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Noise level assessment of a 5-lane Portland cement Concrete Roadway in Louisiana

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Abstract: *Joor Road (La 946) is an Urban 5-lane Portland cement concrete roadway withan annual daily traffic (ADT) of approximately 13,500 with 7 percent trucks and posted speed of 89 kmh. Since being opened to traffic in 2009, residents have been complaining about the high noise levels emanating from the roadway.A comprehensive experiment was developed. The experiment consisted of randomly selecting six Portland cement concrete (PCC) slabs, three north bound and three southbound, in the noisy areas plus an additional slab outside of the noisy area to use as a control. The parameters assessed from each of eleven slabs were, tine depth, tine width, spacing between tines, and randomness of spacing between tines. Additional testing included noise assessments using the Pass by noise analysis, On-board soundintensity (OBSI) noise analysis, and macrotexture.Sound level measurements based on the pass by method indicated the sound levels were excessive (82 dBa) when compared to the Louisiana Department of Transportation and Development's (DOTD) Highway Traffic Noise Policy of 66 dBa for residential areas. Sound level measurements from the OBSI assessment also indicated that sound levels generated by the tire/road contact were excessive with values as high as 110.6 dBa.Pavement macrotexture values in terms of mean texture depth (mm) for the north and south bound lanes were generally within the range of 0.5 to 0.8 mm as recommended by the Federal Highway Administration (FHWA). Tine parameter analysis implied that the sources of excessive noise level emissions were due to excessive tine widths, non-randomness of spacing between tines, and the spacing intervals between the tines. The excessive noise levels were reduced from 82 dBa to 68 dBa by overlaying the PCC pavement with a 25 mm thick asphaltic concrete pavement.*

Keywords:*Portland Cement concrete pavement noise, Asphaltic concrete pavement noise, tine depth, tine width, tine spacing, randomness of tine spacing, Pass By noise analysis, OBSI noise analysis, Noise pollution, Noise in urban areas, environmental guidelines in transportation, pavement noise guidelines*

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I. Introduction

Joor Road (La 946), which is located in Baton Rouge, Louisiana, is an Urban 5-lane Portland cement concrete (PCC) roadway with 3 m concrete shoulders. It has a current annual daily traffic (ADT) of approximately 13,500 with 7 percent trucks and posted speed of 89 kmh. The length of the project under detailed investigation for noise level emissions is approximately 5 km.Since being opened to traffic in 2009, residents have been complaining about the high noise levels emanating from the roadway. In February 2014, Secretary Sherri Lebas requested that the Louisiana Transportation Research Center (LTRC) conduct a detailed investigation on this section of Joor Road. In the summer of 2015, a 25 mm thick asphaltic concrete (AC) overlay was placed on the existing PCC to mitigate the excessive noise.The major objectives of this research were to determine the PCC pavement surface characteristics responsible for the high noise levels on this section of Joor road as well as recommend methods to abate it. The actual noise levels were determined using on board sound intensity (OBSI) instrumentation and pass by noise level measurements.

