Concrete Pavement Performance and Research at the Minnesota Road Research Project – The First Ten Years

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Abstract

The Minnesota Road Research (MnROAD) facility was constructed in the early 1990's to include fourteen plain jointed concrete pavement test sections. Nine of the test sections are interstate highway designs with design lives of 5 or 10 years. The other five test sections are low-volume road designs. With traffic loading beginning in 1994, the test sections have now experienced over 10 years of load and environmental effects. During that time, a tremendous amount of data collection and research analysis has taken place. The condition and ride performance of the concrete pavement test sections is characterized. Significant findings from selected studies are presented. The performance of the 5-year and 10-year design test cells shows that Mn/DOT's current concrete pavement design method needs significant improvement. The lessons learned from the operation of the MnROAD project can be used to improve the next generation of concrete pavement design methods and test facilities.

Introduction

Current methods to design pavements are primarily based on standards developed from the AASHO Road Test (HRB 1962) in the early 1960's. In the late 1980's, a group of pavement experts became concerned that modern materials and methods of construction were stretching those standards unrealistically. The result of that concern was the creation of a next generation test road. That test road, which is now called the Minnesota Road Research Project or MnROAD, was to incorporate current materials and construction methods of the time, and contribute towards the development of a mechanistic-empirical pavement design method for cold (Minnesota) climate conditions.

Located approximately 65 km (40 miles) northwest of Minneapolis, Minnesota, the MnROAD project was constructed from 1990-1994 under the guidance of the Minnesota Department of Transportation (Mn/DOT) and the University of Minnesota. The facility has both high-volume interstate and low-volume local road design pavement test sections. The interstate sections receive live traffic diverted from Interstate Highway 94, and the low volume road sections are on a controlled access loop road. The test sections were open to traffic beginning in August 1994. One of the unique aspects of the MnROAD project is that it is a "real time" pavement performance facility. The test sections are exposed to the environment and allowed to run long enough to measure the effect of Minnesota's severe northern climate on pavement materials.

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Originally, MnROAD consisted of 40 different test sections or “cells”. The focus of this paper is the fourteen original jointed plain concrete test sections. Several more concrete test sections have been added to the MnROAD facility since 1994. These sections will be briefly described, but their performance will not be discussed. Since opening to traffic in 1994, the MnROAD project has contributed to a number of major concrete pavement research efforts. This paper will summarize the results of those efforts. First, however, a description of the MnROAD project, and an update on the condition of the original concrete test sections, will be provided.

Research Significance

The research results obtained during the first 10 years of operation of the MnROAD project will be used to improve the next generation of concrete pavement design methods in Minnesota. Current and future pavement test facilities can also benefit from the lessons learned at MnROAD.

MnROAD Concrete Pavement Test Sections

Test Cell Description The MnROAD project was constructed from 1990-1994 to include 14 plain jointed concrete pavement test sections or “cells”. Of those 14 test cells, five of them were designed using Mn/DOT’s concrete pavement design method (Mn/DOT 1994) (based on 1981 AASHTO design method) to last five years under interstate traffic loading before reaching terminal serviceability. Another four cells were designed using the same method to last 10 years. The remaining five test cells are on the low-volume loop road. These cells were primarily designed to represent local city and county road designs, and are based primarily on the minimum accepted concrete pavement thickness standards of that time. Table 1 summarizes the design variables in the MnROAD concrete pavement test cells. More information on the MnROAD test cells can be found on the MnROAD website http://www.mnroad.dot.state.mn.us/research/mnresearch.asp.

Each of the approximately 150 meter (500 foot) long test cells was constructed to include a variety of instrumentation to monitor load and environmental effects. In the concrete cells, the instrumentation monitors dynamic and environmental strain in the slabs, joint displacement, joint width, slab and soil temperature, and soil pressure. The only original instrumentation that remains functioning after 10 years is the environmental strain and temperature sensors.

Traffic Loading The five and ten-year design cells at MnROAD receive live interstate traffic diverted off the adjacent Interstate Highway 94. Average annual traffic levels are about 1,000,000 CESALs (concrete equivalent single axle loads), with an 80%/20% traffic distribution between the driving and passing lane. HCAADT (heavy commercial average annual daily traffic) is approximately 14%. From August 1994 to April 2004, the mainline test cells experienced approximately 9,000,000 CESALs.

The low-volume loop test cells are trafficked by a standard five-axle semi tractor-trailer truck with two different load configurations. Four days a week, the truck is loaded to the Minnesota legal limit of 356 kN (80,000 lbs) and driven

Table 1. MnROAD concrete pavement test cell dimensions and parameters.

Test Cell	Slab Thickness (mm)	Joint Spacing (m)	Lane Width [Driving/ passing] (m)	Tied Shoulders [Passing Lane only] (m)	Dowel diameter (mm)	Base/ Subbase* Thickness (mm)	Subgrade Type	Drainage
Mainline								
5	190	6.1	4.3 / 4.0		25	76 CL4/ 686 CL3	Silty/Clay	
6	190	4.6	4.3 / 4.0		25	127 CL4	Silty/Clay	
7	190	6.1	4.3 / 4.0		25	102 PASB/ 76 CL4	Silty/Clay	Edge Drains
8	190	4.6	4.3 / 4.0	4.0	25	102 PASB/ 76 CL4	Silty/Clay	Edge Drains
9	190	4.6	4.3 / 4.0	4.0	25	102 PASB/ 76 CL4	Silty/Clay	Edge Drains
10	240	6.1	3.6 / 3.6		32	102 PASB/ 76 CL4	Silty/Clay	Edge Drains
11	240	7.3	3.6 / 3.6		32	127 CL5	Silty/Clay	
12	240	4.6	3.6 / 3.6		32	127 CL5	Silty/Clay	Edge Drains
13	240	6.1	3.6 / 3.6		38	127 CL5	Silty/Clay	
Low Volume								
36	150	4.6	3.6 / 3.6		25	127 CL5	Sand	
37	150	3.6	3.6 / 3.6		None	305 CL5	Sand	
38	150	4.6	3.6 / 3.6		25	127 CL5	Silty/Clay	
39	150	6.1	3.6 / 3.6		25	127 CL5	Silty/Clay	
40	178-140-178	4.6	3.6 / 3.6		None	127-165-127 CL5	Silty/Clay	

Notes: * CL3-CL5 are gravel base materials. PASB is permeable asphalt stabilized base.
All transverse joints are skewed at a 2 ft/12ft angle. 1 inch = 25.4 mm, 1 foot = 0.3049 m.

approximately 80 laps (each day) around the inside lane of the low-volume loop road. One day a week, the truck is loaded to 453 kN (102,000 lbs) and driven in the outside lane, to test the effects of overloaded or future increased load limits on the test cells. From August 1994 to April 2004, the low-volume test cells experienced approximately 270,000 CESALs.

Test Cell Condition After 10 years of traffic and exposure to Minnesota's climate, the 14 original MnROAD concrete pavement test cells remain in good to very good condition. Panel cracking is minimal, and joint faulting remains low for all but one test cell. More specific trends are described below.

