Placement of 3/4-inch Dowels in MnROAD Concrete Test Cell 2437 and Deployment in Interstate Highway 35 in Hinckley Minnesota

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16. Abstract (Limit: 250 words)

This research report examines the dowel placement initial testing and initial test results of the ¾ dowels at the MnROAD facility and in the test sections on Interstate 35 at Hinckley. A 36 ft by 12 ft test section was constructed on November 22, 2024, when the ambient temperature was approximately 35°F. The test cell MnROAD low volume road cell 2437 was instrumented with vibrating wire strain gauges, thermistors, and maturity sensors to monitor strength development and performance. In this initiative, ¾-inch dowels were placed in interior joints of the test cell to evaluate reduced-diameter dowels' effectiveness for sustainable pavement applications. Analytic predictions of the influence of smaller diameter dowels were complicated by paucity of tenable equations from which test results could have been validated. Nevertheless, the sections were subjected to initial monitoring including faulting falling weigh deflectometer and physical observations. The report recommends seasonal measurements for at least 5 years. . At this stage there was no measurable faulting in either test section. Preliminary data indicated high load transfer efficiency (LTE) exceeding 90% at MnROAD, higher than corresponding field tests conducted on Interstate 35 in Hinckley, MN, which showed lower LTE values.

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Final Report

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Executive Summary

This initiative constructed a 36-ft by 12-ft test section (cell 2437) in the MnROAD low-volume loop on the 22nd of November 2024. This research also established a test section in Hinckley where the unbonded overlay (UBOL) sections with ¾-inch dowels are contiguous with UBOL section control with 1¼-inch dowels, and the ¾-inch dowels in the full depth construction sections are contiguous with the full depth construction control with 1¼-inch dowels. The aforementioned dimension was cut out of the existing cell 37 up to the top of the base layer. MnROAD Operations compacted and refinished the base layer and provided and installed two concrete maturity sensors as well as two sets of vibrating wire strain gauges and thermistors.

This initiative placed ¾-inch dowels in the interior joints of the MnROAD test cell. Reduction of dowel diameter explores a sustainable usage of dowels where bases are uniform and provide some load transfer. In systems where mechanical load transfer are indispensable, reducing the bearing area may have huge implications, especially if base is non-uniform. This initiative examines the suitability of the ¾-inch dowels in the interior joints of the MnROAD test cell.

In Chapter 1, the theory of load transfer and the concept of reduced dowel diameter are explored in predicting changes in bearing stress and, in consequence, the implication of using smaller diameter dowels *ceteris paribus*. In Chapter 2, the experimental design is discussed, and the instrumentation and construction process are accentuated. Chapter 3 analyzes the performance of the ¾-inch dowel sections and corresponding control sections on Interstate 35 in Hinckley.

The distribution of falling weight deflectometer results in the contiguous test sections on Interstate Highway 35 in Hinckley does not provide a conclusive comparison of the ¾-diameter dowels section to the control pavement with 1¼-inch dowels. Dowels in the transition panels showed the overall highest load transfer efficiency but not as high as those measured in the MnROAD test cell. The report concludes that there was an unexpected paucity of tenable equations that facilitate prediction of the influence of reduced diameter dowels. However, some references eventuated prediction of a stiffness ratio of ¾ and another facilitated prediction of a stiffness ratio of 1/5 comparing the ¾-inch dowel to the 1-inch dowel. The report did not back calculate stiffness ratio and bearing stresses from the falling weight deflectometer results which, by inspection, were not coherent with analytic predictions.

Chapter 1: Introduction

1.1 Initiatives

A test cell with a concrete composed of increased Alite and Belite content was constructed at the MnROAD low-volume loop. The material was mixed with a mobile mixer onsite. In this segment ¾-inch diameter dowels were placed in the interior joints of the test cell to ascertain their suitability. Furthermore, a test section was established in Hinckley with factorials of contiguous sections to study the performance of concrete roads built with ¾-inch diameter dowels that provide 75% of the projected structural bearing area of a 1-inch dowel, 56% of the cross-sectional area of 1-inch diameter dowel, and only 30% of the modulus of a section with a 1-inch diameter dowel. The latter two variables are deployed whenever the base is non-uniform or structurally compromised. Being cognizant of the effect of mechanical load transfer, the ¾-inch dowels are examined for suitability.

1.2 Research Goals

The study entails analysis of preliminary results and early performance tests. While early performance is useful, this continued monitoring is a better strategy for evaluation of the test cell. Monitoring entails visual inspections, load transfer efficiency over time, periodic petrographic evaluation and an extension of the initial durability tests. Understanding the implications of using smaller diameter dowels is the goal of this research.

1.3 Theory and Mechanism of Load Transfer and implications of Bearing Area

Dowel bars are placed between adjacent slabs in jointed concrete pavement to allow some traffic load to be carried by the leave slab before it begins to leave the approach slab. Without dowel bars as a mechanism to distribute load, high tensile stresses are generated in the loaded slab and high compressive stresses are generated in the underlying base and subgrade [1]. Dowel bars reduce these stresses by transmitting vertical shear and bending moments. The degree to which stresses in the loaded slab are reduced depends on the load transfer efficiency (LTE) of the joint. Although stress LTE is the de facto measure of load transfer, the ease of measuring deflection has rendered deflection load transfer efficiency more ubiquitous in comparison to stress LTE, which is rigorous, expensive and probably fraught with factors that would cause inaccuracy.

