# Effects of Implements of Husbandry ‘Farm Equipment’ on Rigid Pavement Performance


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October 4, 2011

# Acknowledgements


- Professional Nutrient Applicators Association of Wisconsin and Minnesota
- Iowa DOT/IHRB
- Illinois DOT
- Wisconsin DOT
- Minnesota DOT & Minnesota Local Road Research Board
- MnROAD Staff
- Special thanks to Shongtao Dai & Kevin Erb
- Univ. of Minnesota and Iowa State Univ.
- Undergraduate/graduate students for their assistance with the field data collection efforts:
  - Curt Smejkal, Jian Gao, Jianhua Yu, Rahman Shaidur, Ying Lai, Yu Kuang

# Outline

- Objectives
- Test Outline and Key Results
- Summary and Findings
- Recommendations
- Detailed Results and Discussion
    - Field Testing
    - Analysis of Field Data
    - Discussion of Results

# Objectives

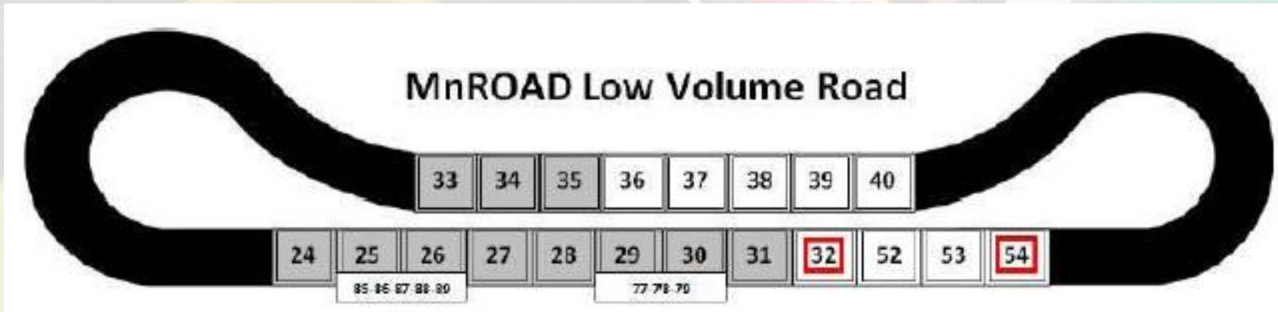
- Determine pavement responses generated by heavy agricultural equipment
- Compare measured responses to a typical 5-axle semi truck
- Develop models to evaluate pavement damage from heavy vehicles

# TEST OUTLINE AND KEY RESULTS

# MnROAD Research Facility

- A comprehensive pavement research facility
- Constructed in 1994 and located about 40 miles NW of the Twin Cities
- Mainline and Low Volume Road (LVR) sections
- Originally more than 4,500 sensors embedded within 40 sections
- Strain gauges, LVDTs, thermocouples, pressure cells, etc.

# PCC Test Sections



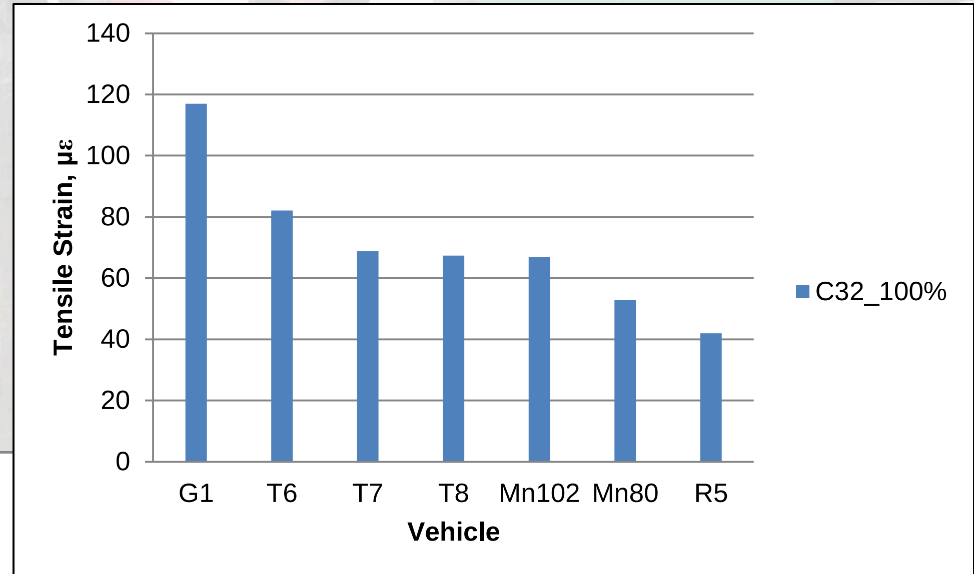

| Section | Cell 32 (Thin section) | Cell 54 (Thick section) |
|---|---|---|
| Surface | 5 in. thick PCC<br>10 ft × 12 ft undoweled | 7.5 in. thick PCC<br>15 ft × 12 ft with 1 in. dowel |
| Base | 1 in. Class-1f<br>6 in. Class-1c | 12 in. Class-6 |
| Subgrade | A-4 subgrade soil<br>(existing subgrade soil) | A-4 subgrade soil<br>(existing subgrade soil) |

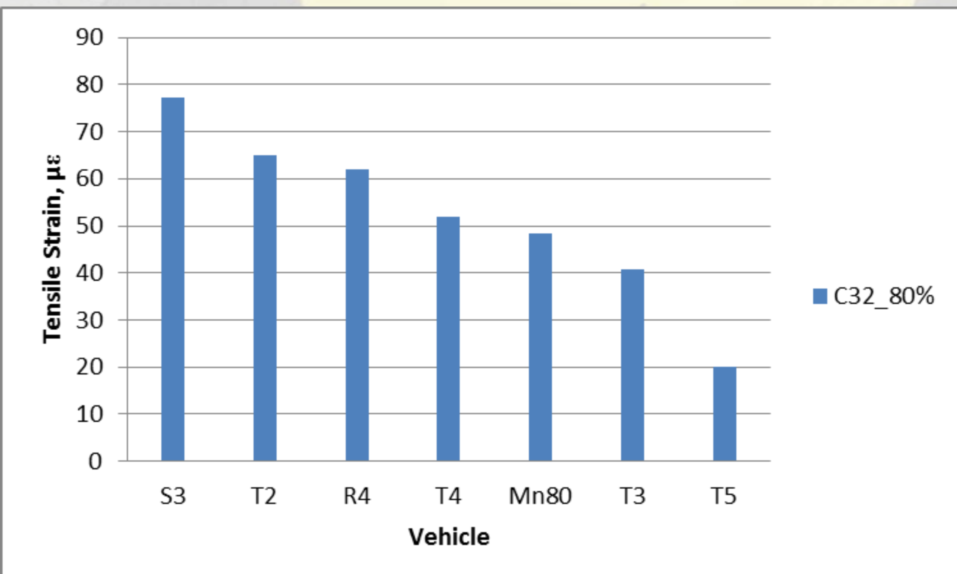
# Test Vehicles


Notes: R4, R5, and G1 are not normally loaded running down the road

# Order of Field Measurement of Critical Tensile Strains on Cell 32

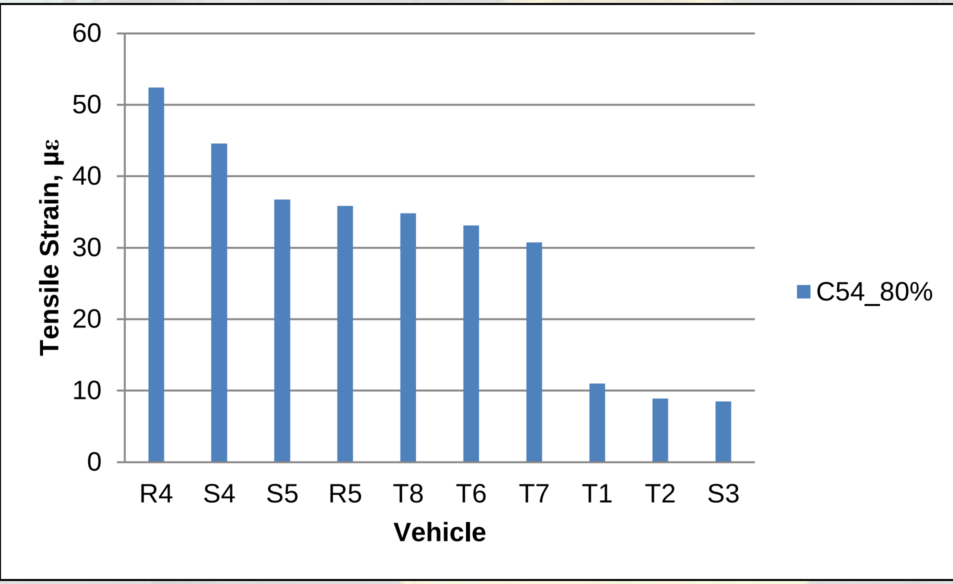
| Season | Vehicle | Sensor |
|---|---|---|
| Spring 08 | S3 | 32CE139 |
| | T2 | |
| Fall 2008 | R4 | |
| | T6 | |
| | T7 | |
| | T8 | |

