



## LOWER OPENING STRENGTHS IN MINNESOTA

What strength do we really need?

ICPA: 60th Annual Concrete Paving Workshop

# OUTLINE

Background

MnROAD Opening Strength Project

Joint Activation

MnDOT Revised Specifications

Closing Thoughts





# BACKGROUND

When can we allow traffic on new concrete?

# WHEN CAN WE ALLOW TRAFFIC ON NEW CONCRETE?

1 / 3 / 7 Days?

2000 / 3000 / 4000 psi Compressive?

150 / 300 / 500 / 650 psi Flexural?

How exactly were these values determined? We'll come back to this.



# PLASTIC LOADING

We all know loading immediately after placement will likely result in extreme levels of damage...





D3 9

24098-PA



STATE TROOPER



*Serving Since 1929*





TINY BEAUTIFUL THINGS  
APRIL 21 TO MAY 8  
289 1737



1 Ave St

Kause  
Lumber

AMD-184



# EARLY LOADING

We know loading in the plastic phase is likely to cause unacceptable damage, and we know that the concrete will perform exceptionally in the hardened phase.

The long-term performance of curing-phase concrete that undergoes early loading is not as well understood, but we do have numerous historical examples available to look at.



# GOODHUE CSAH 6

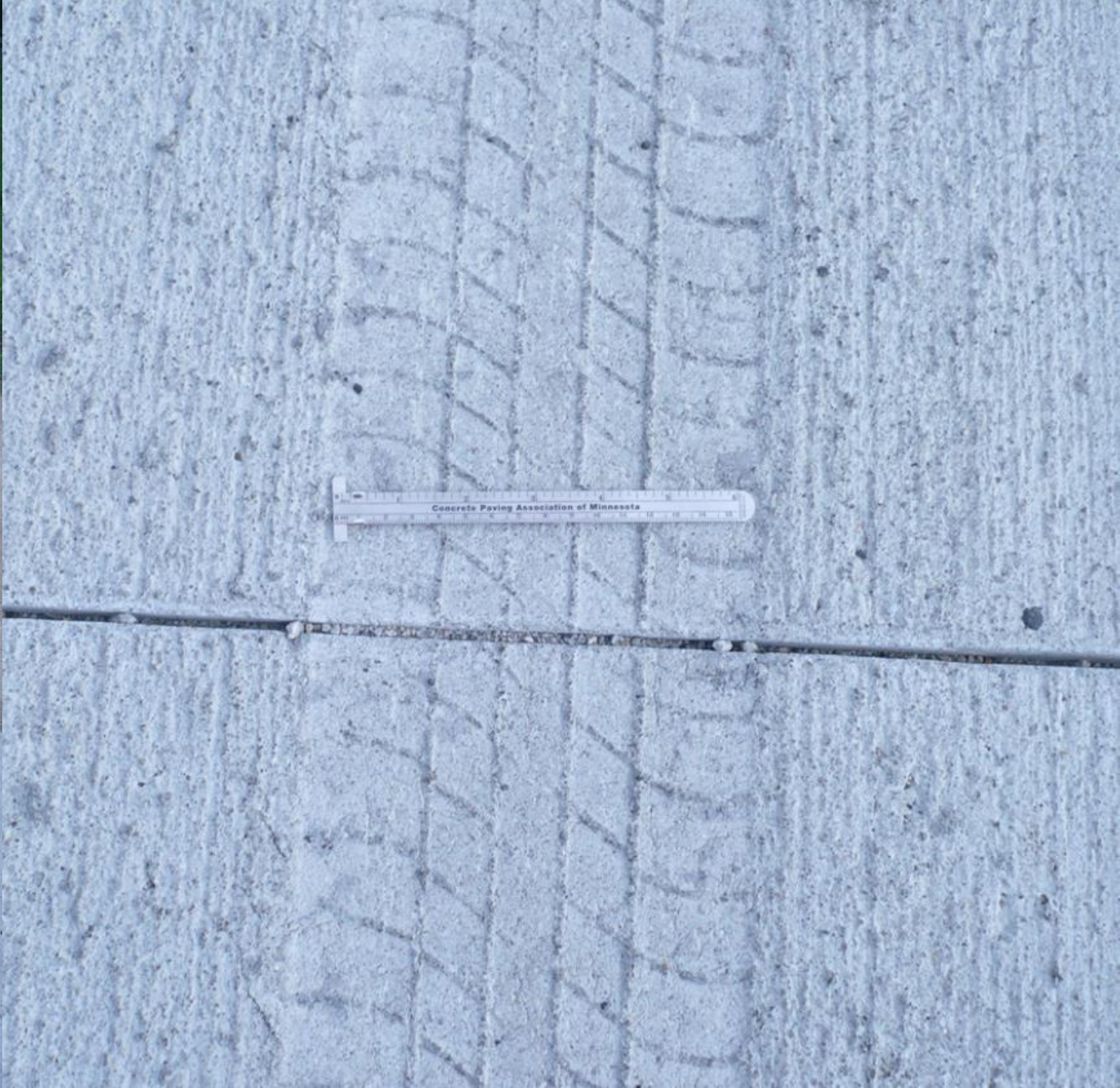
Concrete Pavement: 2016

Resolution: Initial recommendation to Remove & Replace

Revised Resolution: Core and petrographic analysis to be run, if no excessive cracking:

- Allow to remain in place.
- Diamond grind to remove excessive ruts and patches
- Warranty for 2 years







Concrete Paving Association of Minnesota

# I-94 CLEARWATER

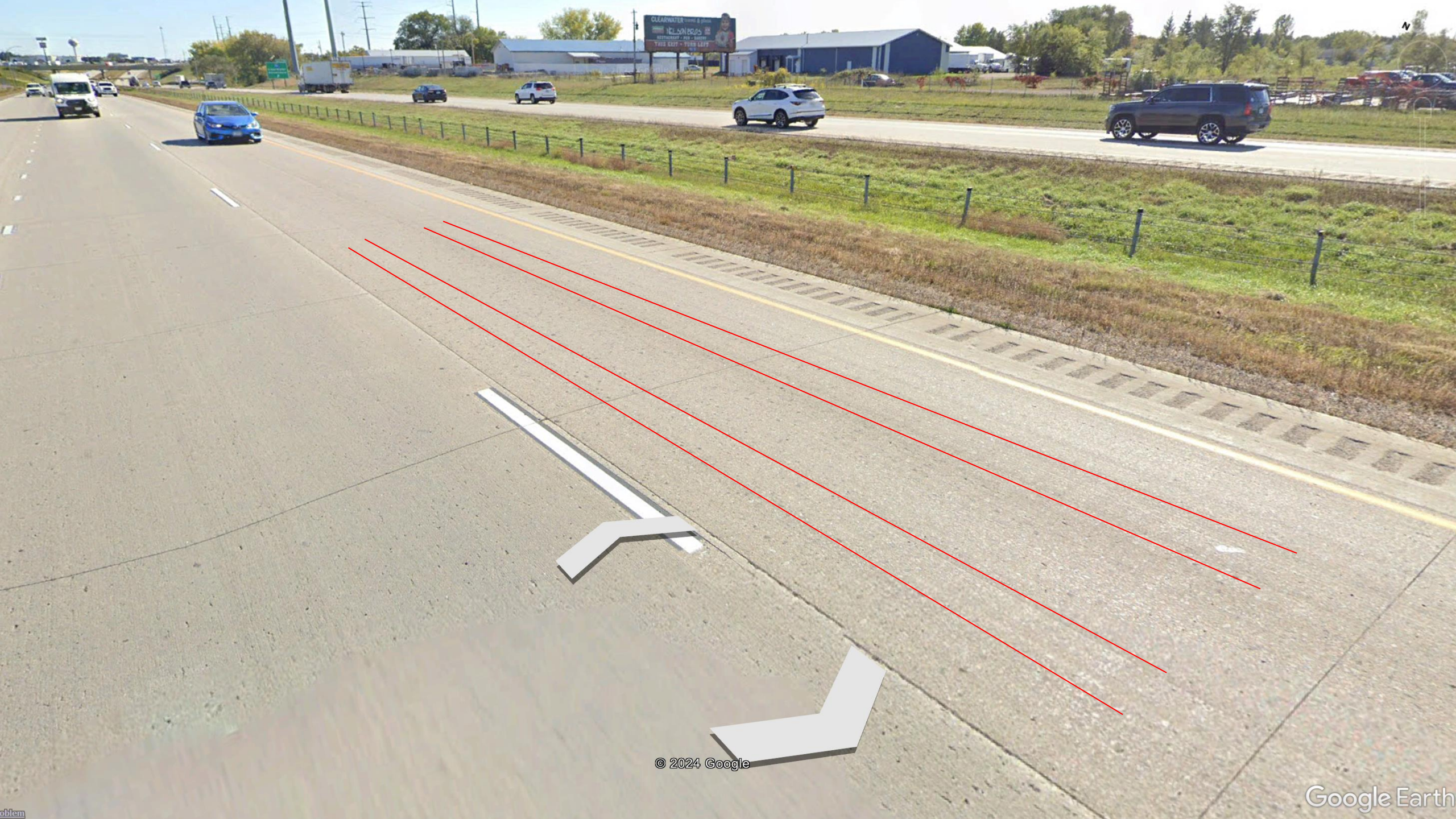
Concrete Pavement: 2013

Canadian Driver Statement: “I just followed my GPS, and it told me to turn here.”