II. Literature Review

Noise generated by vehicles on roadways has been studied extensively internationally *[1-20]*. There are many sources of noise generated by light and heavy vehicles *[1, 2]*. There are noises generated by the vehicle itself (air intake, exhaust outlet, engine block, transmission, and cooling fan) as well as the tire-road surface contact. The amount of noise varies depending on vehicle type, tire type, and travel speed. In higher speed situations (> 40 kmh), the tire-road contact may account for as much as 80 percent of the noise being generated*[1,2]*.Unpleasant sounds are generally described as noise. Though subjective, depending upon the individual, generalizations have been developed regarding noise *[3-5]*. For example, normal conversations occur at around 60 decibels (dBa), hearing hazards occur at levels above 90 dba, and rock concerts can be as loud as 120 dBa. Tire-road surface contact generates sound through a multitude of mechanisms some of which are not fully understood*[5-7]*. Additional noise generation is developed by the tire block protruding into the tine which creates a "pipe resonance effect" as presented in Figure 1 *[5]*. Specific to the PCC pavement surface, depth of tine, width of tine, spacing between tines, and randomness of spacing between tines effects sound generation *[8-10]*.Two main groups are generally used to describe sound generation: structure borne and air borne. Structure borne refers to the mechanical vibrations of the tire such as impact, shock, and adhesion mechanisms, all of which vary based upon tire type, pavement surface, and vehicle speed. [*3,4,11-17]*. Impacts and shocks occur by the tire block making contact and losing contact with the pavement surface as the tire rolls along the highway. This generates vibrations which in turn creates sound pressure waves propagating away from the tire. Adhesion mechanisms emerge due to frictional losses in the contact area between the tire and pavement *[3,4]*.Air borne noise is generated by the pumping of air through the tire tread as it contacts and loses contact with the pavement. Air is sucked in (compressed) as the grooves between the tread block makes contact with the pavement surface and is pumped out (decompressed) when the grooves between the tread block losses contact with the pavement *[3,4,11-17]*. When the pavement is tined (grooved), another mechanism exists for air to be compressed, decompressed, and jetted (pipe resonance) when the tread block protrudes into the pavement groove as presented in Figure 1. The wider the pavement groove, the more volume of air can be displaced resulting in increased sound generation (noise) *[5]*.Sound emissions are also influenced by the macrotexture of the pavement, pavement chemical properties, surface geometry, porosity, elastic properties within the pavement structure, and surface roughness*[1]*.

According to an FHWA sponsored study, the major PCC pavement surface parameters that influence sound generation are, the depth of tines, the width of tines, the spacing between tines, and the randomness of spacing between tines *[8]*. All four of these factors were investigated in this study. Regarding transverse tinning, FWHA states, "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. Narrow (less that 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 spacing's at two locations in Wisconsin that generate low-noise levels and no tire/pavement whine are as follows *[8-10]:*

1. 32/19/22/25/35/22/22/22/22/25/35/13/38 mm
2. 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"

Joor road was constructed under the 2006 Louisiana Department of Transportation and Development (DOTD) specification guidelines *[20]*. Section 601 of the 2006 DOTD Specifications covers tinning and mirrors FHWA guidelines with the exception that the maximum tine depth allowed by DOTD is 5 mm instead of the 6 mm recommended by FHWA *[8][20]*.

III. Methodology

PCC tining measurements

On Joor Road, seven slabs were randomly selected for evaluation, six within the noisy area and one within a quieter area. In order to determine if any significant differences existed between Joor road and another PCC project constructed under the DOTD 2006 specifications, Oneal Lane (I-12 to Florida Blvd.), constructed approximately two years after Joor Road, was selected. Four slabs were randomly selected for evaluation. The assessment consisted of measuring tine depths, tine widths, spacing between tines, and randomness of spacing between tines as presented in Figures 2a to 2c.

Grids were laid out on the selected PCC slabs and tine depth measurements were taken in accordance with DOTD Section 601 from the edge of the slab to the centerline at one foot intervals as presented in Figure 2a. The field data were transferred from field notes into an excel sheet. The collected data were used in statistical analyses (described later) as well as to determine if the tine depths were within the range (3 mm to 5 mm) specified in DOTD Section 601 *[20]*.Spacing between tines and tine widths were determined by examining photographs taken of the slabs as presented in Figures 2b and 2c. A tape with metric units was placed on the pavement slab (approximately 6.1 m in length) from joint to joint and photographed with a 16.1 megapixel camera as presented in figure 2b. The spacing between each tine was recorded into an excel sheet and used in the statistical analyses, which in this case included a statistical test for randomness *[21-23]*. Tine widths were tabulated by recording the width of the first tine from the joint and measuring the tine nearest each foot mark on the tape as it progressed along the slab, which generally produced about 20 tine width measurements per slab.

Statistical analyses of tine data

The statistical method using Tukey groups was used to determine if statistical differences existed between the slabs measured for the parameters of tine depths and widths *[21]*. Random spacing between tines was assessed using a non-parametric test called the "Runs Test" *[22, 23]*. All parameters were evaluated to determine if DOTD 601 specifications were met*[20]*.

