Crash Experience on Tined and Continuously Ground Portland Cement Concrete Pavements

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Crash rates were compared between 290 km of continuously ground and 115 km of transversely tined portland cement concrete pavements in Wisconsin. All 11,219 reported crashes at the study sites during the 6-year period 1988 through 1993 were analyzed. Continuously ground surfaces were found to have lower crash rates than tined surfaces under dry and wet conditions during daytime and nighttime as well as under all four combinations of pavement and light conditions. Ground pavements had 58 percent the crash rates of tined pavements under dry and wet conditions; the ratio was 84 percent when snow or ice was present on the pavement; however, relatively limited vehicular travel occurred under such conditions and these results are viewed as preliminary. Ground pavements had 57 percent the crash rates of tined pavements during daytime; the ratio was 73 percent at night. On the basis of the available data, a hypothesis of increasing crash rates with time (based on frictional property deterioration with pavement age, cumulative vehicle passes since construction, or both) could not be confirmed for either type of pavement texture.

Differences in crash experience between portland cement concrete (PCC) pavements that have been continuously ground during rehabilitation and standard PCC pavements with tined surfaces have not been well established. The current study identified the existence and quantified the extent of such differences between the two types of PCC pavement surface textures under a variety of environmental conditions; crash rate trends for the two surface textures over the 6-year period 1988 through 1993 were also examined.

BACKGROUND AND SIGNIFICANCE OF WORK

It is generally assumed that certain highway crashes (e.g., crashes on wet pavement) are due partially to poor pavement surface friction. A frequently measured index of pavement surface friction is the friction number (FN). It has been documented in the literature that FN decreases with pavement age and that concrete pavement surface texture treatment is directly related to friction properties.

Several studies have ascertained that certain pavement surface treatments (such as tining or grinding in the transverse or longitudinal direction) are associated with a higher FN and "gentler" speed gradients (i.e., a lower drop in FN with increasing speed) than untreated pavements (*1,2*), but no statistically sound studies have been found in the literature that quantify a relationship between FN and crash rates.

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DATABASE

A total of 51 Wisconsin sites were identified for analysis (30 with ground surfaces and 21 with tined surfaces), covering 405 km of concrete pavements. Test sites (ground surfaces) totaled 290 km and control sites (tined surfaces), 115 km. Figures 1 and 2 show samples from a study site with a ground surface and a typical Wisconsin tined site, respectively. The crash analysis was based on the 6-year period 1988 through 1993, during which 11,219 crashes were reported at all study sites. Data on geometrics, traffic volume, truck presence, and percent of traffic during nighttime were available for each study site. Crash, geometric, and volume information was merged to produce one record for each crash. These records were aggregated to produce crash statistics for ground and tined sites.

STUDY OBJECTIVE

The study objective was to compare characteristics of crashes occurring on concrete pavements with continuous longitudinal grinding (test sites) with crashes on transversely tined concrete pavements (control sites). Because crash experience is influenced by roadway, vehicular, and environmental factors, an effort was made to match ground and tined site characteristics to ensure that all factors except surface texture were identical between the two site categories. In the absence of detailed weather information, and in order to account for weather differences among different parts of the state, it was attempted to maintain a balance in the lengths and functional classifications of ground and tined sites selected from each Wisconsin Department of Transportation (DOT) geographical district. It was assumed that driving population characteristics would be identical between tined and ground sites.

ANALYSIS

Given the efforts just described to control for vehicular, environmental, and roadway factors, it was assumed that any crash experience differences between ground and tined sites would be due to differences between the two pavement textures. The focus of the investigation was on factors that affect skid resistance (identified in a literature search), for example, pavement condition (dry, wet, snow or ice). The analysis proceeded from an overall comparison between the two site categories to more in-depth analyses of particular factors. The relation of each analyzed variable to skid resistance

