Effect of Concrete Pavement Surface Texture on Traffic Safety: Longitudinal or Transverse Tines?

Alex Drakopoulos  
Department of Civil and Environmental Engineering  
Marquette University  
P.O. Box 1881  
Milwaukee, WI 53201  
Alexander.Drakopoulos@Marquette.edu

M. Ertan Örnek  
SE Region Office, Wisconsin Department of Transportation  
Traffic Operations Lab, University of Wisconsin, Madison  
141 NW Barstow Street  
Waukesha, WI 53187  
Ertan.Ornek@dot.state.wi.us

ABSTRACT

Longitudinally tined (LT) concrete pavement surfaces were shown to produce less noise than transversely tined (TT) ones, making them more desirable where traffic noise may be an issue, if the two textures are shown to have equivalent safety performance.

The present effort focused on rural freeway crashes between 1991 and 1998. This guaranteed the presence of high speeds and absence of various factors unrelated to pavement texture that affect safety, such as traffic signals, cross-street traffic, etc.

The Wisconsin Department of Transportation uses TT portland cement concrete (PCC) surfaces. California provided the only substantial database for LT PCC. Climatic differences between Wisconsin and California were addressed by using hourly precipitation and travel data to calculate wet pavement crash rates for each of the two states.

No statistically significant difference in the risk for wet pavement accidents vs. dry pavement accidents was identified between the two pavement textures (2.25 times higher risk on wet pavements for TT vs. 2.39 times for LT pavements). The database comprised 72.6 hundred million vehicle miles of travel (HMVM) in Wisconsin and 510 HMVM in California.

Key words: concrete pavement—crash rate—pavement texture—traffic safety—wet pavement
PROBLEM STATEMENT

Longitudinally tined (LT) concrete pavement surfaces were shown to produce less traffic-induced noise than transversely tined (TT) ones, making them more desirable where traffic noise may be an issue. However, before LT surfaces can be recommended for statewide application, they should be shown to have equivalent or superior safety performance to their TT counterparts.

A Technical Working Group (TWG) representing state highway agencies, industry, academia, and the Federal Highway Administration (FHWA) that convened between 1993 and 1996 stated that the purpose of surface texture is to reduce the number and severity of wet weather accidents. The TWG recommended that pavement surface texture safety should be evaluated based on a consecutive three- to five-year period crash analysis.

The present effort was based on eight consecutive years of crash information (1991 to 1998) that was merged with vehicular travel and hourly precipitation information, in order to produce wet pavement crash rates for each of the two pavement surface textures. Wet pavement safety concerns are most prevalent where high operating speeds prevail. This led to a focus on rural freeways that typically operate under uncongested conditions and high operating speeds. The freeway environment guaranteed the absence of various factors unrelated to pavement texture that affect safety, such as traffic signals, cross-street traffic, curbside parking, unusual geometry, etc.

A major challenge for this Wisconsin Department of Transportation-originated study was that the only state that applied LT portland cement concrete (PCC) surface specifications statewide during the past three decades was California. The choice of rural freeways for the analysis provided a background of similar geometry; mountainous-terrain California freeways were excluded from consideration given the flat/rolling Wisconsin terrain. However, climatic differences between Wisconsin and California had to be addressed for a persuasive safety comparison.

RESEARCH OBJECTIVES

The present effort is a comparison of TT Wisconsin PCC pavements with LT PCC pavements. The focus of this comparison is differences in wet pavement crash risk on high-speed facilities. Motivation is provided by findings of lower highway noise levels generated by LT surfaces vis-à-vis concerns for the safety performance of these pavements when compared to the widely used TT surfaces. Departments of transportation would use a quieter pavement surface texture, especially in urban areas, if it is shown not to be detrimental to safety; inferior safety performance will immediately disqualify a surface texture from further consideration.

RESEARCH METHODOLOGY

If safety differences exist between LT and TT pavement surfaces, these differences are expected to be the greatest under wet conditions and especially where high operating speeds prevail. Rural freeways were chosen as the ideal facilities for the desired comparison for a number of reasons:

1. They are typically not congested, thus free-flow speeds are likely to prevail.
2. No intersections are present. Intersections introduce a large number of variables affecting safety performance (number of approach lanes, lane designation, traffic control parameters, cross-street volumes, etc.).
3. There is no friction with on-street parking, pedestrians, and bicyclists.
4. Good quality crash data and other highway information is available.
5. High geometric design standards eliminate to a large extent the influence of sharp horizontal and vertical curves on crashes.
6. Uniform geometric design standards eliminate the influence of differences in state-specific geometric design practices.
7. A large number of crashes are typically available for analysis.