LTE is measured by the amount of differential deflection between the two adjacent slabs in the direction of travel. Equations (1) & (2) are commonly used to calculate LTE, where d_u and d_l are the measured deflections at the joint of the unloaded and loaded slab, respectively, taken at the point of maximum deflection of the loaded slab [2], [3].

$$LTE = \frac{d_u}{d_l} \times 100\% \qquad (1)$$

Dowel bars are designed with the assumption that a dowel acts as a beam and the surrounding concrete acts as a Winkler foundation [4]. The resulting bearing stress (σ_b) applied to the concrete from the dowel under loading is proportionate to the deformation of the dowel. The bearing stress is calculated using the original solution by Timoshenko and Friberg in 1940 shown in equation (5). In this equation, y_0 is the maximum deflection of the dowel at the face of the joint, P_t is the load applied to the dowel, z is the joint width, $E_d$is Young's modulus of the dowel, I_d is the moment of inertia of the dowel, β is the relative stiffness of the dowel and K is the modulus of dowel support. These variables are shown in Figure 1.

$$\sigma_b = Ky_0 = \frac{KP_t(2+\beta z)}{4\beta^3 E_d I_d} \tag{2}$$

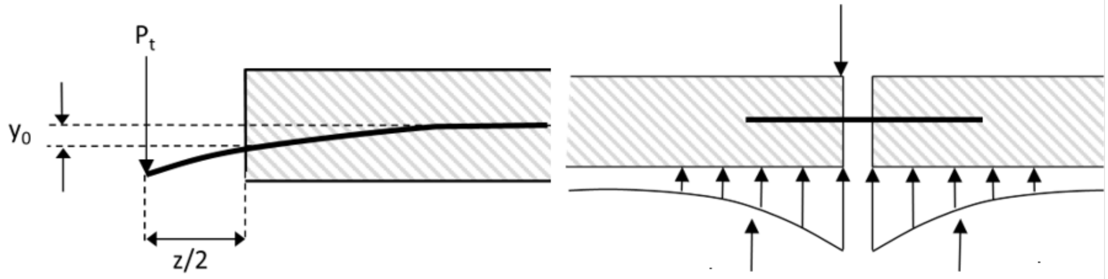
Dowel size and spacing is chosen for efficient load transfer by obtaining an allowable bearing stress (f_b) which is greater actual bearing stress. The allowable bearing is calculated in equation (3), where f_c' is the concrete's compressive strength and d is the dowel diameter.

$$f_b = \frac{(4-d)}{3} f_c' \tag{3}$$

When designing dowels, it is often assumed that the dowel system will provide 100% LTE such that both slabs have equal deflection [4]. This is illustrated in figure 1. Designing dowels for 100% LTE is conservative, as lower LTE will produce higher forces in the loaded slab, lower forces in the unloaded slab, and consequently lower shear force on the dowel.

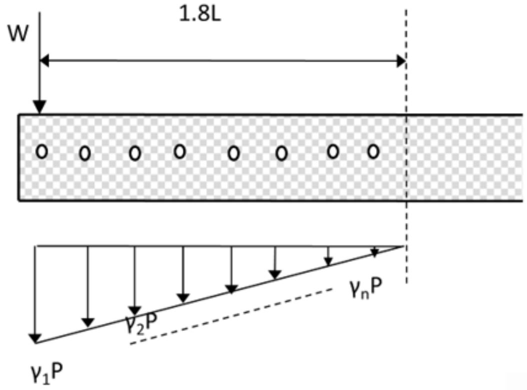
One theory assumes shear force is distributed across the dowel system over a distance of 1.8L from the point of loading, where L is the radius of relative stiffness of the concrete slab [1], [2]. At a distance of 1.8L, the bending moment is maximum, and the shear force is zero. The shear force in each dowel decreases proportionately to an increase in distance from the load (Figure 1).

The degree of bearing stress on the concrete is directly related to the projected horizontal area of the bar [5], [6]. Smaller diameter dowels result in higher and more concentrated bearing stresses on the concrete surface. Increased slab thickness and concrete strength, and decreased dowel spacing, joint width, and modulus of dowel support are factors influencing stresses in the dowels [7], [8]. High bearing stress and repeated loading will eventually begin to wear away the concrete surrounding the dowel. The resulting void space lowers LTE by reducing vertical restraint. Crumbling of the concrete also provides a means for corrosive agents to enter the concrete and reach the exposed dowel. Poor LTE also causes pavements to be vulnerable to faulting between slabs. Faulted pavement is a main cause of roughness and other surface characteristics which are detrimental to ride quality [8], [9]. Faulting is a result of pumping of subgrade material from underneath the leave slab to underneath the approach slab. Bearing is jeopardized by material loss at the interface. Structural reliability of current alternative dowel bars such as the hollow tubes are particularly affected by degradation due to the thinness of steel around the hollow. The mechanism and implication of chemical deterioration is therefore non-trivial.



a) Loaded dowel deformation

(b) 100% Stress transfer efficiency through dowel



$$\sum_{1}^{n} \gamma_n P = \frac{W}{2}$$

$$\gamma_n = 1 - \frac{x_n}{1.8L}$$

$$n = number\ of\ dowels\ within\ 1.8\ L$$

$$x_n = distance\ of\ dowel\ n\ from\ load\ W$$

(c) Shear force distribution across dowel group (assuming 100% load transfer efficiency)

Figure 1.1. Schematics of dowel loading and load transfer

1.4 Implication of Using ¾-Inch Dowel in Lieu of One-Inch Dowel as Reference.

If AGG_{TOT} is the back calculated stiffness of a doweled joint and D is the known dowel stiffness, then the “true” aggregate interlock factor, AGG_0, for this joint can be determined from the following relationship:

$$AGG_{TOT} = AGG_0 + D * S \tag{4}$$

where:

a = the equivalent radius of the applied load.
s = dowel spacing.

