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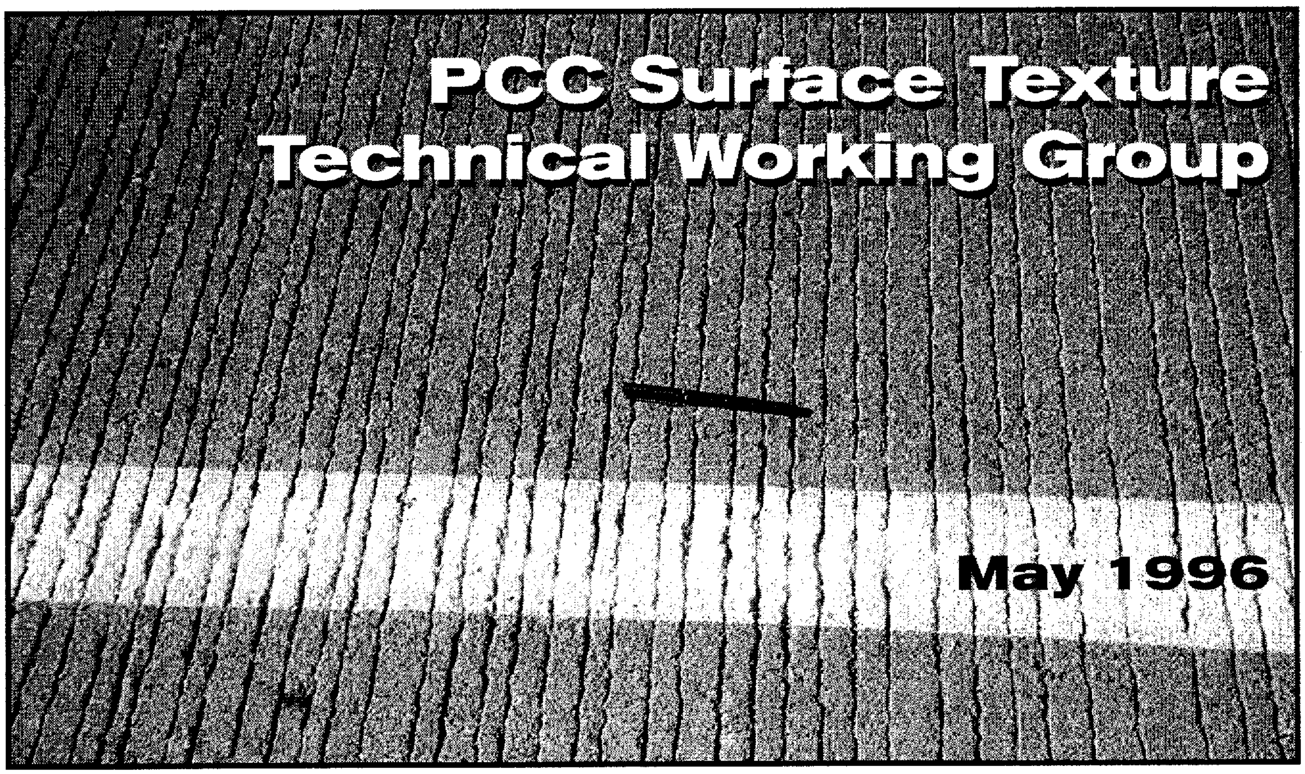
# TIRE PAVEMENT NOISE AND SAFETY PERFORMANCE




TECHNOLOGY
APPLICATIONS

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**15. Supplementary Notes**

Technical Working Group members included representatives from seven State Departments of Transportation, seven industries, one academic institution, eight FHWA offices, and one other Federal agency. Three meetings of the group were held to provide input into the study work plan and into this report, which summarizes the groups' findings.

**16. Abstract**


The annoying noise frequencies produced from tire/pavement interaction on some (usually transversely tined) Portland Cement Concrete (PCC) pavements have concerned both residents living nearby and motorists traveling over them. A Technical Working Group (TWG) was formed to investigate the problem by conducting a review of previous research and by evaluating the results of ongoing research in the United States. The goal of the TWG was to recommend PCC pavement surface textures that will reduce the annoying noise frequencies without compromising safety.

Previous research determined that PCC surfaces constructed for speeds under 80 km/h need only a good microtexture for wet weather stopping. For speeds of 80 km/h or greater, a macrotexture is also needed to reduce the water film thickness and prevent hydroplaning. The exposed aggregate surfaced PCC pavements and the open-graded asphalt friction course pavements combine for the quietest and safest rides where premium textures are desired. Smoother pavements also result in a quieter ride.

Wisconsin researchers, using narrow band frequency analysis techniques, have recently discovered how to objectively measure and analyze the annoying pure tones that create tire/pavement whining or lower frequency rumbling. Noise-reducing construction methods that work most effectively for new pavements are to randomly space (10 to 40 mm) the transverse tines/grooves, construct longitudinal tines/grooves (either according to AASHTO guidelines or to the Spanish plastic brushing method), or construct an exposed aggregate surface. Existing PCC pavements that produce an annoying noise should be retextured (diamond grooving, diamond or carbide grinding, or shotblasting) or resurfaced (PCC overlay or surface laminate, microsurfacing, or a dense- or open-graded asphalt concrete overlay).

Further research needs to determine the relationship between friction numbers and wet weather accident rates and develop improved construction guidelines (specific random transverse tine spacing, repeat pattern, and depth of texturing) to optimize safety and noise considerations.


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# EXECUTIVE SUMMARY: PCC SURFACE TEXTURE TECHNICAL WORKING GROUP FINDINGS

**1. Basis for Surface Texture Selection**—Well designed and constructed Portland Cement Concrete (PCC) pavements can provide safe, durable surfaces with low-noise characteristics. The selection of the surface texture to be provided at specific locations in a State should be based on existing conditions at that site, such as climate, amount of traffic including vehicle type distribution, speed limit, percent grade, conflicting movements (intersections or frequent side approaches), materials quality and cost, and the presence of noise-sensitive receptors. The primary purpose of the surface texture is to help reduce the number and severity of wet weather accidents.

Where the State has data to show that a specific texturing method results in similar wet weather accident rates and/or has similar friction characteristics [when tested with an ASTM skid trailer (Method E 274), preferably with a blank tire (E 524)] to another texturing method or to alternate materials used, the State's proposed method should be allowed. The State's pavement management and highway safety management systems should be organized to develop these comparisons periodically. Due to widely varying conditions at individual project locations, it is unlikely that one surface texturing method will always be the best choice in any given State.

**2. Safety Considerations**—The pavement surface on high-speed (80 km/h or greater) facilities must have sufficient microtexture (usually provided by siliceous sand) and macrotexture [provided by transverse or longitudinal tining (or plastic brushing--Spanish technique) preceded by a longitudinal artificial carpet or burlap drag; or an exposed aggregate surface treatment] to provide good friction characteristics during wet weather conditions. Current research and past experience have shown that longitudinal texturing with only an artificial carpet or burlap drag will generally <u>not</u> provide a safe, durable surface on high-speed facilities. They will usually provide adequate friction on roadways with speeds less than 80 km/h. <u>Both FHWA guidelines and the 1993 AASHTO Guide on the Evaluation and Abatement of Traffic Noise recommend that the designer should never jeopardize safety to obtain noise reduction.</u> Longitudinal tining or grooving should follow the *1976 AASHTO Guidelines for Skid Resistant Pavement Design* (1976 AASHTO Guide) due to the concerns expressed by drivers of vehicles with smaller tires.

Preliminary information indicates total highway fatalities in the United States have increased from 39,235 in 1992 to 41,700 in 1995, reversing a long downward trend. The increasing number of highway fatalities, plus the significant increases in the legal speed limits in many States as a result of the repeal of the national maximum speed limit by section 205(d) of the National Highway System Designation Act of 1995, reemphasize the need for providing safe, durable pavement surfaces.

**3. Need for Quality Mix Designs on Heavily Traveled, High-Speed Highways**—Adequate microtexture is <u>usually</u> most economically provided by specifying a minimum siliceous sand content of 25 to 40 percent of the fine aggregate portion of the mix. *FHWA Technical Advisory T 5080.17, Portland Cement Concrete Mix Design and Field Control,* dated July 14, 1994, reemphasizes good mix design practices. Fine aggregates usually containing a minimum of 25 percent siliceous sand; durable, nonpolishing coarse aggregates; a low water-cement ratio; an adequate air content; an adequate cement factor; and good curing practices are all necessary if a high-quality, durable concrete is to be provided.

Where cost effective and high-quality aggregates are not readily available, consideration should be given to two-layer construction, wet on wet, with a higher quality mix in the thinner (Michigan DOT recommends a minimum thickness of 70 mm based on recent construction experience) surface layer. This may provide a more durable, yet economical concrete pavement.

**4. General PCC Surface Texture Considerations**—Transverse tining, preceded by a longitudinal artificial carpet or burlap drag, remains the most desirable PCC surface texture method for many high-speed (80 km/h or greater) locations. With quality design and construction, it has been shown that pavements with excellent friction characteristics and low-noise levels can consistently be provided. In particular, research demonstrates that transversely tined concrete pavements with low-noise characteristics and minimal splash and spray can be constructed.

With high-quality mix design and construction practices, longitudinal tining or brushing and the exposed aggregate surface treatments will also provide sufficient macrotexture to prevent hydroplaning and reduce the number and severity of wet weather accidents on high-speed highways.

**Transverse tining**—When used, random transverse tine spacing (minimum spacing of 10 mm and a maximum spacing of 40 mm with no more than 50 percent of the spaces exceeding 25 mm) should be specified pending the results of further research. The actual tine width should be 3 mm (+/- 0.5 mm), and the tined depth should be a minimum of 3 mm and a maximum of 6 mm (provided minimum dislodging of the aggregate particles results). Narrow (less than 4 mm width), deep grooves are considered better than wider, shallow grooves for minimizing noise. The average texture depth as measured by the sand patch test (ASTM E 965) should be 0.8 mm with a minimum of 0.5 mm for individual tests. Measurements of **random** spacings at two locations in Wisconsin that generate low-noise levels and no tire / pavement whine are as follows:

32/19/22/25/35/22/22/22/22/25/35/13/38 mm
16/25/22/16/32/19/25/25/25/25/19/22/25/22/10/25/25/25/32/38/22/25/22/25 mm

Wisconsin researchers have now developed a noise measuring system in a vehicle and an analysis method that will identify pavement textures that generate objectionable tonal qualities. The revised noise evaluation procedure was developed when previous research reports and the current study revealed that the subjective noise ratings given by persons in test vehicles on transversely tined and certain other types of textured pavements did not correspond with the objective total noise measurements taken 7.5 m from the pavement edge. Noise measurements were taken inside of vehicles with instruments using a Fast Fourier Transform (FFT) analysis mode to observe narrow band frequencies. It was discovered that there are peak sound pressure levels up to 10 dB(A) around 1,000 Hertz that cause a pure tone that is irritating to the human ear (either a higher frequency tire / pavement whine or, in fewer cases, a lower pitched rumble). The third octave band analysis was not detecting these frequency peaks because averaging of the total sound masked them. The tones were discovered on most uniformly spaced transverse tining. **This is a major discovery because surface textures creating these tonal characteristics can be identified so that they can be avoided on future projects.**

**Longitudinal Tining**—Where longitudinal tining is desired (particularly in noise-sensitive areas or drier climates), it is recommended that the uniform tine spacing be 20 mm, actual tine width 3 mm (+/- 0.5 mm), and the individual tined depth be 3 to 6 mm (with an average surface texture depth of 0.8 mm and a minimum of 0.5 mm for individual tests as measured by the sand patch test ASTM-E 965). Wider longitudinal grooves are particularly objectionable to drivers of vehicles with small tires and must be avoided.

Preliminary information indicates that longitudinal tining at 20 mm spacing, preceded by a burlap or artificial turf drag, will provide a safe, durable pavement if a high-quality surface mixture with adequate microtexture is used that includes a minimum of 25 percent siliceous sand. CALTRANS specifies a minimum siliceous sand content of 30 percent of the fine aggregate portion and a minimum friction coefficient of 0.30 per its standard test procedure.

When considering the use of longitudinal texturing, the disadvantages of slightly slower surface drainage and more splash and spray compared to transverse tining should be considered especially in wetter climates subject to freezing conditions. Where very high speeds are expected (130 km/h or greater), British research indicates that longitudinal textures may not provide satisfactory friction characteristics. The New South Wales, Australia, *Concrete Pavement Manual* also states that longitudinal grooving treatment is unsatisfactory for both stopping distance and for rotational stability of a braked vehicle at high speeds (see appendix H).

**Longitudinal plastic brushing**—Spain has reported the successful use of a combined texture consisting of a longitudinal burlap drag followed by a plastic brush to provide high-friction characteristics while minimizing tire / pavement noise. A minimum of 30 percent siliceous sand is required to assure satisfactory microtexture. An average texture depth of 0.7 to 1.0 mm is required. Skid resistance is reported similar to porous asphalt with an average noise level of 0 to 2 dB(A) or higher (this noise level difference is not discernable by the human ear). Two PIARC study locations in Spain had .29 and .21 Friction Numbers with mean texture depths averaging 1.1 mm and 0.8 mm, respectively, when tested in 1992 at 90 to 95 km/h (55 mph) by an ASTM skid trailer with a blank tire. The $SN_{40}$ ribbed tired friction numbers were .53 and .41 and the $SN_{40}$ blank tire friction numbers were .48 and .27 respectively. The wet weather accident rate for this texture compared to other textures or surface types is not currently available.

**Exposed Aggregate Surface**—The exposed aggregate surface treatment technique is normally constructed on a pavement composed of two layers (wet on wet): top layer 40 to 70 mm thick, 30 percent siliceous sand 0 to 1 mm and 70 percent high-quality chips 4 to 8 mm (Los Angeles abrasion less than 19, polished stone value greater than 50); bottom layer maximum aggregate size 32 mm with lower quality yet durable aggregates. A high-quality concrete, with a maximum water-cement ratio of 0.38, minimum 450 $kg/m^3$ cement content, a plasticizer, and an air entrainment agent, is used in the top layer to ensure durability and to keep the modulus of elasticity as high and shrinkage as low as the bottom layer. Recommended texture depth is 0.9 mm as measured by the sand patch test ASTM E 965 (less depth is reported to result in higher noise). If 60 or more chips per 2,500 $mm^2$ are exposed, the noise will be low. Overfinishing of the surface must be avoided, and special vibrators must be used for the top layer. Advantages include noise similar to porous asphalt, excellent high-speed skidding resistance, and low splash and spray.

Other options that have been used include:

- Sweden has reduced the water-cement ratio and added microsilica to improve wear resistance against studded tires.

- The United Kingdom used 6 to 10 mm chips for a 1.4 mm average texture depth and has obtained excellent high-speed (130 km/h) skidding performance.

- Belgium has constructed CRCP in one layer with an exposed aggregate surface by reducing the maximum aggregate size to 20 mm and increasing the amount of 4 to 7 mm chips.

**5. Profile Considerations**—Some deep transverse tining has resulted in dislodging the aggregate particles with a resulting decrease in pavement ride quality and an increase in objectionable tire / pavement noise. However, a 1974 Belgian study concluded that randomly spaced (15 to 30 mm), deeper transverse tining (5 to 7 mm depth) did not affect the evenness (roughness) of the pavement surface and thus did not reduce the riding quality as compared to untined roads.

The International Roughness Index (IRI) is considered the best current indicator of pavement surface smoothness. European research indicates that the pavement smoothness also affects the noise level and an additional or an improved longitudinal smoother is being used to reduce total PCC tire / pavement noise to a level similar to that of a dense graded asphalt.

**6. Alternative Surface Treatments to Improve Friction Properties of Existing Portland Cement Concrete Surfaces**—There are many tradeoffs necessary in design, construction, materials quality, and maintenance procedures primarily due to the limited funding available. Therefore, it may be necessary to restore friction properties on sections of roadways with a high ratio of wet weather accidents or possibly on pavements having undesirable noise characteristics.

Possible alternatives to restore a skid resistant surface on Portland Cement Concrete (PCCP) pavements include:

- longitudinal or transverse grooving with diamond saws

- retexturing with diamond/carbide grinding or shotblasting

- thin surface laminates or bonded concrete overlays

- surface treatments like epoxy resin/calcined bauxite, Ralumac, or Novachip

- asphalt concrete (AC) overlays (dense- or open-graded)

It is normally more cost effective to retexture the existing concrete surface than provide a thin surface treatment or overlay unless polishing aggregates are involved.

**7. Research Needs**—A review of the State-of-the-Practice and the State-of-the-Art revealed the following areas where additional research is needed:

- Available information supports only a general correlation between friction numbers and wet weather accident rates. Additional analyses over consecutive 3- to 5-year periods is needed to determine (1) the wet weather accident rates of different textures and pavement types and (2) the change in friction numbers and accident rates over time for the different textures and pavement types.

- Much current information is based on initial values of noise for different surface textures, which can change significantly both short- and long-term. The NCHRP Synthesis of Highway Practice Topic 26-05, "Relationship of Pavement Surface Texture and Highway Traffic Noise," study underway will address the change in noise levels and in friction over time. Better information is needed on the change in noise levels for various surface textures for their full service lives so appropriate tradeoffs between noise and safety considerations can be made.

  *These analyses are needed to assure that safe, durable pavement surfaces are being provided. Slight [up to 3 dB(A)] noise increases, which are not discernable to the human ear, should not override the need to provide sufficient macrotexture to prevent hydroplaning on high-speed (80 km/h or greater) facilities. Textures known to cause pure tone frequencies (narrow band analysis) should be avoided.*

- **The appropriate ASTM Committee should address the desirability of using the blank tire (ASTM E 524) for skid inventory purposes due to its higher correlation with wet weather accident rates.** Also, the recently developed PIARC system for skid testing, which includes a concurrent texture measurement to develop an International Friction Index, should be considered for adoption. This method also allows an evaluation of the speed gradient and allows comparisons between different skid testing equipment.

- Additional research appears to be necessary to define the most desirable random transverse tine spacing and repeat pattern to optimize safety and noise characteristics. Also, there are differing opinions regarding the effect of depth of transverse tining on noise generation. It is recommended that the FHWA texture beam data collected in 1995 be analyzed to evaluate the interaction of groove width, depth, and spacing on the generation of objectionable tonal noises. The literature search suggests that the groove width and spacing are more critical than the depth. This conclusion is disputed by some researchers, and this issue needs to be resolved.

- Automated texture measuring devices need to record both longitudinal and transverse texture to obtain average texture depths similar to the sand patch test to help evaluate the surface drainage quality of the various textures. Simultaneous recording of longitudinal grade and transverse cross slope would help to further characterize the surface drainage conditions. Further development of the outflow meter (including specifications to ensure uniformity of manufacture) should be done to help determine the quality of surface drainage.

- PCC construction techniques need to be revised to eliminate short wavelength roughness, which contributes to increased tire / pavement noise. A more accurate method to determine smoothness is needed for construction control. The draft Final Report for NCHRP Project 1-31, "Smoothness Specifications for Pavements," is currently being reviewed for publication.

- The effect of surface texture on drainage (such as friction, splash and spray, and any special winter maintenance considerations) needs to be better defined so appropriate trade-offs can be made. NCHRP Project 1-29, "Improved Surface Drainage for Highway Pavements," nearing completion, should provide improved guidance. However, specific information comparing the effects of longitudinal and transverse textures on surface drainage characteristics and related safety effects is needed.

# 1 TECHNICAL WORKING GROUP SUMMARY

A Technical Working Group (TWG) representing State Highway Agencies, industry, academia, and the Federal Highway Administration (FHWA) has been meeting to update guidance on methods to obtain high pavement surface friction values while minimizing tire / pavement noise. The need for this guidance was based on a number of complaints about tire / pavement noise (high-pitched whine and/or low-pitched rumble) from occupants of adjacent residences and from motorists driving over transverse tined pavements. Also, some State legislatures are mandating corrective actions for sections of roadway deemed to have objectionable noise levels. These complaints have raised concerns about the adequacy of existing guidance to assure adequate friction characteristics while minimizing tire / pavement noise. An existing FHWA Technical Advisory (T 5140.10) will also be updated in 1997 as deemed appropriate. The update will reflect the results of this effort and of additional testing and evaluations to be conducted in 1996 to verify the recommendations made and to resolve some technical issues where current data appears to provide conflicting results.

The TWG initially met on September 27, 1993, to develop a work plan and a field test plan. Preliminary plans for this effort were presented at a special session at the Transportation Research Board meeting in January 1994. The work plan and the field test plan were finalized and distributed on March 14, 1994. The work plan called for review of current guidance on surface texture as it relates to:

- safety (friction and vehicle control)
- noise (inside and outside of the vehicle)
- drainage (cross slope, effect of longitudinal, and transverse tining)
- durability
- ride (profile)
- texture quality (measurement)
- economy of construction

The plan also called for a literature search of previous research efforts in the U.S. and abroad, and close monitoring of current U.S. and foreign research efforts.

The FHWA Office of Highway Operations Research and Development provided major technical assistance by providing equipment and technicians to obtain texture depths by the FHWA texture van, the texture beam, the sand patch test, and the static drainage (outflow meter) test on a variety of State test sections in 1994 and 1995.

A second meeting of the TWG was held on November 1 and 2, 1994. The results of initial field testing and findings from the literature search were discussed, and a schedule for the completion of the TWG's activities was made.

On February 9, 1995, ACPA distributed to the TWG a synthesis, "Optimizing Surface Texture of Concrete Pavement," prepared by Construction Technology Laboratories for the Portland

Cement Association. The synthesis summarized past U.S. efforts and also recent European activities. On April 11, 1995, Draft PCC Surface Texturing Issues Papers and Current Status Report were furnished by FHWA to the TWG for comments.

On November 1, 1995, FHWA issued a policy statement on PCC Surface Texturing that included a preliminary summary of the technical working group's findings. On January 31, 1996, a final meeting of the TWG was held to discuss recent developments and provide comments and recommendations on the final report to close out this effort. On February 14, 1996, a meeting was held to discuss related issues with tire industry representatives. A summary of the meeting and the Rubber Manufacturers Association's October 5, 1995, response to questions raised by FHWA are included in appendix I.

PCC pavement surface texture research projects (friction and/or noise studies) are being conducted or revisited in Arizona, California, Colorado, Iowa, Michigan, Minnesota, North Dakota, Virginia, and Wisconsin. Each of these States have furnished draft or final reports, including experimental data relating to friction and/or noise during the past year. A summary of their efforts and findings to date (except for Arizona) are located in the next section.

Arizona conducted a noise inventory that compared traffic noise generated from asphalt rubber friction courses and tined or grooved PCC pavements. However, no corresponding data on skid resistance or total or wet weather accident rates were considered. The consultant's report, FHWA-AZ96-433 dated February 1996, *"A Comparison of Traffic Noise from Asphalt Rubber Asphalt Concrete Friction Courses (ARACFC) and Portland Cement Concrete Pavement (PCCP)"* had just been published.

Appendix A contains a list of the TWG members, the current guidance on surface texturing for safety, current noise guidance and recent technical publications on pavement friction and noise related issues, and NCHRP surface-texture-related studies.

# 2 U.S. RESEARCH STATUS

**A summary of the experimental studies underway or recently completed in the various States is presented in this section. An expanded summary for each State, including data tables, is located in appendix B. Results and findings obtained from all the test sections are based on States reporting as of April 1, 1996.**

**California:** In 1994, two 17-year-old test sections were retested using a standard ASTM E-274 skid trailer for friction values. Test section number one has a transversely tined texture that has been heavily traveled, and test section number two has a longitudinally tined texture that has been moderately traveled. The most interesting result was the high ribbed (E-501) and smooth (E-524) tire friction numbers (over 40) on the longitudinally tined texture (spaced at 19 mm) for speeds of 96 km/h. California requires 30 percent siliceous sand in its PCC mix and requires a minimum friction of 0.30 as measured by its standard test procedure. Also, the retest showed lower friction numbers for both the 13 mm spaced transverse and 13 mm spaced longitudinal tining sections compared to the test sections with 19 mm tine spacing.

**Colorado:** An experimental project on I-70 east of Denver has nine different texture sections. Friction, noise, texture, and profile tests were taken just before the pavement was open to traffic in October 1994, and then again in June 1995. The first finding was unusual in light of other findings around the country: the variable (16 mm-22 mm-19 mm) transverse tining had the highest friction values for the smooth and ribbed tires, but it was also the noisiest section. The main reason for this is the variable transverse tining had the highest texture depth of 1.72 mm. Friction and noise values behaved in a similar pattern for the variable (16 mm-22 mm-19 mm) transversely grooved section. This section had an average texture depth of 1.24 mm. The section with the lowest noise and the lowest friction number is the longitudinally astro-turf dragged section. This section also had the lowest texture depth of 0.38 mm. The longitudinally tined section produced a low-noise level and maintained a friction number above 36 with a smooth tire at 96 km/hr. The average texture depth was 0.64 mm for this section. The large differences in average texture depth, as measured by the sand patch test in 1995, make a direct comparison of the various textures difficult.

**Iowa:** A test section consisting of nine textures was constructed late in 1993. Initial friction tests were conducted with the ribbed and smooth tire. The transversely tined (spaced at 13 mm) texture had the highest friction numbers from both tests. Additional tests have not been performed, and the priority given this experimental project by the State has been greatly reduced. Additional friction tests are expected to be conducted in 1996.

A method has been developed to produce a mold of the existing pavement texture using plastic material and food coloring. The mold has been effectively used to illustrate to contractor and inspection personnel the surface texture desired.