Five-year Design Test Cells The five-year design cells, designated as Test Cells 5-9, are in very good condition considering they have at least doubled their design serviceability life. Figure 1 shows the history of ride quality for the five-year design test cells, based on the International Roughness Index (IRI). All MnROAD test cells are rated for ride quality several times each year using a special pavement

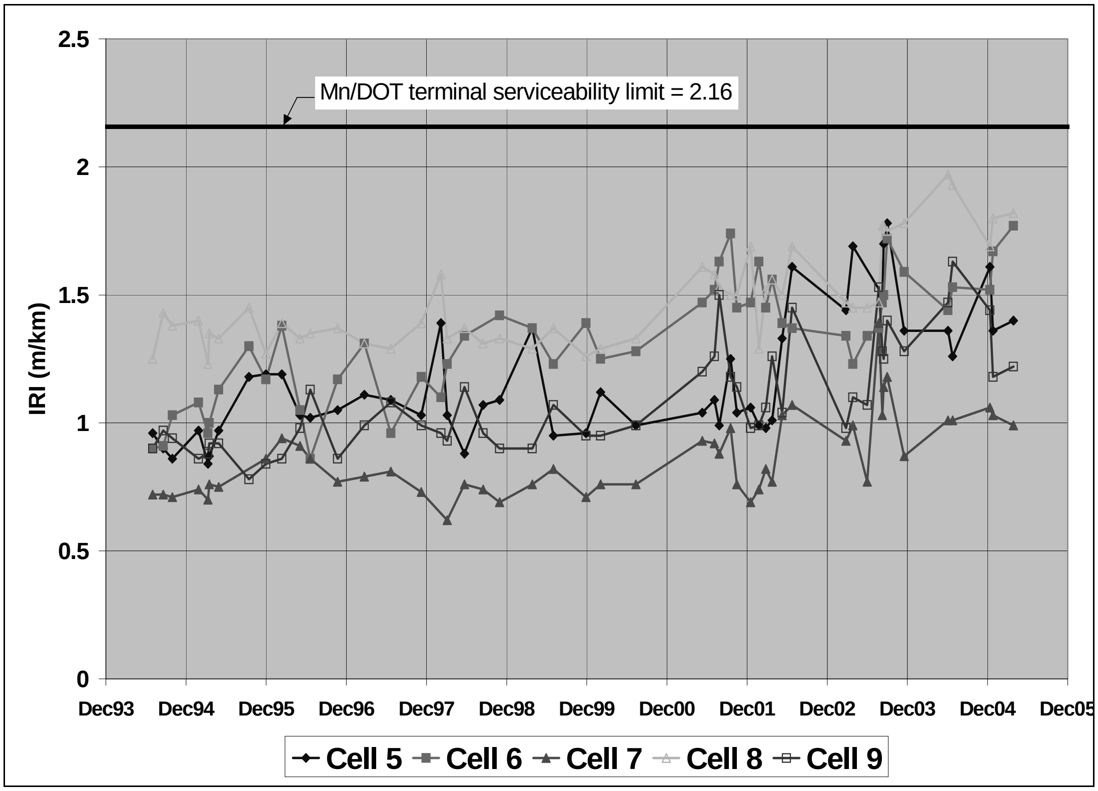

Figure 1. History of ride quality based on IRI measurements for MnROAD five-year design concrete pavement test cells. 1 m/km = 63.48 in/mile.

management testing van. Mn/DOT defines terminal serviceability at an IRI level of 2.16 m/km. The ride quality history of test cell 7 provides additional validation to the theory that initially smooth pavements remain smoother throughout their life (Smith et al 1997).

Test cell 5 is the only five-year design concrete test cell at MnROAD to have load or environmentally caused panel cracking. Although the cause is not yet fully determined, the periodic longitudinal cracking in cell 5 is believed to be a result of loss of support by the upper base layer. See Photo 1. The reconstruction (twice) of a header at the west end of test cell 5 (transition between the concrete and asphalt test sections) may indicate the panels have been slipping down the gradual grade where the test cell is located. This is revealed by the presence of several wide transverse joints throughout the 159 meter (520 foot) test cell.

Joint faulting in the five-year design test cells remains very low. Table 2 shows the average (of 5 joints in each test cell) and the maximum joint faulting as of June 2004. There has been little evidence of pumping of subgrade or base material in these test cells. Joint spalling is very low, and joint sealant (silicon sealant over a foam backer rod) remains in good condition.

Load transfer efficiency (LTE) of the joints in the five-year design test cells has declined to approximately 70%. Table 3 shows the average LTE and differential deflection (leave side of joint, outer wheelpath) for each of the test cells.

Photo 1. Panel cracking in driving lane of MnROAD test cell 5.

Table 2. Transverse joint faulting for MnROAD concrete pavement test cells, June 2004.

Test Cell	Average Joint Faulting (mm)		Maximum Joint Faulting (mm)	
Mainline	**Driving Lane**		**Driving Lane**	
5	0.40		0.9	
6	0.43		0.8	
7	0.48		0.9	
8	0.49		0.8	
9	0.49		1.3	
10	0.30		0.6	
11	0.19		0.7	
12	0.42		1.1	
13	0.25		0.6	
Low Volume	**356kN Lane**	**453kN lane**	**356kN Lane**	**453kN lane**
36	0.33	0.37	0.8	1.0
37	0.68	0.38	1.3	1.6
38	0.47	0.51	1.1	1.2
39	0.40	0.52	0.9	1.2
40	1.93	1.41	3.3	3.2

1 kN = 225 lbs.

Table 3. Joint load transfer efficiency and differential deflection for MnROAD concrete pavement test cells.

Test Cell	Testing Date	Average Joint Load Transfer Efficiency (%)		Average Differential Deflection (microns)	
Mainline		**Driving Lane**		**Driving Lane**	
5	4/21/2004	65		81	
6	4/21/2004	70		79	
7	4/21/2004	75		46	
8	4/21/2004	77		41	
9	4/19/2004	80		33	
10	4/20/2004	82		25	
11	4/20/2004	79		38	
12	4/20/2004	87		38	
13	4/20/2004	85		20	
Low Volume		**356kN Lane**	**453kN lane**	**356kN Lane**	**453kN lane**
36	3/25/2004	85	80	35	41
37	4/07/2004	55	27	147	300
38	4/07/2004	88	87	58	46
39	10/07/2003	80	81	63	63
40	6/27/2003	48	73	261	104

1 kN = 225 lbs.

Ten-year Design Test Cells The ten-year design cells, designated as Test Cells 10-13, are in very good condition. Figure 2 shows the history of ride quality for these cells in terms of IRI. The ten-year design test cells show less variability in ride quality over time, however the magnitudes of IRI are similar to the five-year design test cells.

There is no panel cracking, and a low amount of joint spalling in the ten-year design test cells. Joint faulting is minimal to nonexistent (see Table 2). Joint sealant remains in good condition and there has been little evidence of pumping of subgrade or base material. Load transfer efficiency (LTE) of the joints remains high (see Table 3).