In this study the relationship identified by Ioannides and Korovesis [9] was further elaborated by Harmon and Ioannides [10], Crovetti [11], (Su and Zollinger) [12]. Crovetti and Zollinger [13] developed regression models for that relationship, whereas Hammons and Ioannides [10] had developed a neural network prediction model. Crovetti [11], [13] proposed the following relationship between nondimensional joint stiffness and LTE:

$$LTE = \frac{100\%}{1+1.2\left(\frac{AGG_{TOT}}{Kl}\right)^{-0.849}} \tag{5a}$$

where:

AGG$_{tot}$ = the total stiffness.
ℓ = the PCC slab radius of relative stiffness and
k= a coefficient of subgrade reaction (k-value).

Zollinger's model for this relationship has the following form: :

$$LTE = \frac{100\%}{1+10\left[\frac{0.214-0.183\frac{a}{l}-log\left(\frac{AGG_{TOT}}{Kl}\right)}{1.18}\right]} \tag{5b}$$

Where a = the equivalent radius of the applied load.

A comparison can be made of the predicted effect of replacing the 1-inch dowel with the ¾-inch dowel. Based on Harmon and Ioannides [10], the radius of relative stiffness modulus of subgrade reaction and area of load application are taken as constant in the two scenarios. It also known that the modulus of section for a solid dowel is

$$Z = \frac{\pi d^3}{32} \tag{6}$$

Thus, the relative section modulus is $0.75^3 = 0.42$.

It can be shown that moment of section is:

$$I = \frac{\pi d^4}{32} \tag{7}$$

Assuming Joint Stiffness is map/m = 4 x 3.684 psi/in

Assume K is 150 and radius of relative stiffness is 36-in., stiffness is 14.74 PSI/in. Ratio of effect of ¾ in. will be unchanged.

$$LTE\ Ratio_{\left(\frac{3}{4}\text{ to }1\right)} = \frac{\left[1+1.2\left(\frac{AGG_{TOT}}{Kl}\right)^{-0.849}\right]_{1"}}{\left[1+1.2\left(\frac{AGG_{TOT}}{Kl}\right)^{-0.849}\right]_{(3/4")}} \tag{8}$$

Here there is no theoretical predictor for the influence of reduced dowel size in the equation 5a based on equation 8. It could only be determined experimentally. Even Su & Zollinger [12] do not provide a prediction of the influence of smaller diameter dowels based on equation 5a.

Radius of relative stiffness = the PCC slab radius of relative stiffness.
k = a coefficient of subgrade reaction (k-value).

AGGtot = the total joint stiffness.
Radius of relative stiffness = the PCC slab radius of relative stiffness.
k = the subgrade k-value.

Equation 7. The true aggregate interlock factor equals the back-calculated stiffness of a doweled joint minus the sum total of the known dowel stiffness times dowel spacing. (7)

However, if we revisit these equations, we note that Friberg [15] replaced the modulus of foundation *k* with the expression K_D. The modulus of dowel support, K_0, denotes the reaction per unit area due to applied load when the deflection is equal to unity. Thus, relative stiffness of a dowel embedded in concrete, β , is given by equation 9 [2], [14] [15].

$$\beta = \left(\frac{dk_0}{4EI}\right)^{0.25} \tag{9}$$

K_0 is an important parameter in Friberg's design equation [2]. K_0 is determined empirically because of the difficulty in establishing it theoretically [15]. Literature reviews indicate a wide range of values for the modulus of dowel support. Modulus of dowel support K_0 increases with increased concrete strength (*fc'*), decreases with increased concrete depth below the dowel, and decreases with increased dowel bar diameter. Yoder and Witczak [15] found that K_0 ranges between 300,000 and 1.5 million psi/inch (8,303.972 and 41,519.858 kg/cm^3). For analytical calculations in this chapter, a value of 1.5 million psi/inch (41,519.858 kg/cm^3) is used as suggested by Yoder and Witczak [16] to simulate the worst scenario.(15)

The relative stiffness of dowel will be obtained by observing the ratios of stiffness for the 3/4-inch dowel versus the 1-inch dowel

Whence from equation 9,

$$\text{Relative stiffness} = \frac{\left(\frac{dk_0}{4EI}\right)^{0.25}_{\left(for\,\frac{3}{4} inch\ dowel\right)}}{\left(\frac{dk_0}{4EI}\right)^{0.25}_{(for\ 1\ inch\ dowel)}} \tag{10}$$

By inspection the simplified form has the numerator as $((0.75\ d)^{0.25})^4$ while the denominator is $((\ d)^{0.25})^4$ whereupon the ratio of stiffness is 0.75 based on Timoshenko as presented by Friberg [2].

The bearing stress ratio is further analyzed based on equation 2 assuming joint width is 0.5 inch we denote ¾ dowels as experiment and 1-inch dowels as control (cont).

