Tire-Noise Performance of Selected Montana Highway Pavements:

On-Board Sound Intensity (OBSI) Measurements

Prepared for

The Department of Transportation
Helena, Montana

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1. INTRODUCTION

On-Board Sound Intensity measurements were conducted on 2- to 4-lane highway and segments in the vicinity of Helena and Great Falls, Montana, as well as several sites in western Montana, in an effort to document the tire/pavement noise levels of existing and recently laid pavements. Various types of concrete and Asphalt Concrete (AC) pavements were tested. The AC test sites included Chip Seal and Plant Mix Seal pavement types. In the Helena area, three segments along I-15 were tested; the test sections in western Montana consisted of multiple segments along I-90, US Highway 93 (N-5), Montana Highway 200 (P-6), and Montana Highway 35 (P-52); and a single segment along I-90 was tested in Great Falls. In addition to the measurement and documentation of these existing pavement conditions, other segments were proposed for analysis; however, due to construction, speed limitations, terrain constraints, and/or traveling traffic congestion, further measurements could not be made at the time of testing. This report summarizes the acoustical performance of the selected pavement sections, utilizing the results of on-board tire/pavement noise source measurements.

2. TERMINOLOGY

Below are brief definitions of acoustical terminology used in this report.

- **Decibel (dB).** A unitless measure of sound on a logarithmic scale. For sound pressure level, this applies to the squared ratio of sound pressure amplitude to the reference sound pressure amplitude of 20 micro-Pascal. For sound intensity level, this applies to the ratio of the sound intensity amplitude to the reference intensity amplitude of 1 pico-watt per square meter.
- **A-Weighted Decibel (dBA).** An overall frequency-weighted sound level in decibels that approximates the frequency response of the human ear.
- **Sound Intensity.** The product of sound pressure and particle velocity in the direction of the intensity vector. The sound intensity in a specified direction is the amount of sound power flowing through a unit area normal to that direction.
- **Coherence:** A measure of how similar two signals are. It is computed as a correlation coefficient between the two microphone signals of any one sound intensity probe.
- **PI Index:** The difference between the sound pressure and sound intensity level.
- **Frequency:** Expressed in terms of cycles per second, or Hertz (Hz) (e.g., a frequency of 250-cycles per second is referred to as 250-Hz). High frequencies are sometimes more conveniently expressed in kilohertz (kHz), or thousands of Hertz. The audible frequency range for humans is generally between 20-Hz and 20,000-Hz

3. DESCRIPTION OF FIELD PARAMETERS

A. Test Procedure

On-vehicle OBSI testing was conducted following the provisional American Association of State Highway and Transportation Officials (AASHTO) Standard Method of Test TP 76-10. This was accomplished using a dual-probe sound-intensity fixture with attached microphones. This fixture assembly was connected to and supported by the test vehicle in free space, allowing for measurement positions close to the leading and trailing edges of the tire contact patch. The dual-probe sound-intensity fixture allows the leading and trailing edge positions to be measured simultaneously. Each probe consisted of two ½-inch G.R.A.S phased-matched condenser microphones, installed on ½-inch G.R.A.S 26AK microphone preamplifiers, attached to a plastic probe holder at a spacing of 0.63-inches (16-mm) in a side-by-side configuration, and fitted with spherical windscreens. The probe was positioned 3-inches (75-mm) from the pavement surface and 4-inches (100-mm) from the face of the tire, at locations opposite the leading and trailing contact patch of the tire, and were oriented such that the sensitive axis was directed toward the tire. See Figure 1 for a picture of the setup as installed on the vehicle. Data from the leading and trailing edge positions are acquired separately for the same section of pavement and averaged together during post-analysis. Three or more passes were made

Figure 1. OBSI Equipment Installed on a Test Vehicle

for each test section, which were averaged together during post-analysis. Multiple sections on a site were selected and measured, assuming the length of the test site allowed for multiple measurements. During post-analysis, all measurements for the same pavement section were averaged together, resulting in an average OBSI level per site. In situations where more than one pavement type was identified along a site, each pavement was measured and documented separately.

The measurements were taken at the end of September 2009 using a Chevrolet Impala test vehicle. A Uniroyal Standard Reference Test Tire (SRTT) was used for all measurements under free flow traffic conditions and a load of two people plus OBSI instrumentation. Prior to the sound intensity measurements, the test tire hardness was measured by means of the Durometer Hardness Test[1]. The hardness was averaged across the tire at the Tiger Paw "T" and the Uniroyal "U" and was recorded to be 67 and 65, respectively. Figure 2 shows the SRTT tire. For all roadways with multiple lanes of traffic, testing took place in the right through travel lane, and where possible, in the left through lane as well. A constant vehicle speed of 60 mph (97 km/h) was used with a 'cold' tire inflation pressure of 30 psi.