Noise Analyses

Pass By noise measurements

Pass by noise measurements "A weighted dB(a)" were conducted by setting up a microphone at a distance of 50 ft. from the right wheel path of the outside the lane in accordance with DOTD, FHWA, and AASHTO guidelines *[24, 25, 26]*. The sound pressure level (Leq) in dB(a) was reported using 15 minute moving averages. Sound readings were taken in the morning (≈ 6 am to 9 pm) and afternoon (≈ 4 pm to 6 pm) in the noisy area and in the morning (≈ 6 am to 9 am) outside the noisy area on Joor Road before and after the AC overlay was placed. Since the posted speeds on Joor Road (89kmh) were significantly different than the posted speed (57 kmh) on Oneal Lane, and speed has a huge impact on sound emission, sound measurements were not taken on Oneal Lane. In accord with the noise measurement standards, 15 minute moving averages were calculated throughout the measurement time and the peak 15 minute Leq in dB(a) from the peak hour was used to determine whether or not it was in compliance with the noise levels presented in table 1*[24, 25]*. Joor Road fits into activity Category B based upon FHWA guidelines as presented in Table 1.OBSI noise measuring devices provide a consistent way to determine the noise emission from the tire-pavement contact. OBSI measurements were conducted in accordance with AASHTO TP 76-09 *[27]*. OBSI measurements were taken in both directions and in the inside and outside travel lanes within the noisy areas on the PCC pavement only. Measurements were also taken in the outside lanes of the quieter areas for comparison purposes.In a publication by the National Concrete Pavement Technology Center, OBSI noise based measurements were divided into three categories; low (< 99/100 dBa), middle (99/100 to 104/105 dba), and high (> 104/105 dBa) *[18]*. These rankings were used as a benchmark to evaluate the OBSI noise measurements taken on Joor Road.

Macrotexture data

The high speed profiler was used to collect macrotexture data using a 64 kHz texturing laser both inside and outside of the noisy areason the PCC pavement only *[28]*. Macrotexture values were evaluated based on FHWA criteria that states macrotexture values should be between 0.5 mm to 0.8 mm *[8]*.

IV. Discussion of Results

Pavement tining parameters

Tine depth analyses

Tine depth measurements were taken at seven sites on Joor road with sites 1 to 6 in the noisy area and site 7 outside the noisy area. Four sites were assessed on Oneal Lane (sites 8 to 11). Table 2 presents the descriptive statistics (average and standard deviation) for all eleven sites along with the results from the statistical analysis (Tukey grouping) *[21]*. The Tukey method assigns a letter to each site. Sites with similar letters means that no statistical difference existed while sites with different letters indicate that statistical differences exist. Regarding the sites (1 to 7) associated with Joor Road, the statistical analysis indicated that with the exception of site 2, the tine depths for the sites in the noisy area were significantly different from site 7 (quiet area) with site 7 having the least tine depth. The tine depths were similar between sites 1,3, 5, and 6 and similar between sites 3 and 4. Sites 2 and 4 were similar to site 8 on Oneal Lane. Sites 1 to 7 were evaluated to determine if they conformed to DOTD Section 601 specifications as presented in Table 3*[20]*. The results indicated that all seven sites did not conform to DOTD specifications. All seven sites had tine depths less than 3 mm with only a few having tine depths greater than 5 mm. Though shallow depths can reduce noise emissions, tine depths greater than 6 mm are generally associated with excessive noise emissions. Based on that it was the authors' opinion that tine depth was not the source of excessive noise on Joor Road *[8]*.Regarding Oneal Lane (sites 8 to 11), the results indicated that sites 8 and 11, sites 10 and 11, and sites 9 and ll are similar. Relating Joor Road to Oneal Lane, sites 2 and 7 have something in common to sites 8, 10, and 11. As with Joor Road, all sites had tine depths less than 3 mm and did not conform to DOTD specifications as presented in Table 3*[8]*.There is one issue of concern regarding the shallow tine depths on these projects: potential friction issues. One of the purposes of tining concrete pavement is to provide an avenue for water displacement during the braking process in wet weather as well as reducing hydroplaning. As the tine depths become shallower or non-existent from wear due to traffic, friction issues may emerge.

Tine width analyses

Tine width measurements were taken at seven sites on Joor Road with sites 1 to 6 in the noisy area and site 7 outside the noisy area. Four sites were assessed on Oneal Lane (sites 8 to 11). As previously mentioned, measurements were taken by examining photographs as presented in Figure 2b. Table 4 presents the descriptive statistics (average and standard deviation) for all eleven sites along with the results from the statistical analysis (Tukey grouping) *[21]*. The Tukey method assigns a letter to each site. Sites with similar letters means that no statistical difference existed while sites with different letters indicate that statistical differences exist. Table 5 presents the results of the specification check.