Resolution: Contractor required to diamond grind to meet 10' straight edge requirement described in MnDOT 2301.3.F.

- Concrete office was not consulted.
- Diamond grinding to remove rutting ( $<1/4$ ").





# US 12

Concrete Pavement: 1994

\* Subsequent photos were taken in 2016, no further deterioration as of summer of 2023.

Resolution: Remain in place as-is.











# OPENING STRENGTH

Why 3000 psi? Where did this number come from?

## Vehicle Tire Pressure

- Car: 35 PSI
- Pickup Truck: 35-80 PSI
- Semi-Truck/Trailer: 75-135 PSI

3000 PSI represents a factor of safety of at least 20 over the max tire pressure of a semi.



# DRAWBACKS OF CONSERVATIVE SPECS

“We can’t build concrete because it takes too long to get traffic on the pavement”

- Roadways
- Intersections
- Driveways
- Sidewalks



# RESEARCH MOTIVATION

## Concerns:

- **Durability**

- How is the durability of an early loaded pavement affected?
- How damaging is a rut from an errant vehicle?
- How damaging is an early load without visible ruts?

- **Related**

- Damage vs. strength gain
- Load repetitions vs. damage





# MNROAD OPENING STRENGTH PROJECT

Where Matt Zeller gets to try his  
'crazy' ideas.

## Early loading of Cells 124-424



**4,000 lb axle vs 14,000 lb axle loads (1<sup>st</sup> Cell @ 3hrs)**

# PAVEMENT SECTION

6" PCC

6" Aggregate Base

1" Dowels, 1' Spacing

15'L x 12'W Jointing

Constructed in 2017

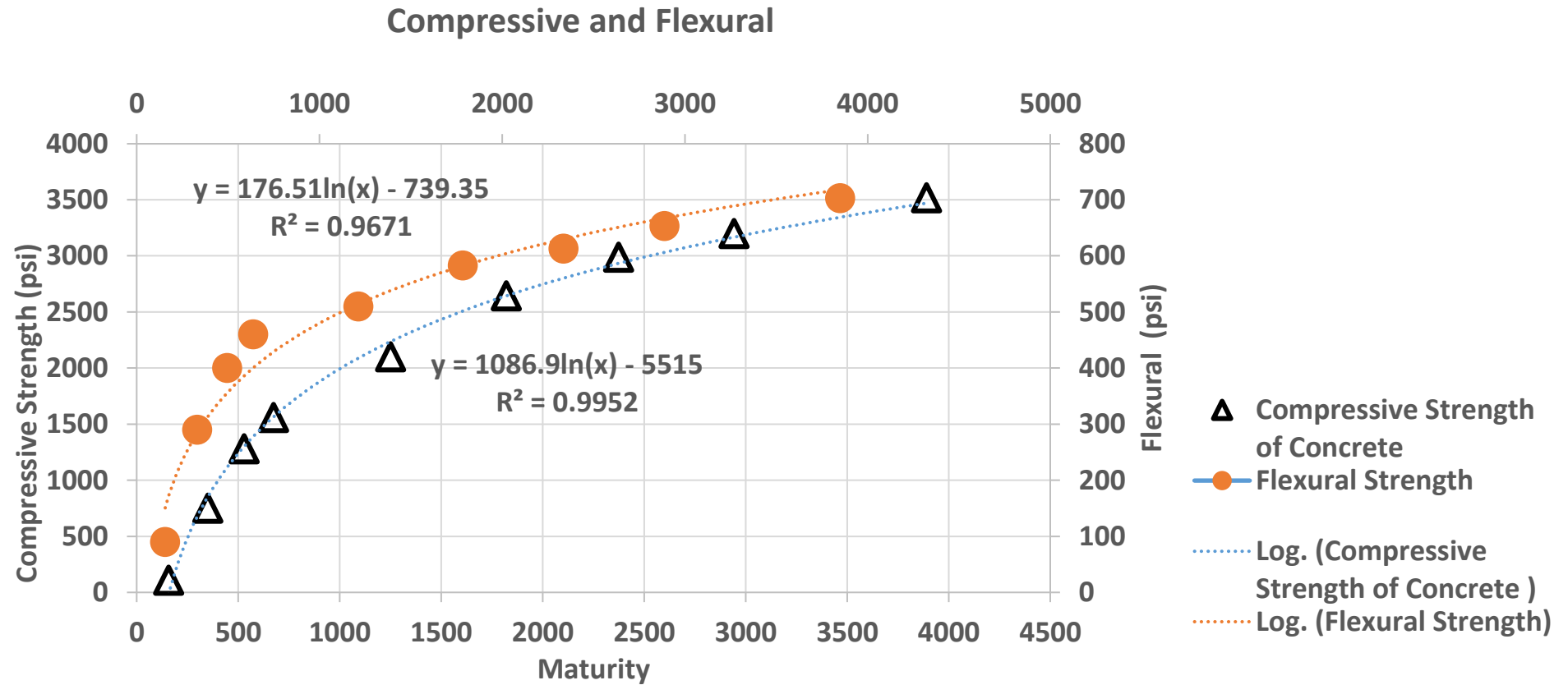
Video Link: [https://www.youtube.com/watch?v=A7n-CaONlwU&ab\\_channel=NRRA](https://www.youtube.com/watch?v=A7n-CaONlwU&ab_channel=NRRA)