Low-Volume Design Test Cells The low-volume design cells, designated as Test Cells 36-40, are in good condition. Figures 3 and 4 show the history of their performance in terms of ride quality. Test cell 40, an undoweled trapezoidal cross-section design is showing significantly different ride quality (IRI) behavior for the 453 kN (102k) loading.

There are a small number of transverse cracks in the low-volume test cells, caused exclusively by settlement of inadequately compacted utility trenches. Joint faulting in these test cells is low, with the exception of test cell 40. As previously mentioned, this test cell has no dowels, and is located over a 127 mm (5 inch) thick gravel base and silty-clay subgrade. See Table 2 for average and maximum faulting levels for each of the low-volume test cells. Test cell 37, also an undoweled section, shows much less faulting, due most likely to a sandy subgrade.

Load transfer efficiency (LTE) of the joints is good, again with the exception of

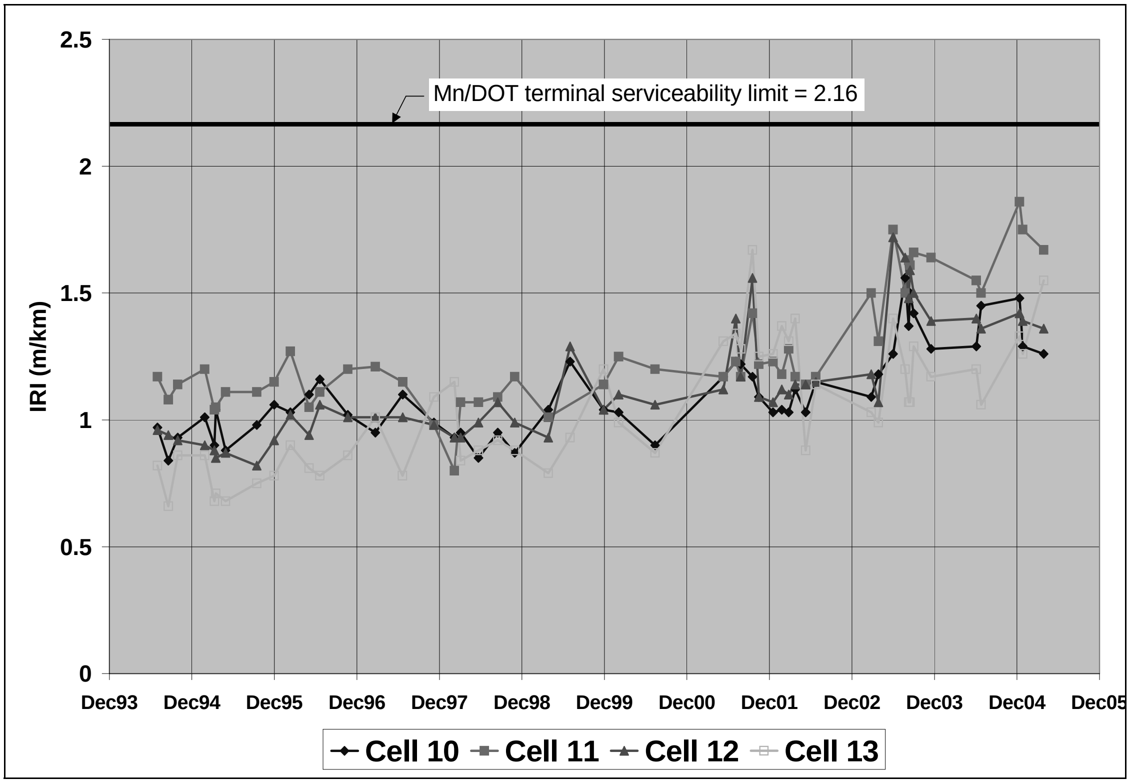

Figure 2. History of ride quality based on IRI measurements for MnROAD ten-year design concrete pavement test cells. 1 m/km = 63.48 in/mile.

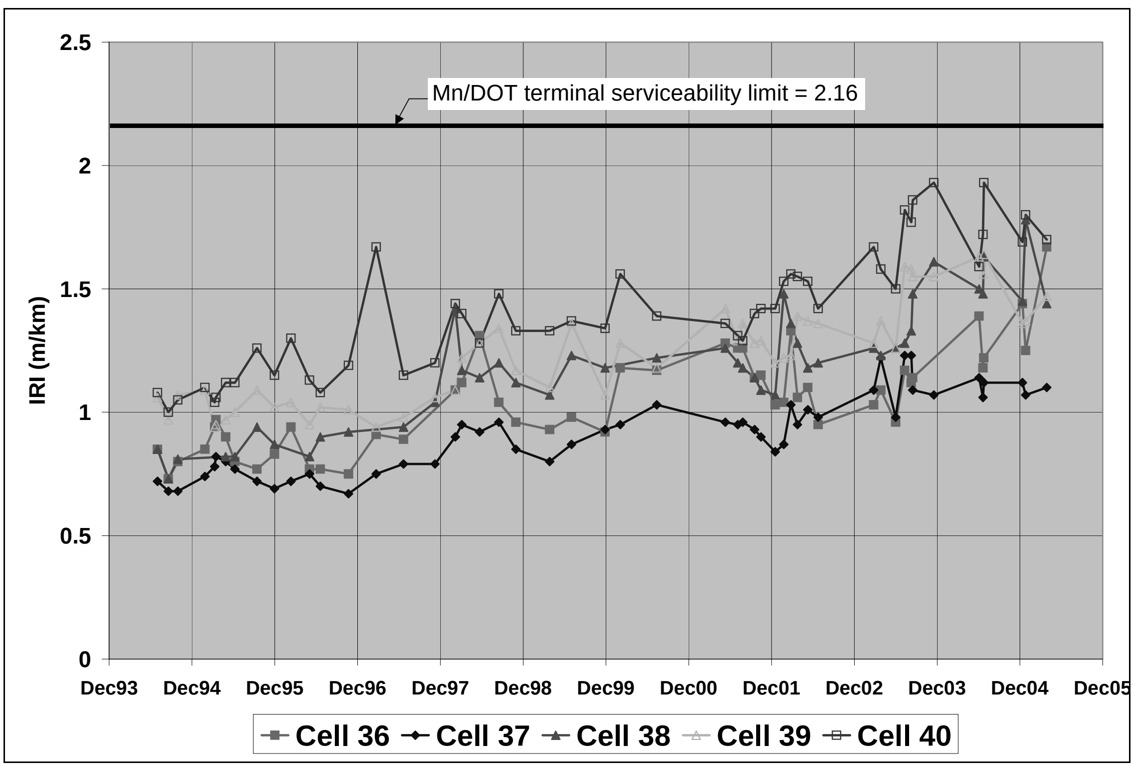

Figure 3. History of ride quality based on IRI measurements for MnROAD low-volume design concrete pavement test cells subject to 80k (356 kN) loading.