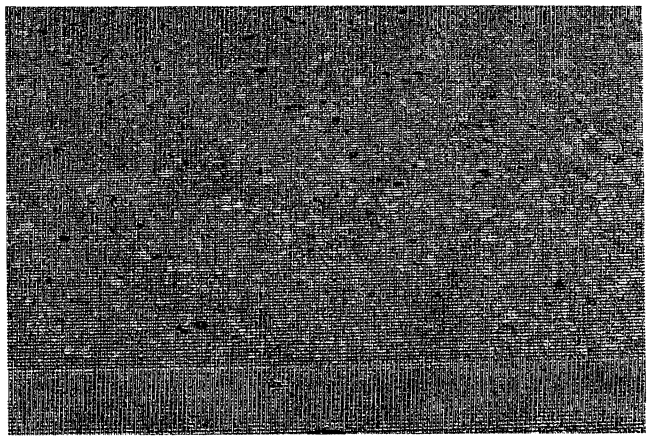

FIGURE 1 Sample from continuously ground pavement site.

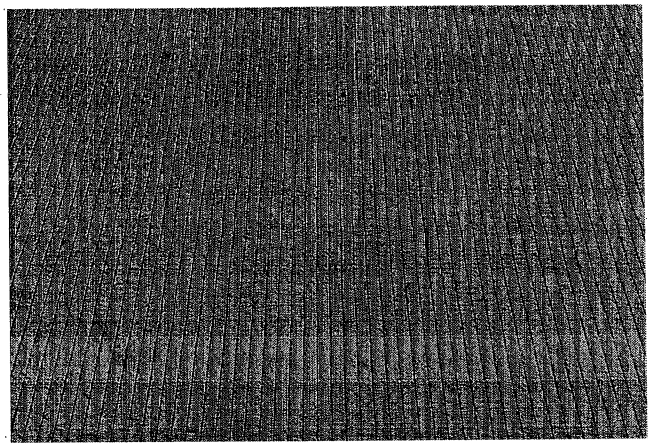

FIGURE 2 Sample from typical Wisconsin tined pavement site.

and possible implications for crash experience are briefly introduced under each subheading, followed by a presentation of findings.

Overall Comparisons

The first question the study attempted to answer was whether overall crash experience differed between tined and ground sites. A comparison of crash rates (crashes per 100 million vehicle-km traveled) between ground and tined sites during the study period indicated that the crash rate for ground sites was lower than that for tined sites (86 and 135 crashes per 100 million vehicle-km traveled, respectively). Table 1 provides relevant information. Total vehicle kilometers traveled and total crashes were higher for ground sites. Ground site crash rates were 60 percent those of tined sites overall.

Pavement Conditions

The coefficient of friction is lower on wet than on dry pavements. It is therefore reasonable to expect a higher crash rate under wet pavement conditions. Although frictional properties of the ground and tined sites were not expected to differ significantly on dry pavements, it is under wet conditions that any crash experience differences between the two textures were expected to emerge, since it is possible that tined and ground site textures may differ in their ability to maintain good friction properties when wet or when snow or ice is present on the pavement.

Areas in which the two textures may differ are in their ability to allow rapid water displacement from the pavement-tire interface and their ability to drain water from (transversely to) the vehicle path. These characteristics may play a particularly crucial role in hydroplaning avoidance during wet pavement conditions. Another difference between the two textures may be in the ease with which snow—and particularly ice—can be removed from the roadway surface during snowplowing operations. All other factors being equal, a higher number of crashes due to loss of control could be expected for textures promoting a stronger ice-pavement bond.

Crash rates for each pavement condition are summarized in Table 2. Ground sites performed better than tined sites under all pavement conditions. Differences were greater under wet and dry conditions, during which ground sites had 58 percent the crash rates of tined sites. Differences between ground and tined sites were less pronounced under snow and ice conditions, during which ground sites had approximately 84 percent the crash rates of tined sites. Crash rates were lowest for dry pavement conditions and increased by 50 percent under wet conditions for both ground and tined sites. When snow or ice was present on the pavement, crash rates for ground sites were 2.6 times higher and those for tined sites 1.85 times higher than rates on the same pavements when dry.