**Michigan:** A 2 km section of pavement with an exposed aggregate surface treatment (constructed of a high-quality two-layer concrete mix-hybrid German/Austrian design) was constructed in 1993 adjacent to a 2 km section of pavement with Michigan's standard concrete mix design and its standard transversely tined (26 mm spacing) texture. Noise measurements taken in 1993 and 1994 showed very little difference in total noise output or third octave band frequencies between the two sections. The Michigan section had friction values considerably higher (about 10 friction numbers) than the European design, although both sections had acceptable values. The initial lower friction values of the European design are believed to be related to the inexperience of the contractor with this type of construction and to the 0 to 4 mm sand (Michigan standard) rather than the 0 to 1 mm sand used in the Austrian specifications.

**Minnesota:** Two existing test sections (originally tested in 1987) were retested for exterior noise and friction values. Both test sections consisted of various transversely tined PCCP textures and dense-graded AC pavements. The exterior noise values were split into their noise spectra frequency range. The quietest sections were the AC pavement and the 26 mm spaced transversely tined PCC pavement. Based on the noise spectra results, it was concluded that noise frequency can differ greatly from one texture to the next without a change in the overall total noise. This is a highly significant finding and highlights the inadequacy of the highway noise measurement and analysis procedures previously used for detecting annoying tonal characteristics.

**North Dakota:** Nine test textures were constructed in 1993 on I-94 at Eagles Nest. The textures were tested for exterior tire / pavement noise and interior vehicle tire / pavement noise. The interior tire / pavement noise tests are unique to other tests because four different vehicles were used to collect the data. Results, so far, are that the skewed tining and variable spaced tining produce the lowest outside tire / pavement noise. The North Dakota study concluded that there is no significant advantage for the transversely tined, longitudinally tined, or skewed tined texture in terms of interior vehicle noise. The 1995 test results have not yet been reported.

**Virginia:** Skid and texture tests were performed on a 25-year-old section of longitudinally tined continuously reinforced concrete pavement on I-64, east of Richmond. The friction values (average over 40 for the ribbed tire) have held up very well during the pavement's lifetime, indicating the durability of the texture is good when constructed with high-quality materials. No wet weather accident data are currently available to compare the longitudinally tined texture with transversely tined textures used elsewhere in the State.

**Wisconsin:** Two test sections are being studied under a major research project to quantify the impacts of the pavement surface texture on noise, safety, and winter maintenance requirements. The concrete texture test sections consist of longitudinally tined, transversely tined, skewed tined, and Skidabrader (shotblasted) sections. The bituminous sections consist of dense-graded, stone matrix, and SHRP mix design asphalt surfaces. Both sections were constructed in 1994 in different locations in the State. Exterior noise was measured with the passby method using a car and a flatbed truck. Friction tests were performed with the ribbed and smooth tire at 65 km/h and 80 km/h. Winter maintenance operations were also observed on all the test sections.

After the exterior noise measurements [for third octave band analysis and for average total noise levels in dB(A)] were taken, empirical evaluations were made by observers in a car driven over the test sections and by subjects standing on the roadway shoulder. The empirical evaluations did not match the objective measurements on the transversely tined PCC pavements (except for the 39 mm uniformly spaced tines). It was determined that the tire / pavement whine needed to be defined through means other than evaluation of total noise. Interior noise measurements were performed on nine transversely tined PCCP sections, three ACP sections, and on a continuously diamond ground section during the fall of 1995, in cooperation with the Minnesota DOT. Three vehicles were used at two different speeds, with five tests run for each vehicle at each speed. A Larson-Davis Type 2900 2-channel, real-time acoustic analyzer was used in the Fast Fourier Transform (FFT) analysis mode to make the interior noise analysis.

The narrow band noise spectrum of the interior measurements were examined and a pattern was detected that indicates the annoying frequencies occurs in the 1,000 Hertz range. The peak sound pressure levels [up to 10 d(B)A] create a pure tone that is irritating to the human ear. In the third octave band analysis, these peaks are averaged into the surrounding noise and become invisible. As a result, the following preliminary recommendations were made:

- randomly space the transverse tines from 10 to 40 mm (with no more than 50 percent of the spacings exceeding 25 mm)
- develop better quality control for the depth of tining
- continue to monitor noise on the existing test sections while constructing new test PCCP sections with a greater variety of transverse and longitudinal tine spacing and depths

## Tire / Pavement Noise Research Results from the United States

The following preliminary conclusions about tire / pavement noise are made from the noise study results in Colorado, Michigan, Minnesota, North Dakota, and Wisconsin:

1. Uniformly spaced transverse tines, particularily those spaced over 26 mm, produce the most irritating tire / pavement noise. This is shown in the results from Minnesota (loudest 65 mm and 78 mm spacing), North Dakota (52 mm, 78 mm, and 104 mm spacing), and Wisconsin (39 mm spacing).

2. The Michigan project has, thus far, not shown a significant total noise or frequency distribution difference between the Michigan standard 26 mm uniformly spaced transversely tined texture and the European exposed aggregate texture. While acceptable, the exposed aggregate surface texture friction numbers are about 10 numbers lower than the standard Michigan transversely tined texture.

3. The Minnesota study found dense-graded bituminous pavement to be quieter than PCC pavement [more than 3 dB(A)] based on total noise. However, it should be noted that the average AC texture depth was significantly less than most of the PCC textures, which is the major reason for this difference. Also, a study of the noise frequency spectrum indicated that total noise is not a true indicator of whether the noise is considered objectionable or not.

4. The interior vehicle noise studies do not show a large range in the total noise levels from the different textures. It is the narrow band frequency distribution (pure tones) that is most significant in determining whether a particular texture results in objectional tire / pavement noise.

5. Using transverse and longitudinal tining together (cross hatching) produces consistently higher total noise based on Wisconsin's results (and Virginia's experience—see TRR Report 652).

6. The noise output from the tire / pavement interaction on PCC pavement changes as speed changes. The transverse plastic broom finish was the quietest in Wisconsin's test section at a passby speed of 96 km/h, but the transversely tined (13 mm spacing) and Skidabrader textures were quietest at 112 km/h passby speed for car and truck test vehicles, respectively.

7. Colorado's variable transversely tined texture was the loudest but also had the greatest average texture depth. However, Wisconsin found a transversely tined section outside of its test area whose tines had greater randomized spacing (repeated each rake pass) that reduced objectionable noise output significantly when compared to the State standard transverse tined texture. The specified randomness of the spacing and the construction quality are initial factors in determining the generated noise characteristics and, ultimately, the resulting level of annoyance to the human ear.

8. Colorado's transversely and longitudinally grooved sections (hardened concrete) are quieter than the tined sections (plastic concrete). The difference could be related to construction practice and emphasizes the need for increased attention to this important feature by project inspectors to verify that the desired texture is being obtained. The use of samples to demonstrate the texture desired would help promote construction uniformity

for both the inspection and contractor personnel. Tire industry experts expected that the sharper saw grooved edges would be noisier than transversely tined grooves with similar depth, width, and spacing.

# 3 SUMMARY OF FOREIGN RESEARCH

There has been a substantial amount of foreign research related to reducing tire / pavement noise. There are two primary concerns when reviewing this literature:

1. Safety is often given little or no consideration when evaluating noise reductions.

2. The effect of surface texture on drainage does not seem to be considered (possibly because 2.5 percent cross slopes are frequently used).

The purpose of this section is to provide a comparison of foreign practices with those currently used in the United States. A more detailed description of the research is given in appendix H. There were nine primary research reports considered during this review:

1. ***Roadside Noise Abatement*, Organization for Economic Co-operation and Development (OECD), 1995, 170 pages.**

   This is a comprehensive discussion of roadside noise abatement, including tire / pavement interaction. Minimal engineering data are presented on the effect of pavement texture on surface drainage, friction, or wet weather accident rates. Its primary focus is on noise abatement from an environmental point of view.

2. ***State-of-the-Art Report and Recommendations for Practice and Further Developments*, BRITE/EURAM Project BE 3415 (Surface Properties of Concrete Roads in Accordance with Traffic Safety and Reduction of Noise), October 1994.**

   This report describes a literature study, laboratory research, and specially constructed test track measurements by representatives of the Netherlands, Germany, and Spain. The researchers considered longitudinal tining and exposed aggregate PCC pavement as the most promising for a noise reducing surface. Porous concrete surfacing was considered to need further development before it could be used in large-scale construction. Further research was recommended for the use of smoother equipment, alternative noise and texture measurement methods, and additional low-noise concretes.

3. ***Measurements on Test Stretches*, Report No. 240/7, BRITE/EURAM Project BE-3415, Berlin Technical University, May 1994.**

   This report describes the measurements of texture, tire / pavement noise, and skid resistance at two German test locations. Measurements were made on test sections composed predominantly of longitudinally tined and exposed aggregate textures. Transversely tined sections were at a minimum because of the assumption that they are inherently noisier. Generally, the longitudinally tined and exposed aggregate sections were within 1 dB(A) of each other, while the transversely tined sections were about 3 dB(A) higher as measured with the passby method. There was greater variation in the noise trailer results. The friction properties were highest for the exposed aggregate sections and lowest for the longitudinally tined sections. There was no correlation found between the friction and acoustic properties.

4. ***Concrete Pavement Manual: Design and Construction,*** **Roads and Traffic Authority, New South Wales, Australia, February 1994.**

This manual takes many of the British research findings and presents them in the form of guidelines for finishing PCC paving. Some of the major aspects of the manual are:

- Microtexture is the critical component for skid resistance at high speeds.
- Macrotexture is viewed as the primary means to remove water to take advantage of the microtexture at higher speeds.
- The effectiveness of the microtexture is largely dependent on the quartz sand content.
- The mortar is the critical component to ensure durability of the surface texture to maintain high friction values.
- Durability depends substantially on cement content, water/cement ratio, and effectiveness of curing.
- Within 80 km/h zones, longitudinal burlap drag with no transverse texture is specified.
- For rural concrete surfaces, a transversely tined finish is specified. Variable (random) tine spacing is used, and the tining operation is closely monitored to obtain the maximum texture.
- Flexibility must be provided in the tining rake so that individual tines can traverse large aggregate stones without disturbing the surface or dislodging them, and the rake should be hinged in such a way that variable pressure can be exerted to adjust for varying "average" surface hardness.
- Longitudinal grooving is viewed as unsatisfactory for both stopping distance and for rotational stability of a braked vehicle at high speeds.

5. **J. Nichols and D. Dash, "Australian Developments to Reduce Road Traffic Noise on Concrete Pavements," 5th International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, April 1993, Volume 2, pages 99 to 106.**

PCC pavement surface textures were evaluated in this paper by examining those with the following variations: burlap drag length, tine depth, tine width, and tine spacing. The tine spacings used were 13 mm, 26 mm, and randomized at 10/14/16/11/10/13/15/16/11/10/21/13/10 mm. It was concluded that the quietest surface texture produced to date (light burlap drag with light transverse tine depth and a randomized, average 13 mm spacing) has acceptable skid resistance in terms of Sideways Force Coefficient and texture depth.

6. **J. C. Van Der Walt, et al., "Design Consideration and Findings of the Surface Texture Improvement on the Ben Schoeman Freeway," Fifteenth Annual Transportation Conference, Pretoria, South Africa, 1995.**

This report summarizes and references previous South African noise studies. A section of transversely broomed PCC pavement had a high accident rate. This report examines the problems with the pavement texture and investigates the possible solutions to the problem. Advantages and disadvantages for longitudinal and transverse tining are examined, along with various combinations of tine width, depth, and spacing. The report reached the following conclusions:

- Durable concrete mixes should be provided.
- Width and spacing of the grooves are critical parameters.
- Cross slopes on pavements wider than 12 m should be increased from 2 to 2.5 percent.
- Alternative methods to SCRIM should be looked at to measure skid resistance.

Additional South African studies are referenced in appendix H.

7. ***International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements*, PIARC Technical Committee on Surface Characteristics C.1, 1995.**

This research report provides data allowing one to define an international scale of friction values called the International Friction Index (IFI). The objective of the experiment was to compare the many different measuring methods used around the world and develop relationships for converting results produced by the different devices to a common scale. The universal friction scale (see "golden curve" in appendix H) requires measurements of the friction and texture of a surface for conversion to other device readings.

8. **Session 8 Papers, "Noise Reducing Surfaces and Skid Resistance and Rideability," 7th International Symposium on Concrete Roads, Vienna, Austria, October 3-5, 1994, pages 81-178.**

This publication contains a variety of papers briefly describing noise and skid research in Europe (United Kingdom, Belgium, Netherlands, Spain, Germany, Austria, and Sweden), as well as Australia (New South Wales) and the United States (Michigan European Concrete Pavement Demonstration Project). Many of the details of construction and noise and skid testing are provided. These papers demonstrate the current state-of-the-art of constructing low-noise concrete pavements with good skid resistance. However, because these are usually short experimental sections, no wet weather accident data are provided, which is the real test of surface texture effectiveness.

9. **Proceedings, XX$^{th}$ World Road Congress, Montreal, Canada, September 3-9, 1995 (Individual Papers of Committees and Working Groups: C1 Surface Characteristics; C7 Concrete Roads; C8 Flexible Roads; and General Report, Question IV, New Techniques for Pavement Strengthening and Maintenance), PIARC.**

The various reports summarize much of the current activity for managing and maintaining pavements, including noise and friction-related issues. In the C1 committee report, increasing exchange of information between road and vehicle engineers is reported. Current efforts in Europe to develop standards for noise reduction of tires is being expanded to include a definition of road surface testing not only for noise but also for safety. There is a major lack of data on wet weather accident rates in Europe as well as in the U.S. Evidence from the U.K., where a policy on enhancement of road texture has been in existence for some years, indicates that there is almost a five times payback in terms of reducing accidents. The policies being presented are based on accident risk ratings of specific sites.

Committee report C7, pages 31-47, provides a summary of activities to reduce concrete pavement noise by increasing longitudinal smoothness and providing the right kind of texture. The effort in Europe is somewhat different than in the U.S. (which has concentrated largely on transversely tined textures) due to the European focus on exposed aggregate surfaces and longitudinal textures.

# 4 SUMMARY OF ISSUES

The discussion of surface textures and the noise produced from the tire moving over them can be addressed as specific issues. Appendices C through G contain issue papers that address common questions and predominant points of view pertaining to this subject. Some duplication of information is provided to make the issue papers individually complete. Summaries of these issue papers are presented in this chapter.

### Issue: General Pavement Surface Type Questions

Pavement texture is needed to reduce the number and severity of wet weather accidents as defined in the *1976 AASHTO Guideline for Skid Resistant Pavement Design*. Each State should have developed a skid accident reduction program to determine when a surface texture will not aid in reducing wet weather accidents. Friction tests done as part of the skid accident reduction program should be performed with a ribbed and a smooth tire to obtain a measure of both the macrotexture and microtexture of the pavement surface. The speed gradient should also be determined and recorded with the friction number. There is no current standard method for measuring tire / pavement noise; however, a prototype procedure has been developed as a byproduct of U.S. research.

### Issue: Safety of PCC and AC Surface Textures

The characteristics that relate to safe pavements (of any material) is adequate microtexture for stopping at all speeds and adequate macrotexture for surface drainage to prevent hydroplaning at high speeds on wet pavement so the tire remains in contact with the microtexture. Each material type and each respective surface texture has advantages and disadvantages when considering safety. Different conditions may suggest the use of a specific material and/or texture to meet design needs. However, safe pavement textures can be provided with either PCC or AC surfaces. In addition to the specified design requirements, good friction and surface characteristics are directly related to good construction practices with high-quality materials.

### Issue: Tire / Pavement Noise on PCC and AC Pavements

A material type selection should not be made based solely on noise considerations from the tire / pavement interaction. Both FHWA and AASHTO currently recommend that safety not be compromised to obtain a slight, usually short-term, initial reduction in noise levels. Properly constructed PCC pavement, with a transversely tined or longitudinally tined surface, matches the performance of dense-graded asphalt considering both safety and noise factors. Available research data indicate it is the construction process, not an inherent material property difference between AC and PCC pavements, that currently results in slightly lower initial noise levels for AC pavements. Exposed aggregate surface treatments and Spanish longitudinal broom texture surfaces also provide comparable noise and safety related performance to the dense-graded AC pavements.

### Issue: Longitudinal and Transverse Tining

Both of these textures are acceptable from noise and safety requirements. The mix design for a longitudinally tined PCC pavement should contain at least 25 percent siliceous sand and high-quality coarse aggregate. The texturing recommendations are the same as for transverse tining except a uniform spacing of 20 mm is recommended due to handling concerns by drivers of vehicles with smaller tires. The transverse tines should be variably spaced between 10 and 40 mm (with no more than 50 percent of the spacing exceeding 25 mm), 3 mm wide, and 3 to 6 mm deep (resulting in an average texture depth of 0.8 mm with no individual test less than 0.5 mm as measured by the sand patch test). The random transverse tine spacing particularly will reduce the tire / pavement noise to an acceptable limit while providing a safe surface in wet weather due to good friction characteristics and reduced splash and spray.

### Issue: Premium Surface Treatments

There are several surface textures for new construction and for existing pavements that have been developed and used extensively or experimentally in the United States and Europe. These textures include: AC and PCC open graded, PCC exposed aggregate, diamond grooving, diamond and carbide grinding and shotblasting, PCC two-layer construction, and PCC chip sprinkling. PCC exposed aggregate may be the best new construction technique for noise reduction and safety. It may not, however, be the most cost-effective approach. Diamond and carbide grinding may not provide a long-term increase in friction when the large aggregate in the existing pavement is susceptible to polishing. Two-layer construction may be a cost-effective option when high-quality materials are not available in the immediate area.

## 5 FINDINGS AND RECOMMENDATIONS

The specific findings and recommendations are provided in the executive summary and will not be repeated here. Due to the almost unlimited combinations of climate; traffic; design, construction, and maintenance practices; materials cost and quality; and contractor experience and availability, the provision of a safe, durable, low-noise pavement surface is extremely complex. This paper is an attempt to summarize the current state-of-the-art and state-of-the-practice to help highway agencies select alternate material types and textures suited for their particular local conditions.

The efforts of the technical working group have helped reach a general consensus on procedures to consistently produce safe, durable, and low-noise concrete surfaces. The additional research suggested will help refine the recommendations presented here and verify that the recommended procedures will obtain the desired results. The assistance of the technical working group members in addressing this issue and reviewing the proposed work plan and draft final report is greatly appreciated.

# APPENDIX A

## Status: Technical Working Group on PCC Surface Texturing

A Technical Working Group (TWG) representing State highway agencies, industry, academia, and the Federal Highway Administration (FHWA)—see list below—has been meeting to update guidance on methods to obtain high pavement surface friction values while minimizing tire / pavement noise. The need for this guidance was based on a number of complaints about tire / pavement noise (high-pitched whine and/or low-pitched rumble) from occupants of adjacent residences and from motorists driving over transversely tined pavements. Also, some State legislatures are mandating corrective actions for sections of roadway deemed to have objectionable noise levels. These complaints have raised concerns about the adequacy of existing guidance to assure adequate friction characteristics while minimizing tire / pavement noise. An existing FHWA Technical Advisory (T 5140.10) will be updated in 1997 as deemed appropriate. The update will reflect the results of this effort and of additional testing and evaluations to be conducted in 1996 to verify the recommendations made and to resolve some technical issues where current data appear to provide conflicting results.

### Current guidance on surface texturing for safety are given by:

- Surface Finishing of Portland Cement Concrete Pavement (PCCP), W. H. Weseman's memorandum to FHWA Regional Administrators, November 1, 1995
- 23 CFR 625—Design Standards for Highways
- FHWA Technical Advisory T 5040.17, Skid Accident Reduction Program, December 23, 1980
- *Guidelines for Skid Resistant Pavement Design*, AASHTO, 1976
- FHWA Technical Advisory T 5140.10, Texturing and Skid Resistance of Concrete Pavements and Bridge Decks, September 18, 1979 (to be updated)
- FHWA Technical Advisory T 5040.28, Developing Geometric Design Criteria and Processes for Nonfreeway RRR Projects, October 17, 1988
- Title 23 Code of Federal Regulations [(CFR) 500.205(d)], December 1, 1993, and non-regulatory supplement published on October 5, 1995 (Transmittal 14, Federal-Aid Policy Guide)
- 23 CFR 635.505(a), Interstate Maintenance Guidelines
- Highway Safety Grant Management Manual [particularly 23CFR Part 1251—State Highway Safety Agency (4/1/94) and Uniform Guidelines for State Highway Safety Programs (7/18/95) - especially Guideline No. 21], which replaced 23 CFR 1204.4, Highway Safety Guidelines (Highway Safety Program Guideline No. 12—Highway Design, Construction, and Maintenance) on October 5, 1995 (Federal Aid Policy Guide Transmittal 14)

## Current noise guidance and technical publications on pavement friction and noise related issues include:

- Highway Traffic Noise Guidance and Policies and Written Noise Policies, Tony Kane's June 12, 1995, memorandum to FHWA Regional Administrators, 86 pp.
- Guide on Evaluation and Abatement of Traffic Noise, AASHTO, 1993, 40 pp.
- ACI 325.6R-88, Texturing Concrete Pavements (Information Only).
- S. H. Dahir and J. J. Henry, *Alternatives for the Optimization of Aggregate and Pavement Properties Related to Friction and Wear Resistance*, FHWA-RD-78-209, Final Report, FHWA, April 1978, 295 pp.
- Fifth International Conference on Concrete Pavement Design and Rehabilitation, Volumes I and II, Purdue University, April 1993, 700 pp.
- C. L. Wu and M. A. Nagi, Optimizing Surface Texture of Concrete Pavements, Portland Cement Association Research and Development Bulletin RD111T, PCA, Skokie, IL, 1995, 108 pp.

## The Technical Working Group is composed of:

### State Highway Agency

| | |
|---|---|
| Leo DeFrain | Michigan DOT |
| James Grove | Iowa DOT |
| Robert Schmiedlin | Wisconsin DOT (replaced Kevin McMullen) |
| Robert Page | California DOT |
| Orlando Picozzi | New York DOT |
| Ken Polcak | Maryland DOT |
| Jon Underwood | Texas DOT |

### Academia

| | |
|---|---|
| J. J. Henry | Pennsylvania Transportation Institute |

### Industry

| | |
|---|---|
| Donald Detwiler | New Enterprise Stone and Lime Company, Inc. |
| Richard Forrestel | Cold Spring Construction Company |
| Stan LaHue | American Concrete Pavement Association |
| Lee Powell | Ballenger Paving Company, Inc. |
| Steve Butcher | Rubber Manufacturers Association |
| Thomas Trussell | Central Atlantic Contractors, Inc. |
| Kevin McMullen | Wisconsin Concrete Pavement Association |

### FHWA

| | |
|---|---|
| Robert Armstrong | Environmental Analysis Division |
| Kurt Dunn | Region 7 Pavement Engineer |
| Dr. Steve Forster | Special Projects & Engr. Division |
| Carlton Hayden | Safety Technology Division |
| Brad Hibbs | Pavement Division |
| Roger Larson | Pavement Division |

| | |
|---|---|
| John Sullivan | Alabama Division |
| Suneel Vanikar | Infrastructure Division |

**Other Federal Agency**

| | |
|---|---|
| Kenneth Feith | Environmental Protection Agency |

## Technical Working Group Activities

The TWG initially met on September 27, 1993, to develop a work plan and a field test plan. Preliminary plans for this effort were presented at a special session at the Transportation Research Board meeting in January 1994. The work plan and the field test plan were finalized and distributed on March 14, 1994. The work plan called for review of current guidance on surface texture as it relates to:

- safety (friction and vehicle control)
- noise (inside and outside of the vehicle)
- drainage (cross slope, longitudinal and transverse tining)
- durability
- ride (profile)
- texture quality (measurement)
- economy of construction

The plan also called for a literature search of previous research efforts in the U.S. and abroad, and close monitoring of current U.S. and foreign research efforts.

The FHWA Office of Highway Operations Research and Development cooperated by providing pavement texture measuring equipment and technicians in 1994 and 1995 to allow uniform measurements of a number of State experimental texturing sections. The TWG has requested that the FHWA conduct additional analyses of the data collected to help identify the surface characteristics contributing to the objectionable pure tone noises. In addition, similar measurements and analysis are planned in the summer of 1996 to help verify that improved guidelines being developed will ensure the construction of pavement textures that do not result in objectionable tire / pavement noises. The FHWA's continued cooperation will be extremely helpful in resolving a number of related technical issues on pavement and bridge deck texturing.

A second meeting of the TWG was held on November 1 and 2, 1994. The results of initial field testing and findings from the literature search were discussed and a schedule for the completion of the TWG's activities was made.

On February 9, 1995, ACPA distributed to the TWG a synthesis, "Optimizing Surface Texture of Concrete Pavement," prepared by Construction Technology Laboratories for the Portland Cement Association. The synthesis summarized past U.S. efforts and also recent European activities and was a major contribution to the TWG's activities. Draft PCC Surface Texturing

Issues Papers and a Current Status Report were furnished by FHWA to the TWG for comments on April 11, 1995.

On November 1, 1995, FHWA issued a policy statement on PCC Surface Texturing that included a preliminary summary of the technical working group's findings. On January 31, 1996, a final meeting of the TWG was held to discuss recent developments and provide comments and recommendations on this final report to close out this effort. On February 14, 1996, FHWA and ACPA representatives met with tire industry representatives to discuss areas of mutual interest and to promote improved communication. Refer to appendix I for a summary of the meeting.

PCC pavement surface texture research projects (friction and/or noise studies) are being conducted or revisited in Arizona, California, Colorado, Iowa, Michigan, Minnesota, North Dakota, Virginia, and Wisconsin. Each of these States has furnished draft or final reports, including experimental data relating to friction and/or noise during the past year. Brief summaries of their efforts and findings to date (except for Arizona) are included in the main report with more detailed information presented in appendix B.