On the Joor Road sites, sites 1 and 5, sites 2, 3, 4, and 6, and sites 2, 3, 6, and 7 are similar. There were many similar grouping overlaps between Joor Road and Oneal Lane, with sites 1,5, and 9, sites 1, 8, and 9, sites 2, 3, 8, 9, and 11, sites 2, 3, 4, 6, 8, 10, and 11, and sites 2, 3, 4, 6, 7, 10, and 11 having statistical similarities. There was a broader range of sites statistically grouped together than with the tine depth data sets.

As presented in Table 5, all sites had tine widths greater than the 3.5 mm maximum specified in DOTD Section 601 and therefore did not meet that specification. Cumulative distribution functions (CDF) were created for Joor road alone and Joor road in combination with Oneal Lane data, both yielding similar CDF's. With that being the case, the CDF (sites 1 to 11) presented in Figure 3 was used to illustrate the fact that 60 percent of the tines were over the 3.5 mm maximum specified by DOTD and recommended by FHWA *[8, 18]*. It has been demonstrated that as tine width increases so does sound emission *[5]*. The authors postulate that the excessive tine widths are one of three PCC pavement surface parameters contributing to the excessive noise on this project, discussed in detail later.

Randomness of spacing between tines analysis

Spacing between tine measurements were taken at seven sites on Joor Road with sites 1 to 6 in the noisy area and site 7 outside the noisy area. Four sites were assessed on Oneal Lane (sites 8 to 11).The randomness of spacing between tines was evaluated using a non-parametric statistics test called the "Runs Test" and the results are presented in Table 6*[22,23]*. The results indicated that approximately 72 percent of the sites on Joor Road do not meet the requirement for randomness while 25 percent of the sites on Oneal Lane do not meet the requirement for randomness. This implies that randomness between tines can be achieved as measured on Oneal lane and it is unknown why Joor Road did not meet that criteria. It has been demonstrated that non-random spacing between tines as well as large spaces between tines will increase sound emissions *[8, 9, 10, 18]*.

Pass by and OBSI noise measurements

Pass by noise measurements were taken between the hours of 6 am to 9 am and 4 pm to 6 pm in the noisy area and between 6 am and 9 am in the quieter area on the PCC and AC pavement surfaces *[24,25,26]*. In accordance with FHWA guidelines, 15 minute running averages from the peak hour were calculated for the noise parameter Leq (dBa) and the highest Leq value from those readings should be used as the Leq for that location. Figure 4a presents the results from noise testing on Joor Road. The peak PCC pavement noise value for the noisy area on Joor Road is 82 dBa while the peak noise value in the quieter area is 74 dBA. Both areas exceed DOTD and FHWA noise level guidelines for residential areas, but there is a considerable difference in magnitude between 82 and 74 dBa: 251 percent in terms of sound pressure. In the summer of 2015, the PCC pavement was overlaid with a 25 mm thick AC pavement. Noise measurements were taken within the time limits previously mentioned on the AC pavement surface and in the "quieter area" on the PCC surface. As presented in Figure 4b, the peak noise level dropped from 82 dBa to 68 dBa indicating a significant reduction in noise resulted from the placement of the AC pavement. The noise level in the quieter PCC area was similar between the readings taken in 2014 and 2015.

OBSI noise measurements were conducted on the PCC pavement only in accordance with AASHTO TP 76-09 standards both inside and outside of the noisy area as presented in Figure 4b. The results presented in Figure 4b represent the average value of triplicate tests. The zone regions shown in Figure 4b represent zone 1 which was considered the low noise level region, zone 2 the middle noise level region or quality noise level zone, and zone 3 considered the high noise level region or "avoid" noise level zone *[18]*. As shown in Figure 4b, the quieter area on the Joor Road PCC pavement was within the bounds of the quality noise level region and the majority of the test results on the noisy section of Joor Road were in the "avoid" noise level zone.