# MNROAD MATURITY CURVE

Hours	ITF
3.00	= 100
5.75	= 200
8.33	= 300
10.50	= 400



# THE 1<sup>ST</sup> EXPERIMENT

Concrete Age:            3 hrs.                    5-3/4 hrs.                    8-1/3 hrs.                    10-1/2 hrs.                    No Load



124

224

324

424

524

Cell x24 Early Loading Sequence		
Maturity (Deg-Hr)	Flexural (psi)	Loads applied to lanes
100	73	1st Load on Cell 124 (forward and back)
200	196	1st Load on Cell 224, 2nd load on Cell 124
300	267	1st Load on Cell 324, 2nd load on Cell 224, 3rd load on Cell 124
400	318	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

Burnham - NCC 2017





# THE 2<sup>ND</sup> EXPERIMENT

Concrete Age: 2 hrs



Cell 524

2 Hours – Cell 524 Transverse Loading Only



















# CONCLUSIONS

Strain gauges picked up first pass only of the snowplow.

No visible damage after 3hrs

No damage seen in cores after 3hrs

80,000 lb. truck, 80 times per day since day 6

Ruts not fixed; no additional damage visible.



# WHEN CAN WE ALLOW TRAFFIC ON NEW CONCRETE?

1 / 3 / 7 Days?

2000 / 3000 / 4000 psi Compressive?

150 / 300 / 500 / 650 psi Flexural?

We'll come back to this.





# JOINT ACTIVATION

Insights from joint activation experiments.