Arizona conducted a noise inventory that compared traffic noise from asphalt rubber friction courses and tined and grooved Portland Cement Concrete pavements. The consultant's report is currently being published.

## Foreign Research or Publications

European, Australian, and South African research in this area has been ongoing for several years. A number of significant reports have been produced that are used to support the findings and recommendations made in this report. A brief summary of some of the more recent publications was provided in the main report and additional details are described in appendix H.

## Related National Cooperative Highway Research Projects

Several NCHRP studies are now in progress that will be of significant help in providing answers to surface texture safety and noise issues:

- NCHRP 1-29, Improved Pavement Surface Drainage, will be completed in 1996, and is expected to consider the effect of longitudinal grade, cross slope, and surface texture (average texture depth and also longitudinal versus transverse tine texture on PCC pavements) on surface drainage and safety.

- NCHRP Synthesis of Highway Practice, Topic 26-05, "Relationship of Pavement Surface Texture and Highway Traffic Noise," is underway, with at least a draft of the report expected to be available by the end of 1996.

- NCHRP Project 1-31, "Smoothness Specifications for Pavements," addresses questions relating to measuring, specifying, and constructing smoother riding pavements. The final report should be available in mid-1996.

# APPENDIX B

## United States Research Status

A summary of the experimental studies underway or recently completed in the various States is presented in this section. This summary includes the scope of research, status, results, and references.

### Individual State Results and Status

### California

**Scope:** Friction tests were conducted in 1994 on research sections originally constructed in 1977 to compare longitudinal and transverse tining. The longitudinally tined section is located near San Diego and the transversely tined section is near Oakland.

**Findings:** Lack of information on the type and quality of the concrete mix and different construction procedures and differing traffic volumes makes direct comparisons of the two sections impossible. However, the friction numbers on the longitudinally tined [19 mm (3/4 in) spacing between tines] section with a smooth tire on the skid trailer at 96 km/h (60 mph) were above 40, which is very good. It was also noted that the friction numbers for both the 13 mm spacings for transversely tined and longitudinally tined textures were significantly lower than for the wider, more durable tine spacings. The California mix design procedures requires a minimum of 30 percent siliceous sand and a minimum coefficient of friction of 0.30 (CALTRANS test procedure).

Some historical information regarding the traffic exposure since the initial construction are as follows:

| Total to 1994 Test | 101 | 805 |
|---|---|---|
| EAL (18,000 lb) | 6,270,000 | 10,640,000 |
| Truck passes | 5,467,000 | 12,967,000 |
| AADT (92) | 17,000 | 76,000 |
| Peak hour | 1,850 | 6,600 |

**Status:** No further testing is planned.

**References:**

Surface Textures for PCC Pavements, Memo to File, Robert Page, California DOT, October 31, 1994 (Revised 7/17/96).

B.F. Neal, *"An Evaluation of PCC Pavement Tine Texturing Patterns,"* FHWA/CA/TL-85/05, Caltrans, November 1985.

B.F. Neal, D.E. Peck, J.H. Woodstrom, D.L. Spellman, *"Surface Textures for PCC Pavement,"* FHWA-CA-TL-78-14, Caltrans, April 1978.

**Test Results:** Results from the 1994 friction tests performed on the test sections, along with the respective speed gradients, are listed below.

### California 1994 Friction Test Results (ASTM E 274 Trailer)

| TIRE TYPE | RIBBED (E 501) Tire | | | SMOOTH (E 524) Tire | | |
|---|---|---|---|---|---|---|
| **TEXTURE TYPE** | 96 km/h | 80 km/h | 64 km/h | 96 km/h | 80 km/h | 64 km/h |
| Long. Broom | 30 | 33 | 38 | 14 | 15 | 19 |
| Trans. (13 mm) | 29 | 35 | 39 | 20 | 23 | 28 |
| Trans. (19 mm) | 35 | 37 | 39 | 26 | 30 | 31 |
| Long. Astroturf | 27 | 32 | 37 | 11 | 14 | 17 |
| Long. (19 mm) | 50 | 54 | 57 | 40 | 48 | 53 |
| Long. (13 mm) | 47 | 52 | 57 | 25 | 29 | 36 |

### California 1994 Speed Gradient

| SPEED GRADIENT | G (96-80) | | G (80-64) | | G (96-64) | |
|---|---|---|---|---|---|---|
| **TEXTURE TYPE** | Rib. | Sm. | Rib. | Sm. | Rib. | Sm. |
| Long. Broom | 0.30 | 0.10 | 0.50 | 0.40 | 0.40 | 0.25 |
| Trans. (13 mm) | 0.60 | 0.30 | 0.40 | 0.50 | 0.50 | 0.40 |
| Trans. (19 mm) | 0.20 | 0.40 | 0.20 | 0.10 | 0.20 | 0.25 |
| Long. Astroturf | 0.50 | 0.30 | 0.50 | 0.30 | 0.50 | 0.30 |
| Long. (19 mm) | 0.40 | 0.80 | 0.30 | 0.50 | 0.65 | 0.35 |
| Long. (13 mm) | 0.50 | 0.40 | 0.50 | 0.70 | 0.50 | 0.55 |

## Colorado

**Scope:** Texture, friction, profile, and noise tests were performed on nine test textures before traffic was released on the reconstructed pavement in the fall of 1994. Tests were repeated in July 1995. The test textures are longitudinal and transverse tining, longitudinal and transverse astroturf drag, and transverse saw cut grooving (see description below).

**Findings:** The variable transverse tining had the highest friction numbers, while the longitudinal astroturf drag and longitudinally tined sections had the lowest noise generation. The transverse and longitudinal burlap dragged sections resulted in very low friction numbers (smooth tire: 15 and 11; ribbed tire: 40 and 32, respectively) at 96 km/h even with 80 to 90 percent silica sand and do not provide adequate macrotexture for good surface drainage. Also, the friction numbers decreased significantly in the first year of traffic. The friction number on the longitudinally tined section was above 36 when tested with a smooth tire at 96 km/h, which is very good. No direct comparison of the splash and spray between the longitudinally and transversely tined or grooved sections was made. A comparison of variable transversely tined (plastic concrete) and variable transversely grooved (diamond sawed into the hardened concrete) sections indicated that tined sections performed slightly better in providing friction, and the saw grooved sections were slightly quieter (up to 4 dBA).

**Status:** Testing will continue for the next 3 years.

**References:**

PCCP Texturing Methods, Field Notes, Ahmad Ardani, Colorado DOT, August 21, 1995.

PCCP Texturing Methods, Technical Report, Ahmad Ardani, Colorado DOT, February 1995.

Colorado DOT Research-Study proposal, Ahmad Ardani, May 17, 1993.

**Test Results:** The following are noise, friction, and texture results for 1994 and 1995:

| SECTION | DESCRIPTION |
|---|---|
| 1 | Transverse tining, uniform 26 mm spacing (State standard) |
| 2 | Transverse astroturf drag |
| 3 | Transverse random tining (16 mm - 22 mm - 19 mm)* |
| 4 | Transverse tining, uniform 13 mm spacing* |
| 5 | Transverse random sawing (16 mm - 22 mm - 19 mm)* |
| 6 | Transverse tining, uniform 26 mm spacing* |
| 7 | Longitudinal sawing, 19 mm spacing* |
| 8 | Longitudinal astroturf drag |
| 9 | Longitudinal tining, 19 mm spacing* |

*Preceded by longitudinal astroturf drag.
All sections first received a longitudinal burlap drag. Sections were planned to be 3 mm deep and 3 mm wide (as constructed measurements were not recorded).

## Colorado Test Section: I-70 at Deertrail

| Test Results: Noise [dB(A)] at 105 km/hr | | | | | | |
|---|---|---|---|---|---|---|
| Pvt Section | Inside Vehicle | | 7.5 m from Road | | Wheel Well | |
| | 1994 | 1995 | 1994 | 1995 | 1994 | 1995 |
| 1 | 68 | 67 | 89 | 87 | 104 | 107 |
| 2 | 67 | 66 | 87 | 83 | 102 | 104 |
| 3 | 68 | 68 | 90 | 88 | 103 | 106 |
| 4 | 68 | 68 | 87 | 86 | 102 | 105 |
| 5 | 66 | 67 | 88 | 86 | 103 | 106 |
| 6 | 67 | 67 | 87 | 86 | 102 | 105 |
| 7 | 66 | 66 | 85 | 82 | 99 | 103 |
| 8 | 66 | 65 | 84 | 82 | 99 | 101 |
| 9 | 68 | 67 | 88 | 84 | 101 | 104 |

Test vehicle was a 1994 Oldsmobile Cutlass station wagon.

| Test Results: Friction (ASTM Method E 274) | | | | | | |
|---|---|---|---|---|---|---|
| Pvt Section | 64 km/h | | 80 km/h | | 96 km/h | |
| | 1994 | 1995 | 1994 | 1995 | 1994 | 1995 |
| 1 | *56/54 | 56/43 | 58/48 | 50/41 | 52/45 | 46/35 |
| 2 | 68/48 | 52/22 | 68/40 | 45/18 | 52/35 | 40/14 |
| 3 | 69/67 | 59/52 | 68/58 | 52/50 | 58/52 | 51/45 |
| 4 | 68/62 | 59/55 | 68/58 | 56/55 | 58/55 | 57/49 |
| 5 | 60/59 | 52/50 | 60/52 | 50/45 | 49/45 | 46/41 |
| 6 | 60/55 | 56/42 | 59/49 | 50/39 | 51/43 | 49/35 |
| 7 | 54/55 | 50/48 | 52/49 | 48/46 | 44/41 | 39/32 |
| 8 | 52/30 | 49/20 | 48/21 | 39/16 | 39/19 | 33/11 |
| 9 | 65/57 | 55/50 | 61/52 | 52/49 | 51/44 | 42/36 |

*Ribbed tire/Smooth tire

| TEST RESULTS TEXTURE | | |
|---|---|---|
| Pvt Section | ASTM E 965 (mm) | |
| | 1994 | 1995 |
| 1 | 0.91 | 1.0 |
| 2 | 0.79 | 0.51 |
| 3 | 1.14 | 1.72 |
| 4 | 1.00 | 1.32 |
| 5 | 1.07 | 1.24 |
| 6 | 1.04 | 0.90 |
| 7 | 1.14 | 1.32 |
| 8 | 0.51 | 0.38 |
| 9 | 1.22 | 0.64 |

### Iowa

**Scope:** Friction and noise tests were planned to be conducted on nine test sections on IA 163 in Polk County. The test sections, constructed in the late fall of 1993, consist of transverse and longitudinal tining of varying depth and spacing, artificial turf drag only, a carbide milled surface, and a transversely grooved surface (see description below).

**Findings:** Friction tests were conducted in October 1994 using ribbed and smooth tires at 56 km/h, 72 km/h, and 90 km/h. The ribbed tire test at 90 km/h resulted in the highest friction number for the transversely tined section, 13 mm spacing and 2 mm depth. The same section had the highest friction under the smooth tire test at 90 km/h, only 6 numbers lower.

**Status:** No noise data and only limited friction and texture measurements are available from the Iowa experimental texturing sections. Friction data will be collected from the test sections during the annual skid testing of the State system in early 1996. Iowa has, however, taken castings from tined sections having low-noise characteristics and has furnished them to the contractor and inspection personnel as an example of what the finished product should look like.

Visual observations on noisy PCCP sections indicated that the tines were pulled unevenly and were too deep (probably creating a wider groove) and caused an objectionable noise inside the vehicle.

**Surface Texture Mold:** Iowa has developed a method to reproduce a PCC pavement texture from an existing surface using molding materials and food coloring. An area of the pavement is cleaned, a mold release agent is sprayed on the surface, a 156 mm by 156 mm frame is sealed onto the roadway, and a polyurethane mix is placed in the mold and allowed to set. This will act as the "negative" field model. The model is taken into the laboratory and a "positive" is made from that model for an exact duplicate of the road surface. Food coloring is added to provide color definition. For more information on the construction of the mold, contact Mr. Robert Steffes, Iowa DOT, 515-233-2748.

**References:**

Correlating Annoyance of Noise Inside a Car to Tining Methods on Portland Cement Road Surfaces, Research Project Proposal, Iowa DOT, December 1994.

Tine Impressions from PCC with RTV Rubber Molds, Steffes, May 1995.

**Results:** The following friction test results were obtained on October 10, 1994:

| SECTION | DESCRIPTION |
|---|---|
| 1 | Transverse tining, 13 mm spacing, 3 to 5mm deep |
| 2 | Transverse tining, 13 mm spacing, 1.5 mm deep |
| 2A | Transverse tining, 19 mm spacing (standard) |
| 3 | Longitudinal tining, 19 mm spacing, 1.5 mm deep |
| 4 | Longitudinal tining, 19 mm spacing, 3 to 5 mm deep |
| 5 | Transverse tining, 19 mm spacing (variable), 3 to 5 mm deep |
| 6 | Transverse tining, 19 mm spacing (variable), 1.5 mm deep |
| 7 | Longitudinal astroturf drag |
| 8 | Milled surface |
| 9 | Transverse grooving (hardened concrete), 13 mm spacing |

## Iowa Test Sections

| Test Results: Texture (E 965) & Friction (E 274) | | | | |
|---|---|---|---|---|
| Pvt Section | ASTM 965 mm | | FRICTION | |
| | | 56 km/h | 72 km/h | 90 km/h |
| 1 | 1.00 | *57/50 | 52/46 | 48/43 |
| 2 | 0.94 | 60/52 | 63/47 | 51/45 |
| 2A | 0.95 | 58/51 | 53/47 | 50/43 |
| 3 | 0.96 | 49/42 | 44/36 | 44/34 |
| 4 | 1.12 | 46/46 | 41/40 | 40/39 |
| 5 | 0.85 | 47/45 | 43/41 | 43/37 |
| 6 | 0.76 | 51/46 | 46/40 | 43/36 |
| 7 | 0.37 | 48/42 | 42/28 | 37/26 |
| 8 | 0.90 | 49/39 | 45/34 | 42/30 |
| 9 | 0.93 | 53/52 | 50/45 | 49/44 |

*Ribbed tire (E 501)/Smooth tire (E 524)

### Michigan

**Scope:** The Detroit, Michigan, I-75 European Demonstration Project compares the exposed aggregate surface treatment and high-quality two-layer concrete mix design to Michigan's standard concrete mix design (including higher quality aggregates not normally used) with a standard transversely tined texture. This section has a very high volume of heavy trucks (5,000 per day), and tire / pavement noise does not dominate.

**Findings:** Friction tests on the sections before they were opened to traffic in 1993 and tests performed in 1994 showed friction increased during this period but that the exposed aggregate surface is about 10 numbers lower than Michigan's standard tined surface (from an average of 37.6 to 42.1 for the exposed aggregate surface and from 46.0 to 53.2 on the Michigan transversely tined section). Reports from Austria have also shown lower friction results initially until the contractors become more experienced with the exposed aggregate surface treatment. A review of the Michigan test sections in May 1994 revealed that many of the 4 to 8 mm particles were oriented with a flat side rather than with an edge pointed up, perhaps because of overfinishing the surface. Also, the sand used was 0 to 4 mm, not 0 to 1 mm as recommended, and some of these larger smooth sand particles were on the surface also. Both these factors would contribute to lower initial skid resistance. With more experience, these deficiencies can be corrected. **However, noise values for the two sections, both inside and outside the vehicle using third octave band analysis procedures, were virtually identical.**

**Status:** The European and Michigan standard sections will continue to be evaluated for ride quality, surface distress, friction, and noise until 1998.

**References:**

First Year Performance of the European Concrete Pavement on Northbound I-75 - Detroit, Michigan, David L. Smiley, Michigan DOT, February, 1995.

Construction of European Concrete Pavement on Northbound I-75 - Detroit, Michigan, Julie Weinfurter, Michigan DOT, July 1994.

**Results:** Michigan Standard (25 mm Transversely Tined) Texture vs. European Exposed Aggregate Section: I-75 in Detroit, Noise and Friction.

1. Measurements taken 17 m from the Michigan and European Sections using a sound level meter (1.5 m high) and a Nagra tape recorder:

| | | | |
|---|---|---|---|
| European | 75.9 dB(A), | 76.7 dB(A), | 76.0 dB(A) - tape |
| Michigan | 75.7 dB(A), | 76.1 dB(A), | 76.4 dB(A) - tape |

2. Measurements inside a Dodge Dynasty traveling at 80 km/h taken with the windows open and closed, using the sound level meter and the Nagra tape recorder:

| | Windows | |
|---|---|---|
| | Closed | Open |
| European | 64.5 dB(A)<br>66.3 dB(A) - tape | 66.8 dB(A)<br>66.7 dB(A) - tape |
| Michigan | 65.2 dB(A)<br>65.9 dB(A) - tape | 67.4 dB(A)<br>67.4 dB(A) - tape |

3. Average friction numbers (ASTM E 274 Skid Trailer) for 1993 and 1994:

| | 1993 | 1994 |
|---|---|---|
| European | 37.6 | 42.1 |
| Michigan | 46.0 | 53.2 |

Presumed use of the ribbed tire (E 501). Values increased during the first year, probably reflecting the wearing away of curing compound as initial tests were taken prior to opening to traffic.

## Minnesota

**Scope:** Texture test sections originally constructed in 1987 on TH 12 near Willmar and I-90 near Albert Lea. The Willmar section was retested for noise production in 1994. The texture sections consisted of transverse tines uniformly spaced from 26 to 78 mm, a variable spaced transversely tined section, an astroturf drag (control) section, and a bituminous section.

**Findings:** The quietest section was the asphalt concrete, followed by the longitudinal astroturf drag control section, followed by the 26 mm transversely tined section. Measurements inside and outside the vehicle were consistent in their outcome. Minnesota concluded that the tire / pavement noise does not begin to dominate until the vehicle reaches 80 km/h, and the noise spectra middle frequency range (third octave band analysis) can differ greatly from one texture to the next without a significant change in the total overall noise. Recent observations by others during a rain indicated that the transversely tined sections had less splash and spray than the dense-graded asphalt section.

**Status:** Minnesota will work with Wisconsin to define the noise frequency that causes objectionable noise (tire whine or rumble) within the vehicle. Minnesota is also cooperating with the Wisconsin efforts to compare the noise and friction of various AC surfaces with the experimental PCC sections.

**References:**

"Additional information for Tire / pavement test done in Willmar last fall," Memo, Mel Rosen, MNDOT, February 14, 1995.

Traffic Noise Tire / Pavement Interaction, Combined Five-Year Studies of I-90 and TH 12, MNDOT, 1987.

**Results:** Noise results are from the 1987 test at Willmar and the 1995 test. Texture tests were taken by the Sand Patch Test (ASTM E 965).

| Pavement Section | Texture Depth (mm) |
|---|---|
| Transverse Variable (26, 39, 52, 65 mm) | 0.41 |
| Transverse (78 mm space) | 0.61 |
| Transverse (65 mm space) | 0.61 |
| Transverse (52 mm space) | 0.68 |
| Transverse (45 mm space) | 0.57 |
| Transverse (26 mm space) | 0.75 |
| Asphalt Concrete | 0.28 |
| Astroturf Drag (Long.) | 0.26 |

## Minnesota Test Section: STA 12 at Willmar

| Pvt Section | Ext. Avg. Car @ 88 km/h | | Ext. Control Car @ 88 km/h | | Int. Control Car |
|---|---|---|---|---|---|
| | 1987 | 1995 | 1987 | 1995 | 1987 |
| 26, 39, 52, 65 mm repeated | 78.5* | 78.7 | 79.5 | 78.2 | 71.4 |
| Astroturf | 74.0 | 75.0 | 73.5 | 74.5 | 67.8 |
| 26 mm | 76.0 | 76.5 | 75.5 | 76.1? | 68.1 |
| 45 mm | 80.5 | 82.0 | 80.5 | 81.1 | 71.1 |
| 52 mm | 80.0 | 80.6 | 81.0 | 79.9 | 71.9 |
| 65 mm | 80.5 | 81.6 | 82.0 | 81.9 | 72.0 |
| 78 mm | 77.5 | 79.1 | 78.5 | 79.1 | 72.1 |
| Bituminous | 70.2** | 72.5 | 68.8** | 72.4 | 65.1 |

*All noise measurements in dB(A).
**Average of three bituminous pavements
All PCC sections transversely tined.
The astroturf section is the control section.

### North Dakota

**Scope:** Reports analyzing the 1993 and 1994 testing in North Dakota are now available. Nine test textures composed of transverse tines uniformly spaced from 13 to 104 mm, transverse variable spaced tining, and a longitudinally tined section are being monitored.

**Findings:** Noise measurements for the nine textured sections were taken 10.7 and 45.7 m from the travel lane and inside four test vehicles. The skewed tining and the variable spaced tining had the lowest noise production outside the vehicle. Noise inside the vehicles was very close in range, with no one section having a great advantage or disadvantage.

**Status:** The test section will continue to be monitored.

**References:**

Evaluation of Tining Widths to Reduce Noise of Concrete Roadways, Mike Marquart, NDDOT, February 1995.

Evaluation of Tining Widths to Reduce Noise, I-94 Eagles Nest to Geck, NDDOT, March 1994.

**Results:** The texture information was determined in 1995 by ASTM E 965. Noise data presented here was obtained in 1994. The 1995 noise data is currently being analyzed.

| Pavement Section | Texture Depth (mm)—ASTM E 965 |
|---|---|
| Transverse (26 mm skew) | 0.60 |
| Transverse (19 mm spacing) | 0.82 |
| Transverse (52 mm spacing) | 0.69 |
| Transverse (78 mm spacing) | 0.49 |
| Transverse (104 mm spacing) | 0.53 |
| Transverse (Variable) (26, 52, 78, and 104 mm) | 0.43 |
| Transverse (13 mm spacing) | 1.17 |
| Longitudinal (19 mm spacing) | 0.37 |
| Transverse (control-26 mm spacing) | 0.76 |

## North Dakota Test Section: I-94 at Eagles Nest

| Pvt Section | Exterior (105 km/h) | | Interior | | | |
|---|---|---|---|---|---|---|
| | 10.7 m | 45.7 m | Ford Tempo | Dodge Shadow | Suburban | Dodge Van |
| 26 mm skew | 70* | 65 | 73 | 74.3 | 71.3 | 75.0 |
| 19 mm | 71 | 69 | 74.3 | 74.9 | 71.6 | 75.2 |
| 52 mm | 69 | 66 | 73.9 | 74.2 | 72.3 | 73.9 |
| 78 mm | 69 | 68 | 73.7 | 73.7 | 72.2 | 73.6 |
| 104 mm | 70 | 67 | 72.8 | 75.1 | 71.8 | 74.3 |
| Var. ** | 67 | 65 | 73.1 | 74.2 | 71.4 | 74.4 |
| 13 mm | 70 | 69 | 73.9 | 74.5 | 72.7 | 73.9 |
| 19 mm Long. | 69 | 69 | 74.7 | 74.5 | 72.1 | 74.7 |
| 26 mm control | 69 | 68 | 75.1 | 75.8 | 72.1 | 76.7 |

*All noise measurements in dB(A).

**Variably spaced at 26, 52, 78, and 104 mm.

Exterior noise for the 26 mm skew and variable tine spacings are questionable because they are located near an overhead structure.

All sections are transversely textured unless otherwise stated.

## Virginia

**Scope:** Texture measurements and skid data are available from a section of I-64 in Virginia that has longitudinal tining and was constructed in 1972. This concrete has a high percentage of siliceous sand in the fine aggregate. The 19 mm (0.75 in) tine spacing with 3.2 mm wide tines preceded by a burlap drag was found to produce the most satisfactory surface.

**Findings:** Friction tests taken in 1994 at 64 km/h (40 mph) with the standard ASTM skid trailer with blank tires showed a range of SN from 37 to 48 for the longitudinally tined CRCP and from 35 to 41 for the adjacent dense-graded AC overlaid section (year unknown). Mean texture depth on the CRCP was 0.89 mm (ASTM E 965).

Also, in another 1972 project on International Terminal Boulevard between I-564 and the International Terminal in Norfolk, which included both longitudinal and transverse tining, TRR 652 states that existing noise measurement and analysis procedures could not detect or identify the sections with annoying tire whine as identified by a technical panel driven through the various test sections.

**Status:** No specific followup effort is planned.

**References:**

Texturing New Concrete Pavements, D. C. Mahone, K. H. McGhee, J. G. G. McGhee, and J. E. Galloway, TRR 652, pp. 1-10.

## Wisconsin

**Scope:** Wisconsin DOT is conducting a major research study to quantify the impacts of the pavement surface texture on noise, safety, and winter maintenance. The concrete texture test sections, consisting of longitudinally tined, transversely tined, skewed tined, and Skidabrader (shotblasted) surfaces, are located on STH 29 near Eau Claire. The bituminous sections, consisting of standard dense-graded, stone matrix, and SHRP mix design asphalt surfaces are located on I-43 near Milwaukee. A literature search of U.S. and European studies was conducted before the test phase. An addendum to the research project measured interior narrow band noise frequencies on nine of the PCCP transverse tined sections, three of the ACP sections, and one of the continuously ground sections. The additional work was performed in cooperation with the Minnesota DOT, and its purpose is to measure the irritating whine that is not detected by total noise measurements.