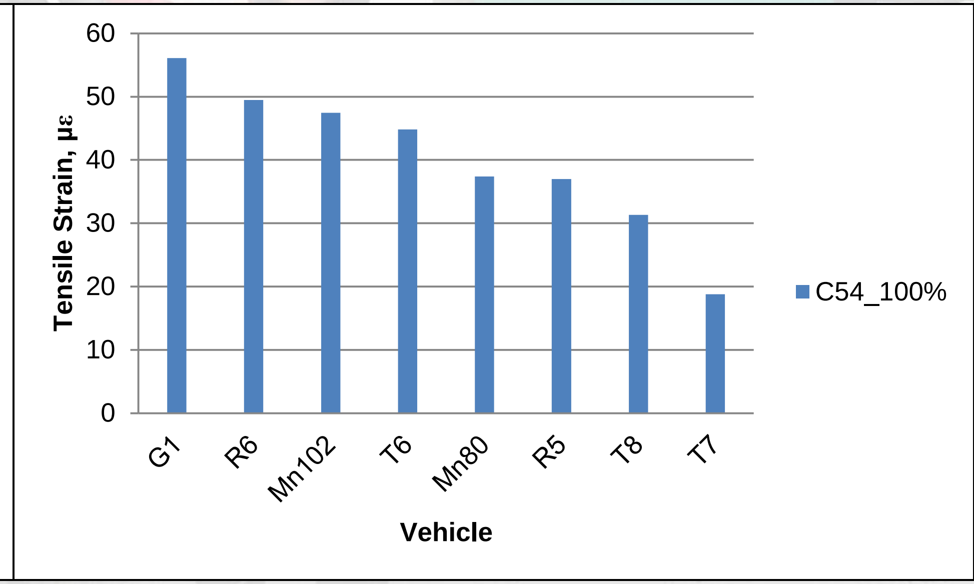



| Season | Vehicle | Sensor |
|---|---|---|
| Fall 2009 | R5 | 32CE139 |
| | T6 | |
| | T7 | |
| | T8 | |
| | Mn80 | |
| | Mn102 | |
| Fall 2010 | G1 | 32CS102 |

# Order of Field Measurement of Critical Tensile Strains on Cell 54

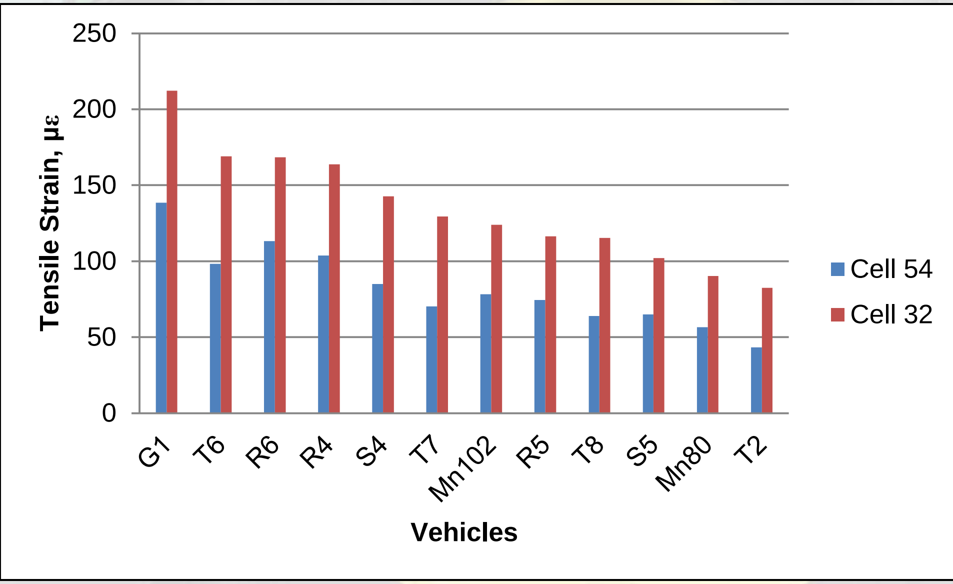


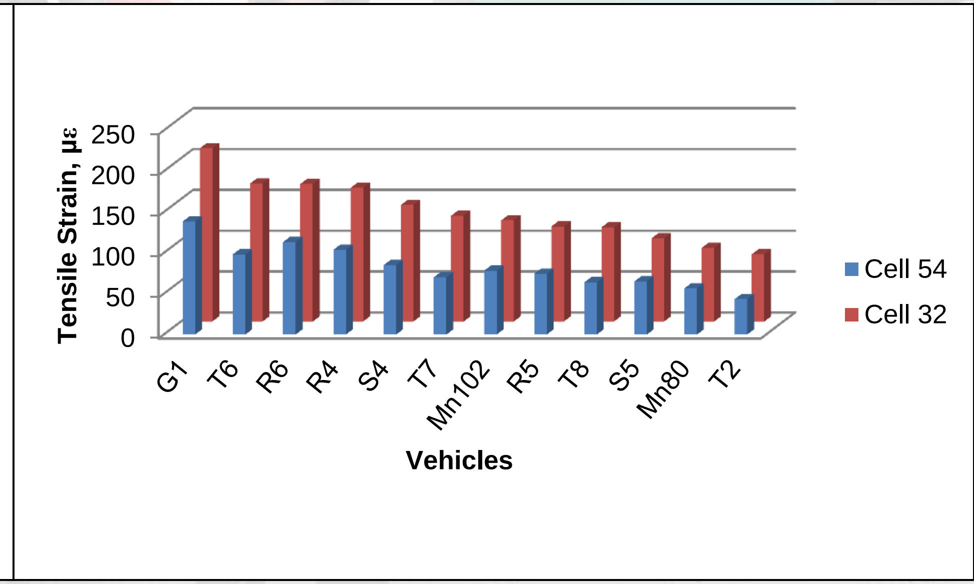




Notes: The reason why the maximum tensile strain produced by T1 and T6 are so great is because T1 was only tested in Spring 2008 while T6 has been tested four time during Spring 2009, Fall 2009, Spring 2010, and Fall 2010. The tensile strains plotted in Figures represent the maximum strain values for each test vehicle. Thus, the effect of seasonal variation was also introduced into the results.

| Season | Vehicle | Sensor |
|---|---|---|
| Spring 2008 | S3/T1/T2 | 54CS6 |
| Fall 2008 | R4 | |
| Spring 2009 | R4/R5/S4/S5/T6/T7/T8/Mn80/Mn102 | |
| Fall 2009 | R5/T6/T7/T8/Mn80/Mn102 | |
| Spring 2010 | R6/T6/Mn80/Mn102 | |
| Fall 2010 | G1/T6/Mn80/Mn102 | |

# Order of Critical Pavement Strains Based on FE Analysis




k = 200 psi/in., ΔT = 0$^o$F, E = 4.5 x $10^6$ psi, μ = 0.15

- ❑ Cell 32: G1>T6>R6>R4>S4>T7>Mn102>R5>T5=T8>S5>Mn80>T2
- ❑ Cell 54: G1>R6>R4>T6>S4>Mn102>R5>T7>S5>T5=T8>Mn80>T2

# Summary of Data Analysis

- ❑G1 (88 kips) and R6 (75 kips) produce higher pavement stresses & strains than Mn80 (80 kips) and Mn102 (102 kips)
- ❑Multi-axle vehicle configuration helps to reduce pavement responses (stresses, strains, & deflections) produced by the farm equipment
- ❑As relative offset increases, pavement responses decrease
- ❑As wander goes up, critical pavement responses decrease

# Summary of Data Analysis (cont’)

- When operated fully loaded all the tested farm equipment generate more stresses and strains compared to standard semi-truck (Mn80)
- Compared to empty farm equipment, fully loaded MnROAD trucks produce higher pavement responses (stresses, strains & deflections)
- Pavement responses measured in Spring 2009 are lower than those in other seasons

# Recommendations

- Vehicles should be driven 18-24 in. away from the slab edge
- When applicable, dowel bars are recommended to minimize the faulting damage and to improve the load transfer efficiency (LTE)
- To carry the same amount of load, tridem or quad axles are recommended for all farm/heavy equipment – having more axels is better for the roadway systems as the loads are distributed into a larger area

# Recommendations (cont')

- The impact of farm equipment on transportation infrastructure system should be studied before the equipment design is finalized (gross weight, axle weight, number of axels, axle spacing, wheel spacing, tire pressure, etc.)
- Pavement design engineers should take into account the existing farm equipment load levels, axle configuration, tire pressure, etc. for pavement design

# What can be done to prevent damage on concrete pavement systems

- ❑ Avoid edge loading
- ❑ Avoid early Spring loading
- ❑ Distribute the loads evenly between the axles
- ❑ Avoid single axle loading when possible
- ❑ Use dowel bars in transverse joints for better load transfer mechanism
- ❑ A better drainage (especially for the pavement foundation) system would lead to better performing, long lasting concrete pavements
- ❑ Having shoulders would help improve the pavement performance and life

# Question from the last web meeting (Kevin Erb)

1 million gallons of product (water) is to be moved. Which vehicle would cause the least damage on the concrete roads?