# JOINT ACTIVATION

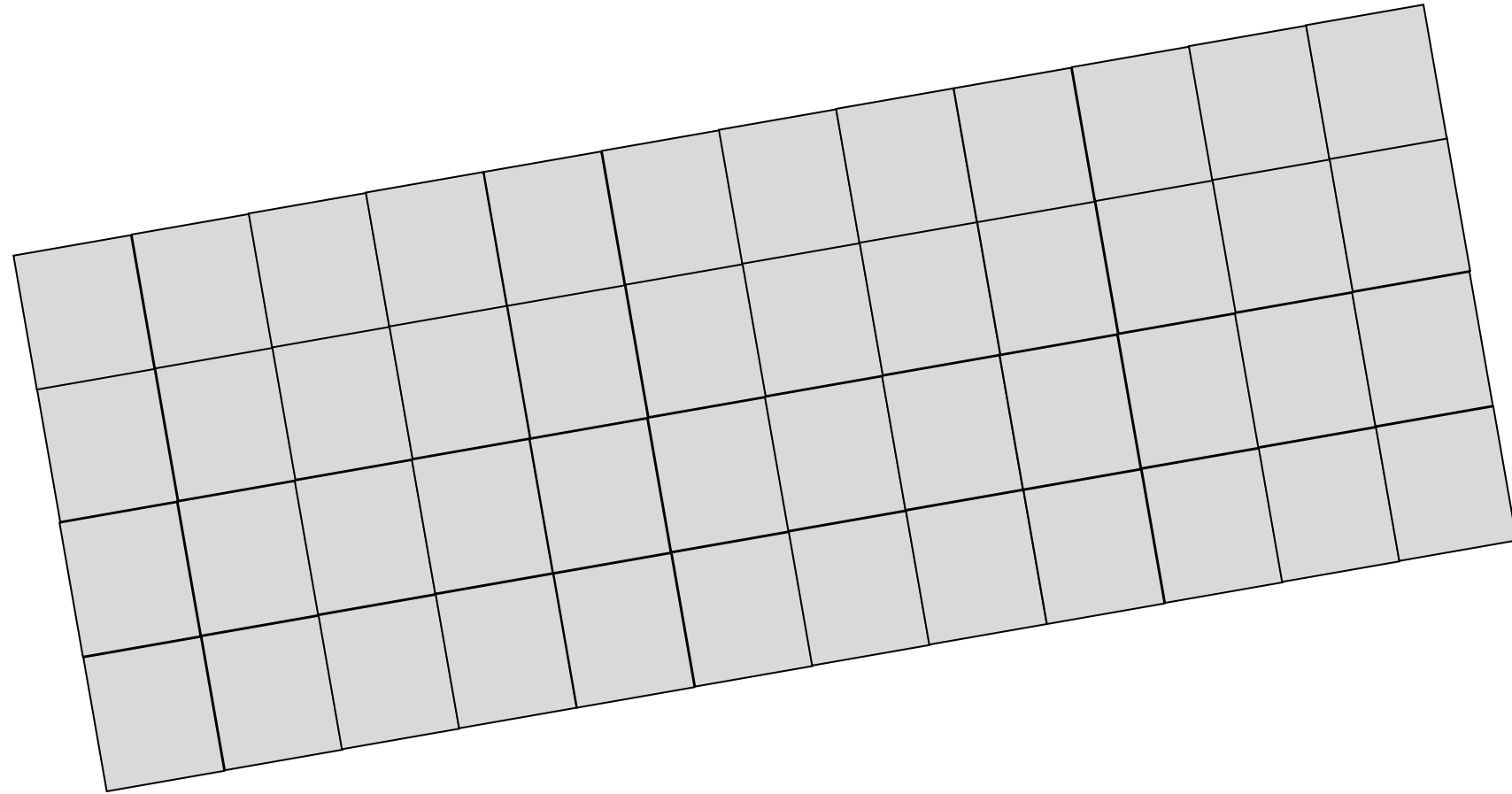
- As concrete sets it shrinks about  $\frac{1}{2}$ " to  $\frac{3}{4}$ " per 100' of length.
- So, a 15' panel will shrink about  $\frac{1}{8}$ " and a 6' panel will shrink about 0.05"
- A 100' slab will expand/shrink by about  $\frac{2}{3}$ " when subjected to a 100-degree temperature difference.
- So, a 15 slab will expand/shrink 0.1" and a 6' slab 0.04"