Pavement macrotexture

Joor Road was assessed with a high speed profiler to obtain its macrotexture in terms of mean texture depth, (MTD) as presented in Figures 5a to 5d on the PCC pavement only. Using the FHWA recommended ranges of 0.5 to 0.8 mm for MTD as a guide, the macrotexture in both the noisy and quieter areas generally fit within the range recommended by FHWA *[8]*. MTD above 0.8 mm can cause excessive noise emissions while MTD below 0.5 mm may exhibit reduced friction characteristics when the pavement is wet.

V. Conclusions

The objective of this study was to identify the source(s) of excessive noise levels on Joor Road and mitigate them. This was accomplished through sound level measurements as well as a comprehensive assessment of the PCC pavement surface. Sound levels (Leq (dBa)) were measured using the pass by and OBSI methods. The PCC surface analysis included measuring four tine parameters which were tine depths, tine widths, spacing between tines, and random spacing between tines. The excessive noise level from the PCC pavementwas mitigated by placing a 25 mm thick AC overlay.

Sound level measurements based on the pass by method indicated the sound levels were excessive (82 dBa) when compared to DOTD's Highway Traffic Noise Policy of 66 dBa for residential areas. Sound level measurements from the OBSI assessment also indicated that sound levels generated by the tire/road contact were excessive with values as high as 110.6 dBa.Tine parameter analysis implied that the sources of excessive noise level emissions were due to excessive tine widths, non-randomness of spacing between tines, and the spacing intervals between the tines. Pavement macrotexture values in terms of MTD for the north- and south-bound lanes were generally within the range of 0.5 to 0.8 mm as recommended by FHWA. Noise levels were reduced from 82 dBa to 66 dBa by placing a 25 mm thick AC overlay on the PCC pavement.

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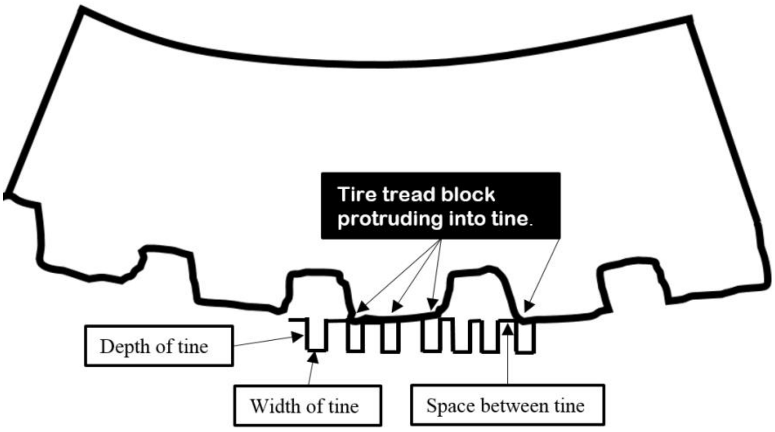

Figure 3 Tread block into pavement surface tine [5]

2a

2b

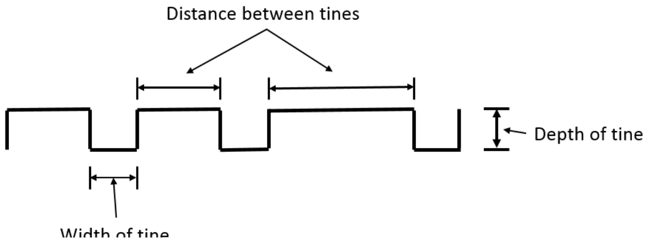

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Figure 2:4(a)PCC tine measurements, 2(b) Photo of tape measurement used for tine width and spacing measurements, 2(c) Schemata of tine depth, width, and distance between tines