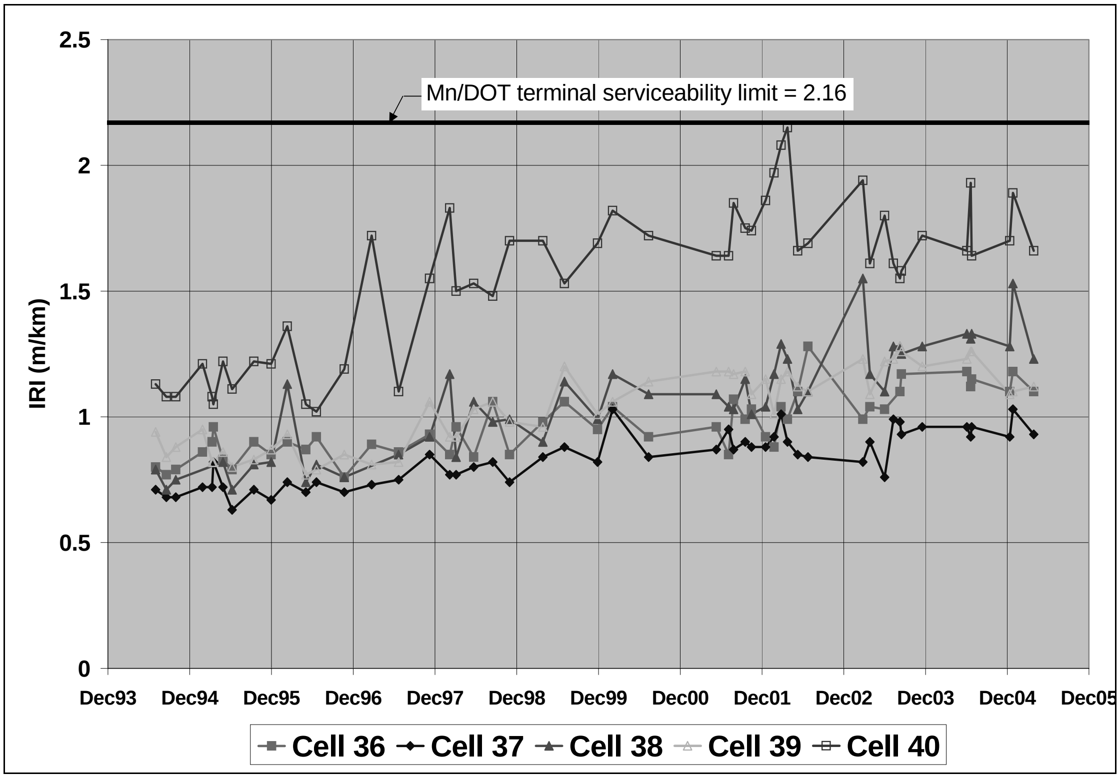

Figure 4. History of ride quality based on IRI measurements for MnROAD low-volume design concrete pavement test cells subject to 102k (453 kN) loading.

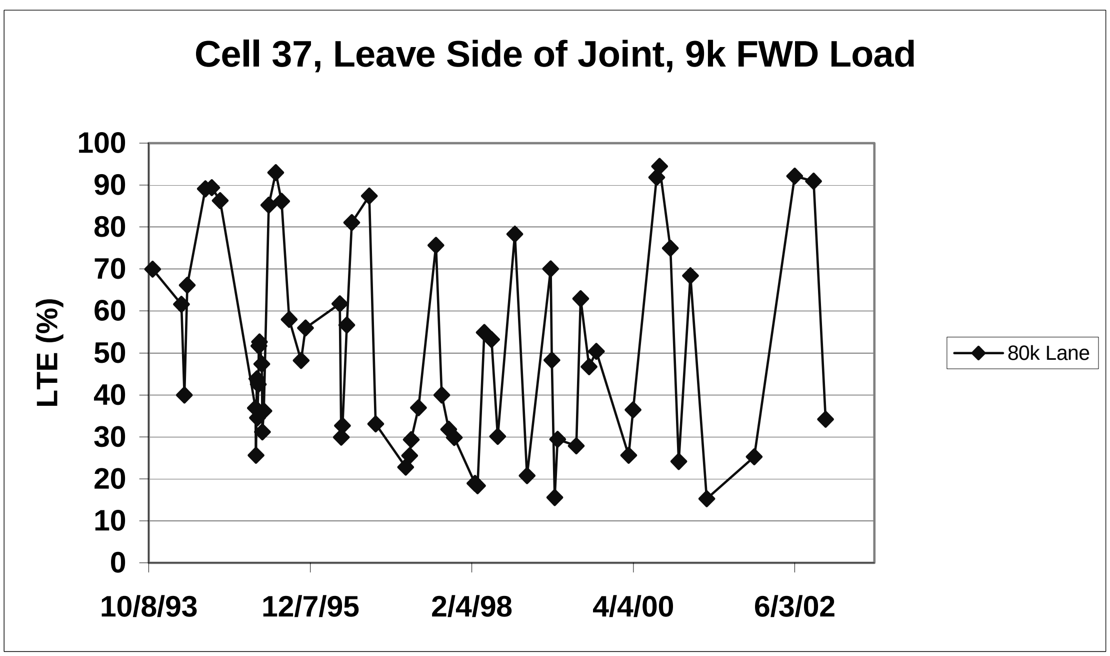

Figure 5. Joint load transfer efficiency (LTE) measurements of undoweled slabs.

undoweled cells 37 and 40. Figure 5 shows the effect joint closure has (on higher temperature days) on the measured LTE in these sections.

While significant pumping of base or subgrade material (at the lane-shoulder joint) has been observed in cells 38-40 (356 kN lane), a forensic investigation in 2003 showed no voids under the slabs. The material being pumped out appears to be coming from the shoulder area. Settlement of the asphalt shoulder immediately adjacent to the edge of the concrete slabs strengthens this premise.

Initial Research Objectives

Before looking at the research accomplished during the first 10 years of the MnROAD project, it is good to review the original concrete pavement research objectives laid out in 1990 (Mn/DOT Report 90-03, 1990). They are as follows:

- 1-C: Validate Mn/DOT and AASHTO design methods.
- 2-C: Develop mechanistically based design method for rigid pavements.
- 3-C: Development of improved mechanistic models for rigid pavements.
- 6-C: Determine pavement damage caused by different vehicles.
- 7: Determine effect of heavier axle loads.
- 10: Determine influence of base/subbase properties upon PCC performance/distress.
- 11: Influence of subgrade type upon pavement performance.
- 12: Improved roadway instrumentation techniques.
- 13: Influence of special design variables upon rigid pavement performance; Edge drains, contraction joints, paving width, joint spacing, trapezoidal cross-sections, cement type and content (LVR Loop), aggregate class (LVR loop).
- 14: Influence of pavement variability upon pavement performance models; Effective modulus of subgrade reaction (k-value), concrete elastic modulus, concrete modulus of rupture, drainage coefficient, joint load transfer efficiency, pavement layer thickness.

While initial research project work plans were drafted for each of the objectives above, they typically were not realized as specific projects. Rather, parts from each of the objectives were incorporated into studies that could be accomplished given the condition and age of the test cells, and the available personnel to do the research. The following section summarizes the results from some of those studies, and identifies the initial research objectives they most closely addressed.