These findings were consistent with expectations of deteriorating crash experience as pavement conditions become progressively more slippery. It should be noted that findings for wet and snow and ice conditions on tined sites were based on a relatively low amount of travel and should be used with caution. Comparisons between tined and ground sites for dry conditions, however,

TABLE 1 Number of Crashes, Vehicular Travel, and Crash Rates for Ground and Tined Sites

	N [a]	Vehicular travel [b,c]	Crash rate [c,d]
Ground sites	7085	82.40	86
Tined sites	4134	30.57	135
All sites	11219	112.97	**Overall rate**: 99

[a] Number of crashes
[b] 100 million vehicle-km of travel
[c] 1 km = 0.6 mi
[d] Crashes per 100 million vehicle-km

TABLE 2 Crash Rates for Different Pavement Conditions

	Crash Rate[a,b]		
Pavement Condition	Ground	Tined	Ratio Ground/Tined
Dry	65	112	58%
Wet	99	170	58%
Snow/Ice	173	205	84%

[a] Crashes per 100 million vehicle km
[b] 1 km = 0.6 mi

were based on a significant amount of vehicular travel and are reliable.

Light Conditions

Pavement surface texture characteristics influence driver perception in a manner that can affect crash experience. For example, differences in pavement surface appearance may lead drivers to believe that ice is present on the pavement when it is not, making them more cautious and leading to lower crash rates. The opposite situation may involve a pavement texture that makes visual detection of ice on the pavement difficult, leading to a higher crash rate since drivers are caught unaware of the dangerous situation. Perception of, but also actual, safety problems are exacerbated during poor visibility conditions such as poor weather, dark conditions, or both.

Skidding problems due to the presence of snow and ice on the pavement can be expected to be more prevalent at night during the winter months, when temperatures drop and ice formation is more likely. Snowplow operators unaware of the presence of ice on a certain pavement because of its texture (especially at night, when ice detection may be particularly difficult) may reduce deicing agent dispersion rates, inadvertently increasing crash rates for this type of surface texture. These considerations led to an investigation of differences between daytime and nighttime crash rates.

Separate daytime and nighttime crash exposure data were compiled on the basis of estimates of percentage of average daily traffic (ADT) occurring during daytime and nighttime. Crash rates were then calculated using number of crashes occurring during daytime and nighttime and the estimated vehicular travel during the same periods. For the purposes of this analysis, nighttime included crashes occurring in the dark regardless of whether the roadway was illuminated. Dawn and dusk crashes were excluded from consideration, eliminating 4.5 percent of all crashes. More crashes and more vehicle kilometers of travel were accumulated on ground than on tined sites. A summary of findings is presented in Table 3.

On the basis of crash rates, ground sites were safer overall, during both daytime and nighttime. Differences between the two types of sites were more pronounced during the daytime, when ground sites experienced 57 percent of the crash rates of tined sites. Nighttime differences were less pronounced, with ground sites experiencing 73 percent of the crash rates of tined sites. Ground sites exhibited a higher nighttime-to-daytime crash frequency ratio than tined sites (68 percent compared with 51 percent). Both types of sites experienced approximately one-fourth of their vehicle kilometers of travel at night. Crash rates were much higher at night for both types of sites, but the ratio of nighttime to daytime crash rates was higher for ground sites, for which nighttime crash rates were 262 percent of daytime crash rates compared with 203 percent for tined sites.

Light and Pavement Conditions

Because crash rates for both light and pavement conditions were found to differ between tined and ground sites, crash rates were compiled for combinations of pavement conditions (wet, dry, snow and ice) and light conditions (daytime, nighttime). Results are presented in Table 4. Ground sites had lower crash rates than tined sites under all examined light and pavement conditions except in the dark when snow or ice was present on the pavement. Crash rates indicated that ground sites performed better than tined sites during the daytime for all pavement conditions.