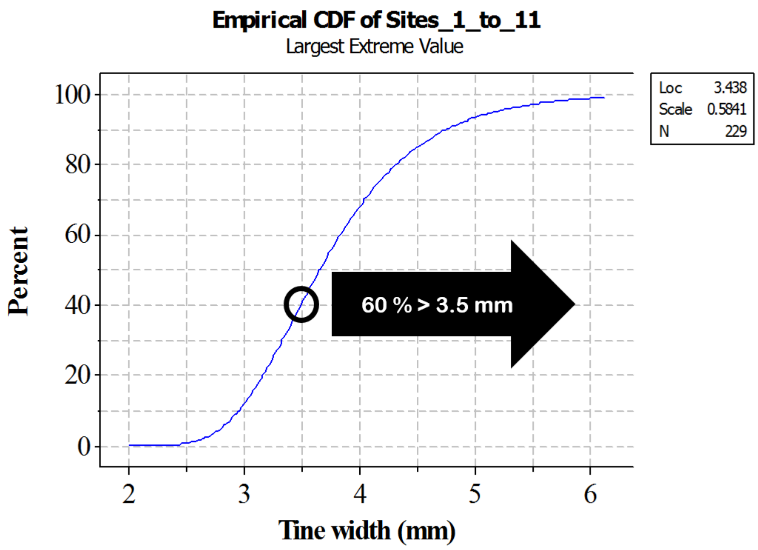
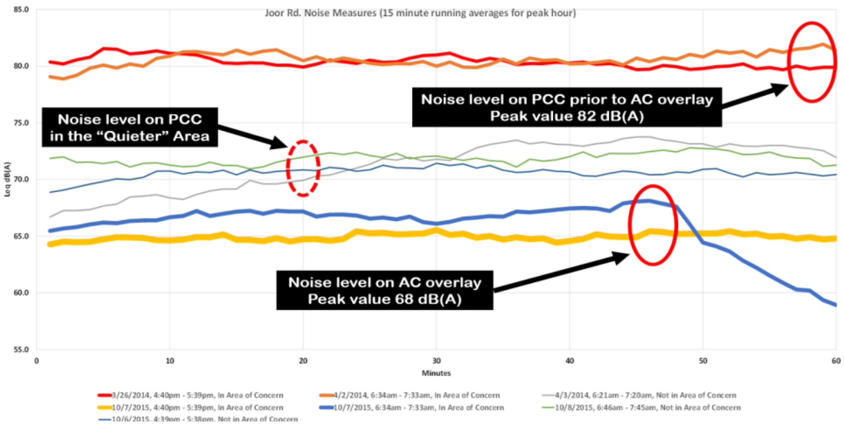
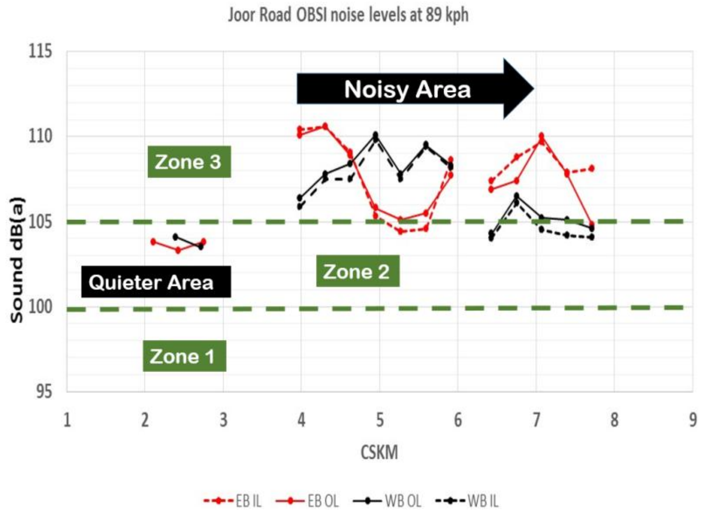


Figure 3 Cumulative distribution function of tine widths (mm)



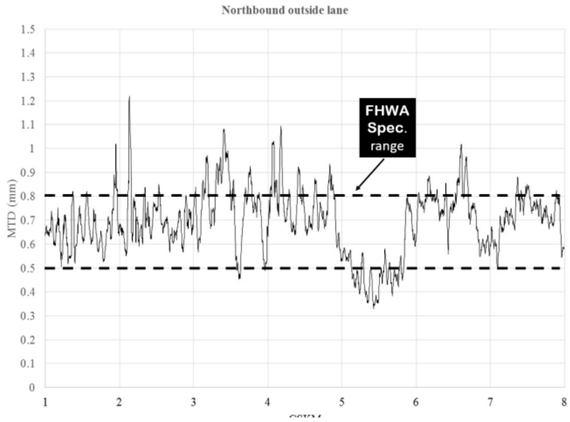
4(a)



