MnROAD Low Volume Road Lessons Learned

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ABSTRACT
The Minnesota Department of Transportation (Mn/DOT) built the Minnesota Road Research Project MnROAD and its low volume road (LVR) between 1990-1993. The 2.5-mile LVR consists of a 2-lane roadway that originally contained gravel, hot mix asphalt, and concrete test sections designed for low volume road research. Each of these test sections are trafficked by a controlled 5-axle tractor-semi-trailer to simulate conditions of rural roads in two load configurations, resulting in the same equivalent axle loads (ESALs). Over the years a number of activities/studies have taken place using information from MnROAD’s LVR. This paper is broken into six areas including the facility, hot mix asphalt, Portland cement concrete, aggregate surfacing, seasonal load limits, and non-pavement related lessons learned. Each area will summarize the first 10 years of findings relating to the LVR and its impact on low volume roadways.

PROJECT DESCRIPTION
The Minnesota Department of Transportation (Mn/DOT) constructed the Minnesota Road Research Project (MnROAD) between 1990 and 1993. MnROAD is located along Interstate 94 forty miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments originally containing 40 test cells. Each MnROAD test cell is approximately 500 feet long. Subgrade, aggregate base, and surface materials as well as roadbed structure and drainage methods vary from cell to cell. All data presented herein, as well as historical sampling, testing, and construction information, can be found in the MnROAD database and in various publications. Additional information on MnROAD can also be found on at: http://mnroad.dot.state.mn.us/research/mnresearch.asp.

Objectives
Researchers have collected tremendous amounts of data over the past 12 years from MnROAD, and many worthwhile results have come out of various studies. The objective of this paper is to summarize several of the studies and the lessons that have been learned from them. While each summary is brief, numerous references are cited for more in-depth review.

Mainline
The mainline consists of a 3.5-mile 2-lane interstate roadway, and the test cells have both 5-year and 10-year pavement designs. Originally, a total of 23 cells were constructed consisting of 14 hot mix asphalt (HMA) cells and 9 Portland cement concrete (PCC) test cells. Traffic on the mainline comes from the traveling public on westbound I-94. Typically the mainline traffic is switched to the old I-94 westbound lanes once a month for three days to allow MnROAD researchers to safely collect data. Over time the mainline has received approximately 6 million flexible Equivalent Single Axle Loads (ESALs) and 10 million rigid ESALs as of December 2005.

Low Volume Road
Parallel and adjacent to the Mainline is the Low Volume Road (LVR). The LVR is a 2-lane, 2.5-mile closed loop that originally contained 20 test cells. Traffic on the LVR is restricted to a MnROAD operated vehicle, which is an 18-wheel, 5-axle, tractor/trailer with two different loading configurations. The "heavy" load configuration results in a gross vehicle weight of 102 kips (102K configuration). The “legal” load configuration has a gross vehicle weight of 80 kips (80K configuration). On Wednesdays, the truck operates in the 102K configuration and travels in the outside lane of the LVR loop. The truck travels on the inside lane of the LVR loop in the 80K configuration on all other weekdays. Figure 1 shows the layout and structural design for each cell on the Low Volume Road.
FACILITY LESSONS LEARNED

MnROAD is one of the world’s largest and most comprehensive outdoor laboratories. As such, a lot of effort goes into the daily upkeep and operation of the facility. The management of equipment, buildings, instrumentation, material storage and handling, and personnel has presented unique challenges over the years, and MnROAD has provided the opportunity to excel in these areas. Questions occasionally arise as to whether or not a 500-ft cell is representative of a larger pavement section and if researchers can learn anything in such a short distance. It has been our experience that significant differences in performance have been observed between cells, allowing researchers to draw valid conclusions.

MnROAD Operations

MnROAD has been able to maintain about 22.5 full-time equivalent staff devoted to MnROAD related activities. MnROAD is also supported part time by a database manager, programmer and web designer, and desktop support, along with Mn/DOT’s District-3 personnel who provide traffic switches for the mainline and help with routine maintenance (labor and equipment) when required. The MnROAD budget is about $950,000 per year. The costs include the labor (Road Research and support), site facilities, and instrumentation costs.

Minnesota government invested $25 million in the planning, design, and construction of MnROAD, and Mn/DOT has also supported the operations since then. Over the years researchers from around the nation and the world have utilized the MnROAD facilities and data. As we approach the reconstruction of many MnROAD test sections in 2007, Mn/DOT management has determined that phase-II of MnROAD would be accomplished through partnerships. To that end the Transportation Engineering and Road Research Alliance “TERRA” was formed to accomplish this goal through its current board members representing industry associations, universities, as well as local, state, national, and international transportation agencies. While the primary focus of TERRA will be to expand pavement related research opportunities, other compatible research will be pursued in order to diversify funding sources.

