MnROAD Low Volume Road Performance Related to Traffic Loadings

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ABSTRACT
The Minnesota Department of Transportation built the Minnesota Road Research Project (MnROAD) between 1990-1993. The Low Volume Road consists of a 2-lane roadway that originally contained hot mix asphalt (HMA) and Portland cement concrete (PCC) test sections. Each of these test sections is trafficked by a controlled 5-axle tractor-semi-trailer. The trucks have two different load configurations, resulting in the same Equivalent Single Axle Loads (ESALs) over time. The first configuration consists of a legally-loaded 80,000 lb truck that runs on the inside lane four days per week, and the second configuration consists of an overloaded 102,000 lbs truck that runs on the outside lane one day per week. This paper compares the field performance of the different MnROAD test sections over time resulting from the different loading applications. As expected, the thermal cracking performance of HMA was not affected by the traffic loadings, as it is a distress caused by the environment. Similarly, the ride quality of both HMA and PCC pavements was not noticeably different between the two lanes. However, rutting and fatigue cracking of asphalt pavements and faulting of PCC pavements 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. The data presented in this paper shows that the concept of ESALs may not be appropriate for mechanistic-empirical design procedures.

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 distinct 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. In general terms the original flexible pavement cells at MnROAD were designed as a structural experiment (layer thickness), and the rigid pavement cells were more concerned with design features (i.e., joint spacing, dowel bar diameter). Therefore, many of the flexible pavements have failed as intended while the rigid pavements are still showing good performance.

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 its web site at: http://mnroad.dot.state.mn.us/research/mnresearch.asp.

Objectives
One of the original MnROAD objectives was to evaluate the damage caused to flexible and rigid pavements under different loading configurations. The “Low Volume Road” section below describes the two different truck loadings that have been applied to the inside and outside lanes on the Low Volume Road. The system has worked out to provide the same number of Equivalent Single Axle Loads (ESALs) to the two lanes, while the load spectra differs considerably. The objective of this paper is to evaluate the effects of traffic loadings on pavement performance at MnROAD by quantifying the differences between the two lanes on the Low Volume Road.

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. Mainline test cells will not be considered in this paper.

Low Volume Road

Parallel and adjacent to Interstate 94 and the Mainline is the Low Volume Road (LVR). The LVR is a 2-lane, 2.5-mile closed loop that contains 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 tractor/trailer operates in the 102K configuration and travels in the outside lane of the LVR loop. The tractor/trailer 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.

Several pavement sections on the Low Volume Road have been reconstructed since 1993. To keep the scope of this paper sufficiently narrow, only the original test cells will be analyzed.

- The original hot mix asphalt (HMA) test sections (Cells 24-31) were built in 1993. All contained PG 58-28 asphalt binder, but they were constructed at different thicknesses and over different base and subgrade types. These sections contained different asphalt contents based on different mix designs, which is an added variable in the experiment. Four of the original eight cells are still in service.
- The original five Portland cement concrete (PCC) test sections (Cells 36-40) were constructed in 1993. All sections used the same PCC mix design, but construction variables include pavement and base thickness, subgrade type, panel length, and inclusion of dowel bars. All five original PCC cells are still in service.

MnROAD Instrumentation and Performance Database

Data collection at MnROAD is accomplished with a variety of methods to help describe the pavement response to loads and the environment and the actual pavement performance. 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, and frost depth. 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. MnROAD staff also 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 material laboratory testing. Data from the sensors or monitoring activities can be requested from the MnROAD database by contacting Mn/DOT researchers.

LOW VOLUME ROAD ESAL APPLICATIONS

The 80K and 102K lanes have received approximately the same number of ESALs over time, even though the 80K lane receives four times the number of passes. The ESAL applications of each truck are calculated according to the procedure set forth in the 1993 AASHTO Design Guide (J). This is based on the measured axle weights, assumed terminal serviceability values, and structural number (HMA) or slab thickness (PCC). While each cell at MnROAD receives a slightly different ESAL with each truck application, for all practical purposes the numbers are the same. ESALs on the LVR are determined by the number of laps (80 per day on average) for each day and are entered into the MnROAD database. Table 1 presents the yearly ESALs applied to the Low Volume Road.