Bearing stress ratio

$$\text{BSR}= \frac{\frac{KP_t(2+\beta z)}{4\beta^3 E_{exp} I_{exp}}}{\frac{KP_t(2+\beta z)}{4\beta^3 E_{cont} I_{cont}}} \tag{11}$$

$$\text{Simplifying BSR}= \frac{\frac{(2+0.375\beta\ cont)}{\beta cont^3\ 0.42 I_{cont}\ (0.320}}{\frac{(2+0.5\beta\ cont)}{\beta^3 E_{cont} I_{cont}}} \qquad (12)$$

Comparing large to small terms:

$$\text{BSR}= \frac{2+0.375\beta\ cont)}{2+0.5\beta\ cont)\ 0{,}1344} \text{ approximates to} \frac{0.375\beta\ cont)}{0.5\beta\ cont)\ 0.1344} = 5 \qquad (13)$$

Analytic predictors for the effect of using ¾-inch dowels are therefore not sufficient to evaluate their effect. Experimental methods in test sections with controls will be the locus classicus. Further analysis (16-19) was made to ascertain the implication of using ¾-inch dowels. Results show a lack of analytic methods to determine the effect of reduced diameter dowels. This lends credence to the idea of a test cell study at MnROAD and to a set of deployment sections on Interstate Highway 35.

1.5 Chapter Summary

The equations for joint stiffness do not necessarily predict the influence of reduced dowels . However, the reduction in bearing area (25%), section modulus (58%) and shear area (45%) are noted in replacing a 1-inch diameter dowel with a ¾-inch diameter dowel. Theoretical bearing stress ratio is estimated at 5. Based on relative stiffness, the ¾-inch diameter dowel yields 75% of the stiffness of the 1-inch dowel.

Chapter 2: Experimental Design

2.1 Background

In the previous chapter, a theoretical concept of load transfer was elucidated. This chapter discusses the actual construction layout.

This initiative constructed a short test cell in the Low Volume Road of the MnROAD Research facility.

2.2 Test Cell and Location

The MnROAD pavement research facility is operated by the Minnesota Department of Transportation (MnDOT). Constructed between 1990 and 1993 and opened to traffic in 1994, MnROAD is located on westbound I-94, northwest of the Twin Cities. The Mainline (3.5 miles of interstate westbound 94) and 2.5 miles of the Low Volume Road (LVR) and the old westbound tracks make up the MnROAD facility. During periodic surface non-sensor measurements at MnROAD, traffic is diverted to the old west bound track. This 3.5-mile track also has test sections but not for accelerated loading scenarios. MnROAD features dedicated pavement test cells equipped with sensors that monitor performance and assess the impact of traffic loads and environmental factors such as temperature fluctuations and drainage. In addition to these sensors, various tests including the International Roughness Index (IRI), Falling Weight Deflectometer (FWD), On Board Sound Intensity (OBSI), and Circular Track Meter (CTM) are conducted on the cells to evaluate different aspects of pavement designs and surface characteristics throughout their service life. The test cells in the Mainline are exposed to actual traffic conditions, while those in the LVR are subject to controlled traffic loading. The LVR is loaded by a dedicated truck with a gross vehicle weight (GVW) of 40 US tons, impacting only the inner lane, while the outer lane is affected solely by environmental loading.

Over the past thirty years, MnROAD has undergone several reconstruction phases to establish new test sections or replace expired sections. This test track is renowned for the plethora of variform designs and materials that characterize a wide range of pavement test cells (numbering up to 60 cells) where each cell is at least 76 m (250 ft) long and 2 twelve-foot-wide lanes. The various designs facilitate extensive studies as strain, moisture, temperature, and state (freeze thaw indication) are constantly and directly loading the database spontaneously. This data is easily retrieved and can be analyzed to deduce trends in response of the pavements to traffic and environmental loads. Additionally, certain performance measurements that are not adapted to sensor installation and automatic data collection are measured directly when traffic is diverted periodically from the test cells at the Interstate 94 westbound (Mainlines) or the 80 daily laps of the 80 kips 5-axle semitrailer on the low volume loop is interrupted to facilitate measurement of falling weight deflectometer measurement for layer moduli and load transfer efficiency friction, ride, and noise. Performance data is fed into the data base and can be retrieved with a simple query. The test cell is located on the inside lane of the north side of the low volume loop.

2.3 Test Cell Details

Table 2.1 shows the location data for vibrating wire strain gauge with thermistor and maturity sensors. In total four vibrating wire strain gauge and thermistor and two maturity sensors.

Table 2.1. Instrumentation and Location Data for Vibrating Wire Strain Gauge Thermistor and Maturity

Model	Seq	Orientation	Sensor Name	Approx. STA	Offset (ft)	Depth (in)	Material
VW	1	Longitudinal	2437VW01	89+75.85	10.5	1	Concrete
VW	2	Longitudinal	2437VW02	89+75.86	10.5	5	Concrete
VW	3	Transverse	2437VW03	89+75.87	10.75	1	Concrete
VW	4	Transverse	2437VW04	89+75.88	10.75	5	Concrete

Maturity Datalogger Body and Cord	Joint 1061
Maturity Datalogger Body and Cord	Joint 1062

Figure 2.1 shows the test cell 2437 (Panel A, B and C) along with the instrumentation. Figure 2.2 showing transverse and longitudinal vibrating wire strain gauges installed and anchored to plastic supports and connected through leads to the cabinet (not shown) near the test cell.