**Findings:** The passby method was initially used to measure noise with a test car and flatbed truck and was later supplemented by interior vehicle noise measurements. Friction tests were performed with a ribbed and smooth tire at 65 and 80 km/h. Preliminary results showed that the transversely tined sections have the best friction, but also have dominant frequencies in the noise spectra (peak pure tone pressure levels up to 10 dB(A) around 1,000 Hz). The asphalt pavements and longitudinally tined sections do not have dominant noise frequencies. The Skidabrader results indicate this equipment might also provide an acceptable exposed aggregate surface if the top layer has a high-quality concrete mixture.

**Status:** The draft Phase I final report is now in the process of development, and a work plan for Phase II is being developed. A further noise analysis will be performed, and the interim report is expected by July 1996.

**References:**

Noise, Safety and Winter Maintenance Characteristics of Pavement Surface Texture in Wisconsin, Draft, Wisconsin DOT, HNTB Corporation, Marquette University, August 1995.

Pavement Surface Texture and Noise Research, Memo, Minnesota DOT, 1996.

Impacts Related to Pavement Texture Selection, Work Plan, WisDOT, September 1993.

"Noise Characteristics of Pavement Surface Texture in Wisconsin," Draft TRB Paper, D. A. Kuemmel, J. J. Jaeckel, A. Satanovsky, S. F. Shober, and M. Dobersek, March 1996, 37 pp.

| Section | Description (as planned*) and Texture |
|---|---|
| 1 | Longitudinal turf drag, 0.22 mm** |
| 2 | Transverse tining, 26 mm spacing, 3 mm deep |
| 3 | Transverse tining, 39 mm spacing, 3 mm deep, 0.22 mm** |
| 4 | Long., 26 mm spaced/Trans., 156 mm spacing, 0.36 mm** |
| 5 | Long. tining, 26 mm spacing, 1.5 mm deep, 0.40 mm** |
| 6 | Longitudinal tining, 26 mm spacing, 3 mm deep, 0.45 mm** |
| 7 | Transverse tining, 26 mm spacing, 3 mm deep |
| 8 | Skewed (1:6), 26 mm spacing, 3 mm deep, 0.46 mm** |
| 9 | Transverse tining, 13 mm spacing, 3 mm deep, 0.46 mm** |
| 10 | Transverse tining, 19 mm spacing, 3 mm deep, 0.47 mm** |
| 11 | Transverse tining, random spacing, 3 mm deep, 0.55 mm** |
| 12 | Transverse plastic broom, 1.5 mm deep, 0.59 mm** |
| 13 | Transverse tining, 26 mm spacing, 3 mm deep |
| 14 | Transverse tining, 26 mm spacing, 1.5 mm deep, 0.60 mm** |
| 15 | Transverse tining, 26 mm spacing, 3 mm deep, 0.60 mm** |
| 16 | Longitudinal turf drag and Skidabrader, 0.65 mm** |

*Actual spacing, width, and depth were not measured. It is recommended that measurements be taken at 30 locations to verify the texture that was actually constructed. The FHWA texture beam measurements taken in 1995 can be used to obtain this data where tests were taken.

** Sand patch texture depth (ASTM E 965)

## Wisconsin Test Section: STH 29 Clark County

| Pvt Sect | FN 40R ** | Texture mm ASTM E 965 | Exterior Noise Car | | | Exterior Noise Truck | | |
|---|---|---|---|---|---|---|---|---|
| | | | 96 km/h | 105 km/h | 112 km/h | 96 km/h | 105 km/h | 112 km/h |
| 1 | 41 | 0.22 | 79.4* | 80.0 | 81.6 | 90.9 | 93.2 | - |
| 2 | - | - | - | - | - | - | - | - |
| 3 | 51 | 0.22 | 83.8 | 84.8 | 88.7 | 92.7 | 93.9 | - |
| 4 | 49 | 0.36 | 85.3 | 87.2 | 88.8 | 93.2 | 95.0 | 95.6 |
| 5 | 40 | 0.40 | 80.1 | 81.0 | 83.0 | 92.3 | 92.6 | 94.5 |
| 6 | 45 | 0.45 | 80.1 | 84.8 | 82.6 | 91.1 | 93.0 | 94.5 |
| 7 | - | - | - | - | - | - | - | - |
| 8 | 41 | 0.46 | 80.4 | 82.9 | 83.3 | 92.1 | 91.7 | - |
| 9 | 47 | 0.46 | 78.0 | 79.3 | 79.5 | 90.8 | 92.0 | 92.3 |
| 10 | 46 | 0.47 | 79.2 | 80.2 | 81.5 | 90.2 | 91.0 | 92.8 |
| 11 | 43 | 0.55 | 80.8 | 81.7 | 83.9 | 91.6 | 93.5 | 93.3 |
| 12 | 42 | 0.59 | 77.2 | 78.8 | 80.0 | 91.5 | 93.1 | 93.9 |
| 13 | - | - | - | - | - | - | - | - |
| 14 | 41 | 0.60 | 80.2 | 81.3 | 82.5 | 91.5 | 92.5 | 93.0 |
| 15 | 46 | 0.60 | 81.9 | 82.7 | 84.2 | 92.5 | 94.0 | 93.7 |
| 16 | 52 | 0.65 | 81.1 | 82.1 | 83.1 | 90.5 | 91.6 | 92.4 |

*All noise measurements in dB(A).

**Friction tests performed in early 1995 (ASTM Method E 274 Skid Trailer with ribbed tire-E 501).

## FRICTION DATA
### STH 29 Texture Test Sections, Clark and Chippewa Counties at One Year of Age (1996)

| Section | Texture Type | 40 mph Ribbed Tire (E501) | 50 mph Ribbed Tire (E501) | 40 mph Smooth Tire (E524) | 50 mph Smooth Tire (E524) |
|---|---|---|---|---|---|
| 1 | Longitudinal Turf Drag | 46.4 | 40.9 | 18.9 | 15.9 |
| 3 | 38 mm Transverse Tine | 52.6 | 48.1 | 39.2 | 34.6 |
| 4 | Hatched | 48.5 | 42.2 | 37.5 | 33.3 |
| 5 | 26 mm Longitudinal Tine, 1.5 mm Deep | 44.7 | 40.4 | 32.9 | 26.8 |
| 6 | 26 mm Longitudinal, 3 mm Deep | 50.7 | 46.4 | 38.6 | 30.3 |
| 8 | Skew | 51.3 | 47.3 | 35.7 | 33.2 |
| 9 | 13 mm Transverse Tine | 52.6 | 47.5 | 32.2 | 28.5 |
| 10 | 19 mm Transverse Tine | 51.4 | 44.6 | 37.6 | 30.2 |
| 11 | Random | 48.6 | 44.3 | 31.0 | 26.8 |
| 12 | Plastic Broom | 44.2 | 34.7 | 16.7 | 11.4 |
| 14 | 26 mm Transverse, 1.5 mm Deep | 48.0 | 41.8 | 26.4 | 21.4 |
| 15 | 26 mm Transverse, 3 mm Deep | 49.3 | 41.6 | 32.1 | 27.1 |
| 16 | Skidabrader | 57.8 | 53.5 | 45.0 | 38.4 |

# APPENDIX C

## Issue: General Pavement Surface Type Questions

**Issue:** Discussions of PCC and AC surface textures will produce common questions and points of clarification. General issues are addressed here, with predominant points of view and supporting information provided.

**Need for pavement texture:** Title 23 CFR 500.205(d) published in the December 1, 1993, *Federal Register* established the following requirement:

> "Pavements shall be designed to accommodate current and predicted traffic needs in a safe, durable, and cost-effective manner."

Additional guidance was furnished in the nonregulatory supplement to the above section published in the Federal-Aid Policy Guide on October 5, 1995. Also at that time, the Uniform Guidelines for State Highway Safety Programs was deleted from the Code of Federal Regulations and incorporated into the Highway Safety Grant Management Manual. Other technical guidance is referenced in 23 CFR 625, Design Standards for Highways. FHWA Technical Advisory T 5040.17, dated December 23, 1980, provides guidance for State and local highway agencies in conducting skid accident reduction programs. Reducing the number and severity of wet weather accidents is the primary reason for requiring pavements with safe, durable surfaces.

The following reports provide extensive information on the need for improved surface textures:

- Proceedings, First International Skid Prevention Conference, Parts I and II, Charlottesville, Virginia, U.S.A., 1959; see also the summary in HRB Bulletin 219, Skid Prevention Research, 1959.
- NCHRP Report 37, Tentative Skid-Resistance Requirements for Main Rural Highways, 1967.
- HRB Special Report, State of the Art: Research on Skid Resistance, Highway Research Board Publication 1561, Washington, D. C., 1968, pp. 34-48.
- HRR Record 376, Anti-Skid Program Management and Related Papers, 22 Reports, Highway Research Board, 1971 (Proceedings of the Anti-Skid Program Workshop held Jan.17-18, 1971).
- NCHRP Synthesis of Highway Practice 14, Skid Resistance, 1972 (updated in TRR 622).
- AASHTO Guidelines for Skid Resistant Pavement Design, 1976.
- Proceedings of the Second International Skid Prevention Conference, Columbus, Ohio, 1977 (published in TRR 621, 622, 623, and 624).

PCA Development Bulletin RD111T, "Optimizing Surface Texture of Concrete Pavement," 1995, provides a good summary of historical activities regarding PCC pavements. Gordon Ray and Leonard Norling's 1974 TRB paper, "More Macro Texture in Concrete Pavement for Greater, Longer-Lasting Skid Resistance," provides a summary of the early research efforts to improve the surface texture of concrete pavements that led to the development of the existing guidelines. *Appendix A of NCHRP Synthesis 14 reports that in 1971 16 States considered skid resistance a major problem, 26 considered it a moderate problem, and 6 considered it a minor problem.*

Balmer's paper in TRR 666 (Pavement Texture: Its Significance and Development) and Balmer and Hegmon in TRR 788 (Recent Developments in Pavement Texture Research) provide excellent background information on pavement texture and its effect on friction, noise, and related properties.

FHWA-RD-79-107 (Executive Summary) and FHWA-RD-78-209, Full Report, "Alternatives for the Optimization of Aggregate and Pavement Properties Related to Friction and Wear Resistance," were prepared by an interdisciplinary team of researchers. In addition to skid resistance, the report addresses such tire / pavement interactions as noise generation, tire wear, rolling resistance, and other performance characteristics.

FHWA/RD-80/505, Pavement Macrotexture Review, August 1980, is a summary of Volume IV of a five-volume report entitled, "Effectiveness of Alternative Skid Reduction Measures," FHWA-RD-79-21 (executive summary) and FHWA-RD-79-22 to 25 (main report), covering macrotexture of pavement surfaces. The report presents the fundamentals of tire / pavement skid resistance, macrotexture measurements, and methods of achieving or restoring macrotexture in new or existing pavements.

Available information suggests that 15 to 35 percent of wet weather accidents involve skidding. It is also estimated that up to 10 percent of wet weather accidents are caused by poor visibility due to splash and spray. Adequate macrotexture is needed to reduce or prevent hydroplaning at higher speeds and to improve surface drainage so that splash and spray are minimized.

**Friction numbers for AC and PCC pavements:** There is a wide variation in friction numbers for both of these pavement types. Examples of both excellent and poor pavement surfaces are available. However, design, construction, and maintenance procedures are available to assure adequate friction properties for both pavement types. Highway Research Board Special Report 61F, page 127, documents the Coefficient of Friction (30 mph) obtained during special skid studies conducted during the AASHO Road Test. The final finish for the PCC with siliceous fine aggregate was obtained with two passes of a double thickness burlap drag. The friction results were generally slightly lower for the PCC surface compared to the asphalt pavement sections.

NCHRP Report 37 and the *1976 AASHTO Guidelines for Skid Resistant Pavement Design* still provide useful background information and guidance in designing and constructing skid resistant surfaces. An updated guideline developed by Corsello for Washington's DOT (WA-RD 312.1, July 1993) concluded that the minimum skid number should be 26 based on current research data input into the original NCHRP 37 methodology. This was based on using a ribbed tire for the skid trailer operating at 40 mph (65 km/h). No corresponding number was recommended if a blank tire were used on the skid trailer. This recommendation has not been verified by other researchers.

**Given the wide variations in climate, materials quality and variability, and design, construction, and maintenance procedures in the various States, FHWA does not support the selection of a minimum skid number for use throughout the U.S. Each State is required to develop a skid accident reduction program to reflect its specific conditions.**

**Skid testing with ribbed and smooth tires:** A large number of studies have documented that the smooth or blank test tire provides a much better correlation between the surface texture characteristics and wet weather accidents than if the ribbed tire is used on the ASTM skid trailer (refer to TRR 788, pages 1 to 6). For pavements with excellent macrotexture, the friction numbers obtained for ribbed and blank tires are similar. A good example of the significance of the two procedures is evident in comparing friction numbers and accident rates before and after longitudinal grooving on highway curves. Testing with the ribbed tires would indicate little or no change in the friction number, although the wet weather accident rates may be reduced by up to 50 percent. Testing with the smooth or blank tire will show an increase in the friction number due to the improved surface drainage under the tire provided by the grooved pavement surface and correlates much better with the reduced wet weather accident rate. For inventory purposes, if only one tire is used, the blank or smooth tire is preferred. The ribbed tire masks much of the pavement surface drainage characteristics. Recent PIARC research efforts to develop an International Friction Index from a test at one speed and a concurrent surface texture measurement are promising; the final report was published in the fall of 1995. Additional research is needed to document wet weather accident rates and friction numbers.

**Speed gradient and friction numbers:** The FHWA recommends that the speed gradient be determined in addition to the friction number. Currently, this means tests at two different speeds and probably also with both the ribbed and blank test tires. The speed gradient and the friction number with a blank tire on the skid trailer provides the best single indicator of the hydroplaning potential of the pavement surface. **As noted above, the proposed PIARC measurement method would greatly simplify the testing procedure and also allow for correlations between different equipment types.**

The Second Annual Tire/Runway Friction Workshop was held at the NASA Wallops Island Flight Facility, Virginia, on May 15-19, 1995. Copies of the Proceedings are now available and plans are well along for a May 1996 meeting. Various types of friction measuring devices and texture measuring equipment were demonstrated on a variety of test pavements. These equipment and procedures are applicable to testing highway pavements also, although different criteria are appropriate for highway and airport pavements. Of particular significance are the high-speed texture measuring devices. However, one critical deficiency in most systems is the inability to consider both transverse and longitudinal texture. This is critical in evaluating the drainage potential for the various textures, such as the longitudinal, transverse, and exposed aggregate textures. Concurrent longitudinal and transverse slope data would help to analyze the surface drainage characteristics that are sometimes ignored or overlooked. Further development of the outflow meter would help evaluate the pavement surface drainage characteristics.

**Tire / pavement noise, total noise (cars vs. trucks), and noise frequency:** On June 12, 1995, the FHWA reissued existing guidance on "Highway Traffic Noise Policy and Guidance" with Mr. Kane's memorandum to Regional Administrators. Of major importance for this effort are the following conclusions regarding pavements (paraphrased from page 38):

- Tire / pavement noise varies with pavement surface types and textures, type of tires, number of trucks in the traffic stream, and vehicle speeds.
- It is difficult to forecast pavement surface condition into the future, and unless definite knowledge is available on pavement type and condition and its noise generating

characteristics, no adjustments should be made for pavement type in the prediction of highway traffic noise levels.

- The use of specific pavement types or surface textures must not be considered as a noise abatement measure.

There are currently no standard ASTM or AASHTO test procedures for measuring tire / pavement noise. AASHTO recently adopted a standard recommended practice for measuring highway noise, FHWA-DP-45-1R, "Sound Procedures for Measuring Highway Noise, 1981." This only applies to total noise adjacent to the roadway. There are no standards for directly evaluating tire / pavement noise, although a variety of techniques to measure interior vehicle noise and to make pavement noise inventories (usually noise trailers) have been used. A specially instrumented 1.2 m x 1.8 m trailer developed by the University of Washington Sound and Vibration Research Laboratory and Washington DOT was effectively used to inventory tire noise on pavements due to tire wear from 1985 to 1991 (WA-RD 276.1, dated August 1992).

Another major problem has been that the A weighted noise scale did not identify those surfaces that result in objectionable high-pitched tire whine or lower frequency rumble, when the broad band frequency spectrum was analyzed. It is usually the tonal noise associated with higher frequencies, not the total noise level that is most objectionable. **Wisconsin researchers, using a measurement procedure based in part on SAE J1477, Recommended Practice for Measurement of Interior Sound Levels of Light Vehicles, have now appeared to solve this problem.** A Larson-Davis Type 2900 two-channel real-time acoustical analyzer was used in the Fast Fourier Transform analysis mode in three different types of passenger vehicles. Pure tones around 1,000 Hz were believed to represent the pavement whine. Similar conclusions were reported by J. Weaver (Deep Grooving of Concrete Roads, Cement and Concrete Association, London, October 1972) and also presented at the 2nd European Symposium on Concrete Roads, Bern, Switzerland, June 1973. Additional testing to verify these early results are being planned for the summer of 1996.

NCHRP Synthesis Topic 26-05, "Relationships Between Pavement Surface Texture and Highway Traffic Noise," is currently being developed, which may provide some additional guidance. TRR 652 (Mahone and McGhee) also documents this problem and similar problems are noted in Missouri research reports [73-3, 74-5, and 78-3 (September 1982)]. Similar conclusions were made in the October 1994 BRITE/EURAM State-of-the-Art Report. A harmonization of the methods for measuring the influence of road surfaces on traffic noise is expected soon as a result of work being done by an European standardization group (ISO/TC 43/SC 1/WG 33). **Wisconsin researchers have now found a method to objectively evaluate the pure tones that result in objectionable tire whining. This procedure should make it possible to identify and evaluate those surface texture characteristics that result in objectionable tonal noises. Guidance can then be developed to improve construction procedures to minimize annoying tonal noises and to verify that this has been accomplished.** The FHWA plans to update existing technical guidance on surface texturing in 1997 when this additional research is completed.

Currently, the Minnesota, Wisconsin, and New Jersey Department of Transportations and the New York Throughway Authority are evaluating possible corrective treatments for existing concrete roadways that are generating objectionable noise. Iowa and Michigan have also reported on previous corrective treatments to address similar problems. Concerns about objectionable noise from widely spaced transverse tining have also been reported in Nevada. This demonstrates that past guidance in this area has not been adequate or effective.

Quite often the difference in noise emissions between AC and PCC pavements is due to the average texture depth provided between the AC and the transversely tined PCC. For similar braking force coefficients, an AC pavement must have a mean texture depth of 2 mm compared to 0.8 mm for the transversely tined PCC, according to research by TRL in Great Britain (TRRL Report 896). **If the AC is quieter, it probably means it has lower skid resistance qualities.**

If objectionable tonal noises (tire whine or lower frequency rumble) can be eliminated, the transversely tined PCC surface will have similar or better friction characteristics, similar total noise characteristics, and less splash and spray compared to dense-graded asphalt concrete surfaces.

Premium quality surface textures are available for both PCC and AC pavements where conditions warrant and their use is cost effective.

**Skid resistant surfaces in urban areas:** It is essential that safe, durable, and cost-effective pavement surfaces be provided in our often congested urban areas. The provision of pavements with good friction characteristics is important to reduce deaths, personal injuries, and property damage associated with skidding accidents or those accidents caused by poor visibility associated with splash and spray. In addition, the costs associated with user delay during accident incidents must be considered. The concern for small (imperceptible to the human ear) 3 dB(A) or less differences in noise emission levels or objectionable tonal noises should not override the need for providing a safe, durable, cost-effective pavement surface.

# APPENDIX D

## Issue: Safety of PCC and AC Surface Textures

**Issue:** The question of safety is generally evaluated in terms of the stopping ability of a vehicle during wet conditions. When the pavement is dry, almost all surfaces provide adequate friction to stop quickly. The characteristics that relate to safe pavements is adequate microtexture for stopping at all speeds and adequate macrotexture for surface drainage to prevent hydroplaning at high speeds so the tire remains in contact with the pavement microtexture. Directional control during stops is also important. **The purpose of surface texture is to reduce the number and severity of wet weather accidents. Is there a safety advantage to either AC or PCC pavements?**

### Findings:

**Dense-graded asphalt** concrete pavement provides a skid resistant surface by the nature of the texture provided by the exposed aggregate. The standard dense-graded AC surface will maintain friction numbers in the 40 to 50 range at 64 km/h, with a speed gradient of 0.3.[1] Dense-graded AC subjected to poor quality materials, poor construction methods, severe climatic conditions, or simply age will lose some degree of skid resistance. Polishing of the aggregate, bleeding of asphalt cement, and rutting of the surface layer are some of the distresses that can contribute to unsafe skid conditions. The normal life span of an AC pavement is approximately 10 to 15 years, assuming good maintenance practice, after which a rehabilitation process is usually required to extend its life.

**Open-graded asphalt** concrete provides good skid resistance by higher levels of macrotexture than a dense-graded layer. In additon, any potential for hydroplaning is further reduced by allowing water to drain through the pore openings on the surface. If the aggregate on the surface is held secure by the asphalt cement, good skid resistance and low-noise properties will be maintained early in the pavement's life. However, aggressive maintenance on the surface needs to be practiced for the 8 to 10 years of its service life to maintain this surface type's desirable characteristics. Particles, such as sand grit or salt that clog up the pore areas on the surface, need to be removed if water is to drain freely and friction is to be kept at an acceptable level. In Europe, experience has shown that the open-graded AC surface needs to be cleaned twice a year to retain most of its desirable properties. Also, an open-graded AC will behave differently during freezing conditions than an adjacent dense-graded AC pavement necessitating knowledgeable maintenance efforts to minimize the effects of early freezing.[2,3]

Open-graded AC friction courses, properly maintained, reduce hydroplaning, provide high wet weather friction, reduce splash and spray, reduce headlight glare during wet weather driving, and reduce traffic noise both inside and outside of the vehicle.[4] Better information is needed on the change in friction and noise properties of this surface type over its service life.

**Transversely tined PCC** pavements with a hard fine aggregate provide excellent skid resistance through a combination of microtexture and macrotexture, along with good surface drainage. The friction properties will generally be present for the life of the pavement (up to 30 years) given that good construction practice and high-quality materials are incorporated, and studded tires are not used extensively. Friction quality can be reduced if the surface is tined too deep or the tines are too closely spaced, causing spalling of the surface under traffic.

**While friction properties are a convenient way to estimate the safety characteristics of various pavement types and surface textures, the real test is whether the pavement texture reduces the number and severity of wet weather accidents.** The following unpublished 1991 to 1993 wet weather accident information for the Minneapolis-St Paul, Minnesota, Metropolitan Area shows the accident rate on various concrete surface textures of different average ages:

**Table 2. 1991 to 1993 Twin Cities Metropolitan Area Accident Rates on Various Concrete Pavement Textures.**

| Type/Condition Concrete Surface | Years Built | Avg. Age | No. of Projects | Wet/Total Accidents (percent) | Wet/Total Accidents Wet and Dry* (percent) |
|---|---|---|---|---|---|
| Transverse Tined | 1980-1991 | 7 | 21 | 13.86 | 19.98 |
| Diamond Ground | 1953-1967 | 32 | 7 | 22.01 | 25.37 |
| Burlap Drag | 1968-1977 | 20 | 10 | 18.45 | 27.57 |
| Worn (Studded Tires) | 1958-1965 | 31 | 5 | 19.62 | 27.92 |

*Eliminates severe ice and snow conditions where the type of surface texture is not a relevant factor. This is considered the most appropriate rate for comparisons by Mn/DOT.

This information supports the reduced wet weather accident rate for transversely tined PCC pavements, although it should be noted that these pavements are significantly younger than the other surface textures/conditions compared. The year the various surfaces were diamond ground was not given. It was indicated that some of these sections were diamond ground to reduce faulting, while other sections were diamond ground due to high wet weather accident rates. **It is recommended that all States conduct this type of analysis to verify that the surface textures being constructed result in low wet weather accident rates.** The absence of this type of information was also noted in the PIARC C1—Surface Characteristics Committee Report from the XXth World Road Congress in Montreal (September, 1995).[2] However, it was noted that evidence from the United Kingdom, where a policy[5] on the enhancement of road texture has been in existence for some years, shows there is almost a five times payback in terms of reduction of accidents. One method for estimating the benefits from increasing the friction number is included in FHWA-RD-78-209, pages 203-211.[4]

**Longitudinally tined PCC** pavement will provide good initial skid resistance, but long-term studies have revealed the surface texture can be greatly degraded and lose its desirable friction properties.[6,7] This characteristic is related to the quality of the aggregates used and is <u>not</u> related only to longitudinal tining. High-quality fine aggregates (siliceous sand) and polish-resistant coarse aggregates are needed for this pavement surface to maintain its safety characteristics. If high-quality aggregates are not economically available, then longitudinal grooving or retexturing may be needed periodically to restore good surface friction properties.

The spacing and width of grooves is critical for longitudinal tining or grooving. Wider tining or grooving is particularly objectionable to drivers of vehicles with small tires. The 1976 AASHTO Guidelines for Skid Resistant Pavement Design recommendations for grooved pavements should be followed.[8] Signs warning of longitudinally grooved pavements have been used in California and other States to reduce (not eliminate) motorcyclists' concerns. Also, this texture results in more splash and spray than transversely tined sections.[9,10] This poorer surface drainage is more of a problem in areas with flat longitudinal grades, in sag vertical curves, and superelevation transitions at curves.[8] These factors would be more important in areas subjected to frequent freezing conditions or heavy rainfalls.