Significant MnROAD Research Studies

Validate Mn/DOT and AASHTO Design Methods (Initial Objectives: 1-C, 14)

Validation of the Mn/DOT and AASHTO pavement design methods was one of the first concrete pavement research projects at MnROAD. This study, by Burnham and Pirkl (1997), took as-built physical characteristics of the MnROAD concrete test cells as input parameters into the Mn/DOT design method (modified 1981 AASHTO method), the 1993 AASHTO method, and the 1984 PCA (Portland Cement Association) method. For each method, the expected test cell life span to reach terminal serviceability (IRI=2.16 m/km or PSR=2.5) was determined. Table 4 shows the predicted test cell serviceability life (in years) from the three design methods. Notice the significant variability in life predictions.

Now that the MnROAD test cells have been under traffic and weather for over 10 years, the predictions from that study can be evaluated. Given the good condition of the five-year design test cells, it is apparent that none of the design methods evaluated can effectively be used to design a concrete pavement that reaches terminal serviceability within 5 years. This is not discerning, however, since a five-year design life is not very desirable in most cases anyway. It is too early to tell how the ten-year design cells will compare to the different life predictions, however their current condition demonstrates it should be at least as long as predicted by the AASHTO 1993 method.

Serviceability lives for the low-volume test cells are not presented here, since their design was controlled more by standard local design practice (based mostly on minimum accepted slab thickness), than by a rational design method. More information can be found in the report by Burnham and Pirkl (1997).

Table 4. Serviceability lives (in years) predicted by concrete pavement design methods available in 1997 (Burnham and Pirkl 1997).

Test Cell	Mn/DOT Method	AASHTO 1993 Method (50% Reliability)	1984 PCA Method
5	5.8	5.1	2.9
6	2.6	3.3	0.7
7	4.4	9.3	2.2
8	2.4	3.2	0.6
9	3.9	7.2	1.6
10	12	19.2	76.4
11	13.1	12	60.2
12	12	16.1	75.9
13	12.1	16.1	69.4

Load Testing of Instrumented Pavement Sections (Initial Objectives: 3-C, 6-C, 7)

From 1995-2000, the University of Minnesota was contracted by Mn/DOT to conduct a large research project titled “Load Testing of Instrumented Pavement Sections.” In that study, select MnROAD test cells (concrete and asphalt) were evaluated for load response to a variety of vehicle types and configurations. Parameters that were studied included axle load, tire size and pressure, vehicle speed, and pavement temperature. The main objectives of the study were to update AASHTO load equivalency factors and to calibrate existing pavement structural models.

Several publications related to the behavior of the MnROAD concrete pavement test cells came from the study (Forst 1998, Glasgow 2002). Among the significant findings was that the interaction effects between the many variables incorporated into the test cells make it difficult to isolate a single variable’s effect on the concrete pavement response. For example, for the five consecutive passes (15 minutes apart) of a vehicle over a test cell, the slab temperature changes systematically, while the tire offset changes randomly.

One of the most important discoveries from this study was the difference between measured and predicted concrete slab strain values. It was found that measured static load strain was on average 24% lower than static strain predicted by an accepted finite element model (JSLAB-92). Measured dynamic strains were up to 74% lower than static strains predicted by the FEM program. This has resulted in modifications to the slab-base interaction models currently incorporated into the next generation of AASHTO concrete pavement design methods (NCHRP 1-37).

Although the study confirmed the extreme challenges involved in load testing pavements in the field, several ways to improve field data collection were discovered. Data collection went from a manual process, involving a large number of people, to an automated system using traffic-counter pressure hoses to trigger the data collection equipment. Another improved testing technique came from the use of a high-resolution video camera, which captures the tire offset relative to the slab location for each pass. While very effective in the field during testing, this method can be tedious during post processing of the data.

Interpreting FWD Tests of Curled and Warped Slabs (Initial Objectives: 3-C, 7, 11, 13)

The University of Minnesota was contracted in 1995 to conduct a research project titled "Interpreting FWD Tests of Curled and Warped PCC Pavements." This study's objective was to improve the structural evaluation of concrete pavements using Falling Weight Deflectometer (FWD) test results, by determining the effects of moisture and temperature on the behavior of concrete slabs subject to dynamic loads. A graphical sample of some of the results can be seen in Figure 6 (Vandenbossche 2003).

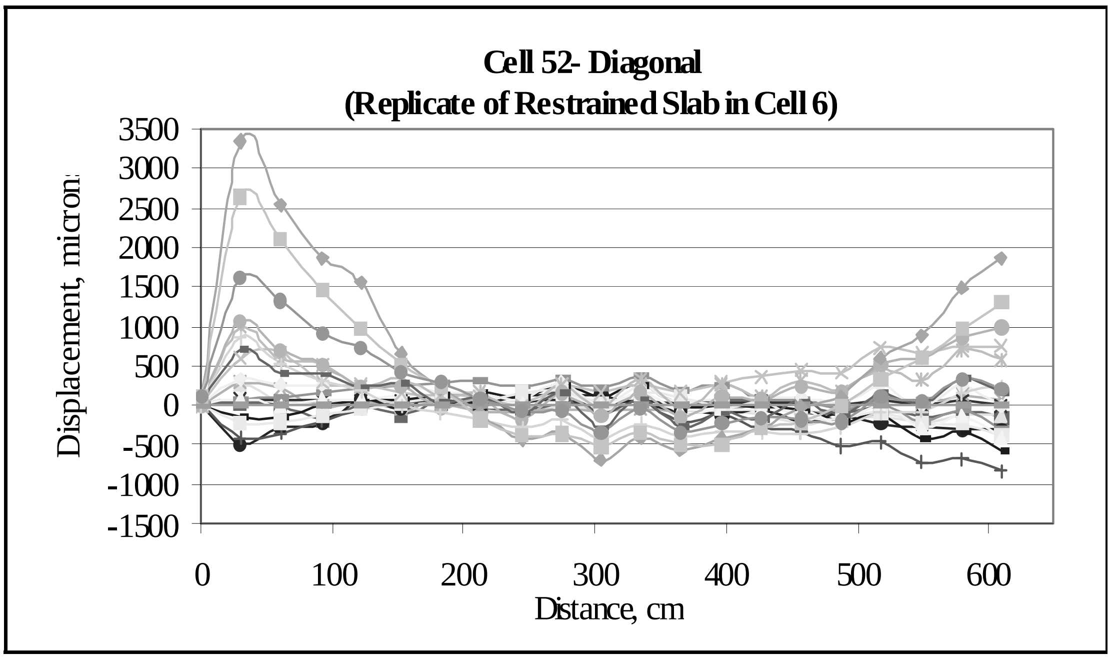

Figure 6. Sample of slab shapes measured during MnROAD curl and warp study (Vandenbossche 2003).

One of the results of the study is that joint load transfer for doweled slabs is generally unaffected by changes in slab temperature (for temps <80°F). Conversely, undoweled slabs have low load transfer capabilities for a large portion of each day (in most cases, throughout the whole day), regardless of available aggregate interlock in the transverse joints.