MnROAD Instrumentation

Data collection at MnROAD is accomplished with a variety of methods to help describe the pavement response to loads and the environment. Layer data is collected from a number of different types of sensors (initially numbering 4,572) located throughout the pavement surface and sub-layers. The sensors measure variables such as temperature, moisture, strain, deflection, frost depth, and a weigh in motion “WIM”. Data flows from these sensors to several roadside cabinets, which are connected by a fiber optic network that is fed into the MnROAD database for storage and analysis. This equipment and the knowledgeable staff have allowed MnROAD to collect research quality data and provide technical assistance to other researchers throughout the world.

Evaluation and Adoption of New Testing Technologies

Several new material testing technologies were evaluated at MnROAD and have since come into widespread use. The dynamic cone penetrometer (DCP) was first used at MnROAD in 1991, and the extensive validation work at MnROAD led to the application of the DCP in current Mn/DOT construction specifications (1). Several portable stiffness gages such as the PRIMA, Humboldt Geogauge, Loadman, and the Quasi-static Plate Load device have also been developed in part at MnROAD. The Automated Laser Profile System (ALPS) was developed at MnROAD to replace the six-foot straight edge rutting measurements on HMA pavements (2). Three types of laser or lightweight profilers have been developed in part at MnROAD, and they are being applied in current Mn/DOT ride specifications. Other examples of technologies evaluated at MnROAD for solving engineering problems include weigh-in-motion (WIM) systems (3), ground penetrating radar (GPR), falling weight deflectometer (FWD), rolling wheel deflectometer, and many others.
MnROAD Pavement Performance Data

MnROAD staff monitor pavement performance on a regular basis, and the data is input into the database. Monitoring data includes ride, distress, rutting, faulting, friction, FWD, forensic trenches, and laboratory material testing.

MnROAD Documentation

A number of research reports have been published and are contained on the MnROAD web page along with other library systems. MnROAD is also documented by its ORACLE database that contains both the instrumentation data and the pavement performance data. A detailed description of the MnROAD database is described in reference (4).

HOT MIX ASPHALT LESSONS LEARNED

MnROAD’s LVR has allowed researchers to collect detailed information to develop and calibrate new designs and try new techniques and materials that may not have been possible on a “typical” public roadway. Table 1 shows the test cells and each of their major failure mechanisms.

Minnesota’s Mechanistic Empirical Pavement Design “MnPAVE”

Researchers at Mn/DOT and the University of Minnesota investigated seasonal trends in the moduli of flexible pavements at MnROAD to calibrate a ME design procedure for Minnesota pavements to be called MnPAVE. To download or learn more about MnPAVE see reference (5) or the following web site: http://www.mrr.dot.state.mn.us/research/mnpave/mnpave.asp. More work is still needed in the area of design guide calibration. A simple comparison was performed to show the design life differences between MnPAVE and the R-Value design. Figure 2 shows that both design procedures differ significantly from the originally stated design life of approximately three years for all of the test sections. The observed field performance of each cell has also differed from the expected design life, with most cells remaining in good condition well past their intended designs.

Low Temperature Cracking

Oil Gravel Test Section Performance

Three oil gravel test sections (Cells 26-28) were built at MnROAD in 1999 and 2000. Oil gravel is a pavement technology imported from Scandinavia in the mid-1990s that consists of a soft asphalt emulsion surface (with technology similar to warm asphalt) over a strong, stable base.

Cell 26 started showing fatigue cracking and severe rutting almost immediately after construction. A forensic analysis determined that the reclaimed base (not the oil gravel surface) failed under traffic loading. Cells 27 and 28 still remain in service. Both sections are showing good performance, with the only distresses being fatigue cracking and cracking along the centerline and edge joints. Importantly, no thermal cracks have been detected in any of the three cells. It is hypothesized that the warm or cold mix technology used during construction significantly reduces the aging of the asphalt binder, allowing it to remain soft for a longer period of time (6).