- Two concrete pavement sections considered:
  (1) 5-in thick and (2) 7-in thick JPCP

# Estimated Product Weights in One Move

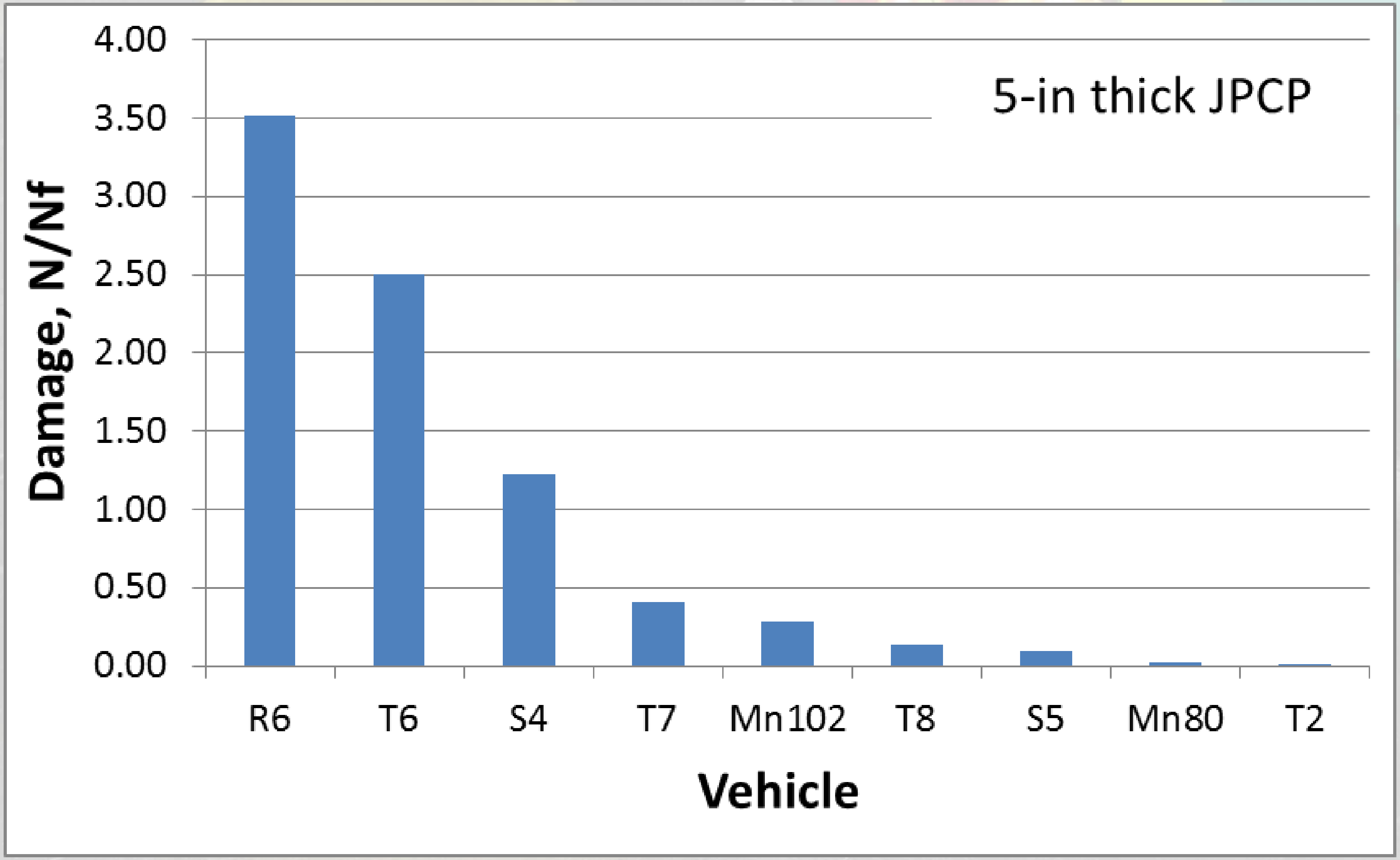
| Vehicle | Max Volume Capacity*, gallons | Max Weight Weight**, lbs. | Number of Passes*** |
|---|---|---|---|
| R6 | 4,200 | 34,860 | 238 |
| S4 | 4,650 | 38,595 | 215 |
| S5 | 4,650 | 38,595 | 215 |
| T2 | 4,000 | 33,200 | 250 |
| T6 | 6,000 | 49,800 | 167 |
| T7 | 7,300 | 60,590 | 137 |
| T8 | 9,500 | 78,850 | 105 |
| Mn102 | 7,650 | 63,495 | 131 |
| Mn80 | 6,000 | 49,800 | 167 |

* Estimated

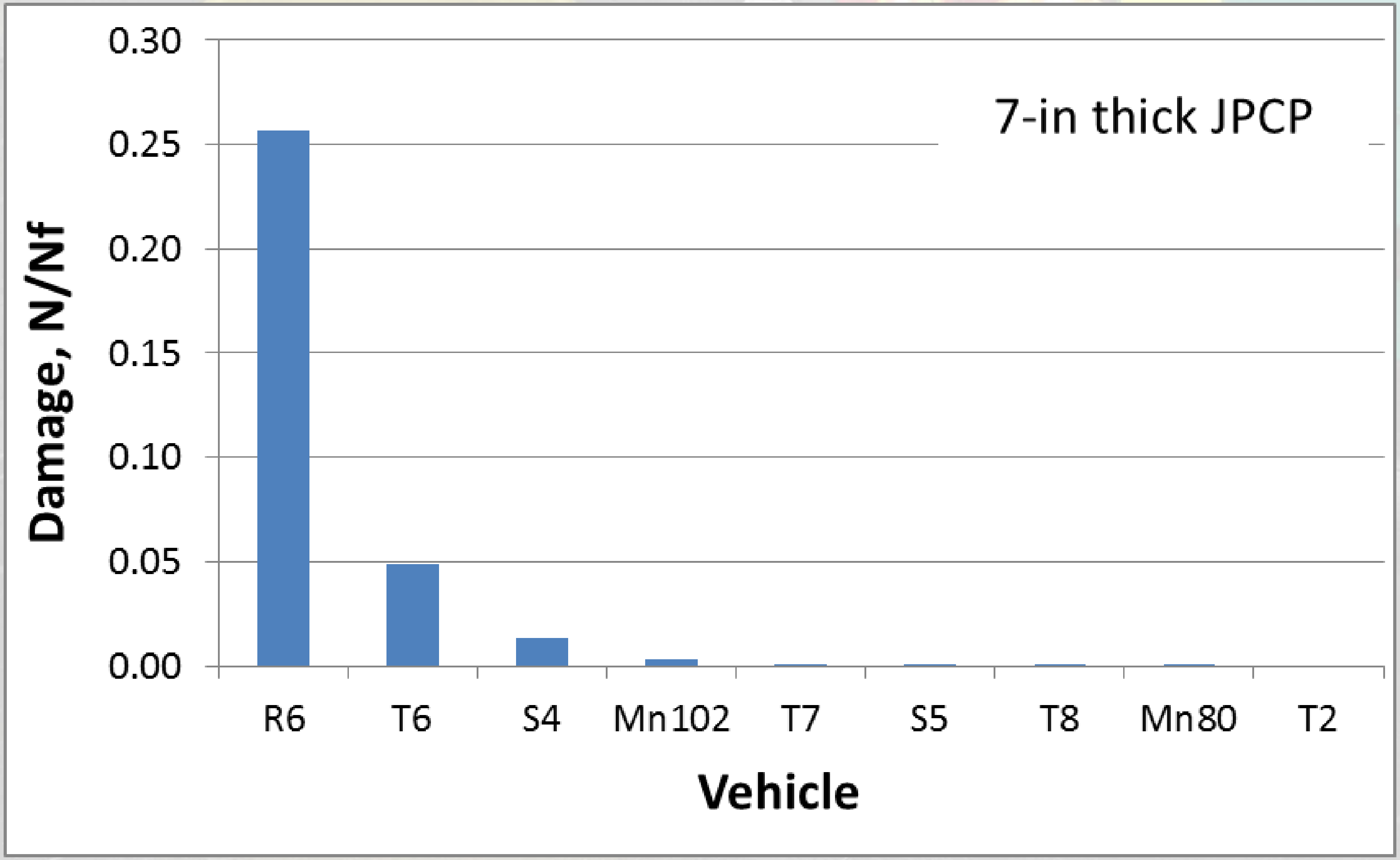
** I gallon = 8.3 lbs.

*** Number of passes = 1,000,000 gallons (8,300,000 lbs.)/Max Capacity

# 5-in thick JPCP, Fatigue Damage



# 7-in thick JPCP, Fatigue Damage

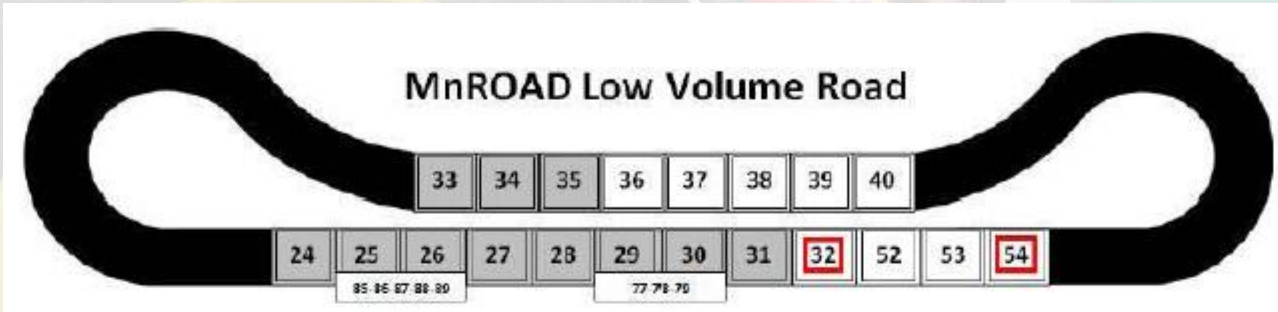


THANK YOU !!!

Questions?
Comments?