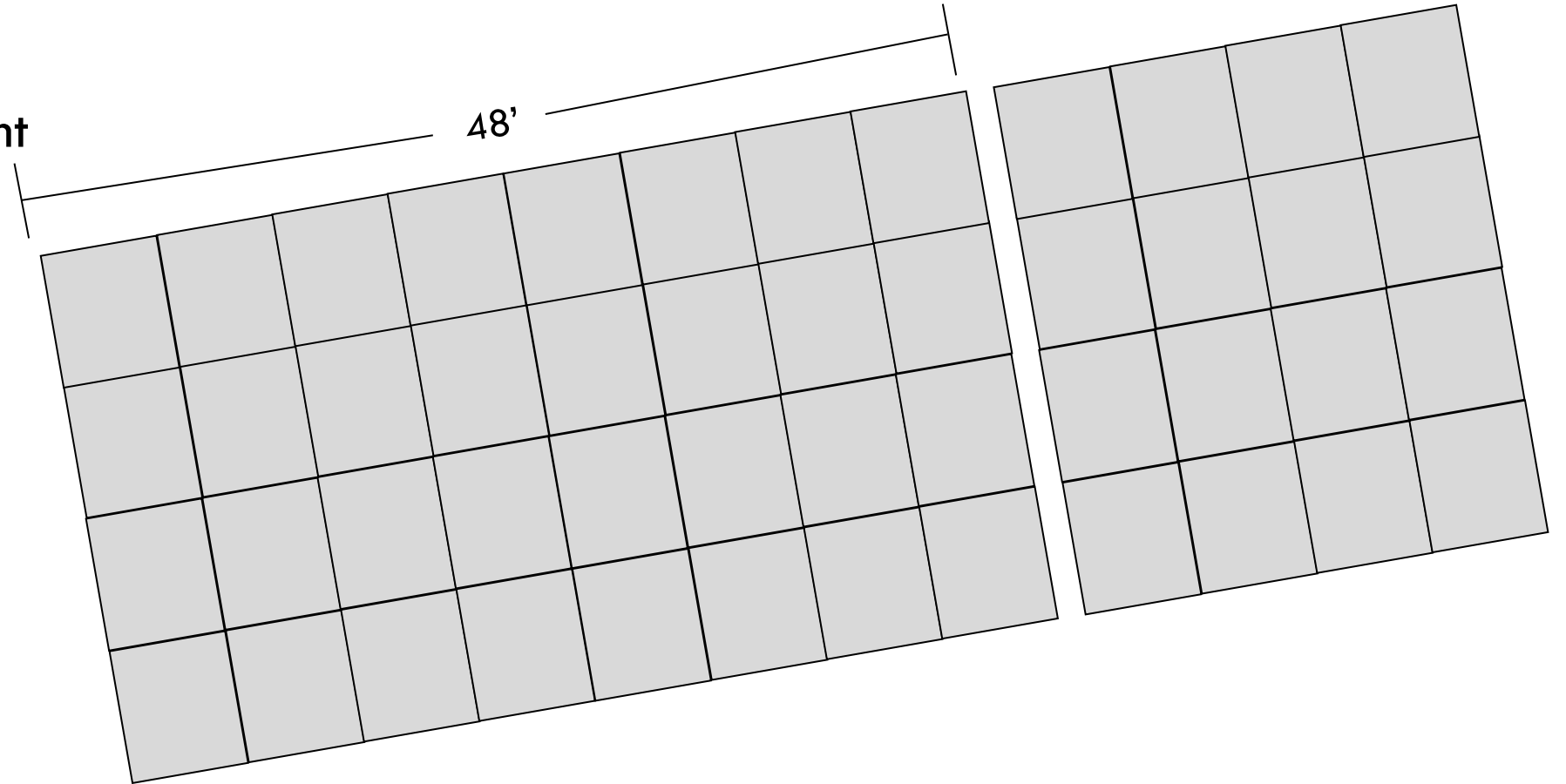
# 6' X 6' JOINTS

If all joints activate,  
the joints should  
barely open/close.



# 6' X 6' JOINTS

If every eighth joint  
activates...



# THE PROBLEM

## All Our Joints are Not Working/Moving/Activating

- Larger panels have more curl and warp
- More joints = smaller joint opening = better aggregate interlock
- Smaller joint opening = less opportunity for incompressible material to infiltrate = less opportunity for pavement buckle





Milwaukee

ft  
25 ft  
in



PR APPD  
PTA-16-414



1

2

3

4

5

6

7

$\frac{1}{8}$

$\frac{1}{4}$

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# THE SOLUTION (MAYBE...)

Get all joints to activate

How?

- Saw deeper – but you lose aggregate interlock
- Saw sooner – but you are prone to see spalling and/or damage around joint
- Early loading – but you might get long-term damage

Testing of early loading began in 2018



# TH 63 Joint Activation -2018



# TH 63 Joint Activation - 2018



# Brown CSAH 15 Joint Activation - 2021



# Stearns CSAH 72 Joint Activation - 2022



# JOINT ACTIVATION/EARLY LOADING

I think we can & should load BCOA early to activate joints

First project TH 63 in 2018

10+/- projects since – mostly thin overlays

I believe we should do this on traditional concrete pavements as well.

Optimum timing appears to be shortly after sawing or about 12 hours.





# JOINT ACTIVATION/EARLY LOADING

Maturity test of TTF = 350 (150 psi flex) seems to be a good target to load

Most likely need to continue to load for several days.

- Brown CSAH 15 had best joint deployment by the entrance to a dairy farm.

Open to construction traffic or batch trucks?

May have to ensure sawing gets through edge of pavement



# MNDOT RESEARCH — JOINT ACTIVATION

MnDOT research report notes:

- The number of joints deployed at each location shortly after loading varied quite significantly
- It is true that several of the projects had an increased number of joints deployed due to the application of early loading, but not to the extent desired
- An important observation, however, is the fact that there appears to be no observable damage to the concrete overlay using the techniques utilized in this study



# NRRA RESEARCH REPORT

MnDOT NRRA Research Report on earlier opening strengths supports allowing traffic on concrete pavements earlier. Refer to final report published 10/12/2021:

“Evaluation of Long Term Impacts of Early Opening of Concrete Pavements”



# NRRA REPORT FINDINGS

- 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
- Current criteria for traffic opening is overly conservative and that modern concrete pavements can safely open to traffic earlier than currently allowed.