Extensive data were available in California for LT pavement surfaces. Wisconsin provided information on TT pavement surfaces.

The following safety performance measures of effectiveness (MOE) were calculated for each year for each of the two states (definitions and interpretations of these MOE are presented in the following section):

- Crash rate
- Wet-to-dry ratio
- Liquid precipitation safety ratio (LSR)

**MOE Definitions and Interpretations**

This section presents the meaning and interpretation of statistics used in this paper. Multiple interpretations of the fundamental LSR statistics are provided for the benefit of the interested reader.

**Crash Rates**

Crash rates were calculated as total crashes per one hundred million vehicle miles of travel (HMVMT = 100 MVMT) and rounded to integer values. A higher crash rate indicates that a higher number of crashes occurred per vehicle-mile of travel and is an indication of poorer safety performance.

\[
\text{Crash Rate} = \frac{\text{Total crashes}}{100 \text{ MVMT}}
\]

(1)

**Wet-to-Dry Ratio**

The wet-to-dry ratio (wet-to-dry crashes) is the number of crashes that occurred on wet pavement, divided by the number of crashes that occurred on dry pavement.

\[
\text{Wet-to-Dry ratio} = \frac{\text{Tot}_\text{Wet}}{\text{Tot}_\text{Dry}}
\]

(2)

where

- Tot_Wet is the number of crashes on wet pavement
- Tot_Dry is the number of crashes on dry pavement
This ratio is affected by the amount of wet precipitation in a given area as discussed below. For example, a wet-to-dry ratio of 0.50 indicates that half as many crashes occurred on wet pavements as did on dry pavements.

Discussion

If the region where this ratio was observed had half as many rain days as it had dry days, then the risk of being involved in a crash on a wet pavement would be equal to the risk of being involved in a crash on a dry pavement. However, the same wet-to-dry ratio (0.50) would indicate that the risk of a wet pavement crash is twice as high as the risk of a crash on dry pavement, if pavements were wet only 25% of the time. Thus, the wet-to-dry ratio is mainly useful in comparisons between facilities that experience similar rainfall patterns. Under similar rainfall patterns, a high wet-to-dry ratio would indicate facilities that are more prone to wet pavement crashes.

Liquid Precipitation Safety Ratio

LSR was defined based on the following formula:

\[
LSR = \frac{\left( \frac{\text{Tot}_\text{Wet}}{\% \text{ time wet pavement}} \right)}{\left( \frac{\text{Tot}_\text{Dry}}{\% \text{ time dry pavement}} \right)}
\]

(3)

where

\text{Tot}_\text{Wet} \text{ is the number of crashes on wet pavement}

\text{Tot}_\text{Dry} \text{ is the number of crashes on dry pavement}

\% \text{ time wet pavement} \text{ is the percent of time a pavement is wet}

\% \text{ time dry pavement} \text{ is the percent of time a pavement is dry}

Discussion

The LSR can be thought of as the ratio of the wet pavement crash rate (number of crashes on wet pavement divided by 100 MVMT on wet pavement, see equation (1)) divided by the dry pavement crash rate (number of crashes on dry pavement divided by 100 MVMT on dry pavement).

\[
LSR = \frac{\left( \frac{\text{Tot}_\text{Wet}}{\text{travel on wet pavement}} \right)}{\left( \frac{\text{Tot}_\text{Dry}}{\text{travel on dry pavement}} \right)} = \frac{\left( \frac{\text{Tot}_\text{Wet}}{\text{total travel} \times \% \text{ time wet pavement}} \right)}{\left( \frac{\text{Tot}_\text{Dry}}{\text{total travel} \times \% \text{ time dry pavement}} \right)}
\]

(4)

Since travel on wet (dry) pavement is calculated by multiplying the total vehicular travel in a year by the percent time that a pavement is wet (dry), total travel is eliminated on the right-hand-side of equation (4), and the result is the right-hand-side of equation (3).
The LSR can also be expressed as follows:

\[
LSR = \frac{\left( \frac{\text{Tot}_{-}\text{Wet}}{\text{Tot}_{-}\text{Dry}}} \right)}{\left( \frac{\% \text{ time wet pavement}}{\% \text{ time dry pavement}} \right)} = \frac{\text{(wet-to-dry ratio)}}{\text{(denominator)}} \quad (5)
\]

Interpretation

That is, LSR is the wet-to-dry ratio divided by an adjustment factor that indicates how much more frequently pavements are wet than dry. If the wet-to-dry ratio is equal to the proportion of time pavements are wet to the time they are dry, then LSR = 1.00 and a motorist has an equal chance to be involved in a crash when a pavement is wet as when the pavement is dry. If the wet-to-dry ratio is greater than the denominator, then LSR > 1.00 and the chances of being involved in a crash are greater on wet pavements than dry pavements.