# FIELD TESTING

# PCC Test Sections

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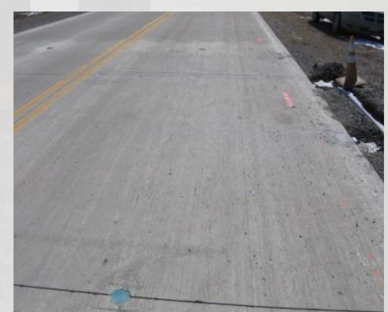
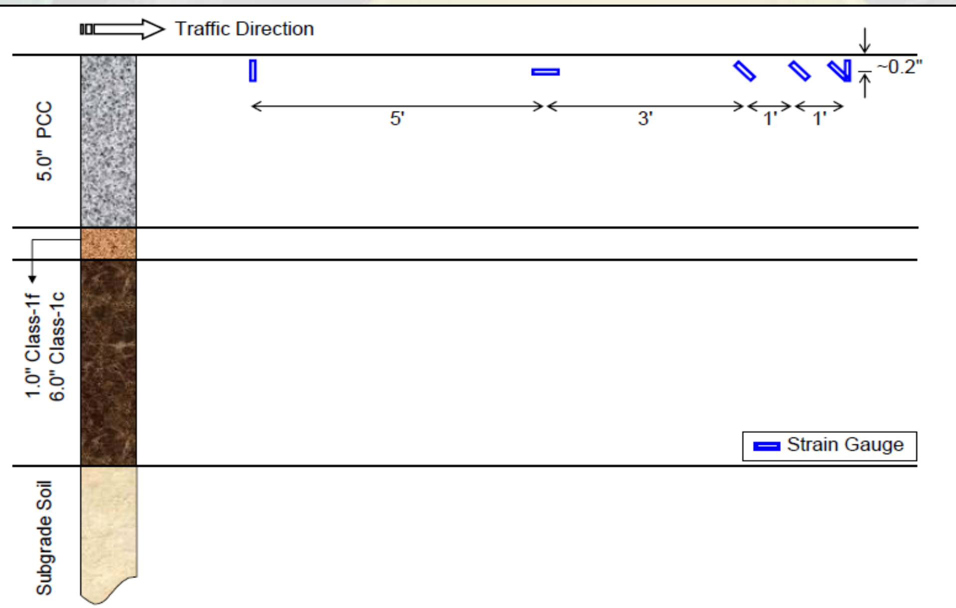


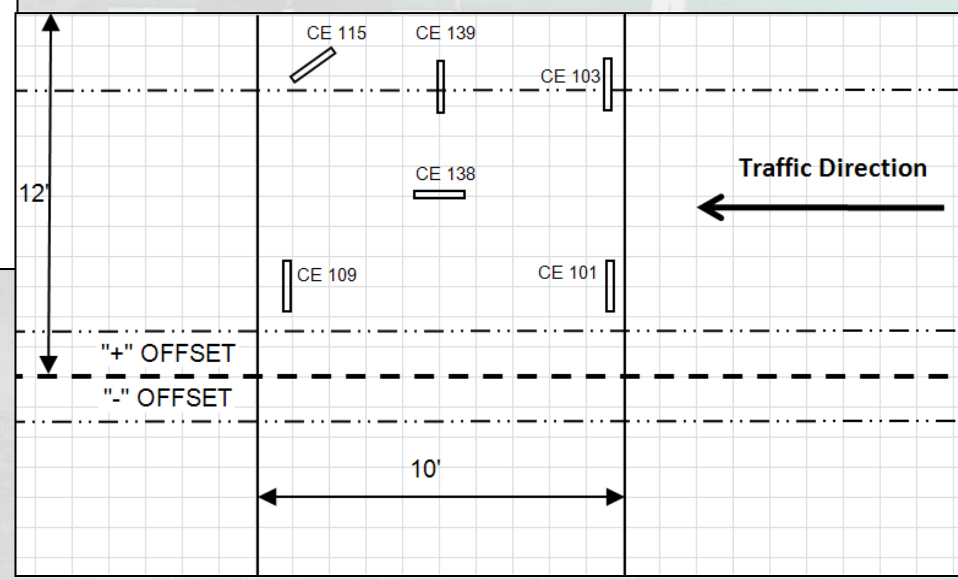
# Cell 32 – Sensor Instrumentation

Profile view




- Strain Gauge
  - Longitudinal
  - Transverse
  - Diagonal

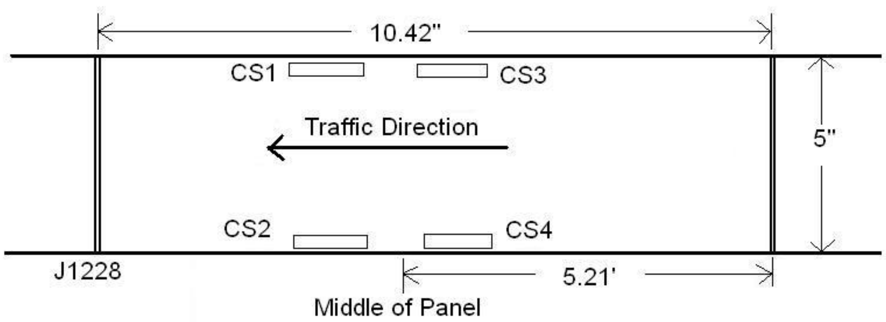
Plan view



# Cell 32 – Sensor Instrumentation (Fall 2010)

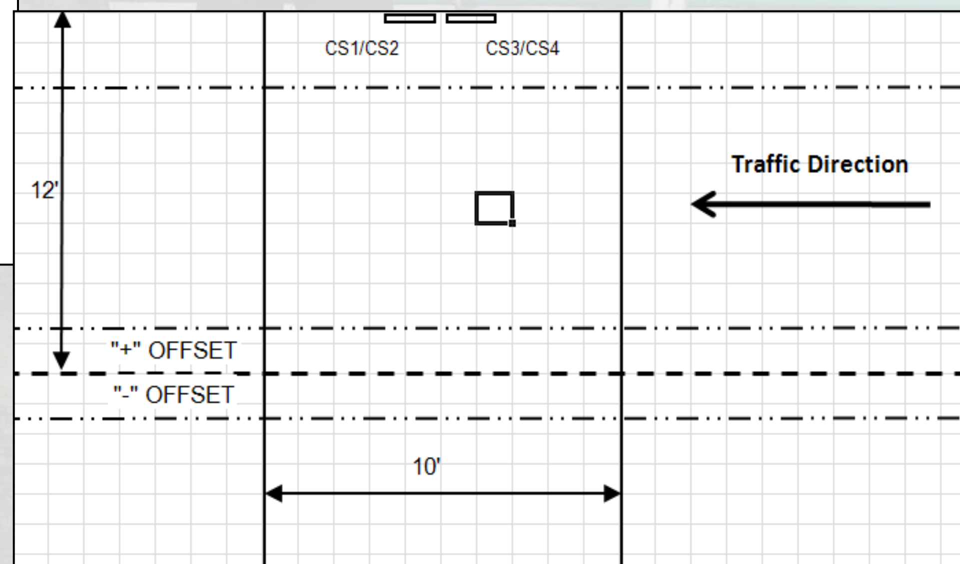
- Strain Gauge
  - Longitudinal

Profile view



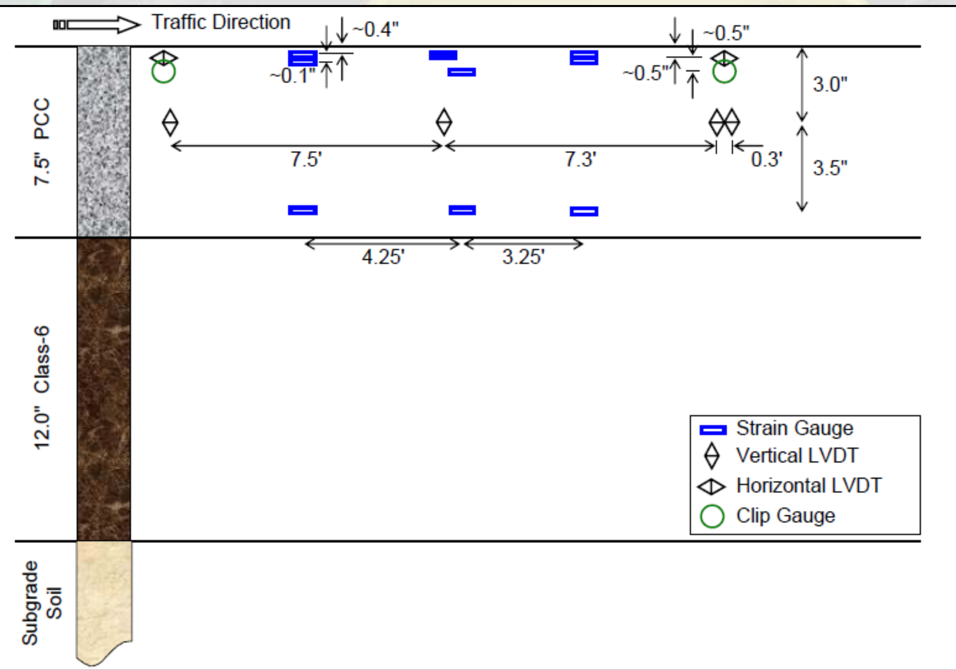

| Sensors | Distance from J1228 (ft.) | Distance from Surface (in.) |
|---|---|---|
| CS1 | 5.06 | 0.78 |
| CS2 | 5.08 | 4.80 |
| CS3 | 5.40 | 0.78 |
| CS4 | 5.38 | 4.68 |