**Exposed aggregate surface treatment** on PCC pavements can have friction qualities close or equivalent to transversely tined pavements. This surface texture is more durable than most other PCC types when exposed to studded tire wear. According to European experience, the surface will have a lower initial friction quality, which will steadily increase as the sand grit and mortar are worn away by traffic, thereby exposing the larger (4 to 8 mm) aggregate and increasing the average surface texture depth. European contractors had a learning curve experience when constructing this surface, with the initial surface friction quality growing after each project.[2,11] This surface generally has a lower total noise level than other currently used PCC textures and is not known to have resulted in either a higher pitched tire whining or a lower frequency rumble.

On I-75 in Detroit, Michigan, the 2 km European Demonstration Project exposed aggregate experimental surface had similar total noise and frequency characteristics (one-third octave band analysis) as the adjacent standard Michigan transversely tined section, but initially had 10 numbers lower skid resistance (although above 40, which is considered acceptable). It is likely that contractor inexperience, overfinishing of the surface, and the use of 0 to 4 mm rather than 0 to 1 mm size sand particles contributed to the lower friction resistance. These deficiencies could be easily corrected in future projects. Monitoring of longer term noise and friction properties of these experimental pavement sections continues.[11,12,13]

**Porous PCC** pavement can be constructed using a gap graded mix and is subject to the same limitations as open-graded AC pavements. The initial experience in Belgium with the pavement showed poor durability in freezing weather, but that has since been resolved. At the current time, this technique is still considered experimental due to difficulties in ensuring bonding to the underlying concrete layer.[2,14]

**Two-layer PCC** pavement construction (wet on wet) provides good friction quality by placing higher quality materials in the upper layer. The choice of texture on the surface would have less limitations from a safety perspective because of these higher quality materials. Locally available durable aggregates or recycled concrete pavement can be used in the lower layer. This technique would also allow the use of newer materials like silica fume or fibers to improve the properties of the thinner surface layer. The added construction cost should be considered in a life cycle cost analysis. This might provide a cost-effective long-term solution, particularly in areas with poorer quality aggregates. While not essential, placing both layers with one paver reduces the probability of delamination of the two layers, which has been a particular problem in the past with some reinforced pavements where this process has frequently been used.[2,11,13]

**Existing PCC pavement surface treatments** include:

- retexturing by longitudinal or transverse grooving, diamond or carbide grinding, and shotblasting
- PCC overlays and surface laminates
- AC open- or dense-graded overlays
- microsurfacing overlays

Grooving (longitudinal or transverse) will generally increase the macrotexture and reduce the hydroplaning potential for longer periods than grinding or shotblasting. The grinding and shotblasting alternatives provide improved friction on highly durable aggregate, but if the coarse aggregate is weak and polishes easily, a low friction surface may be made worse or last only a relatively short time. PCC overlays and surface laminates can be used to restore the surface texture but have a higher cost and, in the past, have had some delamination problems. AC overlays have been used to increase the ride and the friction quality, but there exists the potential for the overlay to debond under traffic or rut if design and construction methods are not good. Relumac and Novachip overlays have been used in the U.S. with good results, although Novachip has been used for only a few years. [4,15]

**Recommendations:** Good friction and pavement surface characteristics are directly related to good design and construction practices and high-quality materials. This is very important without respect to the type of surface or surface texture used. Some of the textures or surface treatments require additional maintenance, and the life cycle cost for the premium treatments (new or rehabilitation) should be compared to the standard treatments. Choice of material and surface texture to be used is up to the individual agency. <u>The surface type selected must provide a safe, durable surface and should be cost effective. Design and service life assumptions should be based on periodic evaluations of both pavement management and wet weather accident data.</u>

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# APPENDIX E

## Issue: Tire / Pavement Noise on PCC and AC Pavements

**Issue:** The central question of noise produced from the interaction of the tire and pavement must first be addressed in relation to AC and PCC pavements, then to the various textures of those respective surfaces.

- Is there an inherent difference between the surface properties of AC and PCC?
- Do PCC pavement surfaces produce more noise, or a more irritating noise, than AC pavements?
- Which PCC surface texture is the quietest, and is that surface comparable to the standard AC pavement surface?
- Is the quietest PCC surface texture safe and cost effective?
- What is the difference in durability of surface textures of AC and PCC pavements?

**General**—Recent measurements to completely revise the FHWA Noise Model have provided some general noise comparisons on different type pavements. However, due to the wide variations even within individual pavement types, any analysis should be based on actual data for a particular State's design, construction, and maintenance practices.

British research shows no basic or inherent difference in AC versus PCC surface texture if the Braking Force Coefficients are equal.[1] Generally, this means that surfaces that are slightly noisier [within 5 dB(A)] generally have better wet weather friction characteristics. Unpublished British research shows that passenger tires that are slightly noisier also generally have up to 7 percent shorter stopping distances.[2] European efforts are now underway to test road surfaces not only for noise but also for safety.[3-C1, p.45]

**Both FHWA and AASHTO currently recommend that safety not be compromised to obtain a slight, usually short-term, initial reduction in noise levels.[4, 14]**

### Asphalt Concrete Pavement

**Dense-graded pavement:** This is the standard type of AC surface, having an initial tire / pavement noise about 73 to 75 dB(A) for automobiles with a wide range from 55 to 82 dB(A).[5] The noisier AC pavements overlap the quieter PCC pavements.

British research data indicate that for equal Braking Force Coefficients dense-graded AC pavements should have an average texture depth of 2 mm, while a transversely tined PCC surface should have an average texture depth of 0.8 mm.[1] These pavement types will then have similar noise characteristics.

Research data also indicate there is no fundamental difference in the surface texture of AC versus PCC. The macrotexture is what contributes to the noise for both pavement types. The microtexture has minimal effect. There is an indication that the construction procedures for AC have generally resulted in about a 3 dB(A) quieter surface.[1] NCHRP Project 1-31, Smoothness

Specifications for Pavements, will address efforts to increase smoothness, which will also reduce some of the pavement tire noise.

While the noise level on new AC pavements in the past generally has been lower than the noise range of new PCC pavement, the tire / pavement noise will increase for dense-graded AC after the first few years. Studies have shown that the tire / pavement noise adjacent to the roadway for dense-graded AC and standard transverse tined PCC pavement are virtually the same after about 5 years.[6] Noise inside the vehicle on an AC pavement generally does not adversely affect the passengers comfort.

**Open-graded asphalt pavement:** The quietest of the most commonly used pavement surfaces has a good skid resistance record if high-quality coarse aggregates are used. It also has a major advantage of greatly reducing splash and spray during rainy weather. However, much of the advantage of this surface type can be lost in a couple of years if the pavement is not aggressively maintained. Special maintenance procedures are also needed in areas with freezing temperatures.[7]

Another disadvantage of this pavement type is it usually has a shorter service life than dense-graded AC surface layers.[3] However, due to its special low-noise and high-friction characteristics, this pavement type is often desirable.

## Portland Cement Concrete Pavement

General—Available research data indicates it is the construction process, not an inherent material property difference between AC and PCC pavements, that currently results in slightly lower initial noise levels for AC pavements. German research is underway to identify ways of modifying the construction process to eliminate short wavelength roughness so similar noise levels can initially be obtained for PCC pavements as are currently obtained on AC construction projects.[3-C7,8] Improved methods to evaluate the initial rideability of both AC and PCC pavements will help identify ways to improve initial ride quality, which will also help reduce noise levels. Research in this area is underway in both the U.S. and Europe.

**Transversely tined surface:** Research has determined that the spacing and width of the tined texture will determine the extent of tire / pavement noise.[9] Tines spaced too far apart (uniform spacing greater than 25 mm) may cause an annoying whine inside the vehicle and may carry up to 2 to 3 miles outside the vehicle to nearby properties. Tines uniformly spaced too close together (13 mm and closer) may result in excessive wear and poor durability of the pavement surface. Random spacing of the tines reduces the probability of objectionable tonal noises.

The tine width should be 3 mm. Deeper, narrower grooves are preferable to wider, shallower grooves because they reduce the noise and are more durable.[9,10]

The depth of tining should be between 3 to 6 mm with an average depth about 5 mm. Greater depth often causes tearing of the aggregate particles from the pavement surface, which results in more surface roughness (poorer ride) and higher noise levels. Australian research indicates that 225 mm tine lengths allow earlier texturing and less tearing of the aggregate than shorter 100 mm tines. The angle of the tines and the pressure on the tines should also be adjustable to improve texture quality and consistency.[10] The texture depth from the preceding longitudinal burlap or artificial carpet drag and the transverse tining should average 0.8 mm with minimum individual test depths of 0.5 mm as measured by the sand patch test (ASTM E 965).

Tined transverse texture randomly spaced between 10 and 40 mm (with less than 50 percent of the spaces over 25 mm), with a tine width of 3 mm and with an average texture depth of 5 mm (range 3 to 6 mm), will usually provide a PCC surface with tire / pavement noise equivalent to dense-graded asphalt with similar or improved friction properties and reduced splash and spray.

**Longitudinally tined preceded by longitudinal burlap drag or broomed surface:** A longitudinally tined texture spaced at 20 mm, 3 mm wide, and an average depth of 5 mm (range 3 to 6 mm), provides a quiet ride.[11] Also, there has been only one report of objection to noise coming from longitudinally grooved concrete road surfaces.[12] Recent friction tests in Virginia and California show satisfactory values after 20 years of regular interstate traffic.

However, the durability of this surface can be low when the concrete mix does not contain 25 percent or more siliceous sand to provide microtexture and nonpolishing coarse aggregates to assure long-term macrotexture. Also, a poorly designed mix can result in very low friction numbers at a high speed and have a high-speed gradient when tested with a standard skid trailer (ASTM E 274) with a smooth or blank (ASTM E 524) test tire.

Surface drainage is also poorer than with transverse tining and has been shown to result in more splash and spray (significant differences have been noted on experimental sections in Illinois and Louisiana and at the Patrick Henry Airport in Virginia). Also, this is a more of a problem in areas with flat longitudinal grades. These factors could also increase the probability of icing conditions, particularly at sag or crest vertical curves and superelevation transitions, in areas subject to frequent freezing temperatures or hydroplaning in areas with frequent heavy rainfall. There is also the tendency to divert some of the surface water into the transverse joints, which are difficult to keep sealed. This could have an adverse effect on long-term pavement performance but this has not been documented.

**Exposed aggregate surface treatment:** This texture is widely used in Europe due to the low noise, high friction, and good durability of the surface layer when properly designed and constructed. This texture has also been found to be more durable than other PCC surface types where studded tires are used extensively.[11] This approach generally requires two-layer construction, with hard, durable 4 to 8 mm coarse aggregate in the upper layer.[3]

**Broom and burlap drag surfaces:** These textures provide the quietest riding surface, but they are not durable and fail to provide adequate skid resistance at high speeds. Broom and burlap drag textures alone should not be considered for a final surface course on high-type, high-speed (80 km/hr or greater) facilities.[13]

**Findings:** It has traditionally been accepted that dense-graded asphalt provides a quieter ride than transversely tined PCC pavement. It has also generally been accepted that a longitudinally tined PCC surface is quieter than a transversely tined surface, but may not provide an acceptable amount of friction at high speeds during wet weather. Research findings provide evidence that both of these views are not accurate.

Transverse tining, properly constructed on a PCC pavement with high-quality materials, can provide a durable surface with high-friction properties and low long-term noise characteristics from the tire / pavement interaction similar to dense-graded asphalt with equivalent friction properties. The tined surface would also have less splash and spray than dense-graded AC during rainy weather and retain its desirable properties longer.

Recent tests have shown that well designed and constructed longitudinally tined PCC pavements can have adequate durability and friction numbers when compared to either transversely tined PCC pavements or dense-graded AC pavements. They also are generally quieter and are not known to have resulted in annoying tire whining occasionally associated with transverse tining. The major disadvantage is poorer surface drainage characteristics, which may or may not be significant depending on climatic conditions (amount of rainfall and/or freezing weather) and roadway geometrics.

**Recommendations:** A materials type selection must not be made based solely on noise considerations from the tire / pavement interaction. Appendix B of the 1993 AASHTO Guide for Design of Pavement Structures provides guidance on factors to consider. Mr. Kane's June 16, 1995, memorandum discusses FHWA policy.[4]

Properly constructed PCC pavement with a transversely tined surface matches the performance of dense-graded asphalt considering both safety and noise factors. If longitudinal tining is chosen, the mix design should call for a minimum of 25 percent siliceous sand and highly durable coarse aggregate to assure both good friction properties and low-noise characteristics. If the exposed aggregate surface treatment is chosen, then high-quality materials and two-layer construction is usually necessary.

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# APPENDIX F

## Issue: Longitudinal and Transverse Tining

**Issue:** Since the 1970s, PCC pavement surfaces in the United States have predominantly been textured by transverse tining. Longitudinal tining has only been used consistently in one state—California—and in one country—Spain—and frequently in southeastern Virginia.

**Longitudinal tining** is considered one of the best noise reducing surfaces by many highway experts and environmentalists. Available research studies have been used to identify the strengths and weaknesses of these two texturing methods.

Longitudinal tining preceded by longitudinal burlap drag or broom: The California standard is 19 mm (3/4 in) spacing between the tines: 2.4 to 3.2 mm (3/32 to 1/8 in) wide and 4.8 mm (3/16 in + or - 1/8 in) deep with a minimum required coefficient of friction of 0.30 as measured by the State standard test procedure. The fine aggregate is required to have a minimum siliceous sand content of 30 percent.[1]

A longitudinal texture has also been constructed in Spain that is reported to be satisfactory. A plastic brush and a texture depth between 0.7 and 1.0 mm are considered the best compromise between tire / pavement noise and skid resistance.[2]

**Advantages:**

1. There is a noise reduction when the tire / pavement interaction is isolated.[1]

2. Vehicles on horizontal curves will have greater force acting to prevent them from skidding off the curve.[1]

3. There are no reports by the occupants in a vehicle of irritating noises or tire whining.[1]

4. Where high-quality surface mixes containing a minimum of 25 percent siliceous sand are used, friction numbers may be satisfactory even when using blank tires at speeds of 96 km/h, based on California retest data on one of its experimental sections. Friction numbers were above 40.[3]

5. Friction tests with an ASTM skid trailer on two sinusoidal longitudinally tined sections in Spain had 90+ km/h smooth tire friction numbers of .273 to .307 (4 tests-average sand patch texture depth of 1.1 mm) on one project and .201 to .239 (4 tests-average sand patch texture depth of 0.8 mm) on the other project.[7] These numbers are much lower (but still considered adequate) than those reported by California, although Spain's use of this technique was patterned after California's experience due to similar climatic conditions. (See references 8, 9, 10, 11.)

   It should also be noted that Germany continues to use only longitudinal burlap texturing on its high-quality concrete surfaces even though the speed is not limited on much of the Autobahn system. However, Germany's accident rate is about twice that of the U.S., and no comparison of available friction test data currently available (using results of 1995 PIARC Study) has yet been made by U.S. researchers. Germany does have a uniform cross slope of 2.5 percent to improve surface drainage.[12,13]

**Disadvantages:**

1. Skid resistance is reported to be reduced compared to that of transverse tining because the macrotexture does not provide equivalent friction at higher speeds in wet weather for both stopping distance and rotational stability.[4,5] Great Britain uses an 130 km/h design speed and will not allow this type of texturing. It also is one of the few countries with published friction standards.[6]

2. Time for surface drainage to take place can exceed other PCC pavement surface types (transverse tining or exposed aggregate), especially on flat grades and sag vertical curve sections.[14] Splash and spray are also increased compared to transverse tining.[15,16] The inability to remove water becomes a bigger problem in areas of high freezing activity or frequent heavy rainstorms. Increasing the cross slope to 2 to 2.5 percent would alleviate some of the drainage problem.

3. The surface can be disconcerting drivers of vehicles with smaller tires because of the "feeling" that steering control has been taken by the pavement.[17] It is important that tine width be kept narrow and the 19 to 20 mm tine spacing be used to reduce this concern. The recommended grooving pattern in the *1976 AASHTO Guide for Skid Resistant Design* was coordinated with tire manufacturers to minimize this concern.[14]

4. Even with high-quality surface mixes, this texture has been worn off within 4 years in areas in Austria with high studded tire usage.[18] This effect does not only apply to longitudinal textures, but most other PCC or AC surface textures as well.

**Transverse tining:** This texture should be preceded by a longitudinal burlap or artificial turf drag; groove spacings from 10 to 40 mm and depths up to 13 mm have been used. Belgian research indicated 5 to 7 mm depth had no adverse affect on profile or ride compared to an ungrooved surface.[19] See recommended texture guidelines below.

**Advantages:**

1. This texture provides one of the most economical, durable, and consistently high friction surfaces for PCC pavements based on skid tests performed.

2. The transverse grooves quickly remove surface water from the driving lanes onto the shoulder. Effective even with flat longitudinal grades.

3. Proven durability and easy maintenance. Performs good in freezing conditions because of its ability to remove water quickly.[19]

**Disadvantages:**

1. Tire / pavement interaction can produce an objectionable noise outside and inside the vehicle. This usually is not due to an increase in the total overall A weighted scale noise but is due to a change in the noise frequency or tonal quality.[20] Previous construction guidelines and specifications have not been adequate to prevent higher frequency whine or lower frequency rumble in some cases.

2. The frictional advantage in tangent sections may be reduced along horizontal curves.[21,22,23]

3. Requires an additional construction operation to get both the longitudinal and transverse texture.

## Findings:

The unacceptable noise produced by the transverse tining can be traced to the spacing between the tines and width of the grooves. Uniform transverse tine spacings greater than 25 mm are frequently associated with objectionable tire whining. Monitoring data indicate that tining with uniform 13 mm center to center spacing is less durable than wider spacings. Random tine spacings have also been shown to reduce tonal noises. Narrow, deep grooves are better than wide, shallow grooves because they produce less objectionable noise and are more durable. However, tearing coarse or fine aggregate particles from the surface must be avoided as this decreases the ride and increases the noise.

Research findings have indicated that transversely tined grooves randomly spaced between 10 and 40 mm (with a maximum of 50 percent greater than 25 mm), width of 3 mm, adjusted to obtain a depth of 3 to 6 mm (resulting in an average texture depth including the longitudinal texturing of 0.8 mm with no individual tests less than 0.5 mm as measured by the sand patch test), will produce a concrete pavement with similar noise and equal or improved friction characteristics as compared to a dense-graded asphalt pavement. At higher speeds, it will have better braking friction characteristics than longitudinally tined sections. These preliminary findings will be evaluated further in 1996.

Construction of the tined surface is an important factor in the noise production and safety aspects. If the tined texture is made with even pressure over the surface with flexible teeth on the rake (to allow the ends to move around large aggregate near the surface) across the surface and if the edges of the tine are straight (not having a ragged texture which increases the groove width), the undesirable noise frequency will be reduced or eliminated.

Comparison of the results from the noise and skid tests from Colorado's Section 5 [variably spaced (16-22-19 mm) transversely saw grooved (hardened concrete)] and Section 3 [variably spaced (16-22-19 mm) transversely tined sections (plastic concrete)] support this finding. Section 5 was 1 dB(A) quieter than Section 1 [26 mm (1 in) transversely tined State standard], while Section 3 was 1 dB(A) noisier during 1995 external testing. Friction tests in 1995 at 96 km/h with a blank tire showed Section 5 had a 6 point higher friction number when compared to Section 1, while Section 3 had a 10 point higher friction number.

Comparing Section 5 directly to Section 3, Section 5 was 2 dB(A) quieter and had a 4 point lower friction number. Tire industry experts had expected the sharper edged sawed grooves to generate more objectionable noise. However, Section 3 had a higher average texture depth in 1995, which may have resulted in a wider groove and thus greater noise (not the larger depth of tining). This issue could be analyzed in more detail by using the results of the FHWA texture beam data to get more detailed information on the actual groove dimensions (width, depth, and spacing). This work is planned by FHWA in mid-1996.

Section 7 (longitudinal saw grooved at 19 mm spacing) was 4 dB(A) quieter than Section 5 (variable transversely saw grooved) but had a 9 point lower friction number. This would indicate that longitudinal saw grooving was quieter than transverse saw grooving, although the variable transverse saw grooving was not truly random, which may have added extra noise and may not have been the optimal spacing.

Section 7 (longitudinally saw grooved at 19 mm spacing) compared to Section 9 (longitudinally tined at 19 mm spacing with about half the average texture depth) was 2 dB(A) quieter and had a 4 point lower friction number. This comparison would indicate that it is the width of the longitudinal groove not the depth that has the most impact on noise. Here again, analysis of the texture beam data may help adddress this issue.

Section 7 compared to Section 3 (variable transversely tined) was 6 dB(A) quieter but had a 13 point lower friction number. Section 7 compared to Section 6 (26 mm transversely tined) was 4 dB(A) quieter and had a 3 point lower friction number. These results are also similar if compared to Section 1, Colorado's standard section. This comparison is based on the total noise level from a third octave band analysis.[24,25,26] It is likely that if the Wisconsin-developed narrow band frequency analysis were conducted, the 26 mm transversely tined section would also generate an objectionable tire / pavement whine, which is not detected by the third octave broad band analysis. **It would be desirable to conduct noise measurements on these Colorado sections early in 1996 using the equipment and procedures developed in Wisconsin. This would help to identify what types of textures should be constructed in Wisconsin in 1996 to verify research findings made to date.** Properly constructed tined surfaces will provide excellent friction and have acceptable noise levels.

Friction for a longitudinally tined PCC pavement can be increased to provide acceptable performance with proper mix design and high-quality materials. Mix design should include fine material of at least 25 percent siliceous sand to provide increased microtexture and maintain acceptable skid resistance. Coarse aggregate should be a hard, durable, nonpolishing material in the event that grinding or grooving is required to (1) restore a smooth ride, (2) provide a skid resistant surface when the mortar is worn away by traffic, and (3) resist wear (but not prevent it) if studded tires are used. This material should withstand future diamond grooving or diamond or carbide grinding to restore an acceptable surface condition in the future if it is found to be necessary.[20]

Additional strengths and weaknesses associated with transverse and longitudinal tining can be found in the summary of foreign research in appendix H.

### Recommendations:

Transverse tining with randomly spaced tines between 10 and 40 mm (with no more than 50 percent of the spacing 25 mm or greater), 3 mm width, and depth of 5 mm (resulting in an average texture depth of 0.8 mm with no individual test less than 0.5 mm as measured by the sand patch test), will reduce the tire / pavement noise to an acceptable limit while providing a safe surface in wet weather. **This recommendation is based on preliminary results from ongoing Wisconsin research and is subject to more detailed analysis and construction of additional test sections in 1996 to verify these findings.**

If longitudinal tining is chosen, the mix design should contain at least 25 percent siliceous sand and high-quality nonpolishing coarse aggregate. The texturing recommendations are the same as for transverse tining except a uniform spacing of 20 mm (3/4 in) is recommended due to handling concerns by drivers of vehicles with smaller tires.

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# APPENDIX G

## Issue: Premium Surface Treatments

**Issue:** There are AC and PCC premium surface textures for new construction and for existing pavements that have been developed and used extensively or experimentally in the United States and Europe. The quality of these surface treatments and cost effectiveness is discussed in this section. Criteria for "Use of Optimal Pavement Surfaces" are discussed in detail in FHWA-RD-78-209.(1) TRR 622 summarizes the effect of pavement characteristics on skidding accidents, noise, and related issues.(2)

**Findings:**

### AC Open Graded

The most comprehensive summary of Porous Asphalt in Practice was provided at the September 1995 XXth World Road Congress in Montreal, Canada. This reference should be consulted for a more complete discussion of the advantages and disadvantages of porous asphalt.(3) Alternate bituminous surfaces used in Europe are also discussed in TRR 622.[4]

**Advantages:** Provides good surface drainage and friction when used as an overlay on a PCC pavement. The pores in the surface also allow sound to be diffused, reducing the tire / pavement noise.(2)

**Disadvantages:** Aggressive maintenance is needed to keep the pores clear of sand and salt particles if the pavement is to maintain good friction and low-noise characteristics. The service life for this pavement type is usually less than dense-graded AC overlays. These factors increase the life-cycle cost of the product. Also some additional maintenance precautions are needed during freezing conditions. (See references 3, 4, 5, 6.)

### PCC Open Graded (Porous Concrete)

**Advantages:** Similar attributes as open-graded AC pavement. Construction of this surface is accomplished in Europe by adding a polymer to the cement to increase freeze thaw and surface durability.(7)

**Disadvantages:** The surface must be carefully maintained to prevent small particles from clogging up the pores. Freezing weather conditions has caused damage to the surface in the past, but those difficulties have been overcome. This procedure is still considered experimental.(8)

### PCC Exposed Aggregate

**Advantages:** This provides a quiet riding surface interior and exterior to the vehicle while maintaining good friction numbers after many years of service. This is probably the most durable PCC surface texture where studded tires are commonly used. (See references 8, 9, 10, 11, 12, 13.)

**Disadvantages:** Construction of this surface is not difficult, but a learning curve is necessary for contractors to achieve its desired qualities. Low friction numbers have been noted during the first few years of the pavement's existence because of sand and mortar particles surrounding the aggregate and until contractors learn the best way to attain a high-quality surface.[9]

### Diamond Grooving, Diamond or Carbide Grinding, and Shotblasting

**Advantages:** These treatments for an existing PCC pavement will generally increase the friction numbers and reduce the tire / pavement noise. Life-cycle costs are generally good for these methods of pavement treatment, and they are relatively quick and easy to apply.[14,15]

**Disadvantages:** If the existing PCC pavement does not have a high-quality coarse aggregate, polishing may occur when exposed, reducing the surface friction. Even if the aggregate is good material for this operation, the effective life of this treatment can be limited to 3 to 5 years if load transfer is not provided and faulting reoccurs.[15]

### PCC Two-Layer Construction

**Advantages:** This is a good construction technique for situations when high-quality aggregate is not available in large quantities.[5,11] The top third of the pavement layer is composed of the high-quality materials, while the lower two-thirds is composed of lesser quality (but still durable) materials. The surface can be textured in various ways according to the specific needs. This technique has been used extensively in Europe for more than 20 years.