This way, LSR allows comparisons of wet pavement performance across areas with different rainfall patterns. In other words, it provides a measure of how many times more likely one is to be involved in a wet pavement crash, relative to being involved in a dry pavement crash if equal mileage is driven under each of these two pavement conditions. Calculation of LSR requires weather and precipitation information as well as information of how long pavements remain wet after precipitation accumulation on the pavement.

KEY FINDINGS

The focus of the present evaluation was a safety comparison of wet TT and LT high-speed pavements. Rural freeways were chosen as the ideal representatives of such pavements for reasons explained in the Problem Statement and Research Methodology parts of this paper. The majority of available mileage was on rural freeways with an average daily traffic (ADT) less than 60,000 vehicles per day (VPD).

Some urban California freeway statistics, of secondary importance to the present analysis (since lower speeds typically prevail on such pavements), are presented here since LT texture is desired in the urban environment because it generates a lower noise level. Very limited information was available for TT Wisconsin urban freeways and is not presented.

An extensive effort was dedicated to collect and analyze friction number (FN) information for relations to wet pavement crashes. Identified FN databases were not comprehensive enough to be representative of all analyzed freeway mileage; furthermore, FN data showed wild fluctuations from year to year and lane to lane, even for pavements with identical construction years and identical traffic volumes. Thus, no further effort was put into developing a relationship between FN and wet pavement crash rates.

Rural Freeways

Table 1 below presents statistics for TT Wisconsin and LT California rural freeway pavements with ADT less than 60,000 VPD. The two pavement surface types had identical crash rates when crashes over the entire 1991 to 1998 period were analyzed (42 crashes per hundred million vehicle miles of travel). During
these years, crash rates were in the 35 to 50 crashes/100 MVMT range for TT Wisconsin pavements; those for LT California pavements were in the 41 to 45 crashes/100 MVMT range.

The database included approximately 1,460 directional miles of California freeways (730 centerline miles) and 230 directional miles of Wisconsin freeways, a ratio of approximately 6:1. Approximately seven times as much travel occurred on the analyzed California freeways as did on the analyzed Wisconsin freeways over the eight study years (510 vs. 72.6 100 MVMT, respectively). The same ratio held in terms of total analyzed crashes in the two states (21,645 vs. 3,048 crashes, respectively).

When the percent time that pavements were wet in each state is taken into account, TT surfaces outperform LT surfaces since the average LSR value was lower for TT pavements at 2.25 vs. 2.39 for LT pavements. However, this difference was not significant at the 0.99 level of confidence.

Table 1. Wisconsin (Trans PCC) and California (Long PCC) rural freeway statistics 1991–1998 (less than 60,000 VPD)