Findings were consistent with expectations: crash rates increased as friction conditions deteriorated (dry → wet → snow and ice) and were higher for nighttime than for daytime. This held true for both

TABLE 3 Daytime and Nighttime Number of Crashes, Vehicular Travel, and Crash Rates

	Ground sites			Tined Sites			Ground/Tined Crash Rates	
	Day	Night	N/D	Day	Night	N/D	Day	Night
Crashes	3922	2670	68%	2580	1326	51%		
Vehicular Travel[a,b]	65.34	17.06	26%	24.3	6.16	25%		
Crash Rate[b,c]	60	157	262%	106	215	203%	57%	73%

[a] 100 million vehicle-km
[b] 1 km = 1 mi
[c] Crashes per 100 million vehicle-km

TABLE 4 Crash Rates for Different Light and Pavement Conditions

Condition		Crash Rate [a,b]		
Light	Pavement	Ground Sites	Tined Sites	Ratio Ground / Tined
Day	Dry	52	93	0.55
Dark	Dry	119	182	0.65
Day	Wet	77	144	0.54
Dark	Wet	181	272	0.67
Day	Snow/Ice	106	154	0.69
Dark	Snow/Ice	430	403	1.07

[a] Crashes per 100 million vehicle-km
[b] 1 km = 0.6 mi

ground and tined sites. However, findings should be viewed with caution for categories with low amounts of travel (snow or ice conditions).

Pavement Friction Deterioration

Friction number deterioration with time is well documented in the literature. For example, the Wisconsin DOT *Facilities Development Manual* (3) provides the following FN predictive equation for PCC pavements (transversely tined):

$$\ln(FN) = 3.99 - 0.0419 \ln(LAVP) - 0.00129DOL + 0.00474HV \quad (1)$$

where

FN = predicted friction number (tested at 60 km/h),
LAVP = summation of all vehicles expected to pass over design lane during service life of pavement (millions),
DOL = limestone, dolomite, or ankerite content of coarse aggregate material (% by weight), and
HV = percent of heavy vehicles in design lane (% lane ADT).

Equation 1 allows the estimation of FN at the end of a pavement's service life as a function of pavement materials and cumulative vehicle passes. Furthermore, it establishes a (negative) FN time gradient: FN is shown to decrease over the service life of a pavement as vehicle passes accumulate on the pavement. A similar concept was documented in a 1971 Federal Aviation Administration report (4) in which FN deterioration was quantified for concrete pavements as a function of cumulative vehicle passes since construction.

Researchers studying surface treatment FN characteristics have determined that pavement surface treatments are indistinguishable in terms of FN after a period of 2 to 5 years. Specifically, a 1979 Louisiana Department of Transportation evaluation of 10 different surface treatments (5) documented significant differences in FN at construction or rehabilitation time, depending on pavement surface texture. However, a decrease in FN with time for all surface textures was documented, which continued until, within a period of approximately 5 years, all tested surface treatments approached identical FN values. Evaluated textures were constructed using burlap drag, a variety of broom types, and metal tines of various spacings to create longitudinal or transverse textures. Another study concluded that although grinding increased FN initially, pavements returned to their initial FN within a period of 2 years in rehabilitated pavements (6).

These findings can be summarized in the following expectations for ground pavements: in the short term (2 to 5 years) grinding provides a higher FN, which should lead to a lower crash rate for skid-related crashes, after which FN for ground surfaces can be expected to be equal to that for other surface treatments, at which point crash rates for skid-related crashes should be equal among surface treatments. In the long term (5 years to pavement life), pavements can be expected to exhibit identical FNs that will continue to decline throughout the life of the pavement. The decline of FN as a pavement ages (FN time gradient) can be reasonably expected to lead to higher crash rates with time—especially for skid-related crashes—regardless of initial pavement surface treatment.

The number of study sites for which crash information was available for the first 2 to 5 years after construction was insignificant; thus, no attempt was made to validate the foregoing short-term expectations of lower crash rates for longitudinally ground compared with tined study sites. Various attempts to validate long-term crash rate expectations using the available data are described in the following paragraphs.