**Disadvantages:** The cost of construction can be high.[13,16] However, where good aggregates are scarce, this can be a cost-effective long-term approach.

### PCC Chip Sprinkling

**Advantages:** This has been an effective treatment for PCC pavements in reducing noise and increasing friction.[2] It is a microsurfacing technique that is quick and cost effective.

**Disadvantages:** Interior vehicle noise may increase as this texture advances in its life. Chips may also come loose and damage windshields.[2]

### Recommendations:

PCC exposed aggregate may be the best new construction technique for noise reduction and safety. It may not, however, be the most cost-effective approach.

If high-quality aggregates are not economically available in large quantities, the two-layer (wet on wet) construction approach is a good alternative. This could be used with either longitudinal or transverse tining, as well as for the exposed aggregate surface treatment. Other approaches, such as the use of silica fume to reduce studded tire wear or the use of fibers to improve surface durability, could also be economically used in the thinner upper layer.

If the aggregate in the existing pavement is high-quality, diamond or carbide grinding or the shotblasting methods may be the most cost-effective approach to restore the surface texture and to reduce noise and increase friction. Diamond grooving (longitudinal or transverse) can also be cost effective and might provide a more durable surface texture on pavements with lower quality (polishing) coarse aggregates.

If high-quality aggregate is not available in the existing pavement, then a thin bonded concrete overlay or surface laminate could be used. A microsurfacing technique and a standard dense-graded or open-graded AC overlay should also be considered.

Reference 17 (pages 99-145) provides decision tables for various maintenance techniques including restoring the surface texture of portland cement concrete pavements. Maintenance techniques described for this purpose are:

- surface dressing
- transverse grooving using diamond discs
- longitudinal grooving using diamond discs
- resurfacing with a bituminous mixture
- planing with diamond discs
- restoration of the anti-skid properties of a surface by shot blasting, and resurfacing with a thin layer of concrete (thickness less than 10 cm)

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# APPENDIX H

## Summary of Foreign Tire / Pavement Noise and Safety Research

In recent years there has been a substantial amount of foreign research related to reducing tire / pavement noise. A review of the literature raises a couple of general concerns that should be recognized when reviewing the research results and recommendations. First, the safety implications of various surface texturing alternatives are sometimes given less weight than reducing noise levels when research recommendations are made. Second, the effect of different textures on surface drainage often do not appear to have been given much study or emphasis. The British Transportation Research Laboratory appears to have performed the most comprehensive research in this area. A brief summary will be made of some of the research studies that have been obtained to supplement the information provided in the recently published Portland Cement Association Research and Development Bulletin RD111T, "Optimizing Surface Texture of Concrete Pavement" (1995). The purpose of this summary is to provide a comparison of foreign practices with those currently used in the United States.

**Reports of special significance include:**

- Roadside Noise Abatement, Research Report 77-95-05-1, OECD, October 1995, 170 pages.
- State-of-the-Art Report and Recommendations for Practice and Further Developments, BRITE/EURAM Project BE 3415, Surface Properties of Concrete Roads in Accordance with Traffic Safety and Reduction of Noise, Center for Civil Engineering Research and Codes, the Netherlands, October 1994, 102 pages.
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- The PIARC Workshop, "Noise Reducing Concrete Surfaces," Vienna, Austria, February 1992, 150 pages.
- International Experiment to Compare and to Harmonize the Pavement Texture and Skid Resistance Measurement Methods, PIARC Technical Committee on Surface Characteristics C1, ref. 01.04.B, Paris, France, 1995.
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- Skidding Resistance of In-Service Trunk Roads, Advice Note HA 36/87, Department of Transport, UK, December 1987.

**Roadside Noise Abatement, OECD, 1995, 170 pp.** This report, prepared by an OECD Scientific Expert Group, is a comprehensive discussion of roadside noise abatement, including tire / pavement interaction. However, little quantifiable engineering data are presented on the effect of pavement texture on surface drainage, friction, or on wet weather accident rates. Most emphasis regarding pavements is on porous asphalts, which initially may have a 3 to 6 dB(A) reduction in noise but without significant maintenance may lose much of its advantage early. This pavement type has an 8- to 10-year service life. German research supports earlier British findings that the noise on pavement types with different binders is identical. No correlation was found between noise and texture depth as measured by the sand patch test. Other texture indexes are being examined. Some interesting approaches to reduce tire / pavement noises are discussed, including radically different voids in the pavement structure and redesign of the wheel. This report does not discuss in detail the issues relating to the different PCC surface textures and effects on safety, drainage, and noise. Rather, it is an excellent overall summary of roadside noise abatement from more of an environmental than an engineering viewpoint.

**State-of-the-Art Report and Recommendations for Practice and Further Developments, BRITE/EURAM Project BE 3415 (Surface Properties of Concrete Roads in Accordance with Traffic Safety and Reduction of Noise), October 1994.**

The report is based on a literature study, laboratory research, and measurements on specially constructed test sections by representatives of the Netherlands, Germany, and Spain. For dense concrete pavements, the longitudinal textures and especially the exposed aggregate technology were considered the most promising. Porous concrete surfacing was considered to need further developmental work to assure bonding to the lower layer. No clear correlation was found between the rolling noise and the sandpatch texture index. The specific results of the specially constructed German test stretches will be summarized in the next section.

### Recommendations for further research included:

- Further noise reductions can be reached by improving the evenness of the concrete surface with optimized smoother equipment.

- More intensive research is needed in noise and texture measurement methods and analysis procedures because there was no clear correlation between the texture profile spectra and the noise measurements. Is was also noted that automated texture measuring equipment measures the longitudinal profile only and does not consider the transverse profile. This does not allow a valid comparison of longitudinal, transverse, and random (exposed aggregate) surface texturing methods as they affect surface drainage.

- The high cost of the surface treatments using epoxy resin with special aggregates suggests cheaper bonding agents, such as polymer modified cement mortars, should be developed.

- Porous concrete needs further development work particularly to assure adequate bonding.

- Study of the production of a low-noise concrete surface by texturing green concrete by imprinting patterns in combination with an optimized smoother was recommended for future development.

The extent to which drainage of the road surface was influenced by the longitudinal texture was not specifically investigated. However, the cross slope on the pavement in Europe is typically 2 to 2.5 percent, which would improve surface drainage.

With conventional-sized aggregates, a low water/cement ratio of 0.40 to 0.42 is needed to make the texture produced by a burlap drag or a comb durable. The addition of microsilica improves the mortar properties. To ensure a high resistance to polishing, at least one-third of the sand must be quartz. Burlap texturing results in somewhat lower skid resistance and 3 dB(A) lower noise levels than conventional texturing with transverse brooming. High skid resistance (compared to a burlap drag finish) can be obtained by impressing 2 mm deep grooves separated by 3 mm into the mortar with a comb. However, this requires more mortar, which can be obtained by raising the sand content 100 kg/m$^3$.

**Measurements on Test Stretches, Report No. 240/7, BRITE/EURAM Project BE-3415, Berlin Technical University, May 1994.**

The report describes the measurements of texture, tire/road noise, and skid resistance at two German test locations. The "Garlstorf" test location on A 7 south of Hamburg was built early in the summer of 1992 and includes 13 sections. The "Wittstock" test sections were constructed in late autumn of 1993 on A 19 between Berlin and Rostock and includes 29 different textures. Concrete surfaces with longitudinal, transverse, and exposed aggregate (random) surface textures were tested.

Two texture profile spectral values, the 5 mm octave Root Mean Square (RMS) amplitude (5 mm) and the 80 mm octave RMS amplitude (80 mm) were considered as the most relevant for an evaluation of the acoustical properties of the road surfaces. Two geometric values, the estimated texture depth (ETD) and the RMS, provide more general information about the surface geometry and its effects on the acoustic and frictional surface properties. The method of measurement of the profiles gives only information on the texture in the direction of the measurement, which could be significantly different for longitudinal, transverse, and random texturing. High amplitudes in the 5 mm range (which represents macrotexture) and low amplitudes in the 80 mm range (which represents megatexture or short wavelength roughness) are considered favorable with respect to tire/road noise reduction. This desired combination was met in only a few of the cases on the specially constructed concrete surfaces . However, single and multiple correlation analyses with the two texture profile measurements and the results of the noise analysis gave only low correlation coefficients.

Results of the statistical passby noise measurement method were summarized for two vehicle noise levels normalized for the reference speed of 120 km/h and two different microphone locations. Trailer noise measurements using the PIARC treaded tire and the average of the results for four commercially available tires were also obtained. These were normalized for a reference speed of 80 km/h. Few transversely textured sections were available to make a valid comparison because previous experience indicated these result in higher initial noise levels. The noise on the longitudinal and exposed aggregate sections were generally within 1 dB(A) of each other and, when available, the transverse section(s) were 3 d(B)A higher, based on the statistical passby method. There was greater variation in the testing results using the trailer method with the transversely tined sections having higher noise levels.

Skid resistance measurements were obtained in two blocked wheel braking force coefficients for the treaded and the smooth PIARC tires, both normalized for the reference speed of 80 km/h. This test is similar to ASTM skid trailer testing. No speed gradient data were reported. <u>The smooth treaded PIARC tire gave similar results as the treaded tire on rough textured pavements but was a better indicator of poor surface drainage on the smooth textured pavement surfaces.</u> The results of friction measurements on these sections can be compared with ASTM skid trailer results using the recently published PIARC procedure but this has not yet been done by U.S. researchers.

Due to the low average texture depth of the Garlstorf sections, the skid resistance of most of the sections with the smooth tire at 80 km/h were relatively low (0.15 to 0.22). The skid measurements with the PIARC treaded tire showed a range from bad to good compared to German requirements. The lowest results were found on the burlap sections and the highest results on the exposed aggregate sections of the "Wittstock" test stretch.

Skid resistance measurements (smooth tire) at the "Wittstock" test stretches averaged 0.26 for the longitudinal textured sections, 0.45 for the random (exposed aggregate) test sections, and 0.29 for the one steel brush transverse textured section.

<u>There was no correlation between the acoustic and the frictional properties of the different road surface textures</u>.

***Concrete Pavement Manual: Design and Construction*, Roads and Traffic Authority, New South Wales, Australia, February 1994.**

This manual is summarized as it takes much of the British research findings and presents it in the form of guidelines for finishing Portland Cement Concrete paving. Profile, texture, noise, and skid resistance are considered. The following information is almost a direct quote from Subsection 10.5.4, "Surface Texture," of the manual. The manual also includes an excellent list of technical references.

**The major aspects of the RTA's policy are as follows:**

- Microtexture is the critical component for skid resistance even at high speeds.
- Macrotexture is viewed primarily as the medium for quickly removing surface water so that tire contact is maintained, thus ensuring optimum benefit from the microtexture.
- The effectiveness of the microtexture is largely dependent on the quartz sand content. This is reflected by the requirement for greater than 40 percent quartz sand.
- The mortar is the critical component for durability of friction. This leads to the conclusion that aggregates susceptible to polishing could be used as long as durability of the mortar can be ensured. (Note by FHWA: For a long pavement service life, it may be desirable to grind the pavement surface to correct roughness during initial construction or to restore ride quality after a number of years of traffic. This would expose the coarse aggregate and could cause low friction numbers if polishing coarse aggregates were used. This has caused a potential problem in Puerto Rico for the reasons given.)
- Durability depends substantially on cement content, water/cement ratio, and effectiveness of curing; all issues on which RTA specifications are justifiably strict.

In terms of skid resistance, maximum effectiveness of surface drainage at the tire / pavement interface is achieved where irregularities have wavelengths of 8 to 16 mm.

For maximum tire grip (wet or dry), the vertical action of the wheel must be as steady as possible and the critical (undesirable) wavelengths lie in the range of 0.5 to 8 m.

Within 80 km/h zones, the RTA normally specify a longitudinal burlap drag with no transverse texturing. Noise generation is 3 dB(A) lower than transversely tined concrete but 1.5 to 3 dB(A) higher than open-graded asphalt. At slower urban speeds, microtexture alone will normally provide adequate friction.

For rural concrete surfaces, the RTA typically specifies a transversely tined finish with an average texture depth of 0.3 to 0.65 mm. This corresponds to an actual groove depth of 1.5 to 3 mm. A pattern of variable tine spacing is specified to prevent tire humming (or whining). This surface provides very good skid resistance, and noise generation is well within the acceptable range for other than urban areas.

The tining operation must be closely controlled to ensure optimum texture depth. The best finish is a sensitive compromise between providing adequate depth for durability but limited depth for ride quality.

Flexibility must be provided in the tining rake so that individual tines can transverse large aggregate without disturbing the surface or dislodging the stone, and the rake should be hinged in such a way that variable pressure can be exerted to adjust for varying "average" surface hardness. Care must be taken to ensure that the pressure exerted to the head is uniform over its full width since a periodic variation in texture depth over that wavelength could increase tire noise emission.

Longitudinal grooving is used by a few isolated road authorities but it is widely held that this treatment is unsatisfactory for both stopping distance and for rotational stability of a braked vehicle at high speeds. Further, for the same overall acoustic pressure level [in dB(A)] some studies report a greater degree of objection to the noise coming from longitudinally grooved concrete road surfaces.[1]

[1]Permanent Association of Road Congresses. Technical Committee Report on Surface Characteristics. 17th World Congress, Sydney 1983.

*Concrete Pavement Manual*, **Appendix 10.5B Comparison of Surfacing for Noise and Friction**

## Generated Noise Levels

Typical values for free-flowing, constant speed motorway traffic (all values reported relative to conventional dense-graded asphalt):

| | |
|---|---|
| Open-graded asphalt (1987) | -6 dB(A) |
| Burlap-dragged concrete | -2.7 " |
| Dense-graded asphalt | 0" |
| Transversely tined concrete | +0.3" |
| Sprayed seal, 14 mm | +2" |

## Friction Characteristics

Open-graded asphalt and tined concrete:
- similar at both 80 and 110 km/h

Burlap dragged concrete:
- inferior to both of the above at high speeds over about 80 km/h

Dense-graded asphalt:
- provides lower friction than each of the above three for all speeds (except for special case of rhyolite aggregate)

**J. Nichols and D. Dash, "Australian Developments to Reduce Road Traffic Noise on Concrete Pavements," 5th International Conference on Concrete Pavement Design and Rehabilitation, Purdue University, April 1993, Vol. 2, pp. 99-106.**

This summary will supplement the information provided above on a few critical issues. The surface textures evaluated in this paper were constructed by using a burlap (Hessian) drag and transverse tining only and were varied by adjusting the following:

- Burlap drag length
- Tine depth
- Tine width
- Tine spacing

The **length of the burlap drag** in contact with the plastic concrete was either 0.6 (light texture) or 1.2 m (coarse texture). The drag was applied in a longitudinal direction to provide secondary smoothing and to reduce surface uniformity to decrease the constant pitch tire whine.

The **tine depth** was altered to produce a light or medium effect. This was controlled by:

1. Delaying the time relative to tining behind the paver.

2. Increasing the length of tines from 100 to 225 mm.

The **tine width** was 2 or 3 mm. Square tines were used. The 2 mm tine width with light burlap drag and light transverse tining had lower friction, lower texture depth, and higher noise than the equivalent 3 mm tine width.

The **tine spacing** used were 13 or 26 mm randomized average spacing to avoid creation of harmonic resonances in traveling vehicles. An example of the randomized spacing, nominally 13 and 13.1 mm average is:

**10/14/16/11/10/13/15/16/11/10/21/13/10 mm**

The coarse burlap drag and light transverse texturing with 26 mm nominal spacing (same spacing as above with every other tine removed) did not show any markedly superior performance to the equivalent 13 mm nominal tine spacing in friction, texture depth, or noise. It was considered that this variable was masked by the effects of the coarse burlap drag.

It was concluded that the quietest surface texture produced to date, the light burlap drag with light transverse tine depth and 13 mm nominal tine spacing, has acceptable skid resistance in terms of Sideways Force Coefficient and texture depth.

**Note:** Additional details on "Surface Finishing of Portland Cement Concrete Pavement," dated December 25, 1995, were received from David Dash as requested by Roger M. Larson, FHWA. A copy of an article by D. M. Dash, "Investigation of noise levels in pavement wearing surfaces and development of low-noise concrete roads," Vol 4. No. 3, September 1995, *Roads and Transport Research*, pp. 44-55, was also received.

**J. C. Van Der Walt, et al., "Design Consideration and Findings of the Surface Texture Improvement on the Ben Schoeman Freeway," Fifteenth Annual Transportation Conference, Pretoria, South Africa, 1995.**

This report summarizes and references previous South African noise studies. This section of continuously reinforced concrete pavement was transversely broomed when constructed in 1989 based on the results of an earlier noise study. A new study was conducted to determine the cause of chain accidents in 1991-92. The general findings of the study included the following:

- 1993 Sideways Force Coefficient of Friction (SFC) measurements showed about one-fourth of the pavement had an SFC lower than the desirable (but unspecified) level of 0.5.
- There was a significant loss in texture depths from 1989 to 1992 attributed to poor cleaning of the surface prior to the original sand patch tests and loss of surfacing due to abrasion of the granulated blast furnace slag concrete mix used to reduce the cost.
- Surface drainage was poor due to a cross slope of less than 2 percent, a build-up of grass and debris at the pavement edge causing ponding, and inlets in median high causing ponding on the fast lane shoulder when any debris accumulated.
- Noise measurements on the CRCP were at least 1 dB(A) lower than on a nearby asphalt wearing course for the same amount of traffic at the test points.

Alternatives to improve the skid resistance and retain a low-noise surface were evaluated. These included a porous asphalt overlay and a retextured surface (grooved). Based on a cost comparison, the retexturing was more cost effective. Both longitudinal and transverse grooving were considered, and the following benefits and disadvantages of each were listed:

## Longitudinal grooves

Advantages:

- Can be applied to small areas to improve skid resistance.
- Noise level is 1 to 1.5 dB(A) lower than transverse grooves.
- Cutting process is faster than transverse grooves.
- Cut grooves do not cause wandering.
- Less effect on road user in terms of traffic accommodation.
- Estimated cost +/- R9.50/$m^2$ depending on groove spacing and textured area.

Disadvantages:

- Do not drain surface water as fast as transverse grooves.
- Skid resistance is not as good as transverse grooves.
- Noise level is not as low as porous asphalt.

## Transverse Grooves

Advantages:

- Can be applied on small areas to improve skid resistance.
- Reduced stopping distance during wet weather. (Has a higher skid resistance than longitudinal grooves.)
- Cross-surface draining is faster than longitudinal grooves (faster drying of road surface).
- Estimated cost +/- R 10/$m^2$ depending on groove spacing and textured area.

Disadvantages:

- Noisier than longitudinal grooves and porous asphalt.
- Cutting process is slower than longitudinal grooves.
- Require more traffic accommodation.
- Require modification to grooving machines.

The groove dimensions have a large effect on the noise level, surface drainage capabilities, and the amount of spalling of the road surface. German research found an increase in noise level on transverse grooves up to 4.5 mm wide to be between 0.5 and 1.5 dB(A), and with 6 to 7 mm wide grooves, the increase in noise lies between 2 and 4 dB(A). Groove dimensions of 4 mm width, 4 mm depth, and spaced 20 to 25 mm apart were recommended.

South African acoustic and environmental consulting engineers were contracted to conduct computer simulations. After computer simulations, a spacing of 25, 25, 22, 25, 25, 22 mm between cutting blades and a groove depth of 6 mm with a +/- 1.5 mm tolerance was proposed in order to improve drainage and inhibit increase in noise. Deeper grooves would keep surface area, and thus road noise the same but would increase drainage volume and air flow volumes.

A groove depth of between 3 and 6 mm was decided on to reduce possible spalling as a result of the CRCP transverse crack pattern. The following groove dimensions were specified for the retexturing project:

- width 3 to 4 mm

- depth 3 to 6 mm
- spacing 25, 25, 22 mm alternately between cutting blades

The average SFC measured after retexturing was 0.500 compared to 0.483 initially in the slow lane. Possible reasons for the minor improvement were listed but included poor quality equipment and additional surface wear taking place after retexturing.

**Conclusions:**

- Alternative methods to SCRIM (SFC) should be looked at to measure skid resistance.
- Durable concrete mix should be provided. (Transverse broom finish texture depth less than 1 mm was not intended for use in the evaluation of low-noise control surfacing.)
- The **width and spacing** of the grooves are the critical parameters. Groove widths should not be wider than 4 mm. Grooves should be spaced 25 to 20 mm, and the minimum depth should be between 8 to 6 mm minimum. Deeper grooves will increase surface drainage and air flow volume.
- Cross slopes on roads with pavement width wider than 12 m should be increased from 2 to 2.5 percent to improve surface drainage on high-volume roads.
- Retexturing has improved skid resistance and especially reduced traffic water spray on the Ben Schoeman Freeway where it was done. The noise levels increased by only 0.9 dB(A) on the retextured test section.
- It was recommended that the rest of the CRCP also be retextured to reduce traffic water spray in wet weather.

## Other South African Studies

The South African Portland Cement Institute furnished copies of the above research and also the following studies for which some brief comments are provided:

1. F. E. van der Wielen, Vehicle Noise on Experimental Concrete Surfaces, 1989 Annual Transportation Convention, Pretoria (16 transversely grooved, three longitudinally textured, three diagonally grooved, and two transversely broomed sections, plus an exposed aggregate section, were evaluated).

2. G. V. Meij, Road Surface Noise—The Texturing of Cement Concrete Paving for Noise Reduction—Selection of Textures, 1989 Annual Transportation Convention, Pretoria (tests on eight different textures were reported, and the transverse nylon brush texture was recommended in noise sensitive areas).

3. M. F. Mitchell, The Road Noise Problem in the South African Context, 1989 Annual Transportation Convention, Pretoria.

**Tentative conclusions drawn from the experiments done are as follows:**

- In rural areas, transverse grooving between 3 and 6 mm in depth is most effective because noise is not a problem and skid resistance is highest.

- Is areas where development is fairly far from the roadway, grooving at 45 degrees to the direction of travel is favored, because it is quieter than transverse grooving and displays good drainage and skid resistance characteristics.

- In sensitive areas, it has been found that a transverse broomed texture is the most effective, provided that great care is taken to achieve the correct texture depth and absolute uniformity of the finish.

**International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements, PIARC Technical Committee on Surface Characteristics C.1, 1995.**

Methods and systems used throughout the world for measuring texture and skid resistance vary significantly. This research report provides data to define an international scale of friction values called an International Friction Index (IFI). Forty-seven different measuring systems, representing 16 countries, are included in this series of friction tests to obtain the IFI. Fifty-four test sites were used, representing a variety of surface conditions. The objective of the experiment was to compare the many different measuring methods used around the world and develop relationships for converting results produced by the different devices to the common scale (IFI).

**Taken from the Executive Summary Conclusions**

The IFI was demonstrated to have an acceptably small error (within +/- 0.03 friction number) using a measure of the mean profile depth and any measurement of friction made by the systems that participated in the experiment.

As a main finding from the International Experiment, there is now a well-defined universal friction scale (IFI) that should be reported with all friction measurements on roads and runways. The two numbers that constitute the IFI are F60 and $S_p$, which are derived from a friction measurement and a texture measurement. These numbers should be used in all applications, including accident investigations, maintenance management surveys, airport operations, etc. In addition, reporting the IFI will make the results from such studies useful in all parts of the world in which IFI has been implemented.

It is also shown that if decision makers establish intervention levels for F60 and $S_p$ (designation F60* and $S_p$*), these levels can be used to determine the proper strategy for remedial action in terms of the data from their own friction and texture systems. From their friction and texture devices together with F60* and $S_p$*, a figure such as the one shown in this section can be generated. It should be emphasized that the intervention levels are determined by the road administrators, and different intervention levels would probably be established for different classes of roads.