LOW VOLUME ROAD CRACKING PERFORMANCE

The concrete cells on the low volume road have very few cracks, and there is no discernable difference between the lanes. All of the HMA test cells at MnROAD have experienced some degree of thermal
cracking. Figure 2 shows a snapshot of the total length of transverse cracking in 1999, the last year when every cell was still in service. After the cracks appeared initially in 1996, they have changed very little in length over time. The graph shows no distinction between the 80K and 102K lanes in terms of thermal cracking performance. This result is as expected, since thermal cracks are initiated by environmental conditions and not by traffic loadings. Even after the cracks appeared, they did not noticeably tend to change severity under the different traffic loadings.

RIDE QUALITY

Ride is defined as a measure of the ride quality of a pavement as perceived by its users or roughness measuring equipment. It is generally measured in terms of International Roughness Index (IRI), which is a measure of a pavement’s longitudinal surface profile as measured in the wheelpath by a vehicle traveling at typical operating speeds. It is calculated as the ratio of the accumulated suspension motion to the distance traveled obtained from a mathematical model of a standard quarter car traversing a measured profile at a speed of 80 km/h (50 mph). The IRI is expressed in units of meters per kilometer (inches per mile) and is a representation of pavement roughness. The ride quality of each MnROAD test section was measured over time with the Pathways van.

Figure 3 shows the IRI of each test cell in 1999, the last year before some cells were reconstructed. Both HMA and PCC sections are shown on the graph. There is no discernable difference between the 80K and 102K lanes. The figure shows that the ride quality of each test section is not affected by the different traffic loadings. This is also as expected, since the ride quality of asphalt pavements depends heavily on transverse cracking patterns. Since the thermal cracking showed little difference between the two lanes, the IRI values would not be expected to show any differences either.

CONCRETE FAULTING PERFORMANCE

The average faulting measurements for four out of the five PCC sections are under 1 mm. At that level, the measurement is likely due to changes in surface texture rather than faulting across the joints. However, Cell 40 shows enough faulting to make an accurate measurement. Even in this case, the average fault depth is about 2.5 mm (0.1 inch) in the 80K lane, while the average fault depth is about 1.5 mm (0.06 inch) in the 102K lane. Both lanes have received about 300,000 ESALs to date, so theoretically the faulting should be the same. Note that Cells 36, 38, and 39 contain dowels and that Cell 37 is built over thick, strong support (12 inch gravel base over a sand subgrade); none of these cells contained noticeable faulting. The combination of no dowels, thin base, and clay subgrade led to the larger (although still quite small) faulting measurements on Cell 40. This data indicates that more repetitions at a lower load produced more faulting than fewer repetitions at a higher load.

ASPHALT RUTTING PERFORMANCE

All of the original HMA test cells have experienced similar rutting behavior over time. Using data from Cell 31 as an example, Figure 4 shows the increase in rutting related to the number of passes, and Figure 5 shows the rutting performance in terms of ESAL applications. These plots tell a very interesting story. Up to about 15,000 load repetitions the rutting values are the same for each lane. Even though the loads were different between the lanes, the heavier (102K) truck did not produce more rutting than the lighter (80K) truck at the same number of repetitions. Figure 5 shows that even though each lane received about 160,000 ESALs the rutting performance is significantly different. The 80K lane rutted more than the 102K lane, which shows that the accumulation of ESALs in mechanistic-empirical design procedures and the associated damage caused by each ESAL may be flawed.

ASPHALT FATIGUE CRACKING PERFORMANCE

The fatigue cracking performance of the HMA test cells also shows marked differences between the 80K and 102K lanes. Table 2 shows the total area of fatigue cracking for each cell at the year at which fatigue
cracking was most evident. Cell 29 should be reviewed with caution, as there appeared to be mixture problems in the first 100 feet of the 102K lane. Every other section showed significantly more fatigue cracking (at least 50%) in the 80K lane than in the 102K lane. This again shows the deficiencies of using ESALs to predict pavement damage or distress. Each lane received the same number of ESALs, but the higher number of load repetitions in the 80K lane led to more fatigue cracking.