Plan view



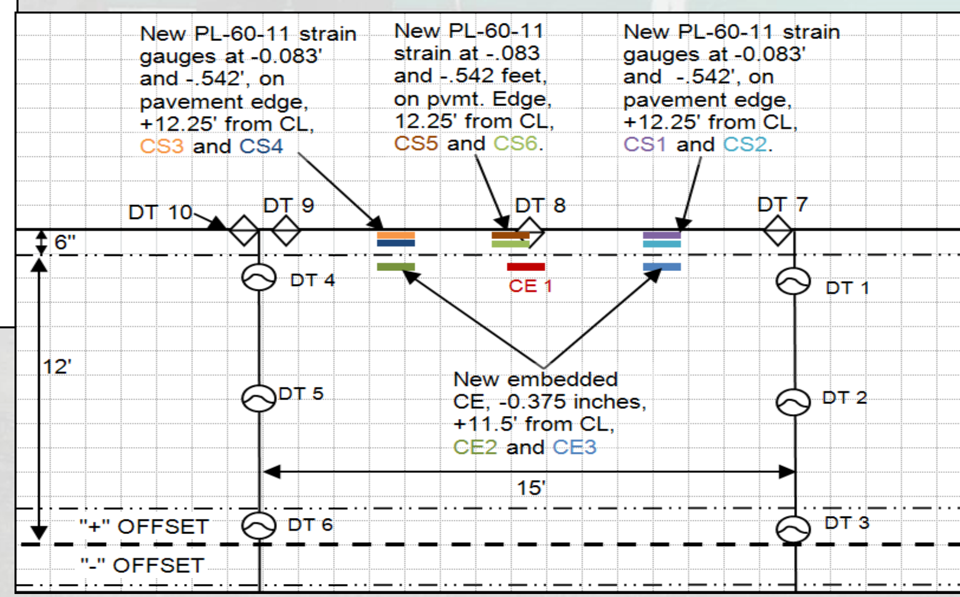
# Cell 54 – Sensor Instrumentation

Profile view



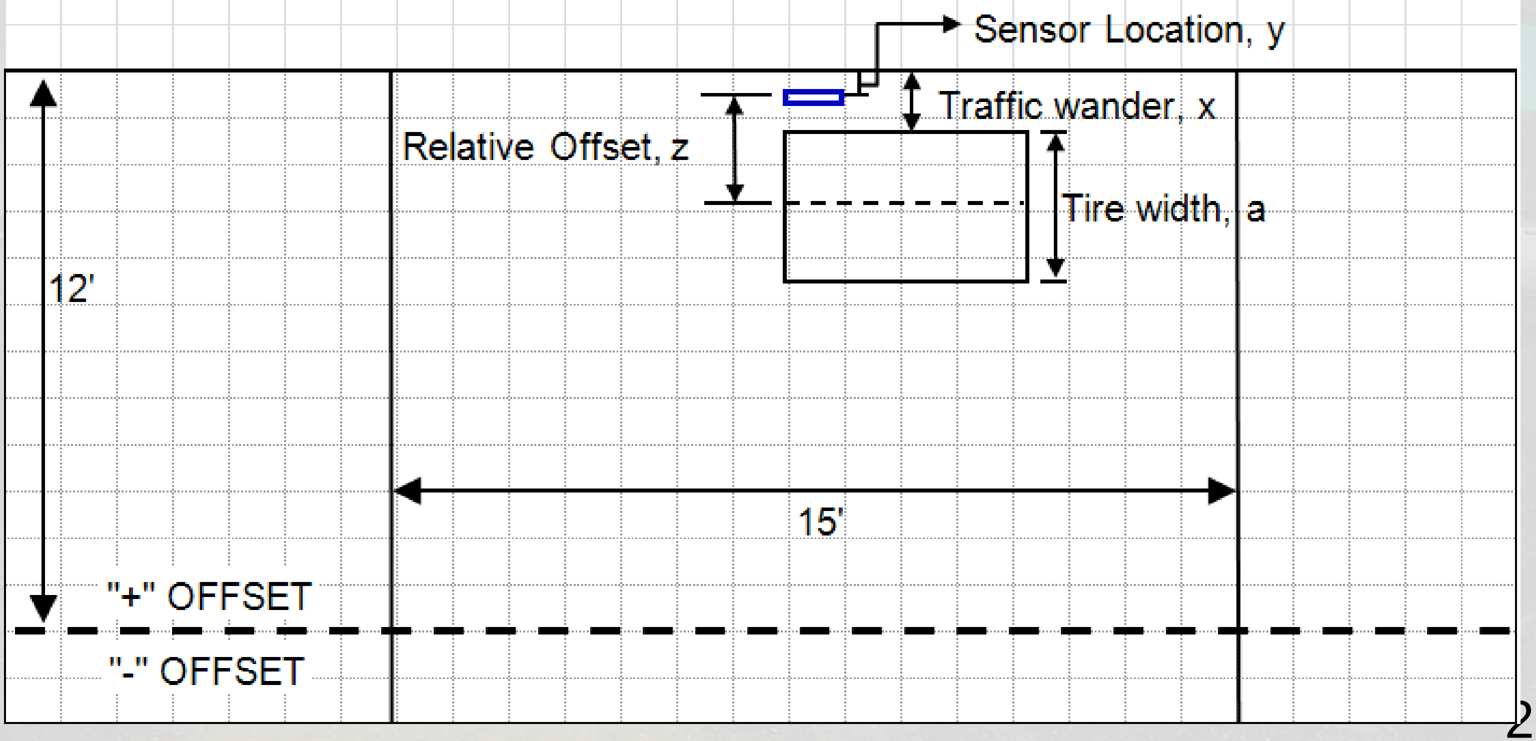

- Strain Gauge
  - Longitudinal
- LVDTs

Plan view



# Relative Offset

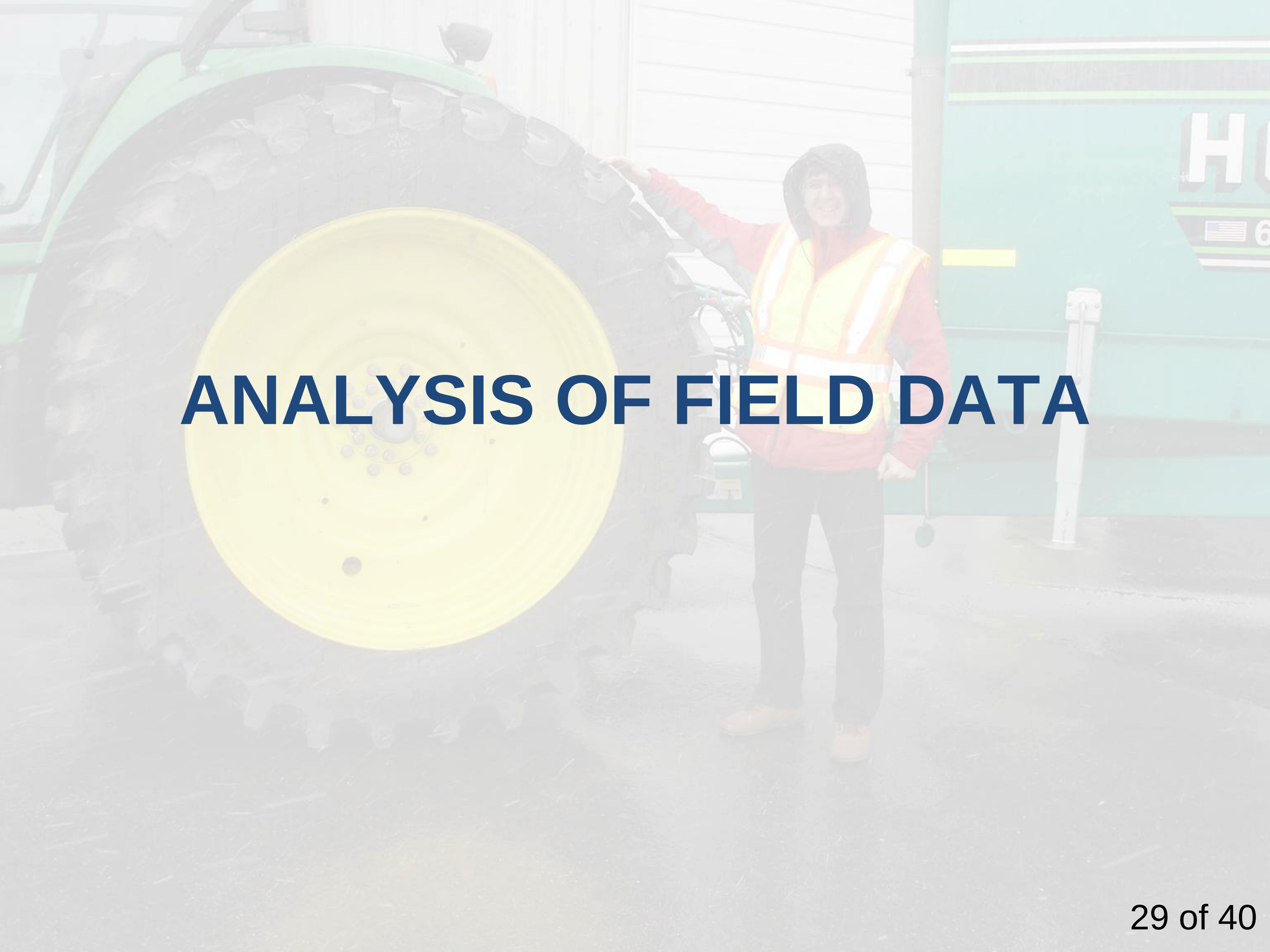
- Relative offset is the distance from the center of wheel to the sensor location
- Relative offset is calculated by: $z = x - y + a/2$
- Positive value: towards centerline, negative value: toward shoulder