Because of the success of meeting these objectives, some additional direct and indirect benefits are:

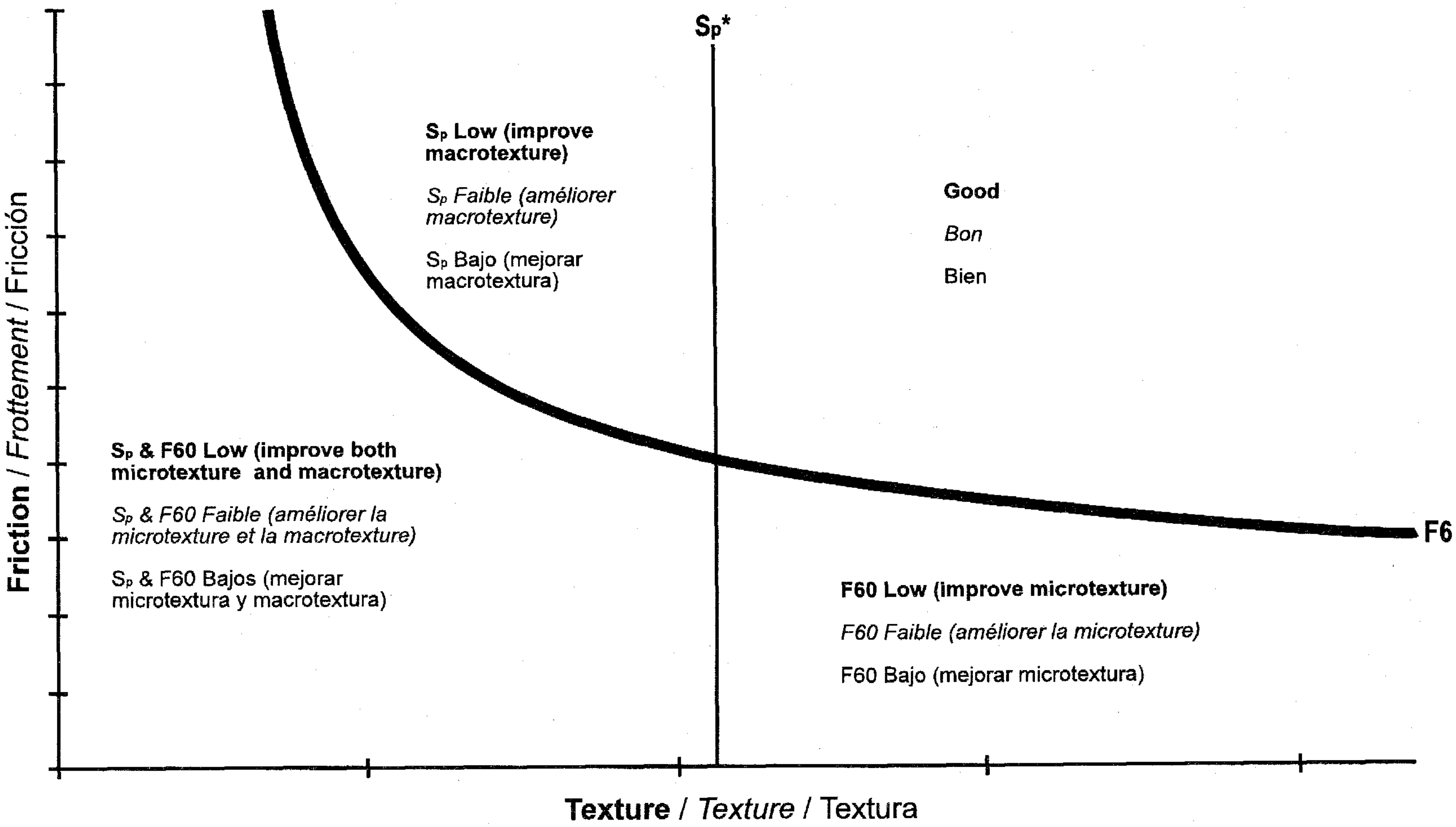
- Road and airport authorities would be able to adapt to a universal scale without having to replace their present control methods or their own experience and historical data.

- Intervention levels will be interchangeable.

- Material suppliers would be able to extend their area of distribution to other countries with harmonized specifications.
- Contractors wishing to work abroad would be able to adapt to specifications based on local control methods.
- Test equipment manufacturers would see their market widen.
- Practitioners and researchers would acquire better knowledge of skid resistance phenomena and of the effect of texture.
- Road and airport users would be able to receive reports of frictional conditions on the same scale in different countries, resulting in improved safety.

**Note:** Due to the wide range of topics covered in the Report of the 7$^{th}$ International Symposium on Concrete roads, Vienna, Austria, October 3-5, 1994 (particularly Session 8 papers, pp. 81-178) and in the **Proceedings, XX$^{th}$ World Road Congress**, Montreal, Canada, September 3-9, 1995, no further attempt to summarize them will be included here. References to research reports from the U.S. and Europe are now available on the CD-ROM "TRANSPORT" by Silverplatter, and other major Permanent International Association of Road Congresses publications are now available on CD-ROM from PIARC, which will make these studies more accessible to U.S. researchers and practitioners.

**International PIARC Experiment**
*Expérience Internationale AIPCR*
Experimento Internacional AIPCR




**Significance of the Areas of a Friction vs. Macrotexture Diagram** / *Signification des domaines du diagramme trottement texture* / Significado de las distintas zonas en un diagrama de fricción textura

# APPENDIX I

## Summary of Meeting with the Tire Industry

****From a February 14, 1996, FHWA Memorandum****

A meeting was held by FHWA with representatives from the tire and concrete industry to discuss the tire / pavement noise issue.

| | | |
|---|---|---|
| Attending: | Roger Larson | FHWA |
| | Carl Hayden | FHWA |
| | Brad Hibbs | FHWA |
| | Ted Ferragut | ACPA |
| | Steve Padula | Michelin |
| | John Rumel | Goodyear |
| | Gloria Bartholomew | Rubber Manufacturers Association |

Roger Larson opened the meeting with an explanation of the issues the TWG has been exploring, what has been discovered through the literature search and U.S. experimentation, and the next steps to be taken in the investigation/research effort.

John Rumel spoke about the European movement to regulate tire noise. His discussions with the Environmental Protection Agency lead him to believe that if Europe passes a tire noise regulation, the U.S. will not be far behind. One of the barriers that has prevented Europe from moving ahead with the regulation is the problem of differentiating tire noise from vehicle noise. The Europeans are pursuing an on-board vehicle noise measurement system, while the U.S. and Japan are pursuing a towed trailer method. The other barrier has been the safety issue; that tires that are 5 dB(A) noisier also have up to 7 percent shorter stopping distance (per unpublished TRL report).

The effects of pavement surface texture and tire tread were discussed in relationship to noise and safety. Ted Farragut asked for whom are we trying to solve this problem? Steve Padula said that the safety of the driver is the number one priority and noise reduction a distant second. <u>Tread on the tire and tining on the pavement remove water and provide a better connection between tire and surface for greater safety, but there is a noise tradeoff for that benefit</u>. In recent years, the noise issue has taken on greater importance for the tire industry because of the quiet riding vehicles now in existence. Automobile manufacturers are requiring greater noise reduction performance for persons inside their vehicle (Japan especially). One of the methods to reduce tire noise is by "pitching," where a repeated tread pattern is lengthened and shortened in a random pattern both around the tire and across the tread to break the noise frequency up. It was agreed that for the tire and the transversely tined pavement, random patterns have to be a truly random.

According to John Rumel and Steve Padula, the antilock brake systems in cars will <u>not</u> significantly affect the tire design or the need for macrotexture and microtexture on high-speed pavement surfaces.

The standards for measurement of noise used by the tire manufacturers are contained within the respective companies. Measurements inside the vehicle are made subjectively because the noise pitch affects people in different ways. The industry uses an assessment by trained personnel to determine what is annoying. Exterior noise tests are objectively measured on various test track surfaces (it is doubtful that the PCCP sections have differential textures). The standards of these tests, subjective and objective, were not elaborated on.

Carl Hayden invited the noise technologists from the tire manufacturers to attend the ASTM E-17 noise meetings.

John Rumel pointed out that there is an ISO 10844 noise standard. A draft International Standard (ISO/DIS 13473-1), Characterization of Pavement Texture Utilizing Surface Profiles—Part 1: Determination of Mean Profile Depth, states that ISO 10844 calls for the use of "mean texture depth" to put limits on surface texture for use as a reference surface for noise testing.

Ted Ferragut volunteered to work with the tire industry to get representative concrete surface textures for its test tracks that help reduce the tire / pavement noise problem while assuring adequate friction.

Tires are still tested for "groove wander" to determine if they will cause a vehicle to sway from one side to another on a longitudinally tined pavement. Longitudinal tining was much more of a problem in the 1970s for both the pavement and the tire industries.

Roger Larson ended the meeting by stating the schedule for completion of the final TWG report (May 1, 1996) and its hoped for results. Copies of the draft report were handed out to the tire industry representatives.

Attached is a copy of the Rubber Manufacturers Assocation's October 5, 1995, response to questions regarding Portland Cement Concrete Pavement Surface Texture.

RMA

RUBBER MANUFACTURERS ASSOCIATION

October 5, 1995

Mr. Brad Hibbs
U.S. Department of Transportation
Federal Highway Administration
400 Seventh St., S.W.
Washington, D.C. 20590

Re: Portland Cement Concrete Pavement Surface Texture

Dear Mr. Hibbs:

Enclosed for your information is the industry coordinated response to the five questions raised in Mr. T. Paul Teng's August letter to RMA on the subject cited above. We hope that our comments are helpful to members of your technical working group. At some future point it may be beneficial to invite interested members of the RMA's Tire Pavement Interaction Noise Committee to meet with your group to better facilitate communication. Please don't hesitate to contact me if you have further questions on this topic. My direct-line number is 202-682-4841.

Again thanks for giving us the opportunity to respond.

Sincerely,

Steven Butcher
L.B.W.

Steven Butcher
V.P. Technical & Standards

Enclosure

QUESTION #1

*Has the tire industry developed a noise measurement or prediction procedure of this type that goes beyond the typical noise level analysis and examines the tone of the tire on the pavement inside the vehicle and off the roadway?*

There are numerous analytical and empirical methods used to predict tire noise performance in the industry. Many of these methods provide analysis of detailed noise spectra from the tire-pavement interaction. Such analyses would indicate the presence of such tones. However, most of these predictive tools are considered to be proprietary since they are based on the design techniques and knowledge of the tire manufacturer.

Due to the manner in which the human ear evaluates the sound quality it is not possible to measure or predict a level correlating to subjective judgment, unless it is to determine a relative ranking between sounds which are identical or similar except for the noise level. Physchoacoustic techniques such as perceived loudness, roughness, sharpness, harmony, spatial selectivity, etc. can be used to improve the correlation between objective measurements or predictions and the subjective analysis by the human ear. Some companies use a mannequin (Aachen Head) and the binaural measurement technique to objectively measure the noise caused by the tire/road interaction. However, this cannot replace subjective noise evaluation which accounts for the spectral density, spectral composition or time content of the noise.

There are also experimental methods utilized for quantifying tire-vehicle noise that can represent tonal content. These tests can be done on the road or in the laboratory. Many tire manufacturers have large diameter road wheels for tire-vehicle noise that can represent tonal content. Many of these road wheels have castings of road surfaces on them to provide more realistic noise characteristics. Either on the road or in the laboratory tonal characteristics in the tire-pavement noise spectra can be isolated.

It is a matter of conjecture whether the analyses discribed above would be sensitive to small changes in the pavement texture. Since such capabilities are not publicized, there is no way to determine the sensitivity of current modeling capabilities.

QUESTION #2

*Does the tire industry use subjective opinion about what noises or tones are acceptable and which ones are annoying? If so, how are such subjective measures made repeatable and reliable?*

Yes, throughout the tire-vehicle industry subjective evaluations are done of the tire-vehicle system. Generally, subjective ratings are determined by trained test drivers according to specific criteria for a given application. testing is often conducted on different road surfaces to evaluate the effect on subjective performance. The repeatability of such subjective ratings is assured by the use of control tires, careful training, and correlation procedures between the tire and vehicle manufacturers.

In addition, there are several commercial vendors of anthromorphic head and torso units which can be placed in a vehicle to collect sound data. These data are analyzed by juries or by computer analysis using recognized metrics for sound quality such as loudness to assess annoyance. Repeatability is assured by microphone calibration and rigid adherence to measurement procedures.

QUESTION #3

> *Could the tire industry provide data that supports the use of a tined or aggressive macrotexture that reduces braking distance and prevents skidding accidents?*

There is no such data available from the industry. The industry has many different testing surfaces, however, they are not designed such that two surfaces with different macrotextures would have the same microtexture. This would make a clean comparison impossible.

QUESTION #4

> *Is there data that supports high friction numbers and low noise production from the pavement/tire interaction on any particular surface texture (e.g., random transverse tines, longitudinal tines...)?*

It has been established, in Europe at least, that friction properties are usually sufficient to provide satisfactory safety in dry conditions. Problems are likely to occur in wet conditions and especially under thick (> 1mm) water conditions.

Under these conditions, safety can be obtained if the macrotexture is sufficiently high so that the water can fill in the gaps between the tire and the road surface. In this case, the road surface will be noisy, because of the high road excitation. On the other hand, poor safety goes along with low noise levels in the case of a non-draining surface with a mean macrotexture--the texture is not sufficient to trap all the water and it is not sufficient to generate much noise.

Finally, a very smooth and non-draining surface is unsafe and generates a high level of noise due to "very efficient" air pumping phenomena. There is no correlation between the acoustic properties of a road surface and its safety properties under high water conditions.

There is probably not data that supports transverse tined surfaces that provide high traction and low noise. However, there have been tests conducted examining road surface performance for both of these characteristics. One such report is "An Examination of the Relationship Between Tyre Noise and Safety Performance," by P.M. Nelson, G. J. Harris, and B. J. Robinson of the Transportation Research Laboratory in Crowthorne, Berkshire, England (0344 770587).

QUESTION #5

*Is this supported or supportable by any of your research? Are there alternate textures that should be considered?*

We have not performed any specific studies which support the numerical limits describing the tine geometry. However, our basic research does support many of your findings, particularly the benefit on tire whine of randomizing the spacing between lateral tines. Also, longitudinal tines in general should not significantly increase tire whine. But they may cause a resonance problem due to the acoustic cavity caused by the tine underneath the contact patch of the tire.

Several tests have shown transversely grooved surfaces to produce strong noise tones that are judged to be annoying by customers. Clearly, regularly spaced tines produce strong tones that change in frequency with vehicle speed and are highly annoying to the vehicle occupant. Using randomly spaced tines would reduce the tonality, but the occupant may still be disturbed. In some instances where the tine spacing is not completely uniform, it is distributed over a small range. Although this will reduce the tonality, it still leads to a rise in a specific range in the tire-pavement noise spectrum which can be disturbing to the vehicle occupant.

As for alternate surfaces, from previous knowledge of surface behavior with regards to safety/traction and noise, a possible surface design choice could be sand asphalt or drainage asphalt. This would not require tines. The problem, however, would be to design an asphalt surface that could retain the high rough microtexture capability that produces adhesion, and could have a high rough macrotexture capability that would encourage water drainage. In addition, the macrotexture can not be too rough because it would eliminate the effects of the rough microtexture and increase noise. We do not have any specific suggestions as to how much roughness of each texture is required. As for tined surfaces, based on TWG's extensive research (ex. "PCCP Texturing Methods" by Ahmad Ardani, March 1995), our information is insufficient to offer an improved alternate tined surface.

Our experience is that, as vehicle manufacturers endeavor to reduce vehicle noise, the customer is becoming more aware of changes in interior noise. More frequently than ever before, our customers are raising questions about the changes in interior noise which occur with pavement changes.

# # #

U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HNG-40

AUG - 9 1995

Mr. Frank E. Timmons
Rubber Manufacturers Association
1400 K Street, N.W.
Washington, D.C. 20005

Dear Mr. Timmons:

We are now in the process of writing the draft final report for the Technical Working Group (TWG) on Portland Cement Concrete (PCC) Pavement Surface Texturing. The literature search of previous research performed in this area, and the current experimentation on-going in the United States have raised questions without immediate answers. Your help in answering these questions would be of great benefit to the effort of the TWG.

The primary problem the TWG is seeking to resolve is the "tire whine" that acts as an annoyance to passengers inside vehicles and urban area residents living in the proximity of the PCC pavement. The "whine", or annoying tonal quality, is not just an increase in the total noise level or a shift to the 1000-2500 Hz range, as regular weighted dBA and frequency analyses fail to pinpoint the problem. There needs to be an alternate method of measurement to detect the whine and determine its probable intensity so practices that contribute to the problem can be prevented. It is this finding that has raised the following questions:

1. Has the tire industry developed a noise measurement or prediction procedure of this type that goes beyond the typical noise level analysis and examines the tone of the tire on the pavement inside the vehicle and off the roadway?

2. Does the tire industry use subjective opinion about what noises or tones are acceptable and which ones are annoying? If so, how are such subjective measures made repeatable and reliable?

This information will aid the highway community to better know how to construct PCC pavements without the annoying tonal sound.

There are also answers to questions related to safety that need additional support for them to be reported. The long held belief that increased pavement friction, created by a tined surface texture, will decrease wet weather accidents, is being challenged by the appearance of more aggressive tire treads and better braking systems.

3. Could the tire industry provide data that supports the use of a tined or aggressive macrotexture that reduces braking distance and prevents skidding accidents?

4. Is there data that supports high friction numbers and low noise production from the pavement/tire interaction on any particular surface texture (e.g., random transverse tines, longitudinal tines...)?

Preliminary indications are that transverse tining (maximum width of 3 mm and texture depth of 3-8 mm), randomly spaced between 15 and 25 mm, preceded by a longitudinal burlap or artificial drag will help prevent the annoying tire whine.

5. Is this supported or supportable by any of your research? Are there alternate textures that should be considered?

Longitudinal tining does not produce this tire whine but has some other disadvantages, particularly in high rainfall or freezing environments. The exposed aggregate surface is promising but has a higher construction cost. The objective is to provide good pavement surface friction characteristics while minimizing pavement/tire noise (annoying tire whine). It would benefit both the highway user and the tire industry if solid evidence could be presented that high friction reduces accidents (particularly wet weather accidents).

We would appreciate any help you may provide, and are willing to meet with your industry representatives to review available data and listen to your recommendations to increase pavement friction while minimizing objectionable tonal sounds on PCC pavements. Please contact Mr. Roger Larson (202) 366-1326 or Mr. Brad Hibbs (202) 366-2226, or fax any questions or comments to us at (202) 366-9981. Thank you for your consideration in this matter.

Sincerely Yours,

T. Paul Teng

T. Paul Teng, P.E.
Chief, Pavement Division

# APPENDIX J

## Comments from the Technical Working Group

The comments received from the Technical Working Group members on an earlier draft version of this report are included in this appendix. Their comments therefor do not necessarily apply to either the current wording of the final report or to the current page numbers. The draft final report was revised to consider the consensus of the TWG as noted in the following minutes of the January 31, 1996 meeting. The individual TWG members comments are included to show their viewpoint if their suggestions were not incorporated into the final report. Where differences remain on significant issues, they have been recommended for further research. The comments and the cooperation of the TWG in reevaluating this complex subject were greatly appreciated.

| Commentors | | | No. of Comments |
|---|---|---|---|
| 1. | TWG Meeting | (1/31/96) | 22 |
| 2. | J. J. Henry | (3/11/96) | 2 |
| 3. | Bob Armstrong | (2/2/96) | 2 |
| 4. | Jim Grove | (2/15/96) | 10 |
| 5. | Bob Schmiedlin | (2/28/96) | 34 |
| 6. | Stan LaHue | (2/26/96 and 10/12/95) | 11 |
| 7. | Don Detwiler | (2/23/96) | 4 |
| 8. | Kevin McMullen | (2/16/96) | 16 |
| 9. | Steve Forster | (10/95 and 3/5/96) | 37 |
| 10. | Leo DeFrain | (10/10/95) | 15 |
| 11. | Jon Underwood | (10/10/95) | 1 |

# TECHNICAL WORKING GROUP MEETING #3

## Minutes - January 31, 1996

## Discussion of Draft Final Texture Report

## Executive Summary

Section 1. Basic for Surface Texture Selection

A comment needs to be made up front that a noise reading of 3 dB(A) or less is not discernable by the human ear. This needs to be repeated every time a noise reading occurs in the 0 to 3 range.

Section 2. Safety Considerations

The raising of the speed limit is addressed in the report by requiring that a macrotexture be used for speeds of 50 mph (80 km/hr) and higher.

Section 3. Quality Mix Design

The Industry commented that a requirement for 25 percent siliceous sand makes it difficult for it to compete in areas with poor quality aggregates. The Industry requested the requirement be for the interstate only. The requirement cannot be limited to only one type facility because microtexture is necessary for friction at low speeds also. It was recommended that provision be made to retexture/resurface PCC pavements constructed with less than desirable aggregate material.

Section 4. General PCC Surface Texture Considerations

Longitudinal tining should receive the same recognition as transverse tining. When bumps are ground out of a longitudinally tined pavement, the sudden change in frequencies does not occur because tining and grinding are in the same direction. (Perhaps transverse grinding/grooving should be required to correct bumps in pavements with transverse tining.)

The uniform 13 mm (½ in) spaced transverse tining should be listed behind the random-spaced tining as the next best alternative. The objection to the 13 mm (½ in) has always been durability, but if it is constructed with 3 mm (1/8 in) depth and good mix design, durability should not be a problem.

The random tine range should be from 10 to 40 mm (3/8 to 1.5 in). The contractor should be required to purchase a manufactured rake for random tining and not be allowed to bend a uniform-spaced rake. Be careful how the specification reads for the random spacing to prevent an overzealous inspector from requiring the exact random spacing (unless this is necessary to ensure that objectionable tire whine is prevented!).

The tine depth requirement should be a target of 3 mm (1/8 in) with a maximum depth of 6 mm (1/4 in). (This recommendation needs to be reevaluated in 1996. It is believed that tine spacing and transverse groove width are critical, not the tine depth.)

The recommended texture depth in the exposed aggregate section should be removed. (This is based on a September 1995 PIARC recommendation in the Montreal Conference that will be referenced in the report.)

**Section 7. Research Needs**

The need for measurement of the noise irritation will be changed based on Wisconsin's research findings. Fast Fourier Transformations are capable of detecting narrow band frequencies that generate objectionable whining noises.

States should obtain road profiler data to address whether the textures have any affect on ride.

Development of the outflow meter (and uniform manufacture of the meter) to determine drainage quality should be included under the automated texture measurement need.

The need to relate pavement friction and wet weather accidents should stand alone. Half life for pavements based on friction needs to be developed.

Antilock brakes need to be considered while addressing the type of tire used in the skid test. (Per tire industry input, antilock brakes will not reduce the need for good pavement microtexture and macrotexture.)

### Issue: General Pavement Surface Type Questions

Page 38: Insert "or objectionable tonal noises" behind emission levels. State again that 3 dB(A) or lower change is imperceptible to the human ear.

### Issue: Safety of PCC and AC surface Textures

Page 40: Under transversely tined PCC, first paragraph, change "studded tires is not allowed" to "studded tires are not used extensively."

### Issue: Pavement/Tire Noise on PCC and AC Pavements

Page 46: Reconsider the recommendation of deep grooves, second paragraph under Transverse Tined Surface.

Page 47: Check location of Newport (not Atlanta) airport. Check validity of final sentence.

### Issue: Longitudinal and Transverse Tining

Page 52: Last paragraph, reconsider, this is an ideal situation. Hard gravel that is not durable in PCCP is fine in ACP.

## General

Change Kevin McMullen from WisDOT to Wisconsin CPA.

Place references in the report.

Move the bulk of the report into appendices and shorten it to about 12 to 15 pages.

Comments on the draft report are due by March 1, 1996. Written comments or a marked up copy of the report are appropriate.

JOHN JEWETT HENRY
P. O. BOX 84
HUNTINGDON, PA 16652-0084
U. S. A.

FAX NO: 1-814-643-6428
TELEPHONE No: 1-814-643-4474

TO: Roger Larson
FAX NO.: 1-202-366-3713

FROM: J. J. Henry
DATE: 11 March 1996

This transmission consists of 1 page including this cover sheet.

I am sorry that I did not make the deadline for comments on the Noise TWG's draft report. However, I do want to congratulate you on a very good report.

There is one inconsistency that should be corrected. On page 18 the skid numbers for the longitudinally tined 19 mm smooth tire results at 96 and 64 km/h are interchanged. Thus the gradients are not positive. The numbers as reported here just do not make sense, a smooth tire skid number of 53 at 60 mph would be highly unusual. The accompanying document "U. S. Research Status" has the numbers in the reverse order so I am sure that it is correct.

I believe that more effort should be made to understand the performance of longitudinal tining/grooving. If properly done, that seems to me to be the best solution. Site 67 in the International Experiment is further evidence of the effectiveness of longitudinal tining. Furthermore, it should reduce the cost of construction given suitably designed equipment.

I am preparing to go to Japan for three weeks, but will be home for another two weeks. If there is anything further I can be reached here.

U.S. Department of Transportation

FEDERAL HIGHWAY ADMINISTRATION
Office of Environment and Planning

**NOTE TO:** Roger Larson HNG-40 **DATE:** 2/2/96

**FROM:** Bob Armstrong HEP-40

**SUBJECT: Comments on Draft Final Texture Report**

The following comments on the subject report are offered for your consideration:

1. p. 38, last sentence: Add "or objectionable tonal noises" after ... in noise emission levels .... Neither the concerns for overall noise levels or frequency spectra should override the need for durability and safety.

2. p. 44, first paragraph under **General:** Replace "update the FHWA Noise Model" with "develop a new FHWA traffic noise prediction model." The new model will be totally new, not just an update.

Overall, I commend you for preparing a thorough report on a very complex subject. Please let me know if I can assist further.

**Mr. James Grove; Iowa DOT**
**February 15, 1996**

1. p. 6, **Transverse tining:** the 13 mm uniform spaced tined should be recommended as an alternate.

2. p. 40, Transversely tined PCC: "studded tires is not allowed" is not really a legality issue but a use issue.

3. p. 43, Existing PCC pavement surface treatments: reword the next to last sentence in the section.

4. p. 44, **Issue:** last question in the section should be one of texture durability, not pavement durability.

5. p. 44, **General:** The second sentence in the second paragraph does not flow well (i.e., friction to noise).

6. p. 46, first paragraph, next to last sentence; it is not clear how ride and noise are related.

7. p. 46, third paragraph; p.51, last paragraph: contention that deeper grooves produce greater noise than wide grooves.

8. p. 52, last paragraph, next to last sentence: a mix with a high sand content can accomplish durability without it being hard and non-polishing.

9. p. 53, **Recommendation:** include 13 mm uniform spacing as an alternate.

10. p. 54, PCC Open Graded, Disadvantages; "damaged" should be "damage."