Cumulative Vehicle Passes and Pavement Age

On the basis of the foregoing discussion, accumulation of vehicle passes over time is expected to be related to deterioration of FN (and, consequently, crash experience) with time. A variety of regression models (both linear and higher order) using crash rate as the dependent variable and cumulative vehicle passes or pavement age as the independent variable were calibrated in an effort to verify the validity of these expectations. Dependent variables were crash rates for all crashes and for crashes under dry, wet, and snow and ice pavement conditions. Independent variables were cumulative vehicle passes since construction, heavy-vehicle passes since construction, and pavement age. Models were calibrated separately for ground and tined sites and for all sites simultaneously. All calibrated regression models had a very poor fit, which may be partially explained by the lack of a continuous crash history for the study sites (no crash information was available for most years after construction for the majority of sites) and imprecise volume information. Estimates of cumulative volume since construction were based on linear extrapolations from study data and may have contained significant inaccuracies for pavements with many years in service, since daily volumes and heavy-vehicle presence may have deviated significantly from the assumed linear trends since construction.

The most accurate crash experience trends available were those for the study years 1988 through 1993, which were investigated next.

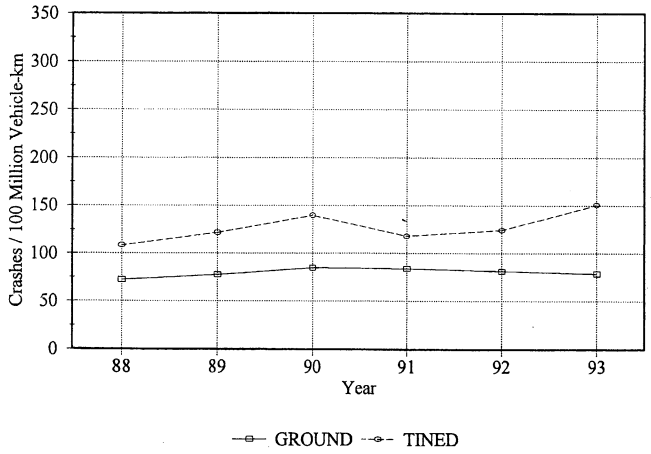

FIGURE 3 Crash rates, 1988–1993: all crashes.

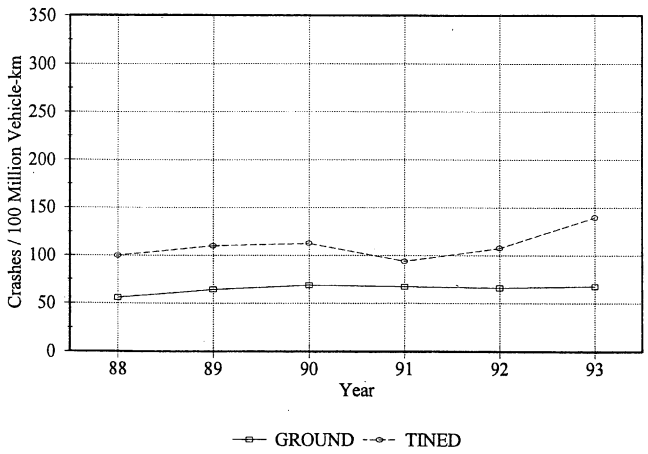

FIGURE 5 Crash rates, 1988–1993: dry pavement.

Six-Year Trends

Crash rates were calculated for 1988 through 1993. From the foregoing discussion, friction-related crash experience could be expected to worsen with time, since FN was expected to decrease with time. Separate crash rates were established for ground and tined sites in an attempt to identify differences between the two site categories. Tined sites had consistently higher crash rates than ground sites for all analyzed years (Figure 3).

Year-to-year crash rate variation was lower for ground than for tined sites. No consistent crash rate deterioration with time was evident for either group of sites, and no consistent crash rate divergence or convergence (i.e., increasing or decreasing crash rate differences with time) could be observed between ground and tined sites.

Daytime and nighttime crash rates for tined and ground sites are presented in Figure 4. Ground sites had consistently lower crash rates than tined sites throughout the study period, both during daytime and nighttime. Nighttime crash rates were higher than those during daytime for each year. This pattern was consistent with that observed in Table 3 summarizing crash rates for all years.

Ground sites had consistently lower crash rates than tined sites for dry pavements (Figure 5) and wet pavements (Figure 6); crash rates for dry pavements were lower than those for wet pavements.