# Data Collection

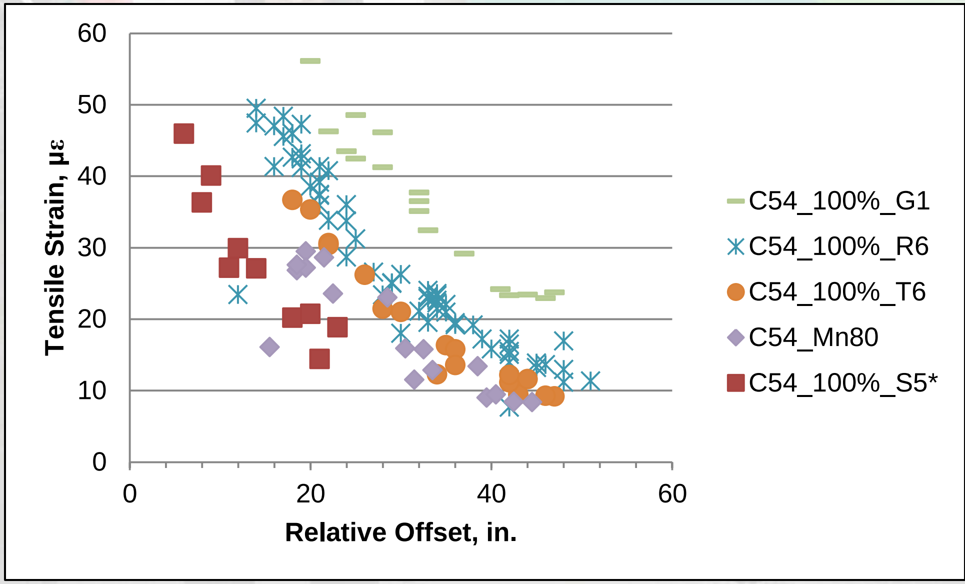
| Test Date | Vehicle Passes |
|---|---|
| Spring 2008 (March 24th – 26th) | 48 |
| Fall 2008 (August 26th – 29th) | 72 |
| Spring 2009 (March 16th – 20th) | 170 |
| Fall 2009 (August 24th – 28th) | 360 |
| Spring 2010 (March 15th – 18th) | 344 |
| Fall 2010 (August 18th – 19th) | 204 |

# ANALYSIS OF FIELD DATA



# Effect of Vehicle Type on Strains

- Pavement response order:
  - G1 > R6 > T6 > Mn80 > S5
- Heaviest axle governs, instead of the gross vehicle weight



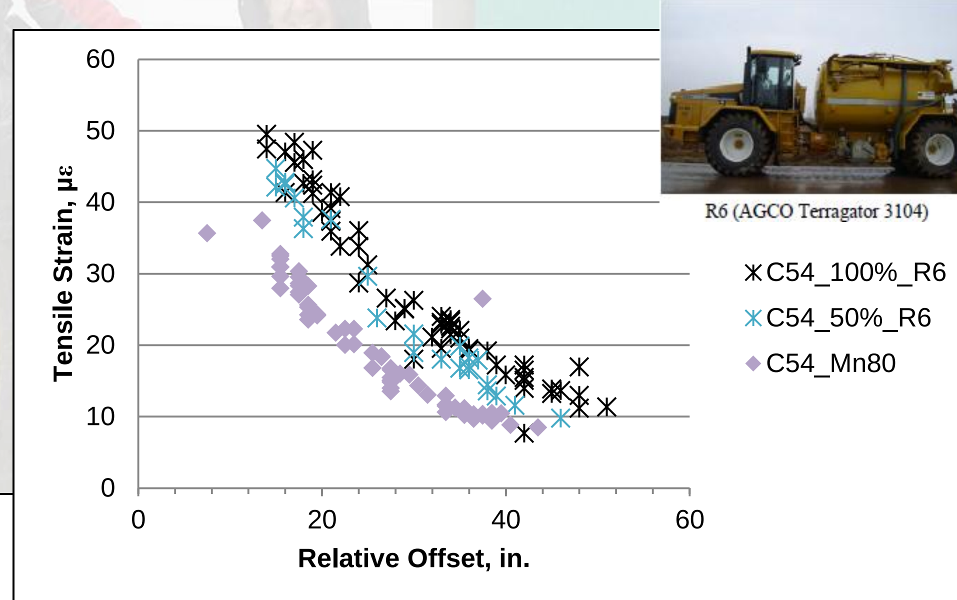


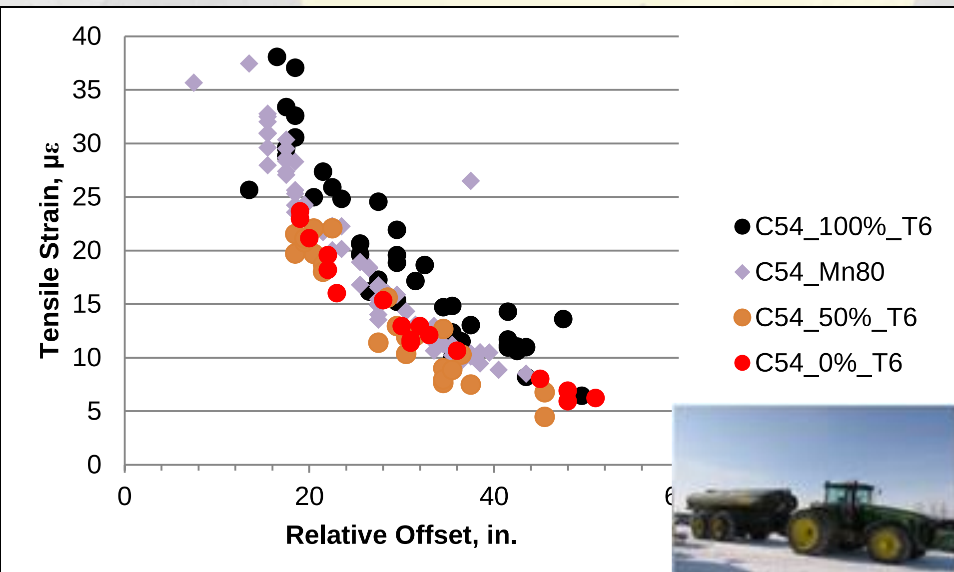
| Weight (kips) | R6 | T6 | Mn80 | G1 | S5 |
|---|---|---|---|---|---|
| Last Axle | 42 | 34 | 36 | 57 | 20 |
| Gross | 75 | 90 | 80 | 87 | 55 |

*: proportioned from 80% to 100%

# Effect of Load Level on Strains

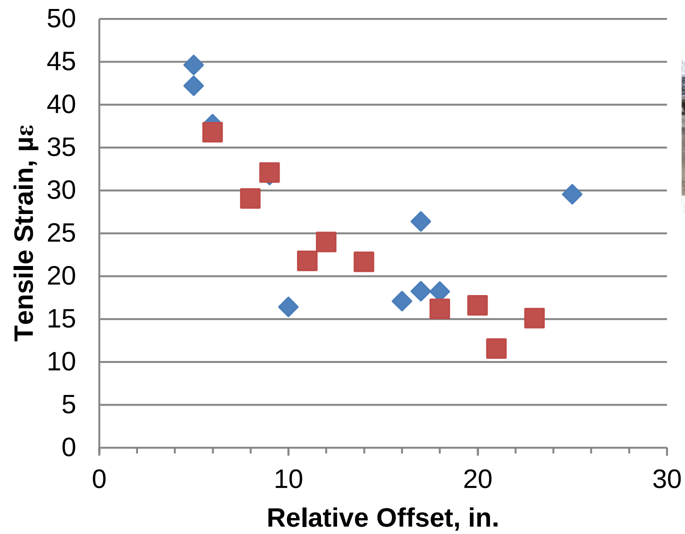
- As load level increases, the pavement tensile strains increase




| Weight (kips) | R6 | | T6 | |
|---|---|---|---|---|
| | 50% | 100% | 50% | 100% |
| 1st Axle | 28 | 33 | 8 | 6 |
| 2nd Axle | 29 | 42 | 21 | 24 |
| 3rd Axle | | | 17 | 26 |
| 4th Axle | | | 21 | 34 |
| Gross | 57 | 75 | 67 | 90 |

# Effect of Tire Type on Strains



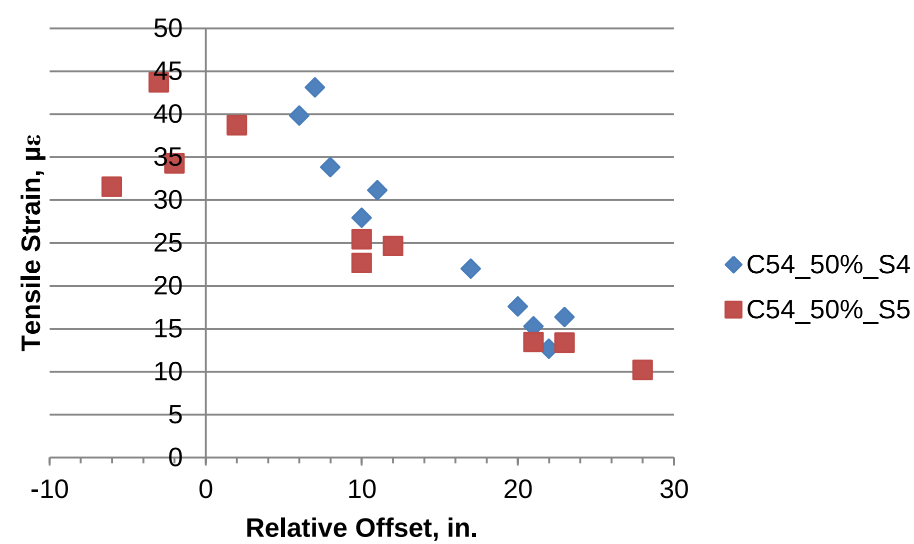

S4 (Homemade 4,400 gal-radial tires)

| 80% | Axle weight (kips) | | Tire Pressure (psi) | |
|---|---|---|---|---|
| Vehicle | S4 | S5 | S4 | S5 |
| 1st axle | 14 | 18 | 81 | 99 |
| 2nd axle | 19 | 20 | 94 | 94 |
| 3rd axle | 20 | 20 | 81 | 73 |