Superpave Test Section Performance

Three Superpave test sections were constructed in 1999. These cells contained the same structural and mix designs except for the asphalt binder type, which differed at the low temperature performance grade. The performance grades for Cells 33, 34, and 35 were PG 58-28, 58-34, and 58-40 respectively. The PG 58-34 and PG 58-40 binder are polymer-modified binders using the Stylink process; the PG 58-28 is not modified.
Significant differences in material properties and pavement performance have been observed between the three cells. Cell 35 developed rutting more quickly than Cells 33 and 34. However, after six years the rutting levels are approximately equal between the three cells (see Figure 3). The real difference between the cells is seen in the cracking performance, as shown in Table 2. Cell 33 has a typical thermal cracking pattern of evenly spaced cracks that travel straight across the pavement. Cell 34 has only two small cracks in the entire 500-ft section. Cell 35 has a shattered appearance of numerous small cracks spaced close together. These cracks appear to be more fatigue in nature, as there are few if any cracks that go straight across the 12-ft pavement lane.

Several laboratory studies have measured the material properties of both the asphalt binders and mixtures used at MnROAD (7-11). A current pooled fund study, Investigation of Low Temperature Cracking in Asphalt Pavements – Phase I, is using field samples from MnROAD and other pavements to evaluate different laboratory procedures, material properties, and pavement features in order to develop an optimal system for selecting low temperature crack resistant materials based on fracture mechanics concepts. Mn/DOT has also proposed Phase II to this study, which will validate the laboratory test procedures, models, and pavement design procedures with test sections at MnROAD.

**Aggregate Base Effects on Thermal Cracking**

Figure 4 shows the progression of low temperature cracking over time in the 80K lane for the eight original LVR cells. The 102K lane shows similar results. Most of the pavements cracked during the cold snap in 1996 and remained relatively constant since then. Cells 24 and 25 are similar in that they were built over a sand subgrade. Cell 24 has a thinner HMA surface with a Class 6 base, while Cell 25 is a full depth pavement. Cell 24 has significantly more thermal cracking, which seems to indicate that the added friction between the asphalt layer and the Class 6 base led to an increase in low temperature cracking. Cell 26 did not experience any thermal cracking in the 80K lane, and the cracking in the 102K lane totaled only 40 ft. The softer and wetter clay subgrade allowed the pavement to slide without building up large tensile stresses, in comparison to Cell 25, which was a full depth pavement on sand. Cell 27 had the most low temperature cracking of any cell on the Low Volume Road, which again illustrates that the added friction from the Class 6 base leads to more thermal cracking. Cell 28 had less than half the amount of thermal cracking as on Cell 27. The Class 5 gravel base on Cell 28 induced less friction and therefore less cracking. Until recently Cell 29 (Class 4 base) has had less thermal cracking than Cell 30 (Class 3 base), and they have both shown less thermal cracking than Cells 27 and 28. Cell 31 has shown much less thermal cracking than Cells 28 and 30. Cell 31 has a thin HMA surface like Cell 28, but it includes a Class 5 base over a Class 3 subbase. The combination of different materials and thicknesses has lead to a reduction in thermal cracking (12). Detailed information on the MnROAD aggregate base properties can be found in reference (13).

**ESAL Damage Factors in Relation to HMA Pavement Performance**

The total number of ESALs applied over time to each lane of the MnROAD Low Volume Road has been equal, while the 80K lane received approximately four times the number of passes than the 102K lane. A comparison of the field performance of the different MnROAD test sections over time resulting from the different loading applications yields some interesting information. As expected, neither the thermal cracking performance nor ride quality of HMA was affected by the traffic loadings. However, rutting (see Figure 5) and fatigue cracking were more severe in the 80K lane than in the 102K lane. The higher number of repetitions at a lower load level in the 80K lane produced more distress than the lower number of repetitions at a higher load level in the 102K lane. This data implies that the concept of ESALs may be
flawed, and the consideration of load spectra (an option in recent mechanistic-empirical design procedures) may be more appropriate in terms of predicting pavement damage under traffic loadings (14).

**Mesabi Hard Rock Demonstration**

In a partnership formed with the Minnesota Department of Natural Resources (DNR), the Local Road Research Board (LRRB), the Minnesota Department of Transportation (Mn/DOT), and other partners, MnROAD test cell 31 was reconstructed in 2004 with a hot mix asphalt that contained 80% Mesabi Select Hard Rock aggregate (a waste rock from taconite mining in northern Minnesota). The purpose of this test cell is to demonstrate to the industry that Mesabi Select Hard Rock can be used to produce an asphalt mixture meeting Mn/DOT specifications. It also demonstrates that the mixture can be placed like other HMA mixtures, and through instrumentation installed at the MnROAD site, its performance can be documented and quantified. Mn/DOT will monitor the Mesabi Select Hard Rock test cell for performance and document its rutting, ride, strength, and crack formation (15). Cell 54 was also reconstructed at the same time using Mesabi Select Hard Rock aggregate to demonstrate similar performance measures in concrete pavements. After two years of service life, both pavements are performing as well as or better than other conventional pavements, and neither shows any distress.