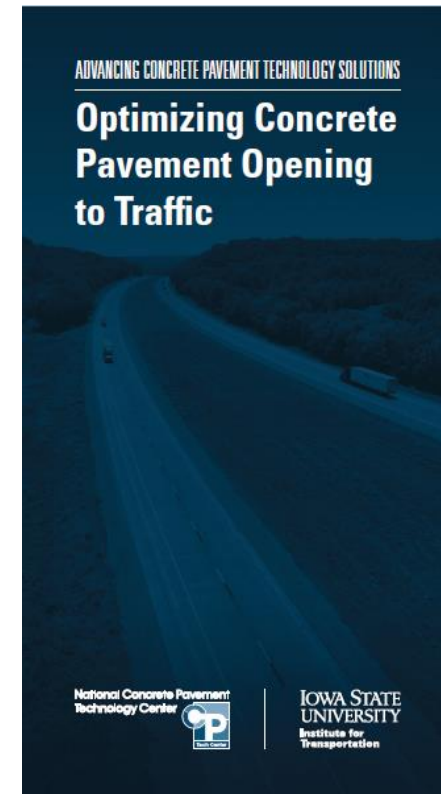
# OPTIMIZING CONCRETE PAVEMENT OPENING TO TRAFFIC

## Executive Summary

- Instances of significant pavement fatigue damage due to early opening were not reported in the case studies or the literature.
- **Strategic Highway Research Program (SHRP)** recommends a minimum flexural strength of **300 psi** with third-point bending and/or a minimum compressive strength of **2,000 psi**.

## Background

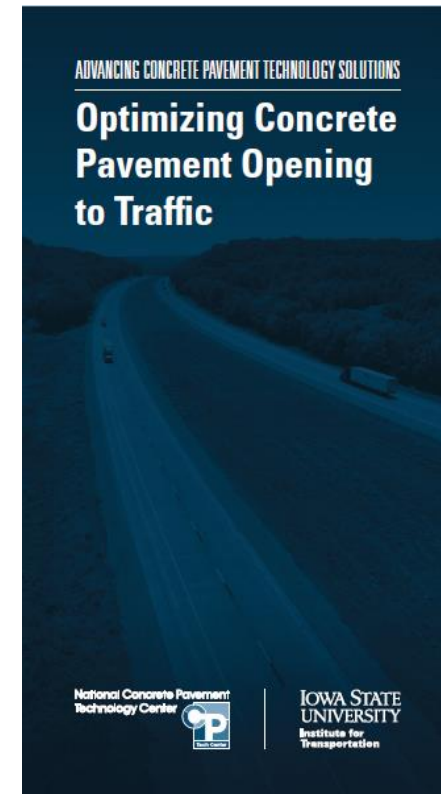
- Current practices regarding opening to traffic are largely based on rules of thumb rather than data (Antico et al. 2015a, Freese et al. 2016a, Freese et al. 2016b, Khazanovich et al. 2021).



# OPTIMIZING CONCRETE PAVEMENT OPENING TO TRAFFIC

## Full-Depth Repairs

- For repairs up to 12 ft in length, a flexural strength of 300 psi or a compressive strength of 2,000 psi appear to be reasonable opening criteria under most conditions.