**Wisconsin Department of Transportation**

DIVISION OF HIGHWAYS
Truax Center
3502 Kinsman Blvd.
Madison, WI 53704-2507

February 28, 1995 6

Roger Larson
FHWA, Pavement Division, HNG-42
400 Seventh Street, SW
Washington, D.C. 20590

Subject: Review comments on the Draft Report
**"Tire Pavement Noise and Safety Performance"**
- by the PCC Surface Texture Technical Work Group

Dear Mr. Larson:

I realize that, as the new kid on the block, this is my first kick at the cat and, therefore, some or most of my comments have probably already been looked at, mulled over and addressed many times before. I also fully recognize and appreciate the effort put into this report by all the committee members and in no way would expect that my comments should carry more, or even equal, weight than those of the other members. With that said, and hopefully understood, I feel entirely comfortable in communicating my viewpoint of the report.

Generally, I find the report hard to follow. It's format is very confusing and leads to statements being made two, three and even four times. I would consider changing the format to that of a standard report: a brief (one to two page) abstract; an Introduction and or Background; a Summary of the literature search; a Summary of current research; Conclusions; and, Recommendations. Keep it simple, straightforward and to the point.

Also, even though this is a **Technical Working Group on PCC Surface Texturing**, the report falls into a trap of comparing the results to AC pavements. I feel that by doing this we are not only jeopardizing the objectivity of the report (by making it a black vs white issue), but are limiting the thinking and, thus, the outcome. Why not simply cut to the quick and try to find the **Best** PCC pavement texture and be done with it. After all, PCC is a much more malleable medium than AC.

Now that I've got those thoughts off my chest my specific comments are included in the attached pages.

Roger Larson
February 28, 1996
Page 2

It was a real pleasure working with you and the group for the short time I was involved. If I can work with any future TWG's, I would consider it an honor.

Sincerely,

Robert B. Schmiedlin, P.E.
WisDOT Highway Research Supervisor

RBS:k00378

## Review Comments for

## TIRE PAVEMENT NOISE AND SAFETY PERFORMANCE
(draft report)

Page 5:

1 - Suggest changing the first sentence to "...can provide safe, durable traffic surfaces with low noise characteristics."

2 - Suggest a colon in the fifth line down after "...conditions at the site, such as:"

3 - Suggest changing the Fourth line from the bottom to read "...noise emissions where tradeoffs **are being considered.**"

Page 6:

4 - The last sentence in first paragraph of Par. 4 would read better if changed to "...transversely tined concrete pavements **with low noise characteristics and minimal splash and spray can be constructed.**"

5 - There is some concern for the validity of the second paragraph of Par. 4. Do we know this to be true? I can understand use of longitudinal and brushing for low speeds - but is there sufficient data for their use on **high speed highways**?

6 - The last paragraph on this page titled **Transverse tining** - Wisconsin research strongly demonstrates that random transverse tine spacing should be 10mm to 40mm. I had thought that the committee had agreed that this would be the recommendation.

Page 7:

7 - The continuation of the previous page - The spacings reported for the Australian random tining doesn't go far enough. The first grouping is to close and not much variation. Likewise, the second grouping given doesn't vary near enough to eliminate the "whine".

Page 9:

8 - In Par. 6, the second bullet statement referring to diamond grinding and Skidabrader. There is a nagging question in my mind in referring to the Skidabrader as **experimental**. It has seen wide use - having been used in most, if not all states, and has seen significant use on airport pavements - O'Hare and Dallas airports were recently skidabraded. It is seen as very cost-effective. These applications can't be experimental. I would caution that bias may be entering the fray here.

Page 12:

9 - Update the member listing to reflect Kevin McMullen as an Industry rep. and myself as a State Highway rep.

Page 16:

10 - In the list of preliminary conclusions, the fourth one, referring to interior noise, is not clear. I'm not certain what it means.

Page 17:

11 - The first sentence should be changed to read "**However, Wisconsin found random transverse...**"

12 - The next sentence should be changed to read "**The specified randomness of the spacing and the construction quality are critical factors in determining the generated noise characteristics and, ultimately, the resulting level of annoyance to the human ear.**"

13 - Under **California** and **Findings** - the spacings and speed given in the underlined statement should be in metric.

Page 19:

14 - Near the middle of the page the "**were**'s" should be changed to "**was**", i.e.,
"...transversely tined or grooved sections <u>was</u> made.", and
"...in providing friction, and the grooved section <u>was</u> slightly...".

15 - The asterisk statement should start with "Preceded" not "Proceeded".

Page 20:

16 - What speed were the noise measurements taken at??

Page 23:

17 - The asterisk at the bottom of the table is not noted in the table.

Page 30:

18 - In the first paragraph describing the Wisconsin project, the locations should be STH **29**, not 124, and I-**43**, not 94.

19 - There is no mention of this findings relative to interior noise. This is an important part of this project and needs to be noted.

Page 40 - 41:

20 - The table should be on one page - not split between the two.

Page 43:

21 - In the middle of the page, the sentence starting with "Overlays are good methods..." - What kind of overlays are we referring to - And - use "delaminate" instead of "come up".

Page 44:

22 - General comment relating to the **Issue** - I was under the assumption this was a "PCC texture" issue/paper - not a comparison of AC vs PCC pavements.

23 - Last sentence in the **General** discussion - I feel the sentence is non-relevant to the issue. It simply muddies the water - more like a green mule than anything.

24 - The first sentence in the "Dense Graded Pavement" discussion at the bottom of the page mentions the dBA's but gives no clue as to the speed the readings refer to.

25 - The last sentence at the bottom of Page 44 refers to "British research data indicates..." - What is the basis for the British findings? And, is it relevant? Do we accept it carte blanche? Is it supported by adequate research and reliable data? And, has it been duplicated/verified??

Page 48:

26 - The last sentence of the first full paragraph compares the splash and spray of tined PCC pavements vs dense graded AC pavements. If this were truly an objective, unbiased analysis of AC vs PCC, then the comparison would be made with the open-graded AC.

27 - The first sentence of the next paragraph is doing the old AC vs PCC comparison. Again - Objectivity! We have no long term data. And it is biasing the paper by comparing the "best" PCC with the "worst" AC. Why not just stick to the real issue, i.e., the basis for the recommendations as stated in the next paragraph?

Page 50:

28 - The noted mentioned near the top of the page referring to the longitudinal burlap drag used in Germany is not relevant to the issue at hand - Longitudinal vs Transverse **Tining**.

Page 51:

29 - In the second sentence under **Findings** referring to a spacing of 30mm being associated with tire whining - The Wisconsin study has identified the objectionable "whine" for uniform spacings greater than 13mm.

Page 52:

30 - In the middle of the page, everything following the sentence starting with "Results from Colorado's comparison..." is superfluous. It merely needs to be stated that "Results from several recent studies support this finding".

Page 53:

31 - The first sentence in **Recommendations** - Again, Wisconsin's data shows that truly random spacings ranging from 10mm to 40mm, with most less than 25mm, are best. Isn't that the spacing the committee agreed would be in this report?

Page 54:

32 - Under **Findings** - I've already hounded you on this point, but one more time... If the real issue is "Premium PCC Surface Treatments", then why do we get caught including a discussion of "AC Open Graded". This is really beyond me...

Well, that's it. Be assured my comments are meant to be constructive, not critical.

Respectfully Submitted:

Robert B. Schmiedlin, P.E.
WisDOT Highway Research Supervisor

AMERICAN CONCRETE PAVEMENT ASSOCIATION
acpa

3/4/96

February 26, 1996

Mr. Paul Teng, P.E.
Chief, Pavement Division
Federal Highway Administration
400 Seventh Street, S.W.
Washington, DC 20590

Dear Paul:

The January 31, 1996, TWG meeting on Texturing PCC Pavements was a most worthwhile session and was well attended. We have reviewed the minutes and they are not only timely, but also well written. We compliment Roger and Brad for a job well done.

We have completed our final review of the pending TWG report and offer the following comments:

1. Please refer to our October 12, 1995, letter to you on this same subject. Our October 1995 comments of the TWG report summarized our concerns verbally discussed with you at our September 19, 1995 meeting. Although some modifications were made to permit other type textures, we believe there are concerns in our October 12 letter that remain unsolved. We would appreciate your further consideration of these comments.

2. We have reviewed Mr. Kevin McMullen's comments and endorse them. He has furnished them to you under separate cover of the Wisconsin Concrete Pavement Association. We believe Kevin has been an asset to our TWG.

3. We have also reviewed Don Detwiler's February 23, 1996, memo to TWG members and believe he brings into focus long-term conditions that impact safety. His comments are excellent and demonstrate a builder's point of view. Please give them your serious consideration.

We strongly believe more emphasis from FHWA is needed on evaluating wet-weather accidents. Wet weather accident statistics will prove what surface is safest.

Page Two

Finally, your November 1, 1995, Action Memorandum is a welcome modification to your previous policy. We believe it is essential for States to have the feasibility to adjust to actual project conditions. In our travels throughout the States, this has been a continuous issue. Through your efforts and a strong partnership with the States and Industry, we have come to a new and better policy. We appreciate the efforts of the TWG. Thank you.

S. P. LaHue
Gerald F. Voigt
Theodore R. Ferragut

| | | |
|---|---|---|
| S. P. LaHue, P.E. | Gerald F. Voigt, P.E. | Theodore R. Ferragut, P.E. |
| Director - Highways | Director - Technical Services | Vice President - Government Affairs |

SPL/GFV/TRF:dah

c: M. J. Knutson
Kevin McMullen
Donald Detwiler
Thomas Trussell
Richard Forrestel

Attachments: ACPA October 12, 1995, letter to Teng
D. Detwiler's February 23, 1996 memo to TWG members

October 12, 1995

Mr. Paul Teng, PE
Chief, Pavements Division
Federal Highway Administration
400 Seventh St., SW
Washington, DC 20590

Dear Mr. Teng:

Thank you for asking us to comment on "Summary of PCC Texture Technical Working Group Findings." As we discussed at the September 19th meeting at our office, a brief summary on the subject would be a step in the right direction. However, we continue to have some serious reservations concerning the opinions expressed.

This TWG was basically formed to study the issue of pavement-tire noise. The summary paper, however, generally focuses on skid. Unfortunately, we believe the authors are more concerned with supporting transverse tining than presenting solid noise results. Our conclusions from working with the TWG and our own independent studies are therefore offered for consideration in your summary:

- the pavement/tire interaction for all pavement surfaces produces noise ranges of 60-63 decibels, when measured 5 meters out and up from the shoulder. These are relatively imperceptible differences.
- some transverse tined concrete surfaces produce higher, and possibly objectionable, pitch to abutting property owners. This can easily be corrected by either random transverse tining or by longitudinal tining.
- there are relatively insignificant tradeoffs between transverse tining and longitudinal tining when considering the overall properties of skid, noise, spray, splash, and cross drainage.
- noise should not be a determining factor in pavement selection.

In Paragraph 2. - Safety Considerations, it is stated that "current research and past experiences have shown that longitudinal texturing only with an artificial carpet or burlap drag will generally not provide a durable, skid resistance surface on high speed facilities." We do not believe this statement is supported by State practice. During the past few years, ACPA has observed and discussed texturing with many State officials on our annual van trips. Just two weeks ago in West Virginia on I-79, we inspected 24 year old pavement sections that had a burlap drag and longitudinal texturing. These sections had acceptable skid numbers (States annual inventory data) and no record of wet weather accidents. There are literally thousands of high speed facilities that fall into this category and perform extremely well. From our perspective, the quote from the summary does not capture "our" past experience.

We believe Paragraph number 3 is covered in Paragraph 4 and can be eliminated. We agree with your conclusion that mixes with sufficient quantities of siliceous sand will provide a good microtexture. We hope you have no problem with our conclusion that if these same mixes are tined in either direction, they will provide roughly equivalent skid values. The authors should also know that two-layer construction is currently under consideration as a study topic for High Performance Rigid Pavement. Two-lift construction is far from ready as an everyday practice and is probably destined for use in specialty work only. By the way, many State mixes do not meet this siliceous sand criteria but do have very adequate wet weather pavement performance.

In Paragraph number 4, the splash and spray issue is once again introduced to downplay longitudinal tining. It is our observation that all tined surfaces significantly reduce splash and spray compared to dense graded surfaces. If there is a splash-spray improvement with transverse tining over longitudinal tining, it is minor, and is countered by a longitudinal tining having a slightly lower noise level.

Finally, we strongly believe that the States should have maximum flexibility to design the total pavement structure, including the texture. We do not believe noise should be allowed to influence pavement selection, especially when alternative acceptable texture types are available.

We look forward to seeing the final summary and report.

Sanford P. LaHue, PE
TWG Member

Theodore R. Ferragut, PE
Vice President, Government Affairs

New Enterprise Stone & Lime Co., Inc.

P.O. Box 77 • New Enterprise, Pennsylvania 16664 • Corporate Office: 814-766-2211
Fax: 814-224-6800

February 23, 1996

Members of the Technical Working Group on Surface Texturing:

I have deliberated over the final proposed product of this group and after much deliberation feel that the attached comments should become a part of the document due to the impact which our deliberations and research should have upon the pavement determinations in the future.

If state agencies are to consider the safest pavements regardless of the noise factor, then transverse texturing should be considered foremost. However, if noise becomes a primary consideration, and skid resistance of the concrete pavements remains as a prime consideration of the agency, alternate pavement types should only be considered after thorough analysis of the pavement life skid resistance of the alternate pavements.

Since most skidding accidents happen on wet and saturated conditions, and since great consideration is given to the various numbers on alternate pavements, testing should be done on 1, 3, 5, and 7 year old pavements under accident conditions. Testing should show that concrete pavement retain their shape over these periods and thus do not show lower skid numbers over time. The alternate pavement type should show severe rutting over time and thus show significantly reduced skid numbers (if any) due to the hydroplaning on the water in the resultant ruts.

If noise and skid resistance are both prime in pavement type considerations, such selection should only be made after consideration of actual accident condition pavements over their entire life. Not to consider such empirical data over the course of the pavement life, and thus to disregard the obvious is tantamount to signing the death warrant on those motorist to whom our design recommendations are entrusted. Skid resistant numbers on new pavements is irrelevant to the total task to which we have been entrusted if the total pavement over the life of its existence is not taken into account. Accident statistics should also bear out that most accidents occur after the pavement has matured and that the alternate pavement, in this case, matures at a much more rapid rate than the concrete pavements herein addressed.

In summation, while we have undergone extensive investigation and ultimate resolution as to the preferred method of safety texturing for concrete pavements, we should incorporate into the body of our resolution direction that specifying agencies should account for the safety of the motorist over the entire life of the pavement above all other considerations in their pavement selection process.

I respectfully submit that these considerations be incorporated as a permanent part of our ultimate document. I thank you all for your time and have enjoyed all of the deliberations and resultant efforts that have been placed into the formulation of this document.

Very truly yours,

NEW ENTERPRISE STONE & LIME CO INC

Donald L. Detwiler
President, CEO

WISCONSIN CONCRETE ★ PAVEMENT ASSOCIATION

February 16, 1996

Roger ~~Larson~~ *fmf*
FHWA, Pavement Division, HNG-42,
400 Seventh Street, SW
Washington, D.C. 20590

Dear Mr. Larson:

Enclosed are my comments on the draft report "TIRE PAVEMENT NOISE AND SAFETY PERFORMANCE". Please review them and if you have any questions, please feel free to give me a call.

Both you and Brad Hibbs did a great job putting the report together and addressing all the relevant issues. I hope each of the technical working group members thank you for a job well done. You certainly have my thanks and appreciation. I look forward to seeing the final report in print.

I would also like to thank you for letting me be so involved in this effort. This proved to be a very valuable experience for me both in my Wisconsin Department of Transportation position as well as my new position representing the association. I also would like to thank you for keeping me involved after I switched positions.

The recommendations in your report indicate that more work is required in the future, especially in the noise vs. pavement age area. The association will support any future efforts and will do as much as possible to help. Please contact me if you come to Wisconsin in the future, we would be happy to have you visit.

Sincerely,

Kevin W. McMullen

Kevin W. McMullen, P.E.
Vice President

Comments on the draft report:

**TIRE PAVEMENT NOISE AND SAFETY PERFORMANCE**
by Roger Larson and Brad Hibbs, Federal Highway Administration

**General Comments:**

1. The report does an excellent job summarizing all the issues. You should be commended.

2. There exists the need to reference much of the contents of the report. Successfully, doing so will increase the value and credibility. Please make sure it does not appear that the contents are the law according to Larson and Hibbs.

3. The report is too long. Appendixes should be utilized as we discussed at the January 31, 1996 meeting. This is needed because the same thing is said many times in the report. A short and very concise report is always the most effective.

**Specific Comments:**

1. Page 6, second paragraph, Need for Quality Mix Designs on Heavily Traveled, High Speed Roadways. I understand and agree with the principals you are presenting here. However, reality is that the cost of importing aggregates a long distance can be too great. Take the Milwaukee County situation, the nearest "high" quality aggregates are 150 miles away. The costs of the imported aggregates should be compared to the costs of retexturing the pavements out in the future through a life cycle cost analysis.

2. Page 6, fifth paragraph, transverse tining. The 6 millimeter depth is too great. This cannot be constructed without pushing aggregates around the surface. We cannot portray that deeper than most current standards is better. I fear that if this published the possibility exists for building noisy pavements yet. There is a balance here. The 3 -5 mm depth under current specifications is good.

3. Page 7, second paragraph, transverse tining. The discussion should be expanded to state that if random textures cannot be obtained the next best transverse tining is 1/2" or 13mm spacing. Short spacing is better than the 1" or 1.5" standards used by many states.

4. Page 9, last paragraph, Research needs. The first bullet states that the noise testing has not been able to define the objectionable tire whine: The Wisconsin research project has done this. Can you state so and expand on it?

5. Page 10, third bullet, Use of blank tire. Has the relationship of the blank tire and

wet weather accidents truly been found? Never really seen this in print. You must reference where and who found this relationship.

6. Page 10, last bullet, random tining. Does more research really need to be done to define the optimum random tining? We are in a position where we know random tining is better. Therefore, the states and FHWA need to change guidance and specifications to reflect this known fact. Then if more research is needed, it should be done. Don't delay any recommendations to go to random tining, because of the perceived need for more research. Incremental change is good.

7. Page 16 and 24, The Michigan Research Project. The TWG and this report recognizes that the exposed aggregate surface will produce lower noise levels. The noise data does not reflect that. Reinforce that the high volume of trucks and the engine and stack noise is overpowering the pavement/tire noise. There should be a recommendation for test sections built with exposed aggregates. Also, the additional costs of constructing this texture is tough for the states too absorb at this time. FHWA should develop a means for paying for the extra cost.

8. Page 16 - 21, Colorado Research Project. The noise data collected on this project contradicts with the recommendations made in this report. Recognize that fact and address the possible reasons why. Something is wrong here.

9. Page 16, number 6, US Research Status. Brings up an issue that really has not been discussed by the TWG, the impact of vehicle speed and tire pavement noise. Does this mean that there may be an optimum texture for each posted speed limit. Should we be building the same texture on an urban expressway with a 45 MPH speed limit that we build on a rural interstate highway. Is the same level of texture required. We have played with the idea of not tining roadways in urban areas that are posted for anything less than 55 MPH speed limit.

10. Page 38, last paragraph. small and imperceptible differences in noise should be defined. Is this the 3 dBA rule of thumb? If so, say that. Then this should be brought out in the discussions of noise data in the different US research projects.

11. Page 40, accident data. I know the situation, the asphalt pavement data was not included for political reasons. But, as a matter of principal and a bit of stubbornness on my part, I have to pursue the issue and ask the question. Can the asphalt pavement get put back into this chart? Having it there, would greatly improve the value of presenting this data as well as reinforce the need for surface texture on high speed roadways.

12. The tradeoff issues associated with noise and friction need to be investigated, like accident rates and splash and spray during wet weather. If the public could be given a better understanding of the tradeoffs between texture and the other issues, I wonder if noise would be as big of a problem as it is in some areas of the US.

13. Page 46, second paragraph, Transversely Tined Surface. Is there really evidence that 13mm tining may result in excessive wear and poor durability of the pavement surface? Please reference this. If you don't have a reference, please remove this.

## COMMENTS FROM STEVE FORSTER, FHWA

**Preliminary Findings 3/96**

**Executive Summary**

1. Basis for Surface Texture Selection, fourth sentence: specify the method of ASTM skid trailer test.

2. Safety Considerations, first sentence: Is 65 km/h considered to be "high speed?"

3. Safety Consideration, last sentence: Is the 1976 AASHTO Guideline for Skid Resistant Pavement Design the latest version?

4. General PCC Surface Texture Considerations, Transverse Tining, fourth sentence: identify the sand patch test as ASTM #E965.

5. Same section, seventh sentence: Tines 1.5 to 3 mm deep may be too shallow.

6. General PCC Surface Texture Considerations, Longitudinal Plastic Brushing: Provide the friction numbers along with the friction coefficients.

7. Profile Considerations, first and last sentence: Insert the word "quality" after pavement ride. Insert the phrase "to a level" after tire/pavement noise.

## COMMENTS FROM STEPHEN FORSTER, FHWA

**draft Final Report 10/95**

**Executive Summary**

General PCC Surface Texture Considerations

1. First paragraph, last sentence: Add the phrase "and also" after graded asphalt surfaces.

2. Transverse Tining, second sentence: dislodging of coarse aggregate.

3. Transverse Tining, third sentence: Narrow, deep grooves should be 3 - 4 mm in width.

4. Transverse Tining, The Australian random tine spacing repeats too often. Groove depth of 1.5 mm is too shallow.

5. Longitudinal Tining, last sentence on British testing: Good comments, policy based on test results, not speed limits.

6. Longitudinal Plastic Brushing, third sentence: Average texture depth of 0.7 to 1.0 to too low.

Profile Considerations

7. First sentence: Dislodging of the coarse aggregate.

Alternative Surface Treatments...

8. Next to last star: Should be "Ralumac."

Research Needs

9. First Star: Further research dependant on Wisconsin research.

10. Second Star: The outflow meter data should help evaluate surface drainage quality.

11. Fifth Star: Consider also the effect of pavement age on texture and friction.

**U. S. Research Status**

12. Research Results, #1: What is the basis for stating that tine spacing over 26 mm causes the loudest tire/pavement noise? Research indicates that it is spacing over 39 mm.

13. Research Results, #4: "The vehicle interior noise..."

14. Colorado Test Results - Friction: Place the "*" on the other side of the "56/54."

15. Colorado Test Results - Texture: Identify Sand Patch as ASTM E-965.

16. Iowa Test Results - Texture and Friction: Identify Sand Patch as ASTM E-965.

17. Minnesota Test Results: Identify Sand Patch Test as ASTM E-965.

18. North Dakota Test Results: Identify the FHWA Texture Van test method.

19 Virginia Test Results: Identify the test method to obtain the mean texture depth of 0.89.

**Issue: General Pavement Surface Type Questions**

20. Use NCHRP Report 37: The minimum skid number of 26 is too low.

**Issue, Safety of PCC and AC Surface Textures**

21. Findings, First paragraph: Dense graded AC provides skid resistant through the nature of the exposed aggregate.

22. Findings, Second paragraph: Eliminate "age hardening of the asphalt."

23. "Open Graded AC provides good skid resistance by higher levels of macro-texture than a dense graded layer. In addition, any potential for hydroplaning is further reduced by allowing water to drain..."

24. Open Graded AC: The clogging of the open graded AC may not be as much of a problem in the U. S. It is a matter of surface durability.

25. "Transverse Tined PCC pavement with a hard fine aggregate provides excellent..." "...and studded tires are not used."

26. Longitudinally Tined PCC, second sentence: Explain why high quality aggregates are more important in longitudinally tined PCCPs than in transversely tined PCCPs.

27. Porous PCC, second sentence: Poor durability of the texture would be a problem in the northern region of the U. S.

**Issue: Longitudinal and Transverse Tining**

28. Findings: Use of 25% siliceous sand in the mix should be true no matter what the texture.

29. Recommendations: Over what distance is the spacing random? This should be discussed.

30. Brite/Euram Report: Are the "0.15 to 0.22" numbers related to skid numbers in the report?

# COMMENTS FROM LEO DEFRAIN

**Preliminary Findings 10/95**

**Executive Summary**

1. Basis for Surface Texture Selection, first sentence: Replace the term "skid resistant" with the term "proper friction" to reduce the negative aspect of the issue.

2. Safety Considerations, first sentence (and other locations): Clarify the term "high type" in reference to the facilities discussed.

3. Safety Considerations, fourth sentence (underlined): Define "slight" noise reduction.

4. Need for Quality Mix Designs on High Type, High Speed Highways, second paragraph, first sentence: The underlined portion of the sentence, "higher quality mix in the thinner layer," implies it is okay to place "low quality" concrete in the lower layer. This would cause a problem in States like Michigan, where "D" cracking starts from the bottom of the slab and moves up.

5. Profile Considerations, third sentence: Is the IRI method the best and most current method to measure pavement smoothness?

6. Alternative Surface Treatments, last sentence: It is questionable as to whether it is more cost effective to provide a thin surface treatment rather than to retexture when polishing aggregates are involved. It depends on the amount of time it takes the aggregates to polish.

To: Mr. Brad Hibbs
HNG-42

From: Jon Underwood
Technical Working Group on Pavement noise Member

Subject: Comments on "summary of Findings"

I feel summary of findings is very thorough and good summary of our discussions. My only comment or concern is page 3 - Safety Considerations:

Fourth line down you discussed exposed aggregate surface treatment. I am concerned that, without further reading, a user might be confused. It does not state that the exposed aggregate must be a good skid resistant, limited polish rock. This is important since the aggregate must provide both the micro and macro texture necessary for a skid resistant roadway.

Thanks for all the help and good work.

*U.S. Government Printing Office: 1996 — 514-837