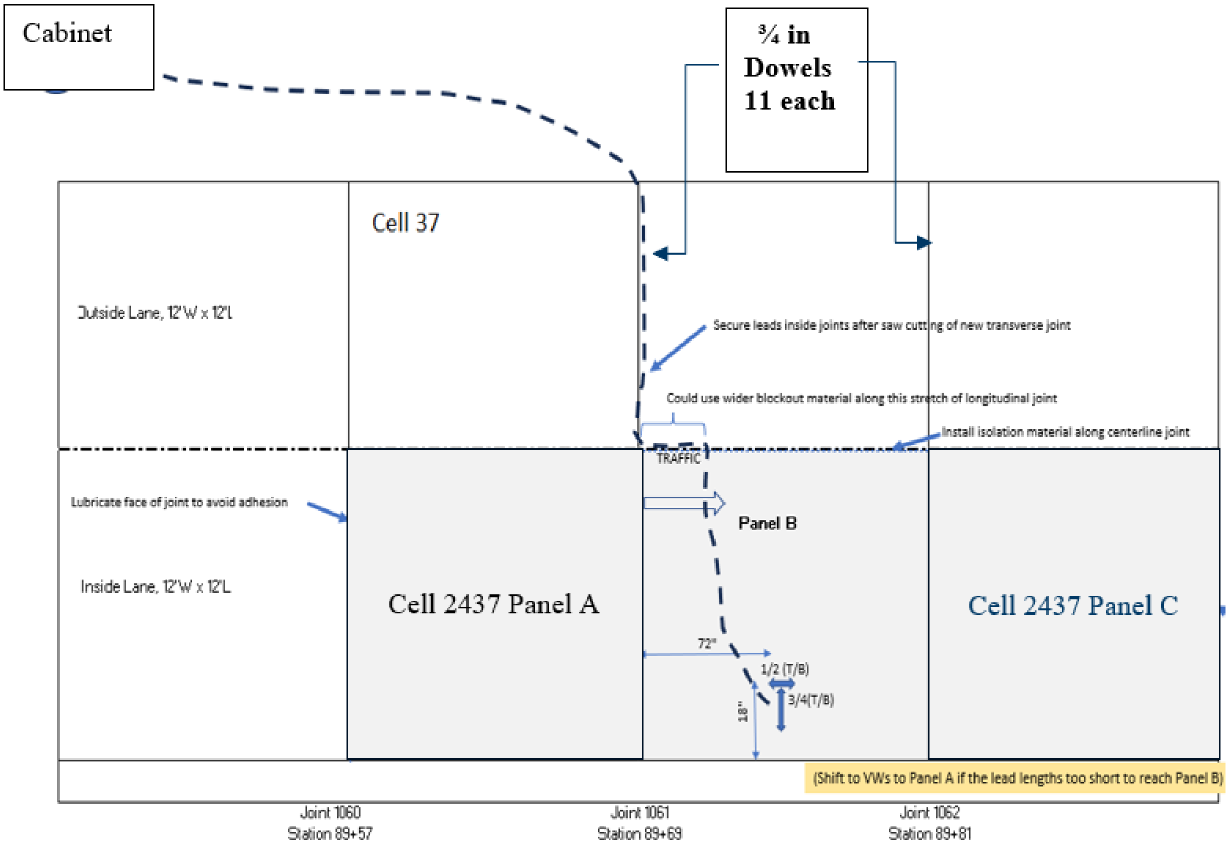


Figure 2.1. Instrumentation and dowel location record

The preexisting pavement was cut out by MnROAD forces on November 10, 2024, using power concrete cutters that ensured a smooth vertical; edge around the entire perimeter of the 12 ft x 36 ft section (2).

Figure 2.2. Aerial view of the low volume road and inset: Cell 2437 in perspective

Placement began at 9:00am on 11/22/2024. The air temperature during paving was 35 degrees Fahrenheit. MnDOT used an existing contract with a local concrete paving contractor. A local testing company was retained to do plastic, rheological, mechanical, and transport properties testing. Figures 2.3 to 2.4 show the paving process.

Figure 2.3. Aerial View of the accentuating sensor location

Figure 2.4. Aerial View of the pavement placement process progressing from NW to SE

Due to the characteristic rapidity of strength gain exhibited by the material, joint establishment by saw cutting was feasible and MnROAD forces commenced sawing within 3 hours of paving. Transverse joints were sawn to a 2-inch depth. This sawing process did not generate sliver spalls as would be typical of early sawing when the concrete has not gained sufficient strength.

2.4 Joint Sawing

Due to the characteristic rapidity of strength gain exhibited by the material, joint establishment by saw cutting was feasible and MnROAD forces commenced sawing within 3 hours of paving. Transverse joints were sawn to a 2-inch depth. This sawing process did not generate sliver spalls as would be typical of early sawing when the concrete has not gained sufficient strength. The joints were left unsealed.

2.5 Chapter Summary

Test cell built at MnDOT MnROAD Low Volume Road provided a location for experimentation of ¾-inch dowels. Location of sensors and concomitant test cell details were geocoded. In the next chapter, a discussion of the deployment section in Hinckley, Minnesota will be discussed.

Chapter 3: Deployment of ¾-inch Dowels on Interstate 35 in Hinckley, Minnesota

3.1 Background

In the last chapter the details of the relevant MnROAD test cell were discussed. This chapter now focuses on the deployment sections at the research test sections on Interstate 35 in Hinckley Minnesota.

3.2 Data Tables

Table 3.1 and Table 3.2 show four-hour and one-day test results of compressive strength and flexural strength from trial mixing in the plant performed by the product manufacturer.