<table>
<thead>
<tr>
<th>Year</th>
<th>Wear Surface</th>
<th>Crashes per 100 MVMT</th>
<th>Wet to dry crashes</th>
<th>Total crashes</th>
<th>Liquid safety ratio</th>
<th>Length miles</th>
<th>100 MVMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>Trans. PCC</td>
<td>47</td>
<td>.19</td>
<td>267</td>
<td>2.21</td>
<td>119.7</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Long. PCC</td>
<td>42</td>
<td>.08</td>
<td>2668</td>
<td>1.62</td>
<td>733.5</td>
<td>63.4</td>
</tr>
<tr>
<td>1992</td>
<td>Trans. PCC</td>
<td>40</td>
<td>.28</td>
<td>233</td>
<td>3.18</td>
<td>121.4</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>Long. PCC</td>
<td>41</td>
<td>.11</td>
<td>2608</td>
<td>2.42</td>
<td>733.5</td>
<td>63.4</td>
</tr>
<tr>
<td>1993</td>
<td>Trans. PCC</td>
<td>46</td>
<td>.20</td>
<td>391</td>
<td>2.16</td>
<td>166.8</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Long. PCC</td>
<td>42</td>
<td>.09</td>
<td>2663</td>
<td>1.71</td>
<td>733.5</td>
<td>63.4</td>
</tr>
<tr>
<td>1994</td>
<td>Trans. PCC</td>
<td>40</td>
<td>.08</td>
<td>345</td>
<td>1.21</td>
<td>166.8</td>
<td>8.6</td>
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<td></td>
<td>Long. PCC</td>
<td>42</td>
<td>.09</td>
<td>2646</td>
<td>2.60</td>
<td>731.6</td>
<td>63.6</td>
</tr>
<tr>
<td>1995</td>
<td>Trans. PCC</td>
<td>40</td>
<td>.12</td>
<td>382</td>
<td>1.51</td>
<td>185.6</td>
<td>9.6</td>
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<tr>
<td></td>
<td>Long. PCC</td>
<td>44</td>
<td>.14</td>
<td>2720</td>
<td>2.27</td>
<td>730.1</td>
<td>62.5</td>
</tr>
<tr>
<td>1996</td>
<td>Trans. PCC</td>
<td>50</td>
<td>.23</td>
<td>522</td>
<td>4.07</td>
<td>196.8</td>
<td>10.4</td>
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<tr>
<td></td>
<td>Long. PCC</td>
<td>45</td>
<td>.14</td>
<td>2922</td>
<td>2.93</td>
<td>730.8</td>
<td>64.5</td>
</tr>
<tr>
<td>1997</td>
<td>Trans. PCC</td>
<td>35</td>
<td>.13</td>
<td>411</td>
<td>2.39</td>
<td>219.7</td>
<td>11.6</td>
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<td></td>
<td>Long. PCC</td>
<td>42</td>
<td>.09</td>
<td>2726</td>
<td>2.66</td>
<td>719.8</td>
<td>64.6</td>
</tr>
<tr>
<td>1998</td>
<td>Trans. PCC</td>
<td>40</td>
<td>.14</td>
<td>497</td>
<td>2.16</td>
<td>233.7</td>
<td>12.5</td>
</tr>
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<td></td>
<td>Long. PCC</td>
<td>42</td>
<td>.19</td>
<td>2692</td>
<td>3.06</td>
<td>715.4</td>
<td>64.4</td>
</tr>
<tr>
<td>Overall</td>
<td>Trans. PCC</td>
<td>42</td>
<td>.16</td>
<td>3048</td>
<td>2.25</td>
<td>233.7</td>
<td>72.6</td>
</tr>
<tr>
<td></td>
<td>Long. PCC</td>
<td>42</td>
<td>.12</td>
<td>21645</td>
<td>2.39</td>
<td>728.5</td>
<td>509.7</td>
</tr>
</tbody>
</table>

California Urban Freeways

Aggregate eight year statistics for all California urban freeways with an ADT of less than 60,000 VPD are presented in Table 2 below.

Table 2. California urban freeway statistics 1991–1998 (less than 60,000 VPD)

<table>
<thead>
<tr>
<th>Wear Surface</th>
<th>Crashes per 100 MVMT</th>
<th>Wet to dry crashes</th>
<th>Total crashes</th>
<th>Liquid safety ratio</th>
<th>Length miles</th>
<th>100 MVMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long. PCC</td>
<td>76</td>
<td>.17</td>
<td>23132</td>
<td>3.45</td>
<td>278.4</td>
<td>304.2</td>
</tr>
</tbody>
</table>
Eight year statistics for urban freeways with an ADT of more than 60,000 VPD are presented in Table 3. A very substantial database supported these findings, with approximately 490,000 crashes. Crash rate statistics were exceptionally stable through the analyzed time period.

Table 3. California urban freeway statistics 1991–1998 (more than 60,000 VPD)

<table>
<thead>
<tr>
<th>Wear Surface</th>
<th>Crashes per 100 MVMT</th>
<th>Wet to dry crashes</th>
<th>Total crashes</th>
<th>Liquid safety ratio</th>
<th>Length miles</th>
<th>100 MVMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long. PCC</td>
<td>100</td>
<td>.16</td>
<td>486892</td>
<td>3.22</td>
<td>1114.6</td>
<td>4863.0</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Essential Background

A TWG representing state highway agencies, industry, academia and the FHWA convened in the early 1990s to address tire/pavement noise generated by TT pavements. The TWG published a comprehensive report that stated that “the purpose of surface texture is to reduce the number and severity of wet weather accidents.” Analyses over consecutive three- to five-year periods were recommended to determine the wet weather accident rates of different textures and pavement types and the change of accident rates over time for the different textures and pavement types. Reliance on FN as a traffic safety surrogate was discounted by the TWG which stated that “available information supports only a general correlation between friction numbers and wet weather crash rates.”

The focus of the present effort was a comparison between LT and Wisconsin TT PCC pavement surface textures. It was desired to compare wet pavement safety performance of these two pavement textures based on extensive crash data spanning multiple years as recommended in the TWG final report.

Since Wisconsin did not have LT pavements, this effort would necessarily have to rely on an inter-state data comparison. Data from neighboring states were desirable, but after an extensive search, the only identified state with adequate LT pavement mileage, crash, and vehicular travel information was California. This information came from the well-documented FHWA-supported HSIS database. Hourly precipitation information was used to calculate the number of hours Wisconsin and California pavements were wet and vehicular miles of travel during these hours. This information was used to provide a fair comparison of TT and LT wet pavement performance across the two states, despite their rainfall pattern differences.