Figures 7 through 10 present comparisons between crash rates for ground and tined sites for dry pavements during daytime, wet pavements during daytime, dry pavements during nighttime, and wet pavements during nighttime, respectively. In all cases ground sites were shown to outperform tined sites, and results were consistent with those presented in Table 4. Significant crash rate fluctuations with time were evident for crash categories with small sample sizes.

SUMMARY OF FINDINGS

For detailed findings, refer to Tables 1 through 4. A summary of the most reliable crash rates (i.e., results based on significant vehicular travel) can be found in Table 5.

- Continuously ground sites were found to have lower overall crash rates than tined sites.
- Ground sites were found to have lower crash rates than their tined counterparts under all pavement conditions. Crash rates were lowest for dry conditions, increased for wet pavements, and further increased when snow or ice was present on the pavement. Ground sites had 58 percent the crash rates of tined sites under dry and wet pavement conditions; the ratio was 84 percent when snow or ice was present on the pavement.

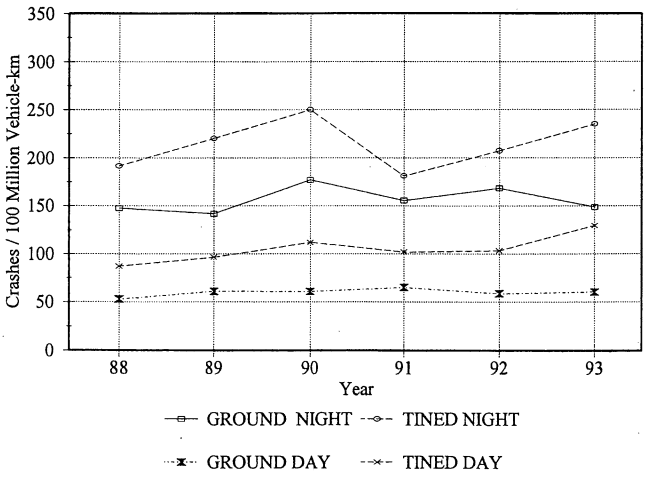

FIGURE 4 Crash rates, 1988–1993: daytime and nighttime.

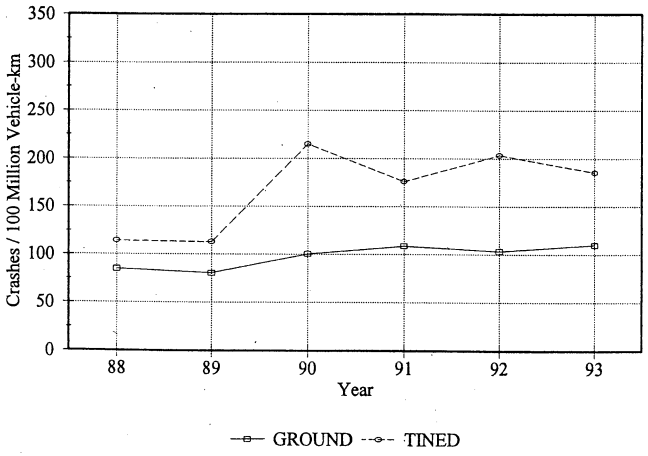

FIGURE 6 Crash rates, 1988–1993: wet pavement.

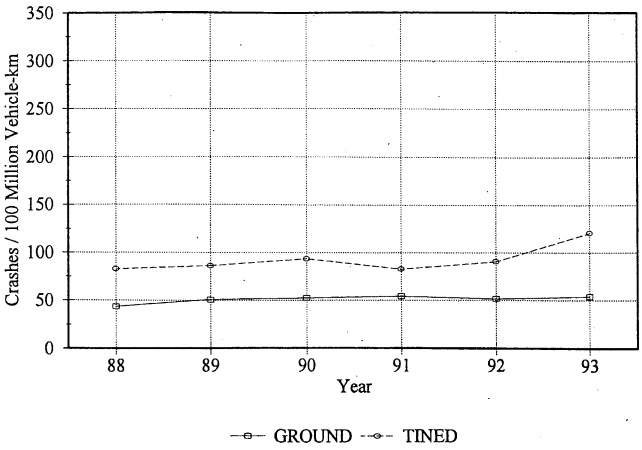

FIGURE 7 Crash rates, 1988–1993: daytime, dry pavement.