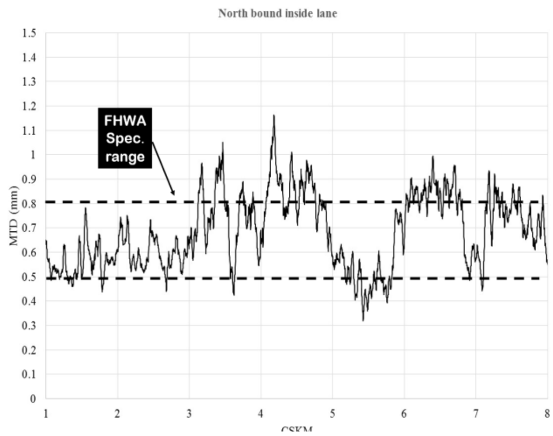
4(b)

Figure 4: 4(a) Pass by noise measurements (PCC and AC pavement), 4(b) OBSI noise measurements (PCC pavement only)

Legend: EB=East bound, IL=Inside lane, WB=West bound, CSKM= control section km (longitudinal distance (km) along roadway)



5a



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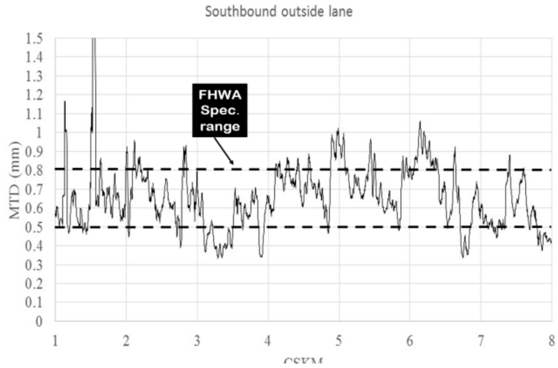

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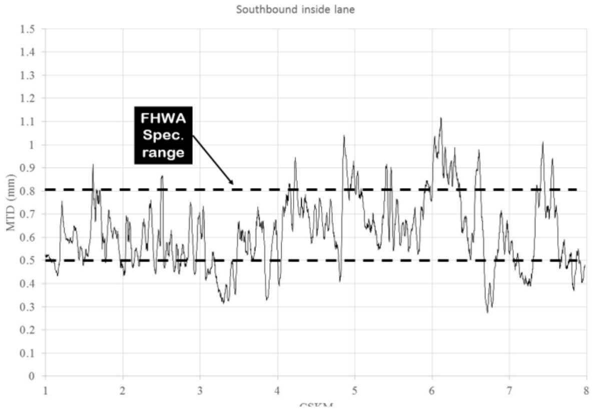

5d

Figure 5: 5(a) Northbound outside lane PCC macrotexture, 5(b) Northbound inside lane PCC macrotexture, 5(c) Southbound outside lane PCC macrotexture, 5(d) Southbound inside lane PCC macrotexture

Legend CSLM= control section km (longitudinal distance (km) along roadway)

MTD = mean texture depth

Table 1 FHWA noise abatement criteria

Activity category	Activity Leq (h)	Evaluation Location	Activity Description	In Louisiana, Impact occurs when Noise Level ***is equal to or greater than*** the values below*
A	57	Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.	**56**
B	67	Exterior	Residential (includes undeveloped lands permitted for residential).	**66**
C	67	Exterior	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings. (Includes undeveloped lands permitted for these activities).	**66**
D	52	Interior	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios.	**51**
E	72	Exterior	Hotels, motels, offices, restaurants/bars, and other developed lands, properties or activities not included in A-D or F. (Includes undeveloped lands permitted for these activities).	**71**
F	------	------	Agriculture, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing.	**n/a**
G	------	------	Undeveloped lands that are not permitted.	**n/a**

*These values are consistent with the FHWA's requirement for consideration of traffic noise impacts 1 dBA below their noise abatement criteria.