Table 3.1. LTE on 11-25-24 on Cell 2437

Location	LTE %	LTE %
Joint 2 Before	97.1	93.8
Joint 3 Before	97.1	95.6
Joint 2 After	95.3	95.4
Joint 3 After	96.6	95.4

The previous chapter showed the results obtained so far in the test cells as well as the Interstate 35 test section. This chapter now shows the data obtained in the Hinckley deployment section and performs a narrative of how the performance data vary from control. The layout of joints is shown in Table 3.2

Table 3.2. Layout of Joints in the 35W Test Section

Joint	Section Type	FWD Station ID (after, before)
1 (South end)	Full depth replacement 1 ¼” control	1, 2
2	Full depth replacement 1 ¼” control	3, 4
3	Full depth replacement 1 ¼” control	5, 6
4	Full depth replacement ¾” dowel	7, 8
5	Full depth replacement ¾” dowel	9, 10
6	Full depth replacement ¾” dowel	11 ,12
7	Transition joint	13, 14
8	Unbonded overlay ¾” dowel	15, 16
9	Unbonded overlay ¾” dowel	17, 18
10	Unbonded overlay ¾” dowel	19, 20
11	Unbonded overlay 1 ¼” control	21, 22
12	Unbonded overlay 1 ¼” control	23, 24
13 (North end)	Unbonded overlay 1 ¼” control	25, 26

Table 3.2 shows the layout of the falling weight deflectometer (FWD) sensors used in the test sections

Table 3.3. The layout of the FWD sensors used in the test sections

Sensor	Distance from Load (inches)
D10	-12
D1	0
D2	8
D3	12
D4	18
D5	24
D6	36
D7	48
D8	60
D9	72

3.3 Narrative

Based on the layout load transfer efficiency (LTE) before joint (LTE before) = D10/D1 where D10 is the deflection of sensor 12 inches before the joint and D1 is deflection as measured by sensor under the load. Similarly, the LTE after is the D3/D1 where D3 is the deflection recorded by sensor D3 located 12 inches from the load and across the joint from the load .These values were averaged for various load levels of 6000 lb, 9000 lb and 12000 lb drops using the standard 1-ft diameter plate. After the analysis, a descriptive statistic of the data was presented in Table 5.3 and Figure 5.1 based on the factorials in Table 5.1 and the sensor configuration in Table 5.2. Results showed that the transitional sections showed the highest mean LTE, followed closely by the ¾-in experimental UBOL subsections. While all the LTEs ranged from 77% in the full depth ¾-inch dowel experimental section to 89% in the transitional joints, this spread does not separate the performance of the experimental sections distinctly and incontrovertibly from those of the control sections. As performance changes occur over time, there may later be a clearer dichotomy, but the current data did not show any statistically significant reduction in LTE in comparison to the control sections.

Table 3.4. Load Transfer Efficiency (LTE) Distribution in each of the Hinckley Interstate 35 Subsections

	Full depth replacement control After	Full Depth Replacement ¾-inch Dowel After	Unbonded Overlay ¾" dowel After	Unbonded Overlay Control After	Full depth replacement control Before	Full Depth Replacement ¾-inch Dowel Before	Unbonded Overlay ¾" Dowel Before	Unbonded Overlay control Before	Transition Joint After	Transition Joint Before
Mean	0.772	0.768	0.804	0.830	0.771	0.773	0.866	0.816	0.885	0.873
Standard Error	0.003	0.001	0.014	0.021	0.002	0.002	0.066	0.014	0.006	0.012
Median	0.771	0.769	0.803	0.811	0.773	0.775	0.803	0.815	0.889	0.863
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.011	0.004	0.048	0.072	0.008	0.006	0.230	0.048	0.012	0.024
Sample Variance	0.000	0.000	0.002	0.005	0.000	0.000	0.053	0.002	0.000	0.001
Kurtosis	2.389	4.765	-1.881	5.051	2.697	-1.154	11.478	1.195	1.758	3.604
Skewness	0.708	-1.943	-0.045	2.015	-0.929	-0.711	3.361	-0.613	-1.469	1.865
Range	0.046	0.014	0.126	0.268	0.031	0.017	0.822	0.184	0.025	0.052
Minimum	0.752	0.758	0.737	0.758	0.753	0.763	0.768	0.710	0.869	0.856
Maximum	0.798	0.772	0.864	1.026	0.784	0.780	1.590	0.894	0.893	0.908
Sum	9.268	9.221	9.643	9.963	9.256	9.271	10.393	9.793	3.540	3.491
Count	12	12	12	12	12	12	12	12	4	4
Largest(1)	0.798	0.772	0.864	1.026	0.784	0.780	1.590	0.894	0.893	0.908
Smallest(1)	0.752	0.758	0.737	0.758	0.753	0.763	0.768	0.710	0.869	0.856
Confidence Level(95.0%)	0.007	0.002	0.031	0.046	0.005	0.004	0.146	0.030	0.018	0.038

3.4 Discussion

The Highest LTEs were observed in the transitional joints and the lowest were found in the full depth control section. Compared to LTE on Cell 2437, observed values on Interstate 35 were all lower than the LTE observed at MnROAD (and the mean LTE in Hinckley, MN (5.4 and Figure 5.1,)). It is possible that the ¾-inch dowel was sufficient for load transfer in a 6-inch pavement but not for 9 inches on the Hinckley deployment sections. However, one of the UBOL experimental (¾-inch dowel) sections showed very high LTE, but these were all lower than 90% whereas all the LTE measurements in the test cell read above 90%. It may be meaningful to start the ¾-in. dowels in thinner pavements and develop a body of knowledge.