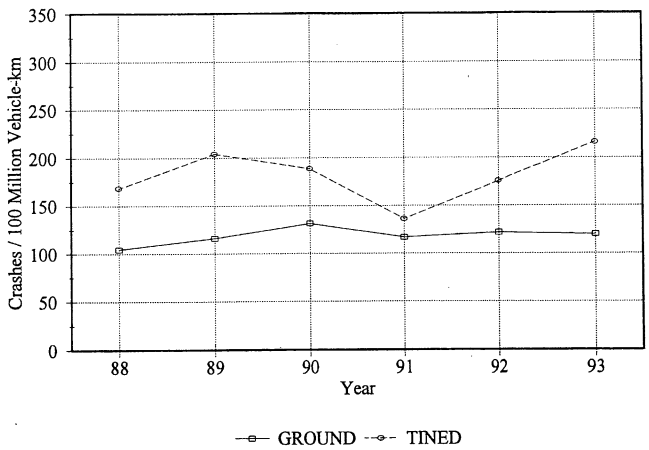

FIGURE 9 Crash rates, 1988–1993: nighttime, dry pavement.

- Crash rates were lower in daytime than nighttime; ground sites performed better under both conditions (57 percent and 73 percent, respectively, of tined-site daytime and nighttime crash rates).
- Results for the combination of pavement conditions (dry or wet) and light conditions (daytime or nighttime) showed that ground sites had lower crash rates than tined sites in every category. Nighttime crash rates for dry or wet pavements were higher than any daytime category (dry or wet pavement) for a given pavement surface treatment.
- The analysis of crash rate relations with pavement age and cumulative vehicle passes since construction was inconclusive. Crash rates for the period 1988 through 1993 verified the foregoing findings for light and pavement conditions for each year individually.

CONCLUSIONS AND RECOMMENDATIONS

Longitudinally ground PCC pavements were found to have better overall crash rates (measured in crashes per 100 million vehicle-km of travel) than transversely tined PCC pavements. Areas of concern that need to be addressed in future research efforts were identified and are described below.

The principal motivation for the use of different pavement surface treatments is to improve surface friction and thus reduce crashes. Although direct friction measurements were not part of this evaluation, improved friction properties for continuously ground pavements may provide a plausible explanation for the lower crash rates associated with this particular surface treatment in Wisconsin. Expectations of identical crash rates between ground and tined PCC pavements based on previous research findings (according to which different PCC pavement surface treatments were expected to have identical FNs 5 years after construction) were not confirmed here; ground pavements were found to exhibit lower crash rates regardless of pavement age. Ground PCC pavements also had consistently lower crash rates than tined ones for each of the 6 years for which crash rate information was available.

Expectations at the outset of this study were that if one surface treatment was superior to the other, differences would be more prevalent during wet pavement conditions. However, those expectations were not confirmed here: ground pavements had 58 percent the crash rates of tined pavements under both dry and wet surface conditions; differences were less pronounced (84 percent) under snow and ice conditions. Results for wet and dry conditions were based on an adequate accumulation of vehicular travel; however,

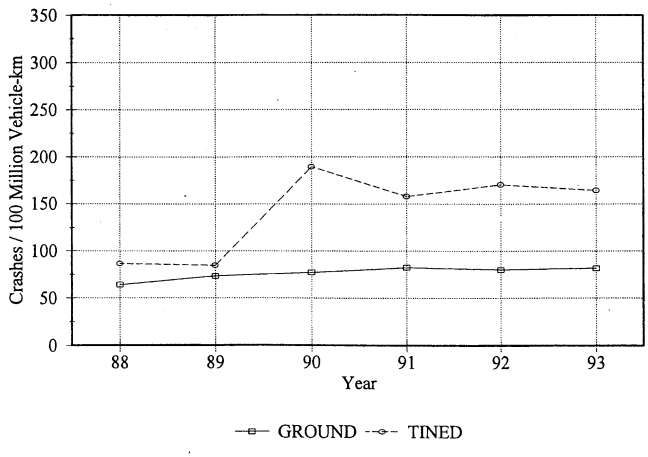

FIGURE 8 Crash rates, 1988–1993: daytime, wet pavement.

