce visible damage on the pavement to affect the IRI
- Data after 22 months
- No difference between lane loaded with snow plow truck (31,000 lbs) vs. dump truck (9,000 lbs)

Conclusions

MnDOT/NRRA research supports allowing traffic on concrete pavements earlier

- The current strength criteria for opening concrete pavements to traffic are empirical and conservative.
- Extensive analysis of pavement performance, non-destructive testing, and embedded sensors could not identify any long-term damage associated with those early loadings
- Finite Element Analysis and Mechanistic-Based Early Opening Damage Analysis performed
- This experiment showed no damage occurring at an estimated 73 psi flexural strength
- Current criteria for traffic opening is overly conservative and that modern concrete pavements can safely open to traffic earlier than currently allowed.
If you still aren’t sure – Web-Based Tool

- Better assess the risk of early opening by accounting for the rate of concrete strength gain, traffic volume, load characteristics, and pavement structure properties.

- Simulations performed with this tool compared well to data gathered at MnROAD.

MnDOT Requirements
Closed Period for New Pavement – 2005 Spec

• Newly constructed pavement may be opened to use by light vehicles (axle loads of 2700 kg (6000 pounds) or less) 72 hours after the concrete has been placed.

• New pavement shall be closed to use by construction and general public traffic for 7 days or according to the values listed in the Table 2301-A whichever is the shorter.

<table>
<thead>
<tr>
<th>Slab Thickness (mm)</th>
<th>Flexural Strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 (6.0)</td>
<td>3.4 (500)</td>
</tr>
<tr>
<td>165 (6.5)</td>
<td>3.4 (500)</td>
</tr>
<tr>
<td>175 (7.0)</td>
<td>3.4 (500)</td>
</tr>
<tr>
<td>190 (7.5)</td>
<td>3.3 (480)</td>
</tr>
<tr>
<td>200 (8.0)</td>
<td>3.2 (460)</td>
</tr>
<tr>
<td>215 (8.5)</td>
<td>3.0 (440)</td>
</tr>
<tr>
<td>225 (9.0)</td>
<td>2.7 (390)</td>
</tr>
<tr>
<td>240 (9.5)</td>
<td>2.4 (350)</td>
</tr>
<tr>
<td>255 (10.0)</td>
<td>2.4 (350)</td>
</tr>
<tr>
<td>≥265 (≥10.5)</td>
<td>2.4 (350)</td>
</tr>
</tbody>
</table>

2023 New Spec Opening to Traffic (2301) Concrete Pavement

• Do not open a new pavement slab to general public traffic or operate paving or other heavy Equipment on it for 7 Calendar Days, or until the concrete has reached a minimum flexural strength of 300 pounds per square inch, or minimum compressive strength of 2,000 pounds per square inch; whichever occurs first.

• Inserted in nearly all 2023 projects with a change order

• Most new 2024 projects should have this language in the contract

• Result: only taking 1-day vs. 2-3 days to get strength, seemed to save a day or more for construction this summer on most projects
O.2 Local Passenger Traffic Pavement Access

The Contractor may at their own risk allow local passenger traffic (total gross vehicle weight not to exceed 10,000 lbs or equivalent to a ¾ ton pickup truck) to drive across the new pavement slab to access their residence or business after satisfactory completion of all initial joint sawing, excluding early entry sawing, in accordance with 2301.3N.2, “Joint Establishment.”

Prior to placement of any concrete pavement, provide a Quality Control Plan to the Engineer for acceptance which provides the Contractor’s plan for management of local traffic during concrete pavement placement including a procedure for identification of vehicles allowed to drive across the new pavement.

If any damage occurs, the Engineer will evaluate the concrete pavement in accordance with 2301.3.Q, “Workmanship and Quality.”
Opening Strength Requirements

- Agency Opening Strength Requirements – 2020 (From a survey by Tara Cavalline)
  - Construction traffic
    - 500 – 650 flexural (2,200 – 3,500 psi compressive)
  - Regular traffic
    - 500 – 650 psi flexural (3,000 – 4,500 psi compressive)
    - Minnesota 350 – 500 psi flexural based on pavement thickness (3,000 psi compressive)
  - Construction Traffic – 300 -460 psi flexural depending on k-value and thickness
  - Public Traffic (6-8 inches) – 300-630 psi flexural depending on k-value, thickness and ESALS
  - Public Traffic (8-10.5 inches) – 300-470 psi flexural depending on k-value, thickness and ESALS
Case Studies

• Washington DOT – Strength-Maturity 2009
• Iowa Bonded Concrete Overlay
• Field Evaluation of early opening of full-depth repairs – SHRP, Georgia and Ohio
• California Interstate Reconstruction
• Full-depth patching of CRCP – Virginia DOT
• Overnight Lane Closures - Indiana

Slide from Norb Delatte, NC2 presentation 09-15-2022

NC2 MAP Brief Winter 2021 Recommendations

• For concrete construction, it is often thought that higher strength is more conservative. However, given the experience of early cracking and durability problems with some EOT concrete, particularly mixtures designed for very short closures, that approach may not be conservative for paving. Instead, it is probably better to reduce opening strength requirements and use more durable mixtures.

• Agencies should reduce opening strength requirements. Experience suggests that the opening strengths provided in the tables in the Appendix are reasonable.

• When possible, agencies should use conventional paving mixtures for early opening to traffic, particularly for weekend closures.

• Agencies should consider maturity, UPV/impact-echo, and other NDT technologies rather than curing time for opening pavements to traffic.
Technical Summary 2023 Recommendations

- The current strength requirements set by some state transportation agencies for opening concrete pavements to traffic may be overly conservative.
- Excessive strength requirements lead to concrete mixtures that may achieve the required strength quickly but may not be durable in the long term.
- Instances of significant pavement fatigue damage due to early opening were not reported in the case studies or the literature.
- For opening to traffic, the Strategic Highway Research Program (SHRP C-206) recommends a minimum flexural strength of 300 psi with third-point bending and/or a minimum compressive strength of 2,000 psi.
- Alternatively, a damage-based online tool has been published that uses early opening damage analysis to determine cracking risks for a given pavement system loaded at a given strength (Khazanovich 2021).

Questions?

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