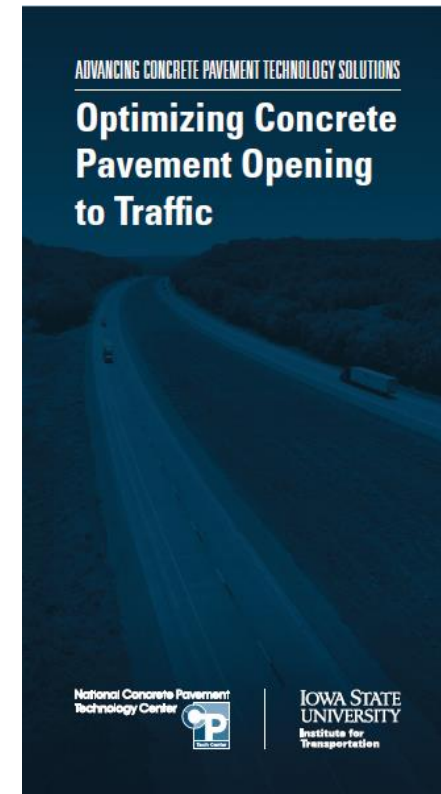
Technical Summary  
September 2023



# OPTIMIZING CONCRETE PAVEMENT OPENING TO TRAFFIC

## Fatigue Damage

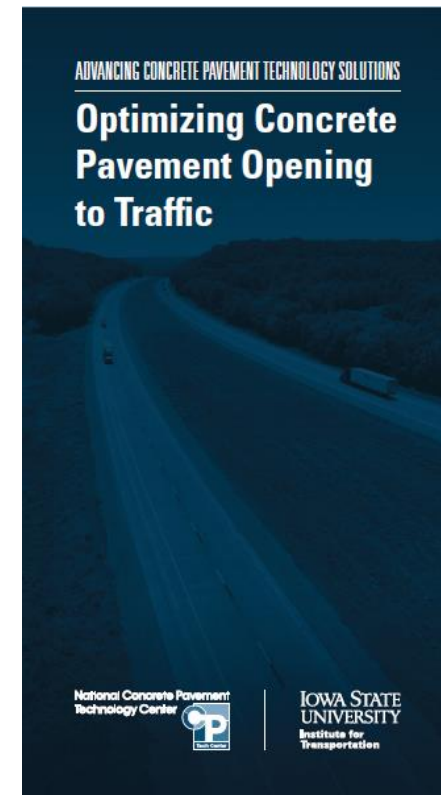
- Khazanovich et al. (2021) continued the research by Antico et al. (2015b). Six test cells were constructed at the MnROAD facility in 2017 and load tested. Despite loading as early as 2 to 10 hours after paving, no damage was observed.
- The test cells were investigated using strain gauge and MIRA nondestructive testing (NDT) data, roughness measurements, falling weight deflectometer (FWD) testing to determine whether any loss of load transfer occurred at doveled joints, and petrographic examination of cores.



# OPTIMIZING CONCRETE PAVEMENT OPENING TO TRAFFIC

## Fatigue Damage (cont)

- The researchers concluded that the current criteria for opening to traffic are overly conservative and that modern concrete pavements can safely open to traffic earlier than currently allowed, especially when the traffic consists of lightweight/passenger vehicles.
- The experiment showed that no damage occurred at an estimated flexural strength of 73 psi (Khazanovich et al. 2021).







# MNDOT REVISED SPECIFICATIONS

Now that we have real data...

# MNDOT 2020 OPENING STRENGTH SPEC.

## Opening Pavement to Traffic

- 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 meeting the requirements of Table 2301.3-7, **or minimum compressive strength of 3,000 pounds per square inch;** whichever occurs first.

Table 2301.3-7

Minimum Strength Requirements for Opening Pavements  
to Construction and to General Public Traffic

Slab Thickness (inch)	Flexural Strength (pounds per square inch)
≤ 7.0	500
7.5	480
8.0	460
8.5	440
9.0	390
≥ 9.5	350



# MNDOT 2020 OPENING STRENGTH SPEC.

## 2020 Opening Strength Spec (amended 2023)

### Opening Pavement to Traffic (S-153.31)

Delete and replace the first paragraph of 2301.30 with the following:

- 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.



# MNDOT SPECIAL OPENING STRENGTH

Upon request of the Engineer, the MnDOT concrete office also has an unofficial specification available to allow general lightweight traffic (F-250 or lighter) onto the concrete pavement after the joints are sawed.





# CLOSING THOUGHTS

What strength do you feel comfortable driving on?

# A CLOSING THOUGHT EXPERIMENT

In Minnesota, a common winter activity is to go ice fishing.



# Ice is Never 100% Safe!

Minimum Ice Thickness Guidelines for New Clear Ice Only



## Ice Safety Tips

- Double the thickness guidelines for white or snow-covered ice.
- Carry two large nails to use as ice picks if you fall through.
- Avoid pressure ridges and areas with current.
- Warn children about the dangers of thin ice.
- Don't drive on the ice at night.
- Avoid alcoholic beverages.

[mndnr.gov/icesafety](http://mndnr.gov/icesafety)

**mn** DEPARTMENT OF  
NATURAL RESOURCES

# A CLOSING THOUGHT EXPERIMENT

What are the flexural & compressive strengths of fresh water ice?

Answer:

- 90 – 135 PSI Flexural
- 530 – 740 PSI Compressive

What is the k-value of the liquid water underneath?

Answer:

- 0 PSI/in





# SO, WHEN ARE YOU COMFORTABLE ALLOWING TRAFFIC ON NEW CONCRETE?

1 / 3 / 7 Days?

2000 / 3000 / 4000 psi Compressive?

150 / 300 / 500 psi Flex?



# QUESTIONS?



# THANK YOU



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