Another significant finding from the study was that support conditions measured by a FWD were similar in each MnROAD concrete test cell. This may explain the similar ride quality and distress performance observed so far for most of the concrete test cells, regardless of the type of base layers supporting the slabs. The study also found that the stiffness of the subgrade provides a significant contribution to the k-value backcalculated directly under the slab. The drained stabilized bases did not contribute significantly to increasing slab support, but did drastically reduce the number of voids detected under slabs. Finally, surface profile measurements revealed that large positive temperature moments (bottom of the slab warmer than the top) produce sufficient deformation in the slab, such that it is unsupported along the whole length of the transverse joint due to upward curvature. Additional results from this project can be found in references by Vandenbossche *et al.* (2002 and 2004).

Edge-Joint Sealing As Preventive Maintenance (Initial Objectives: 10, 13, 14)

This study, conducted in 1999-2000, set out to evaluate the effect routing and sealing of a lane-shoulder edge joint would have on the volume of water drained to an edge drain (Olson and Roberson 2003). In this study, the driving lane-shoulder edge joint was routed and sealed on MnROAD concrete test cell 8. MnROAD test cell 7 served as the control section.

It was observed that before sealing, there was no significant difference in the volume of drain water (as measured at the outlet of the edge drain) between the control and test section. After sealing the lane-shoulder joint in test cell 8, there was a significant reduction in measured drain water volume, 89% between test and control. It was determined that edge drains primarily drain the lane-shoulder edge joint, and that the presence of edge drains does not necessarily provide positive drainage for the entire pavement system. This study recommended that sealing lane-shoulder edge joints should be considered an effective preventive maintenance technique for concrete pavements.

Thermal Expansion Rate of Concrete Pavement (Initial Objectives: 2-C, 3-C, 12, 13, 14)

In 2001, Burnham and Koubaa demonstrated a new approach for estimating the thermal expansion rate and long-term drying shrinkage of concrete pavement slabs, based on MnROAD data. By analyzing the first 7 years of data from MnROAD vibrating wire strain sensors, the effects of slab restraint and seasonal temperature and moisture variations on the thermal expansion rate and drying shrinkage were demonstrated.

By examining the measured environmental strain versus slab temperature for

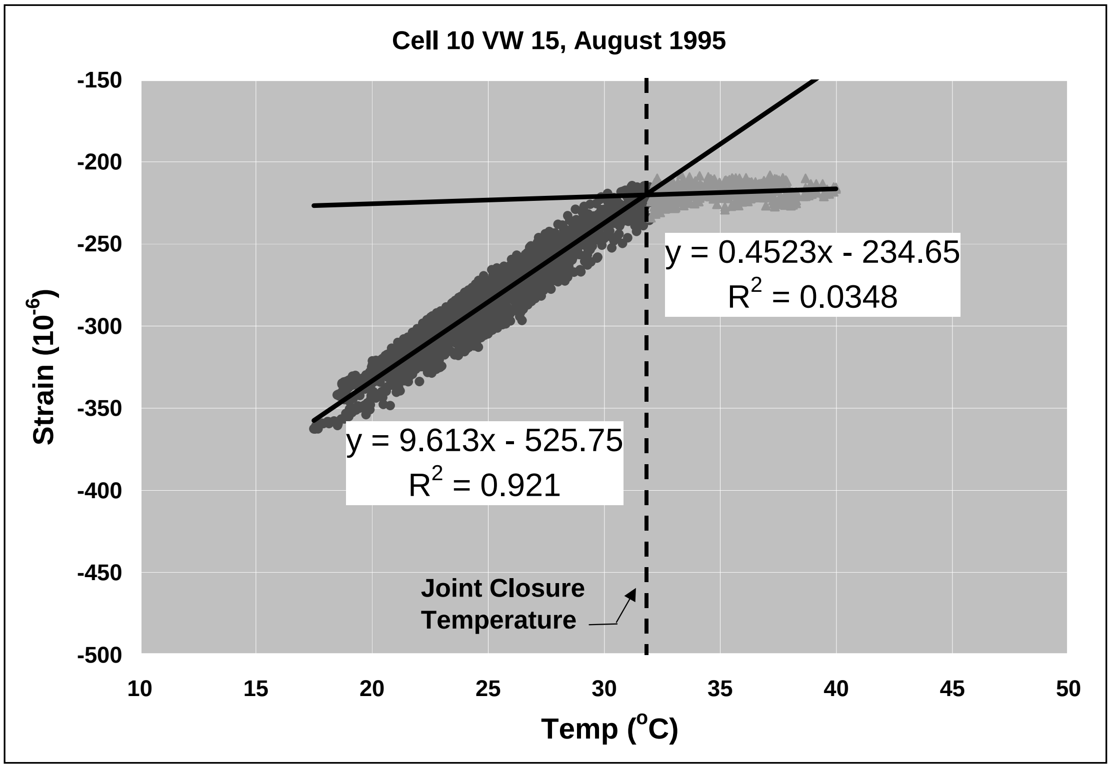

Figure 7. Effect of slab restraint demonstrated by change in measured rate of thermal expansion (Burnham and Koubaa 2001).

several seasons, periods of slab restraint could clearly be identified. See Figure 7. While the critical slab temperature at which the slab experienced expansion restraint occurred as expected during the hot summer months, restraint was also discovered at lower slab temperatures during the spring season. It is believed this is a result of slab expansion due to increased moisture content, thus requiring less temperature expansion before the joints close. It was also shown that the rate of slab expansion varies from the top of the slab to the bottom, and also varies with daily heating and cooling cycles.

This study also demonstrated the seasonal variation and long-term trends in drying shrinkage for the MnROAD concrete pavement slabs. An example is shown in Figure 8.

Tire Load Proximity Correlation Curves (Initial Objectives: 3-C, 6-C, 7, 13)

The magnitude of the response measured by a sensor in a pavement is controlled by the proximity of the tire load. Since tire wander has been incorporated into nearly every load test study at MnROAD, a method was needed to adjust dynamic load strain data for tire proximity. Burnham (2004) determined a number of correlation curves that could be used to adjust dynamic strain data for tire wander. The effect of slab temperature gradients on the correlation curves was also determined. Results from the study can be seen in Figure 9.