**Maintenance Efforts for Rut Filling and Transverse Crack Repair**

Micro surfacing mixtures are made of high quality aggregate and asphalt emulsion components. An evaluation of the field performance of a “softer AC” (PG 48-34) micro surfacing mixture was performed on four cells on the Low Volume Road in 2005. The emulsion was used to produce micro surfacing scratch, rut-fill, and wear course mixtures.

Pre and post-construction evaluations of reflective cracking, rutting, and smoothness were performed. Early results from this research show the “soft-AC” micro surface design has a moderate effect in decreasing transverse reflected cracks and is effective in decreasing longitudinal reflective cracking and rutting. Researchers will continue to monitor reflective cracking and evaluate the effectiveness of micro surfacing over sealed cracks (16-17).

**CONCRETE LESSONS LEARNED**

There were five low-volume concrete pavement test cells built originally at MnROAD (cells 36-40). The differences in design were panel length (12’, 15’, 20’), joint type (doweled, undoweled), and subgrade type (silty clay, sand). In 2000, three more concrete pavement test cells were added to the low-volume test road (cells 32, 52, and 53). Cell 32 was constructed to be a low initial cost design, with a slab thickness of 5 inches and undoweled joints. Cells 52 and 53 were built to replicate one of the Mainline test cells (cell 6) for a curl-and-warp study.

**PCC Predicted Design Life and Performance Observations**

After 12 years of traffic and weather, the original five test cells are in very good condition. Figure 6 shows the ride quality history of the test cells in terms of IRI (International Roughness Index) for the 80K lane (18). The 102K lane shows similar trends.

Based on the trends shown in Figure 6, one can say all of test cells, except cell 40 in the 102k lane, have many more years of service before rehabilitation would be considered. A study by Burnham and Pirkl in 1997 (19) demonstrated that serviceability lives for these test cells ranged from 25 to 100 years (see Figure 7), depending on which design method was used, showing the inconsistencies in our current design methods and the need to continue detailed monitoring on test facilities like MnROAD. The results clearly justify the need for a more rational design method, taking into account modern day traffic loads, materials, and construction practices.
While the original low-volume concrete test cells have gone nearly 12 years without panel cracking, the newer 5 inch thick test cell 32 has several cracks after only 5 years of traffic. There are several corner-cracked panels in the 80K lane, and three longitudinally cracked panels in the 102K lane.

**PCC Embedded Sensor Findings**

While the LVR test cells have not experienced advanced signs of distress after 12 years, important research findings have been accomplished utilizing the data from their embedded sensors. One study (20) utilized vibrating wire sensor data from MnROAD to estimate the rate of thermal expansion of concrete pavement test slabs in the field. This study demonstrated that different parts of the slab experience different rates of thermal expansion throughout each day. This study also showed that joint closures due to temperature and moisture could be measured, and that the closure conditions were seasonally variable. Finally, the measured shrinkage (predominantly drying shrinkage) of test slabs in the field took over four years to level off.

While originally designed to replicate one of the thinner interstate highway designs at MnROAD, cell 52 was recently used to develop load proximity curves for analyzing load response data (21). These curves allow data from tire loadings not directly over the sensors to be translated and used in stress analyses. The curves also show how the loads are distributed at different points within a panel.

A study by Burnham in 2003 (22) used strain data from test cell 32 to study the load response of thin PCC pavements. This study not only characterized the seasonal and daily changes of measured dynamic strain within a thin slab, but also demonstrated the effects of load magnitude and position.

**ESAL Damage Factors in Relation to PCC Pavement Performance**

Beside data from sensors, useful empirical observations have been made using the MnROAD low-volume test cells. Pumping of subsurface material up through the lane-shoulder joint was noticed early in the life of the test cells over the silty-clay subgrade (cells 38-40). A forensic investigation revealed that the material was predominantly being pumped from underneath the shoulder, rather than under the corners or mid-panel edge of the concrete slabs. This explained the reason for settlement of the asphalt shoulder near the edge of the concrete pavement.

While cell 40 has a thickened edge design (7-5.5-7 inch), its performance does not exceed the uniform 6 inch thick designs used for the other original concrete pavement cells. The use of doweled transverse joints, for sections over a silty-clay subgrade in particular, has proven to be a much more important factor in increasing the performance of low-volume concrete pavement designs.