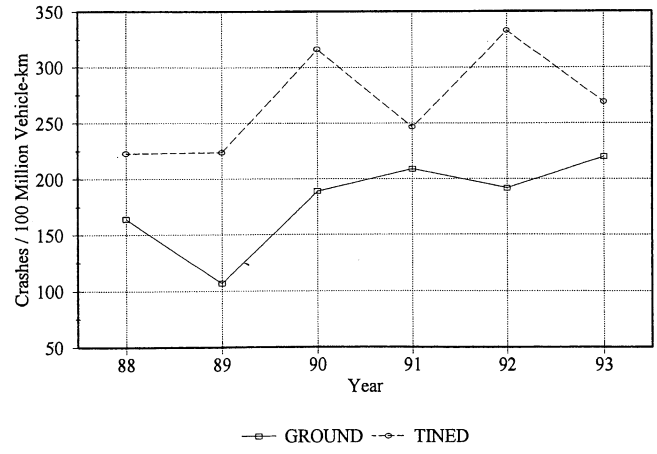

FIGURE 10 Crash rates, 1988–1993: nighttime, wet pavement.

TABLE 5 Most Reliable Crash Rate Findings

		Crash Rate [a,b]
All sites	Ground sites	86
	Tined sites	135
Pavement condition	Ground sites: dry pavement	65
	Ground sites: wet pavement	99
	Tined sites: dry pavement	112
	Tined sites: wet pavement	170
Light condition	Ground sites: daytime	60
	Tined sites: daytime	106
	Ground sites: nighttime	157
	Tined sites: nighttime	215
Pavement and light condition	Ground sites: daytime, dry	52
	Tined sites: daytime, dry pavement	93
	Ground nighttime, dry pavement	119
	Ground sites: daytime, wet	77
	Ground sites: daytime, snow/ice	106

[a] Crashes per 100 million vehicle-km
[b] 1 km = 0.6 mi

additional data are necessary for reliable conclusions on the relative performance of ground and tined PCC pavements under snow and ice conditions.

Crash rate comparisons between continuously ground and tined PCC pavements reveal that although ground pavements are preferable to tined ones in terms of crash occurrence, the benefits of grinding are less pronounced during nighttime. Indeed, ground pavements have a higher ratio of nighttime-to-daytime crash frequencies than tined pavements (0.68 compared with 0.51, respectively). This observation has a parallel in crash rate comparisons: the ratio of nighttime to daytime crash rates is 2.62 for ground pavements but only 2.03 for tined pavements. Furthermore, ground pavements have 57 percent the crash rates of tined pavements during daytime but 73 percent the crash rates of tined pavements during nighttime.

It is reasonable to assume that the source of this nighttime "problem" for ground PCC pavements would not be surface texture or environmental factors, since ground surfaces have superior performance during daytime—their friction properties would not deteriorate during nighttime—and environmental factors are identical for ground and tined surfaces during both daytime and nighttime. The problem thus may originate with driver perceptions during nighttime, which affect driving behavior; however, an investigation of driver perceptions was beyond the scope of this study.

On the basis of the major findings of this research project, grinding PCC pavements is recommended as a safety enhancement, notwithstanding preliminary findings of higher crash rates for ground concrete pavements during nighttime when snow or ice is present on the pavement. Grinding of PCC pavements can be expected to lead to lower crash rates on both wet and dry pavements during daytime and nighttime.

Additional research is necessary into comparisons of nighttime crash rates between ground and tined pavements in order to (*a*) explain the higher proportion of nighttime (compared with daytime) crashes on ground pavements, and (*b*) answer conclusively the question of whether ground pavements indeed have a higher crash rate at night when snow or ice is present on the pavement.

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