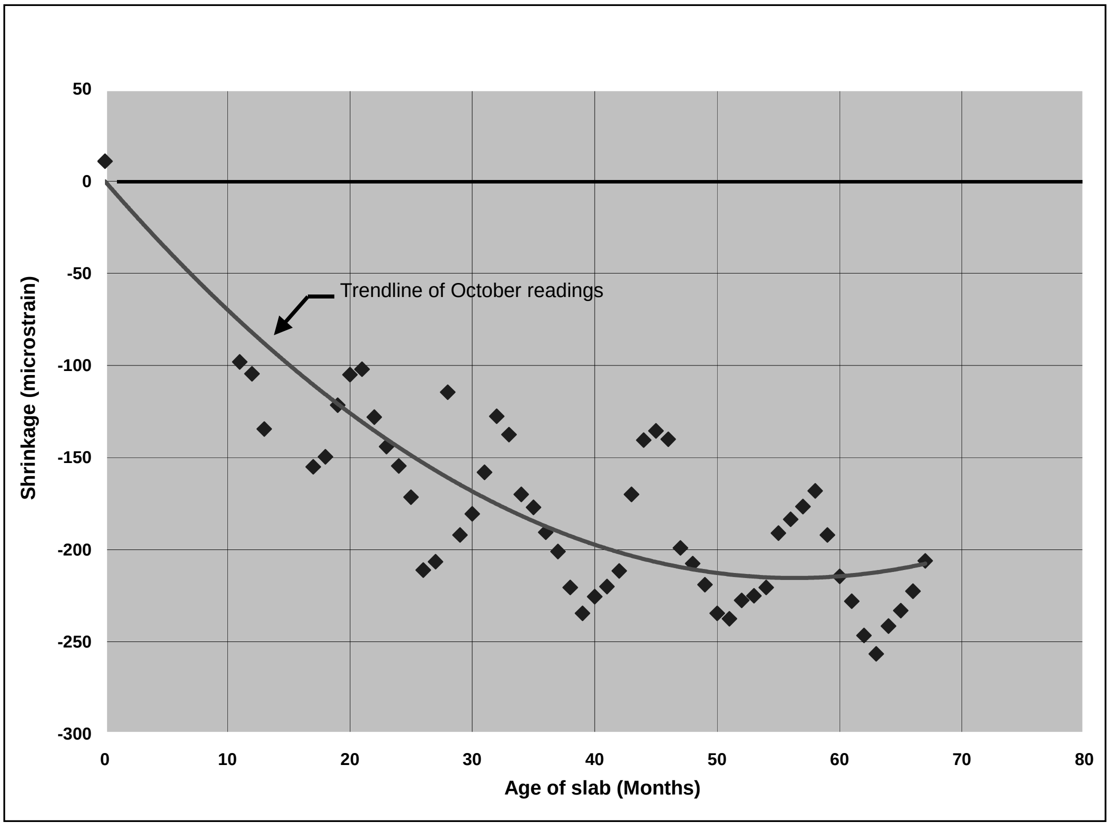

Figure 8. Measured long-term drying shrinkage of MnROAD test slabs (Burnham and Koubaa 2001).

Improved Concrete Pavement Instrumentation Techniques (Initial Objective: 12)

When MnROAD was constructed, it was the most heavily instrumented pavement test facility in the world. Time and harsh climatic conditions have taken its toll on the sensors, and after 10 years, only environmental instrumentation remains functioning. Most of the dynamic strain sensors lasted about 5 to 7 years.

As the dynamic strain sensors in the concrete test cells stopped functioning, select ones were removed through coring. A study by Burnham (1999) was undertaken to examine the as-built orientation of the sensors, and to determine if new dynamic strain sensors could be effectively retrofit into the test slabs. Observation of the cored out sensors revealed that rotational shifting and some limited breakage of the sensors had occurred during construction. Laboratory testing showed the small amount of rotational shifting of the sensors caused negligible differences in measured strain. Significant differences were found between the design and as-built depths of the sensors. Obtaining the as-built depth of the sensors allows researchers to more accurately analyze the measured strain data.

New dynamic strain sensors were retrofit into core holes (from the original sensors) using standard Mn/DOT concrete patch mix. The retrofit sensors provided measurements with similar strain magnitude and behavior as the original embedded sensors. Long term performance of retrofit sensors using this method is still under examination.

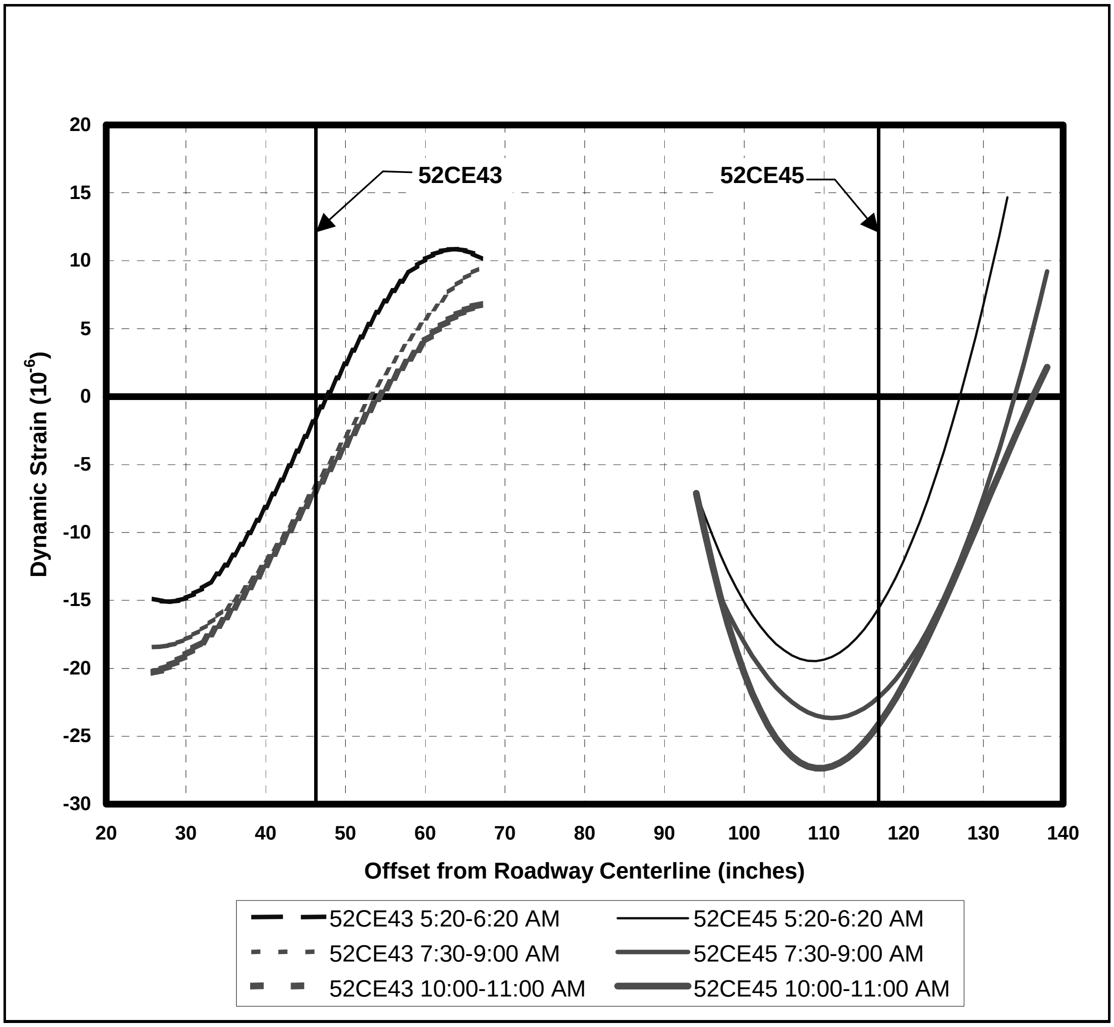

Figure 9. Sample of correlation curves developed for axle position versus dynamic strain (Burnham 2004). 1 inch = 2.54 cm.