The PCC pavements at MnROAD have shown similar results to the HMA sections in terms of damage associated with traffic loadings. The ride quality of PCC pavements was not noticeably different between the 80K and 102K lanes. However, faulting of PCC pavements was more severe in the 80K lane than in the 102K lane. Again this data implies that the concept of ESALs may not be appropriate for mechanistic-empirical design procedures for concrete pavements (14).

**Whitetopping Performance**

In 1997 three ultrathin whitetopping (UTW) and three thin whitetopping (TWT) pavement test sections were constructed on the MnROAD Mainline. These test sections were placed to measure the performance of low-volume type designs under accelerated traffic loading conditions. Ultimately, the goal of the test sections was to provide comprehensive field performance data that, in the future, might be used in the development of a rational design procedure for whitetopping. The cells varied in overlay thickness and joint spacing. Over 3.5 years of existence and 4.7 million ESALS, both temperature- and load-related distresses were observed on the UTW sections. Typical distresses included corner breaks, transverse cracks, and reflective cracks. There were no noticeable distresses in the TWT sections. The thin and ultra-thin whitetopping test sections at Mn/ROAD have shown that whitetopping is a viable rehabilitation alternative for asphalt pavements. The importance of choosing an optimum panel size was exhibited (23-}
24). In 2004 the three UTW cells were replaced with four whitetopping cells to further study this pavement technology.

**UNSURFACED ROAD LESSONS LEARNED**

The initial phase of the study was to build four test sections to identify or develop evaluation procedures for use on aggregate and chip seal roads. These procedures would then be used to evaluate the performance of the sections at MnROAD. A second phase was begun in September of 1996 to compare the performance of common surfacing aggregates. Part of the evaluation was to evaluate two aggregate tests (adsorption and surface dielectric) that were developed by the Finnish Road Administration to predict performance. The aggregate sections were removed from service in August of 1999.

**Performance of MnROAD Aggregate Sections**

The performance of the sections was monitored closely during this study. The most relevant performance indicators applied to this project included rutting, corrugation (washboarding), ride, and blading requirements. Truck passes were counted to measure the traffic applied in each lane. Structural data including deflection tests, dynamic cone penetrometer tests, and laboratory strength tests were collected. The results of the project indicate that the surface dielectric test was more useful than the adsorption test in predicting the moisture and frost performance of aggregates in this experiment. Other conclusions drawn from the aggregate road research include:

- Aggregate gradations alone are not reliable predictors of performance.
- On the basis of rutting, the equivalent truck loadings were approximately equal, indicating that the ratio of the truck factors as calculated by AASHTO method holds and that the accumulation of ESALs on the legal and overloaded lanes were similar.
- The most dominant deterioration modes for the sections were rutting or washboarding. Washboarding was much more dependent on the number of truck passes than the truck loadings.
- Forensic studies showed that most of the rutting occurred in the aggregate, not in the subgrade.
- Dynamic Cone Penetrometer, resilient modulus, and shear tests conducted in the laboratory predicted the coarse graded aggregate (Class IC) would not perform as well as the fine graded aggregate (Class IF). This was confirmed by the field performance.

**Limitations of MnROAD Facility for Studying Aggregate Roads**

After five years of service, sufficient data was collected on the aggregate roads at MnROAD, and researchers decided it was best to conduct its research efforts away from MnROAD and on actual aggregate roads throughout the state. The MnROAD Aggregate Committee cited these reasons for abandoning the cells:

- Aggregate materials needed to be evaluated under the varied traffic of a typical low-volume road.
- Test sections needed a variety of materials, subgrade types, and environments found in Minnesota.
- The transitions from paved to aggregate surface caused distresses not related to the actual aggregate structural design at MnROAD.
- Longer test sections are needed to develop adequate evaluation.
- High maintenance of test cells, especially in the transition zones between cells.
- Damage to test equipment and the semi-truck caused by driving on the aggregate test cells.

**SEASONAL LOAD LIMITS**

Investigation into seasonal trends led to significant revision in Minnesota policy concerning spring load restrictions and winter load limits. By adjusting the reference temperature on which certain thawing index equations were based, researchers using MnROAD data found that spring-thaw predictions
could be significantly improved. The effect of these improvements were felt throughout the state of Minnesota upon adoption of the new spring load recommendations into policy: Mn/DOT estimated in 1999 that the improved timing of the restrictions would potentially increase a low volume road’s service life by 10% and save the state of Minnesota $10 million annually, a number which has (along with winter load increases) risen to over $21 million annually since that time.