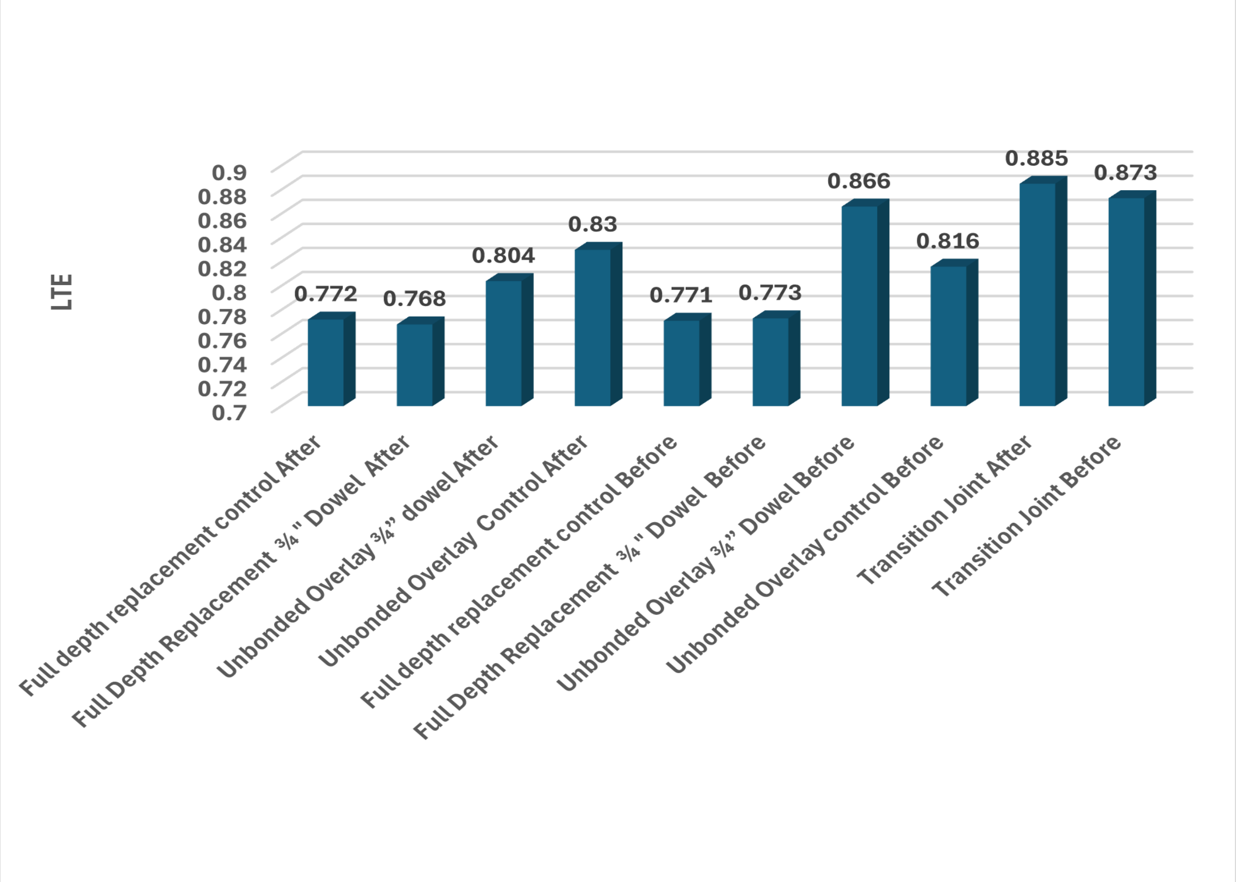


Figure 3.1. LTE in test sections on interstate highway 35 in Hinckley MN

Table 3.5 shows initial faulting results on Interstate Highway 35 in Hinckley, MN. These are extremely low and are of the order of magnitude of surface texture. Initial values are necessary as subsequent measurements with respect to time will be compared to these initial values.

Figure 3.2 and Table 3.5 shows the faulting depth measured in the Hinckley deployment sections. At this incipient stage of performance faulting was measured but not detected. Generally, less than 1mm faulting was of the order of texture anomalies. Subsequent periodic monitoring will be useful because joint distresses will show up in the future if the experimental sections wield insufficient load transfer.

Table 3.5. Initial Faulting Results on Interstate Highway 35 in Hinckley, MN

Joint	Section Type	Faulting Depth (mm)	Faulting Depth Inch
1 (south end)	Full depth replacement 1 ¼” control	0.27	0.01
2	Full depth replacement 1 ¼” control	0.41	0.02
3	Full depth replacement 1 ¼” control	-0.2	-0.01
4	Full depth replacement ¾” dowel	-0.15	-0.01
5	Full depth replacement ¾” dowel	0.19	0.01
6	Full depth replacement ¾” dowel	0.49	0.02
7	Transition joint	0.58	0.02
8	Unbonded overlay ¾” dowel	0.82	0.03
9	Unbonded overlay ¾” dowel	0.76	0.03
10	Unbonded overlay ¾” dowel	0	0.00
11	Unbonded overlay 1 ¼” control	0.03	0.00
12	Unbonded overlay 1 ¼” control	0.31	0.01
13 (north end)	Unbonded overlay 1 ¼” control	0.44	0.02