CONCLUSIONS

The MnROAD Low Volume Road test sections were affected by different deterioration modes. Low temperature cracking of asphalt pavements and ride quality of both asphalt and concrete pavements is more affected by the environment than by traffic loadings, so there was little difference in behavior between the two lanes. However faulting of concrete pavements and rutting and fatigue cracking of asphalt pavements was more severe in the 80K lane than in the 102K lane. For these distress types even though the number of ESALs was the same between the two lanes, the higher number of load repetitions caused more damage in the pavement.

The total number of ESALs applied to each lane of the MnROAD Low Volume Road was the same, while the 80K lane received approximately four times the number of passes than the 102K lane. The data presented in this paper shows that the concept of ESALs may not be appropriate for mechanistic-empirical design procedures. The distress types evident at MnROAD that are caused by traffic loadings were more affected by the number of load repetitions than the number of ESALs applied. 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. At this difference in load (22,000 lbs) the pavement performance was more affected by the number of passes than the total ESALs. 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. Future research should evaluate the differences between ESALs and load spectra in order to expose flaws in the current ESAL calculations and to determine the inherent reasons for these flaws.

REFERENCES


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FIGURE 5 HMA Rutting vs. Total ESALs.
<table>
<thead>
<tr>
<th>Year</th>
<th>80K Lane Total Laps</th>
<th>80K Lane Total ESALs</th>
<th>102K Lane Total Laps</th>
<th>102K Lane Total ESALs</th>
<th>80K Lane Total Laps</th>
<th>80K Lane Total ESALs</th>
<th>102K Lane Total Laps</th>
<th>102K Lane Total ESALs</th>
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<td>7,412</td>
<td>889</td>
<td>6,760</td>
<td>3,245</td>
<td>12,122</td>
<td>889</td>
<td>10,334</td>
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<td>1995</td>
<td>10,979</td>
<td>25,059</td>
<td>3,830</td>
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<td>10,979</td>
<td>40,999</td>
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<td>1996</td>
<td>19,577</td>
<td>44,680</td>
<td>6,406</td>
<td>48,496</td>
<td>19,577</td>
<td>73,123</td>
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<td>74,412</td>
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<td>1997</td>
<td>26,451</td>
<td>60,379</td>
<td>8,578</td>
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<td>98,808</td>
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<td>1998</td>
<td>36,384</td>
<td>83,074</td>
<td>11,046</td>
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<td>135,930</td>
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<td>12,861</td>
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<td>15,326</td>
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<td>186,832</td>
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<td>2001</td>
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<td>17,416</td>
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<td>57,653</td>
<td>215,324</td>
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<td>2002</td>
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<td>19,147</td>
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<td>67,423</td>
<td>251,723</td>
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<td>2003</td>
<td>73,023</td>
<td>166,482</td>
<td>21,034</td>
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<td>72,953</td>
<td>272,328</td>
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<td>2004</td>
<td>76,970</td>
<td>175,433</td>
<td>22,286</td>
<td>168,969</td>
<td>76,900</td>
<td>287,020</td>
<td>22,198</td>
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<td>2005</td>
<td>82,806</td>
<td>188,676</td>
<td>24,368</td>
<td>184,749</td>
<td>82,736</td>
<td>308,746</td>
<td>24,280</td>
<td>282,787</td>
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### TABLE 2  Total Area of Fatigue Cracking by Cell

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<thead>
<tr>
<th>Cell</th>
<th>Year</th>
<th>80K</th>
<th>102K</th>
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<td>24</td>
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<td>28</td>
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<td>371</td>
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<td>29</td>
<td>2004</td>
<td>133</td>
<td>337*</td>
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<tr>
<td>30</td>
<td>2004</td>
<td>47</td>
<td>24</td>
</tr>
<tr>
<td>31</td>
<td>2003</td>
<td>355</td>
<td>219</td>
</tr>
</tbody>
</table>

* Cell 29 had an inconsistent HMA mix on the west end.
FIGURE 1  MnROAD Low Volume Road Layout.
FIGURE 2 Hot Mix Asphalt Transverse Cracking Performance.
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