**NON-PAVEMENT LESSONS LEARNED**

Several non-pavement related research activities have occurred at the MnROAD research facility. Many of the projects provided financial returns to MnROAD through the establishment of Mn/DOT-Vendor partnerships. Whether or not MnROAD received compensation from these partnerships, the ability to conduct numerous activities outside of pavement research proves the importance and worth of the MnROAD facility for researchers in many industries around the world. A small sampling of non-pavement research activities includes:

- **SafeTruck Development** – University of Minnesota used the LVR to examine emerging sensing and control technologies that enhance vehicle safety (29).
- **Culvert Design** – Large 60 inch corrugated polyethylene pipes were instrumented to understand the behavior of thermoplastic culverts under low fill heights (30).
- **Solar Walk** – An area middle school uses the LVR to teach a lesson about the Solar System.
- **Schwing America** – Used the LVR to test a new brake design on their concrete mixer trucks.
- **Michelin & Toyo Tires** – Used the LVR to test new tire designs.
- **FWD Calibration Center** – MnROAD will become an LTPP-sponsored FWD calibration center for the North Central Region.
- **AURORA-NCHRP Study** – Compare field performance of RWIS sensors to performance under controlled laboratory conditions.
- **SRF Consulting** – Field-testing and evaluation of prototype diode-lighted raised pavement markers to determine their ability to enhance centerline and fog line visibility.
- **Solar Vehicle Study** – University of Minnesota used the LVR for field-testing their solar vehicle.
- **Nissan Vehicle Sensor Study** – Used LVR to calibrate and validate in-vehicle guidance and human-factors related sensor performance at various vehicle speeds.
- **Federal Radiological Monitoring and Assessment Center** – MnROAD was used for an exercise to meet federal and state requirements for emergency preparedness for the Monticello Nuclear Power Plant if an accident ever occurred.
- **Intersection Decision Support System** – Developed strategies to reduce rural intersection crashes.

**CONCLUSIONS**

Since its inception, MnROAD has provided a variety of important benefits to transportation agencies, the pavement industry, and the general public. Since gathering its first data more than a decade ago, MnROAD has achieved a solid return on investment, with estimated savings on materials and maintenance costs statewide easily outweighing the cost of constructing and operating the facility. Future research at MnROAD has both national and regional interests and will define the 2007-2008 reconstruction, which is expected to cost $5.0 million and include both new construction and rehabilitation. Several high priority proposals have been posted for pooled fund studies and are being funded by other agencies and groups. MnROAD will continue to develop, sustain, and communicate a comprehensive program of research on pavement, materials, and related transportation engineering challenges, including issues related to cold climates.
REFERENCES


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**FIGURE 2** Expected Design Life of Low Volume Road HMA Cells.

**FIGURE 3** Rutting Accumulation on MnROAD Cells 33-35.

**FIGURE 4** Thermal Cracking Progression Over Time on Original LVR Cells.

**FIGURE 5** HMA Rutting vs. Total ESALs.

**FIGURE 6** Ride Quality History of MnROAD LVR PCC Test Cells for 80K Lane (16).

**FIGURE 7** Expected Design Life of Low Volume Road PCC Cells (17).
<table>
<thead>
<tr>
<th>Test Cell (Construction #)</th>
<th>Description of Cells</th>
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<tr>
<td>24, 25</td>
<td>HMA on sand subgrade</td>
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<td>26(1), 26(2)</td>
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<td>27, 27(2), 28</td>
<td>3 inch HMA over granular base</td>
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<td>27(3), 28(2)</td>
<td>Oil Gravel over large stone base</td>
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<tr>
<td>29, 30, 31</td>
<td>HMA over granular base</td>
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<tr>
<td>31(2)</td>
<td>Mesabi HMA over granular base (new)</td>
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<td>33(2)</td>
<td>Superpave HMA over granular base</td>
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</tr>
<tr>
<td>34(2)</td>
<td>Superpave HMA over granular base</td>
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</tr>
<tr>
<td>35(2)</td>
<td>Superpave HMA over granular base</td>
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LTC – Low Temperature Cracking
Construction # - Construction Number – Blank is original 1994 test cell – See cell map in Figure 1.
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<td>Class-1c</td>
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### FIGURE 1  MnROAD Low Volume Road Layout.
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FIGURE 3 Rutting Accumulation on MnROAD Cells 33-35.
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