Table 2 Tine depth metrics and statistical results

Roadway	Site No.	Average (mm)	STDEV. (mm)	Tukey grouping					
Joor Road	1	3.41	1.1915	A					
Joor Road	5	3.28	1.1747	A					
Joor Road	6	3.22	1.1194	A					
Joor Road	3	2.88	0.9840	A	B				
Joor Road	4	2.38	0.9344		B	C			
Oneal Lane	8	2.08	0.7945			C	D		
Joor Road	2	1.95	0.5471			C	D	E	
Oneal Lane	10	1.84	0.7587			C	D	E	
Joor Road	7	1.81	0.9063				D	E	
Oneal Lane	11	1.45	0.7360					E	F
Oneal Lane	9	1.05	0.8926						F

Table 3 Tine depths

Site	Road	No. of points	D < 3 mm (%)	3 mm ≤ D ≤ 5 mm (%)	D > 5 mm (%)	Meets Specification
1	Joor	64	20.3	75.0	4.7	No - Exceeds 5 mm and less than 3 mm
2	Joor	64	90.6	9.4	0.0	No - Less than 3 mm
3	Joor	64	37.5	60.9	1.6	No - Exceeds 5 mm and less than 3 mm
4	Joor	64	64.1	35.9	0.0	No - Less than 3 mm
5	Joor	64	25.0	68.8	6.3	No - Exceeds 5 mm and less than 3 mm
6	Joor	64	29.7	62.5	7.8	No - Exceeds 5 mm and less than 3 mm
7	Joor	64	85.9	14.1	0.0	No - Less than 3 mm
8	O'Neal	52	75.0	25.0	0.0	No - Less than 3 mm
9	O'Neal	52	96.0	4.0	0.0	No - Less than 3 mm
10	O'Neal	52	83.0	17.0	0.0	No - Less than 3 mm
11	O'Neal	52	92.0	8.0	0.0	No - Less than 3 mm

Table 4 Tine width metrics and statistics

Roadway	Site No.	Average (mm)	STDEV. (mm)	Tukey grouping				
Joor Road	5	4.50	0.5477	A				
Joor Road	1	4.38	0.7891	A	B			
Oneal Lane	9	4.07	0.5542	A	B	C		
Oneal Lane	8	3.90	0.7003		B	C	D	
Joor Road	3	3.74	0.4364			C	D	E
Joor Road	2	3.64	0.4781			C	D	E
Oneal Lane	11	3.53	0.4993			C	D	E
Joor Road	4	3.48	0.5356				D	E
Oneal Lane	10	3.40	0.4757				D	E
Joor Road	6	3.38	0.4976				D	E
Joor Road	7	3.31	0.5585					E

Table 5 Tine width specification check

Site	Road	No. of points	W < 2.5 mm (%)	2.5 mm ≤ W ≤ 3.5 mm (%)	W > 3.5 mm (%)	Meets Specification
1	Joor	21	0.0	9.5	90.5	No - Exceeds 3.5 mm
2	Joor	21	0.0	38.1	61.9	No - Exceeds 3.5 mm
3	Joor	21	0.0	28.6	71.4	No - Exceeds 3.5 mm
4	Joor	21	4.8	57.1	38.1	No - Exceeds 3.5 mm and less than 2.5 mm
5	Joor	21	0.0	4.8	95.2	No - Exceeds 3.5 mm
6	Joor	21	0.0	61.9	38.1	No - Exceeds 3.5 mm
7	Joor	21	0.0	76.2	23.8	No - Exceeds 3.5 mm
8	O'Neal	21	0.0	28.6	71.4	No - Exceeds 3.5 mm
9	O'Neal	21	0.0	14.3	85.7	No - Exceeds 3.5 mm
10	O'Neal	20	0.0	65.0	35.0	No - Exceeds 3.5 mm
11	O'Neal	20	0.0	50.0	50.0	No - Exceeds 3.5 mm

Table 6 Random spacing between tines

Roadway	Site Number	Tine spacing Random "Runs Test"	Tine spacing Not Random "Runs Test"
Joor Road	1		X
Joor Road	2	X	
Joor Road	3	X	
Joor Road	4		X
Joor Road	5		X
Joor Road	6		X
Joor Road (*)	7		X
Oneal Lane	8	X	
Oneal Lane	9		X
Oneal Lane	10	X	
Oneal Lane	11	X	
(*) Located outside of Noisy Area			

Kevin Gaspard. "Noise level assessment of a 5-lane Portland cement Concrete Roadway in Louisiana." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 14.4 (2017): 68-78.