S4: Radial tires

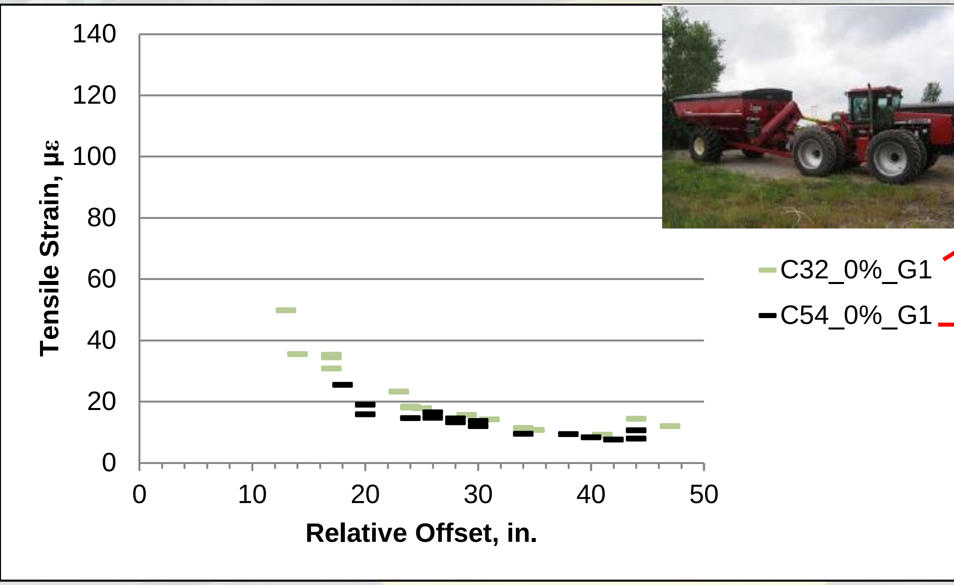
S5: Flotation tires

- No significant differences between flotation and radial tires



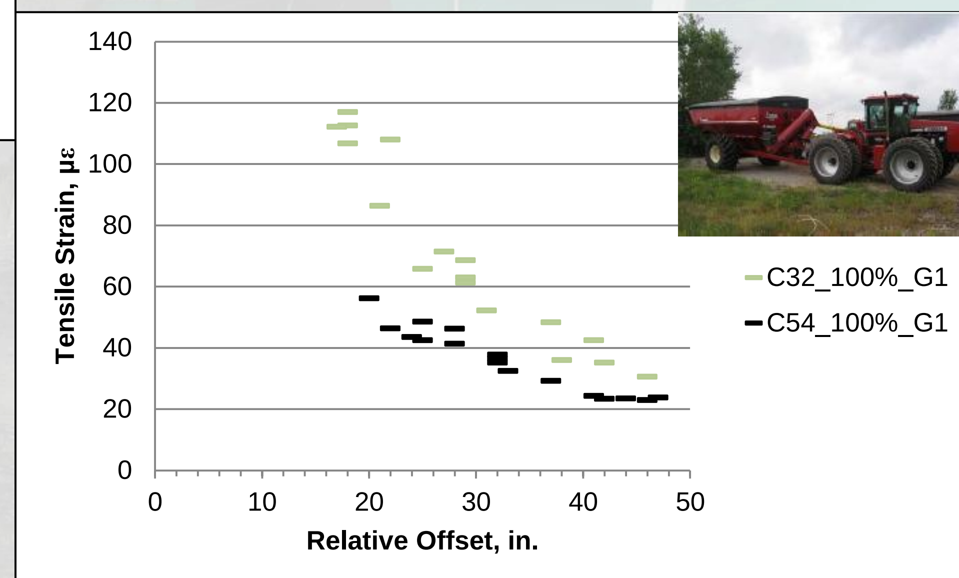

| 50% | Axle weight (kips) | | Tire Pressure (psi) | |
|---|---|---|---|---|
| Vehicle | S4 | S5 | S4 | S5 |
| 1st axle | 13 | 16 | 88 | 97 |
| 2nd axle | 15 | 16 | 81 | 90 |
| 3rd axle | 16 | 15 | 77 | 81 |

# Effect of Slab Thickness on Strains




**Cell 32 (Thin section)**
5 in. thick PCC
10 ft × 12 ft undoweled

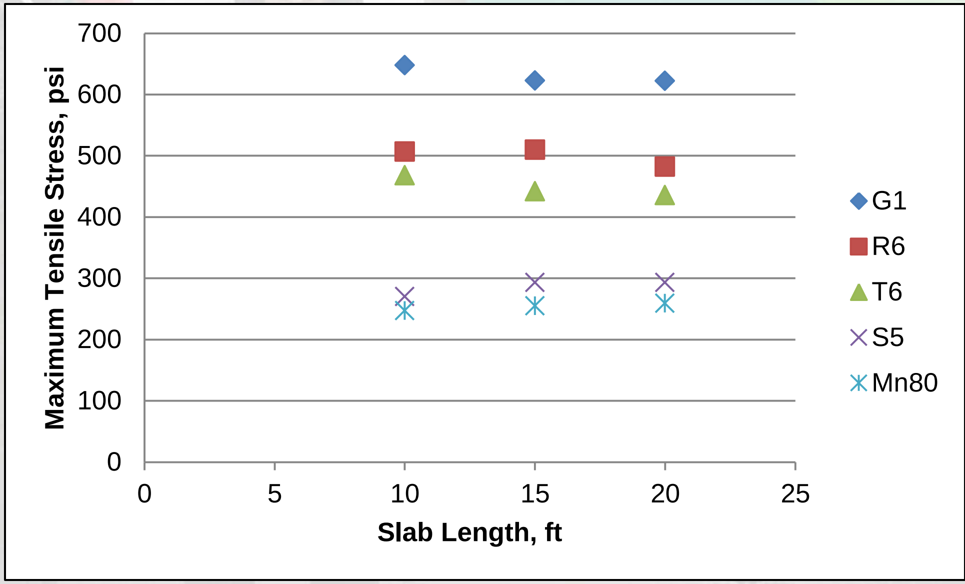
**Cell 54 (Thick section)**
7.5 in. thick PCC
15 ft × 12 ft with 1 in. dowel




- ❑ Thicker pavement slab helps to reduce pavement tensile strains
- ❑ Thinner pavement slab is more sensitive to heavy loadings

# Effect of Slab Length on Strains (FE analysis)

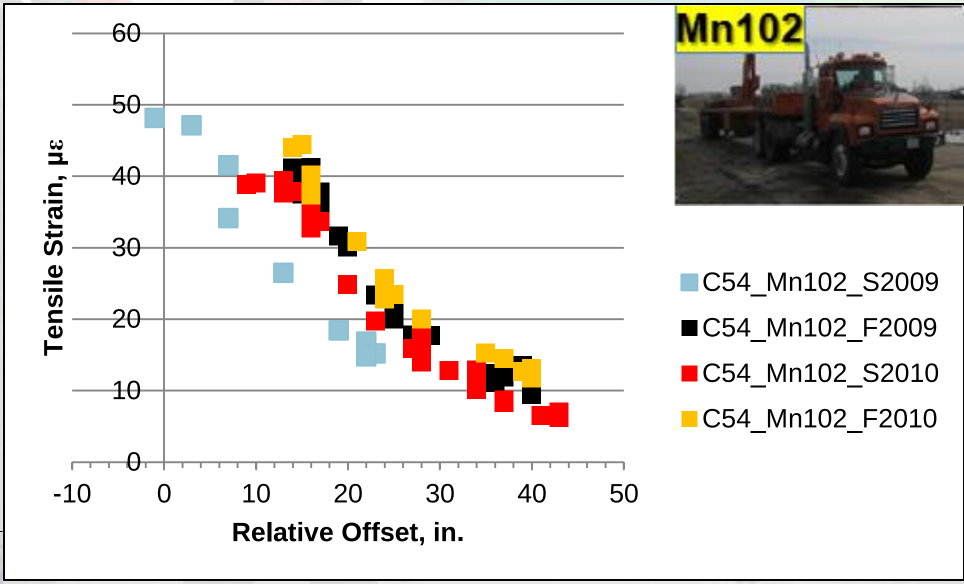
- Correlation between slab length and maximum tensile stress varies from vehicle to vehicle
- For G1 and T6, as slab length increases, the pavement maximum tensile stress decreases
- For R6, maximum tensile stress increases first and then drops
- For S5 and Mn80, as slab length increases, pavement maximum tensile stress increases