Eight years of data were analyzed in accordance with TWG recommendations in order to provide stable statistics based on the largest available database. Reduced friction under wet pavement conditions was the major TWG safety concern. This concern was addressed by focusing the analysis on rural Wisconsin and California freeways with ADT lower than 60,000 vehicles per day. Lower congestion levels and higher operating speeds are typically present at such facilities, conditions that result in lower friction numbers for any given pavement. If TT and LT pavements differed in safety performance under wet pavement conditions, their differences would be most clearly demonstrated where higher speeds were present. In addition, the freeway environment eliminated the safety influences of intersecting facilities, parked vehicles, pedestrians, intersection right of way control devices, and severe geometry.
Conclusions

1. Use of FN as a freeway pavement safety performance surrogate was shown to be impractical due to wide FN seasonal and spatial variations for similar age pavements experiencing similar levels of traffic.
2. Among rural freeways, Wisconsin TT freeway pavements were found to have similar safety performance to California LT pavements when pavements were wet. This finding was supported by a very substantial database spanning eight years and took into account vehicle miles of travel on wet pavements in each analyzed state. The comparison between high-speed facilities of high design standards provided evidence that the two pavement textures provided similar safety performance under the most adverse conditions: the combination of high operating speeds and wet pavement.

California data on urban freeways were analyzed in order to provide baseline statistics for LT PCC pavement surface applications, should LT pavements be applied in Wisconsin in the future.

3. Among California LT PCC pavements, urban freeways with ADT less than 60,000 VPD had statistically significantly higher crash rates than rural freeways. This finding is consistent with findings across the United States for urban freeways, regardless of pavement texture.
4. Urban LT California freeways with ADT higher than 60,000 VPD had statistically significantly higher crash rates than similar freeways with lower ADT. Traffic volume should be taken into account when analyzing crash rates for a given pavement surface texture.
5. The risk of being involved in a crash on wet pavements based on the LSR was higher on urban LT freeways than rural LT freeways; however, urban freeways with lower ADT had the highest chances of wet pavement accident involvement. Traffic volume should be taken into account when analyzing the risk of being involved in a wet pavement crash on a given pavement surface texture.

Primary conclusion summary

1. LT PCC pavements are expected to display similar wet pavement safety performance to TT PCC pavements on high-speed, high-design standard facilities (rural freeways), with an ADT less than 60,000 VPD.
2. The chances of being involved in a crash on wet LT pavements is higher for urban than rural freeways, a result consistent with crash experience across the United States. The chances of being involved in a crash on wet urban LT freeways are higher when the ADT is lower than 60,000 VPD.

RECOMMENDATIONS

1. Based on the findings of no significant wet pavement safety performance differences between LT and TT pavement textures on rural freeways, it is recommended that the comparison between the two types of pavements is extended to include safety performance under winter pavement conditions (when snow or ice are present on the pavement). If no differences are found between the two pavement textures under winter weather conditions, the construction of LT pavements would be recommended for rural Wisconsin freeways, given the benefit of lower levels of traffic-generated noise.
2. LT texture is used extensively by the California Department of Transportation (Caltrans) District 3, which is in charge of an extensive network of snow routes. Contacts with the District 3 Office of Maintenance Equipment and Emergency Operations are recommended in order to address any
winter maintenance concerns related to LT surfaces. Such contacts will identify the types of winter maintenance equipment, materials and policies in force by Caltrans.

3. It was indicated in the literature search that initial attempts at constructing LT textures in California were abandoned due to concerns about the quality of ride for motorcycles and light vehicles. It is recommended that extensive communications are exchanged with departments of transportation that are currently constructing LT textures (especially Caltrans) in order to avoid similar pavement surface construction pitfalls when/if they are first introduced in Wisconsin.

4. The main motivation for the introduction of LT freeway pavements in Wisconsin is their applicability where noise concerns exist, for example in the urban environment. The safety performance of California LT pavements has been addressed herein. Safety performance should be the paramount criterion in choosing a pavement surface texture. Therefore, a comprehensive comparison with the safety performance of pavement textures currently in use in urban Wisconsin freeways is recommended. If one surface texture is shown to be clearly superior in terms of safety, that surface texture should be chosen for application in the urban environment. If LT pavement surfaces are on par with their counterparts, construction of urban freeway LT pavements may be recommended based on noise, durability, material availability, or other pertinent considerations.
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REFERENCES