Several new techniques in mounting embedded sensors into concrete pavement have evolved from experience with the MnROAD test cells. While the original sensors were mounted primarily on steel dowel baskets, sensors are now suspended on steel wire between wood dowels located approximately 1.5 inches (38 mm) from the sensor. See Photo 2. Using the new mounting technique, a sensor survival rate of over 90 percent has been achieved during slip-form paving. Mounding of concrete around the sensors and supports prior to the paver passing is the key to that high level of success.

Newer MnROAD Test Cells

Since 1994, several new concrete test cells have been constructed on the low-volume loop road at MnROAD. Test cells 32, 52 and 53 were constructed in 2000. Test cell 32 was designed to test the lower limit of thickness [127 mm (5 inches)] and construction cost for a concrete pavement subject to low volume traffic. As of fall 2004, this cell is performing well, although the joints are beginning to fault, since the

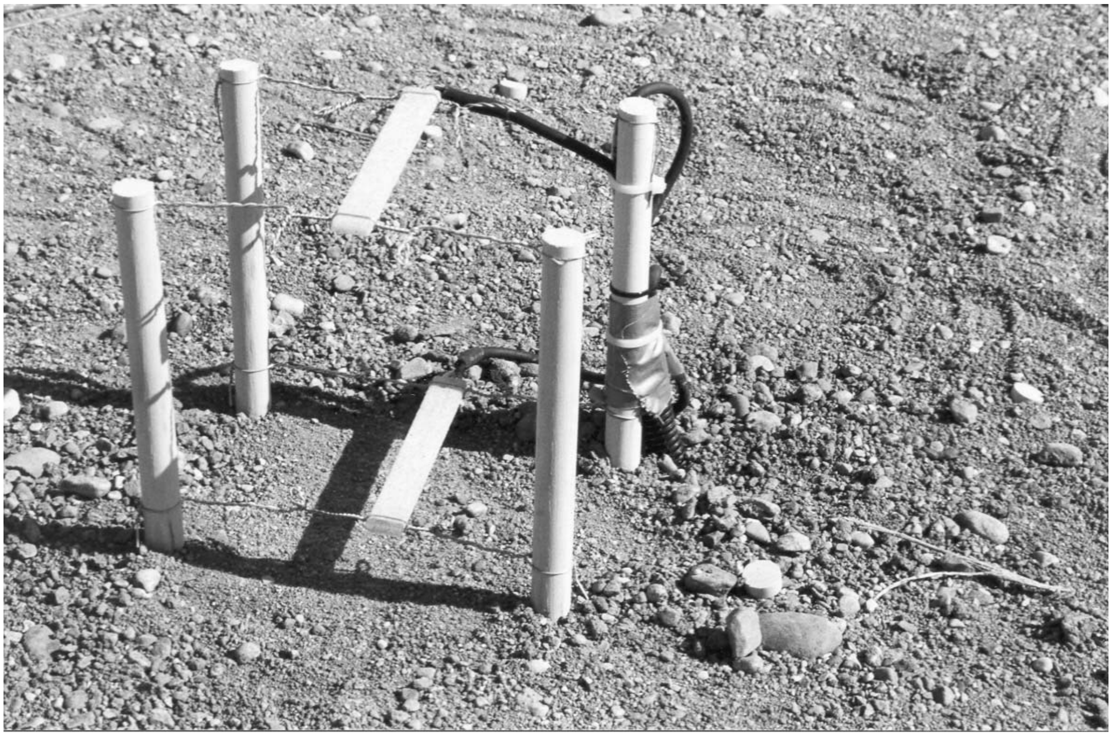

Photo 2. Current mounting technique for embedded strain sensors in concrete pavement at MnROAD.

pavement is undoweled. Test cells 52 and 53 [190 mm (7.5 inches)] were constructed to replicate test cell 6 on the mainline. Locating this test cell on the controlled access low volume road loop allows for more flexibility and availability to seasonal load testing. Another feature built into test cell 52 is different dowel bar sizes and types, including fiber reinforced polymer (FRP) dowels. Additional information on test cells 32, 52 and 53 can be found in the construction report for these cells (Burnham 2001).

Although not strictly concrete pavement test sections, several ultra-thin and thin whitetopping test cells were constructed on the MnROAD mainline road in 1997. These test cells have produced a significant amount of knowledge towards understanding the design and repair of this type of asphalt pavement rehabilitation.

Lessons Learned

The Minnesota Road Research Project or MnROAD, was constructed in the early 1990's to contribute towards the development of a mechanistic-empirical pavement design method for Minnesota. Looking back after 10 years of operation and research at the MnROAD, it is clear many lessons were learned.

The research studies listed above demonstrate that despite the good condition of the concrete test cells at MnROAD, a large amount of knowledge has been gained. Perhaps the most important lesson learned at MnROAD is that there is too many design variables incorporated into the test cells. One example is that the 5-year and 10-year design test cells have different lane widths. Also, there are only 3 cases where only 1 variable changed between test cells. So while a lot of variables are accounted for, side-by-side comparison is not practical. On the other hand, the similarity in the performance of the test cells also suggests some of those variables may not be as important as believed.

Another lesson was learned with regards to instrumentation of pavement test sections. Several MnROAD studies pointed out that sensor layouts need more repetition within a test cell. MnROAD has demonstrated that a small number of sensors will not survive the paving process, and eventually the sensors and wires will deteriorate with age and exposure to the environment. By designing repetition into the layout of the sensors, both the length of time measurements can be taken, and the ability to confirm measurements, will be increased.

Since MnROAD is a longer term testing facility, other interesting factors have come into play. For instance, the concrete pavement construction details specified by Mn/DOT have changed over time. Mn/DOT now specifies non-skewed transverse contraction joints. The fourteen original MnROAD concrete pavement test cells have skewed transverse joints. This will not significantly effect the strain measurements that have been taken over the years, but could reduce some of the benefit of the large amount of joint load transfer data that has been collected. The data will still be beneficial to the majority of the concrete pavements that Mn/DOT is responsible for, since calibration of new rehabilitation design methods is equally important to new construction design methods.

It is important to emphasize the unique operation of the MnROAD project. By allowing the test cells to be exposed to the natural weather conditions, they experience the daily and seasonal stresses from the slab warping and curling that takes place. Longer exposure to the environment also reveals any tendencies toward loss of support and pumping in a design. Also, MnROAD is trafficked by a wide variety of actual vehicles. The performance of the test cells, therefore truly represent the behavior of concrete pavements in Minnesota.

The performance of the MnROAD 5-year and 10-year design test cells demonstrates that Mn/DOT's current design methods need significant improvement. While a new mechanistic-empirical design has not been created specifically for Minnesota, the continuing archive of ride quality, distress, and load response data from the MnROAD project will be used to calibrate the new mechanistic-empirical design recently developed on a national level (NCHRP 1-37). The lessons learned from the operation of the MnROAD project can also be used to improve current and future concrete pavement test facilities.

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Disclaimer

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