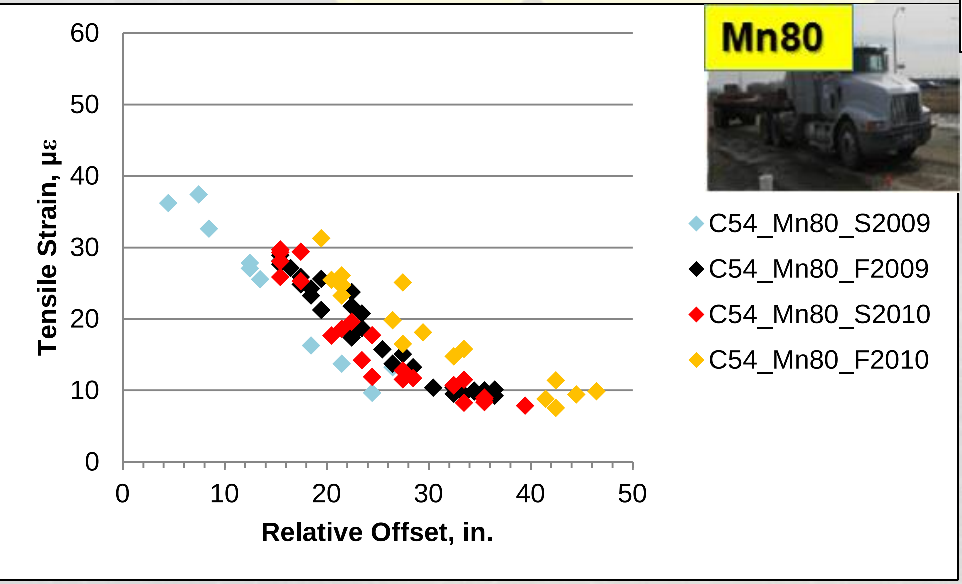



Notes: h = 7 in., k = 200 ksi, E = 4.5M psi, μ = 0.15

# Effect of Seasonal Change on Strains

- Pavement tensile strains produced by Mn80 and Mn102 in Spring 2009 are lower than those produced during other seasons

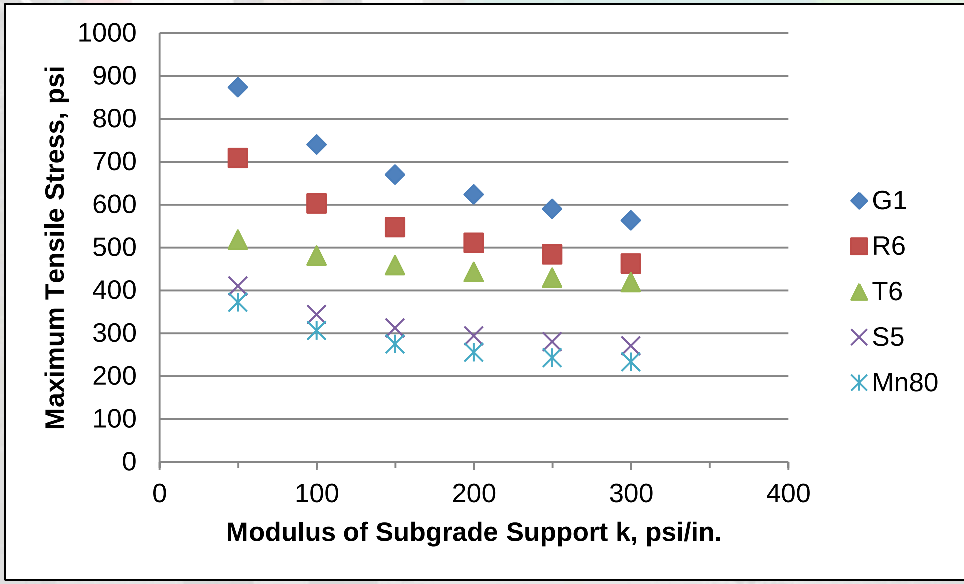



- Similar field conditions for the other seasons
  - Subgrade freeze/thaw condition

# Effect of Modulus of Subgrade Reaction on Stress (FE analysis)

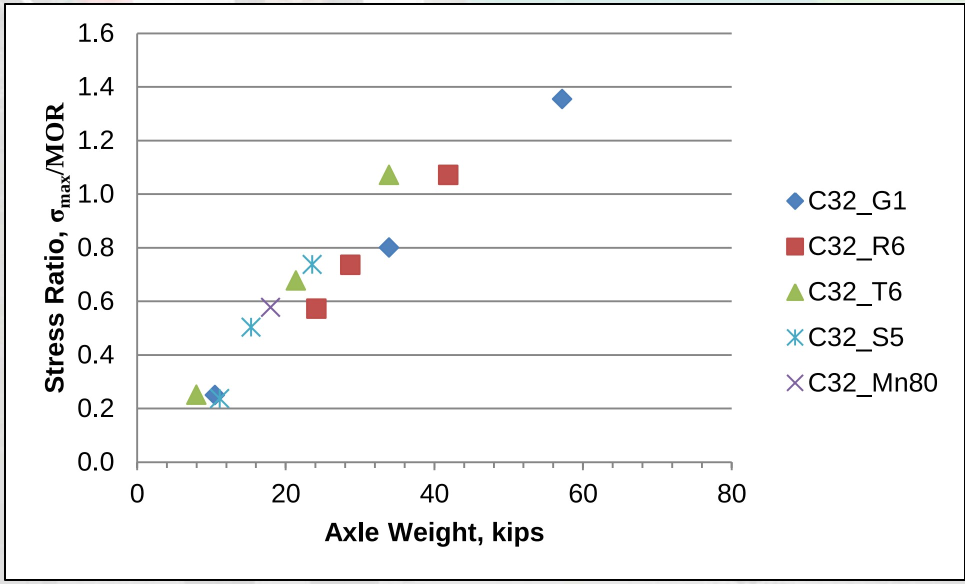
- As k value increases, the maximum tensile stress decreases
- Nonlinear relationship
- G1 produces the highest maximum tensile stress for all k value
- Mn80 produces the least maximum tensile stress for all k value




Notes: h = 7 in., L = 15 ft, E = 4.5M psi, μ = 0.15

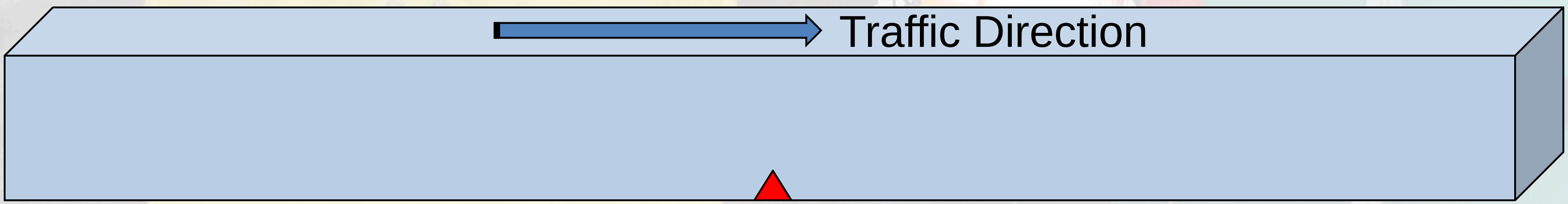
# Effect of Axle Weight on Stress Ratio

- There is a linear correlation between the axle weight and the stress ratio
- Stress Ratio (SR) = $\sigma_{max}$/MOR
  - MOR: Modulus of Rupture
- According to PCA, no fatigue damage is expected if stress ratio is less than 0.5
- Axle load can not exceed 18 kips




Notes: Data point correspond to 0%, 50%, and 100% load levels, respectively, for each of farm equipment. Mn80 truck was 100% loaded at all times.

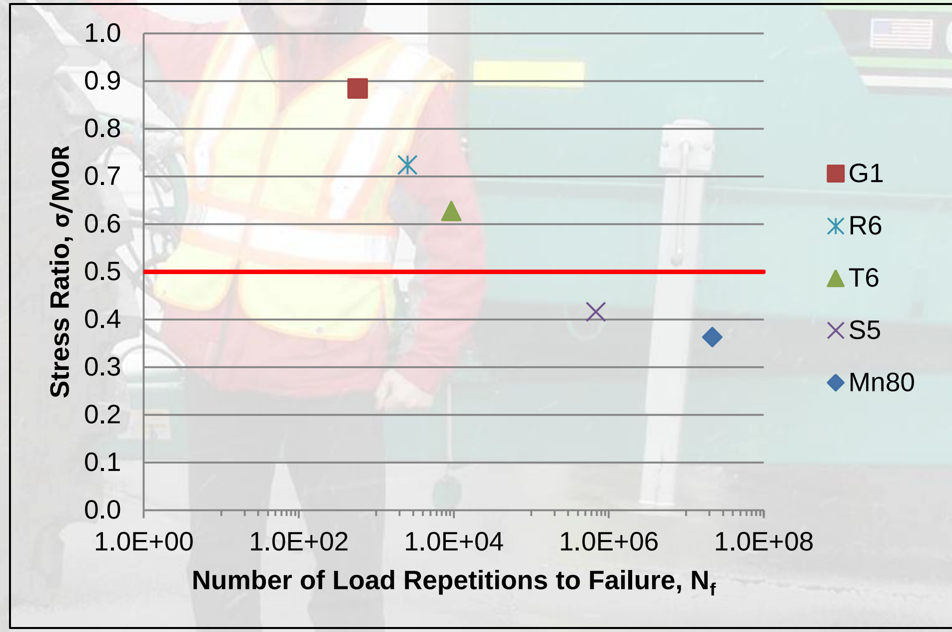
# Critical Location for Concrete Slab




▲ Critical Location of Concrete Slab: bottom edge, midway from the slab joint

# Fatigue damage: Vehicle Comparisons (Cell 54)

- Stress Ratio (SR) = $\sigma_{max}$/MOR
  - MOR: Modulus of Rupture
- According to PCA, no fatigue damage is expected if stress ratio is less than 0.5




k=200 psi/in., ΔT = 0 ºF

# THANK YOU !!!

Questions?
Comments?

# Extra Slides