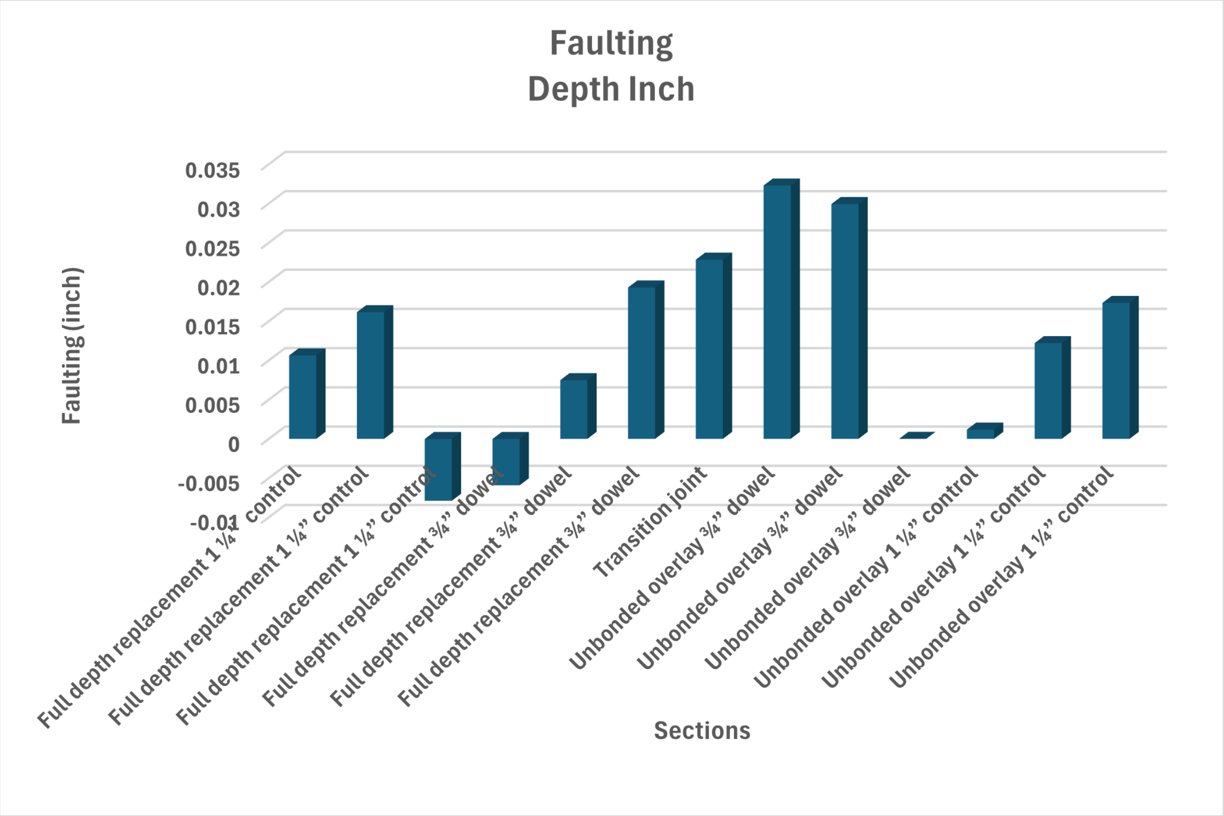


Figure 3.2. Faulting in the Hinckley deployment sections. This is of the texture order of magnitude

3.5 Chapter Summary

Deployment sections showed no faulting and slightly lower load transfer efficiency than the test cell at MnROAD. Annual monitoring of the deployment sections with falling weight deflectometer, ride and faulting measurements are anticipated. Initial rest results are not consistent with the theoretical evaluation of bearing stress ratio, but a 5-year performance trend determination, at the minimum, is required to adequately evaluate the implications of using ¾-inch dowels.

Chapter 4: Chapter 4: Conclusion and Recommendations

The initiative investigated the field characteristics of a ¾-inch dowelled concrete joint at MnROAD and in Interstate 35 in Hinckley. Reduction of dowel diameter explored a sustainable usage of dowels where bases are uniform and provide some load transfer. It also studied a newly established test section in Hinckley where the UBOL sections with ¾-inch dowels are contiguous with UBOL section control, and the ¾-inch dowel in the full depth construction sections are contiguous with the full depth construction control.

The LTE at MnROAD were quite high and higher than all the test sections in the Interstate 35 Hinckley deployment. The hypothesis of sufficiency of the small diameter dowels corresponding to thinner pavements may lend credence to this, because some of the small diameter dowel sections exhibited LTEs comparable to the transitional sections where the LTE was highest, although this result is not conclusive until results are obtained from at least 5 years of monitoring.

This test cell and corresponding network test sections will benefit from periodic monitoring and the rendition of periodic performance reports from cores distress mapping and FWD measurements. The distribution of falling weight deflectometer results in the contiguous test sections on Interstate Highway 35 in Hinckley does not provide a conclusive comparison of the ¾-diameter dowels section to the control pavement with 1¼-inch dowels. Dowels in the transition panels showed the overall highest load transfer efficiency but not as high as those measured in the MnROAD test cell. Theoretical prediction of the implication of using ¾-inch dowels was found to negate the basic concept of allowable bearing stresses. Many other previous relevant research initiatives examined in this study did not portray analytically a prediction for the implication of using lower diameter dowels. These made prediction analyses difficult, but some analysis was still possible because some references eventuated prediction of a bearing strength ratio of ¾ and another facilitated prediction of a stiffness ratio of 1/5 comparing the ¾-inch dowel to the 1-inch dowel. The report did not back-calculate stiffness ratio and bearing stresses from the falling weight deflectometer results, which by inspection were not coherent with analytic predictions. Seasonal measurements at the MnROAD facility and annual monitoring of the deployment sections with a falling weight deflectometer, as well as ride and faulting measurements, are recommended.

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