Figure 2. Photograph of Uniroyal SRTT

The Bruel & Kjaer PULSE System was used to acquire the sound data in narrowband Fast Fourier Transform (FFT) and third octave band levels using a 5-second averaging time. The microphones were calibrated using a Larson Davis Model CAL200 acoustic calibrator set for 94 dB at the beginning and end of each measurement day. OBSI quality metrics of coherence between the two microphones comprising each probe and the difference between sound pressure and sound intensity level were monitored during data acquisition. The real-time data for the four microphones were also monitored.

[1] ASTM D2240 – 05, Standard Test Method for Rubber Property-Durometer Hardness.

B. Measurement Sites

The Montana Department of Transportation identified 15 test sites along highway segments in the vicinity of Helena, Great Falls, and parts of western Montana; the site locations and surface types are given in Table 1 and are shown on the map in Figure 3 (provided by the Montana Department of Transportation).

Site #	Route	Direct	Location	Surface (Year Installed)	Test Date
1	N-8	E-W	US Hwy 12, MP 46.5 to 49.5	Transverse Tine PCC (1979)	Not Measured
2	I-90	E-W	I-90, MP 0 to 4.2	Transverse Tine PCC (1976)	9/16/2009
3	I-90	E-W	I-90, MP 21.7 to 27	Transverse Tine PCC (1984)	Not Measured
4	I-90	E-W	I-90, MP 39 to 43.7	Transverse Tine PCC (1987)	Not Measured
5	N-5	N-S	US Hwy 93, MP 103 to 106	Burlap Drag PCC (2000)	9/15/2009
6	I-15	N-S	I-15, Cedar Street to Burlington Northern Railroad Lines	Plant Mix Seal (2008)	9/17/2009
7	I-315	E-W	I-315, MP 0 to 2.8	Plant Mix Seal (2007)	Not Measured
8	I-15	N-S	I-15, MP 190 to 190.5	New Chip Seal (2007)	9/17/2009
9	I-15	N-S	I-15, MP 270.5 to 282	New Chip Seal (2007)	9/18/2009
10	P-6	E-W	Montana Hwy 200, MP 99 to 116	New Chip Seal (2009)	9/15/2009
11	I-90	E-W	I-90, MP 53.8 to 64	New Chip Seal (2008)	9/16/2009
12	I-15	N-S	I-15, MP 200.4 to 217.4	Medium to Older Chip Seal (2003)	9/17/2009
13	N-5	N-S	US Hwy 93, MP 48.3 to 56	New Chip Seal (2008)	9/15/2009
14	P-52	E-W	Montana Hwy 35, MP 0.2 to 2.8	Failed Chip Seal (2005)	9/15/2009
15	N-60	E-W	US Hwy 87/89, MP 87 to 90	Dowel Bar Retrofit with Diamond Grind (2009)	Not Measured

Table 1. Test Sites Identified for Noise Monitoring

For some of the selected test sites, the entire section identified in Table 1 was not used, depending upon traffic conditions, roadway topography (i.e., elevation changes, curvatures, etc.), and speed limits. Sites 5, 10, and 14 were all two-lane highways, and measurements were taken in each lane at these sites. The other sites had 4 lanes, and with the exception Site 2, measurements were made in each lane. At Site 2, measurements were taken in the right and left through lanes in westbound direction only; the downward grade in the eastbound direction prevented the vehicle from traveling at a constant 60 mph and could not be tested. As indicated in Table 1, Sites 1, 3, 4, 7, and 15 were not measured. Site 1, which was located along US Highway 12 in Helena, and Site 14, which is located along US Highway 87/89 in Great Falls, consisted of local traffic congestion, speed limitations, and stop lights that prevented OBSI testing. Site 3 was partially located within a construction zone along I-90 with one lane blocked off and a lower speed limit. The part of the segment not in a construction zone contained steep grades and sharp turns with speed limits as low as 35 mph. Additionally, Site 4 on I-90 and Site 15 on US Highway 89/87 were completely within construction zones, which contained lane shifts, blocked lanes, pavement changes, and lowered speed limits. Photographs of the test pavements were taken at selected test sites, as shown in Figure A-1 (note: photos for each test pavement are not shown due to roadside safety concerns).

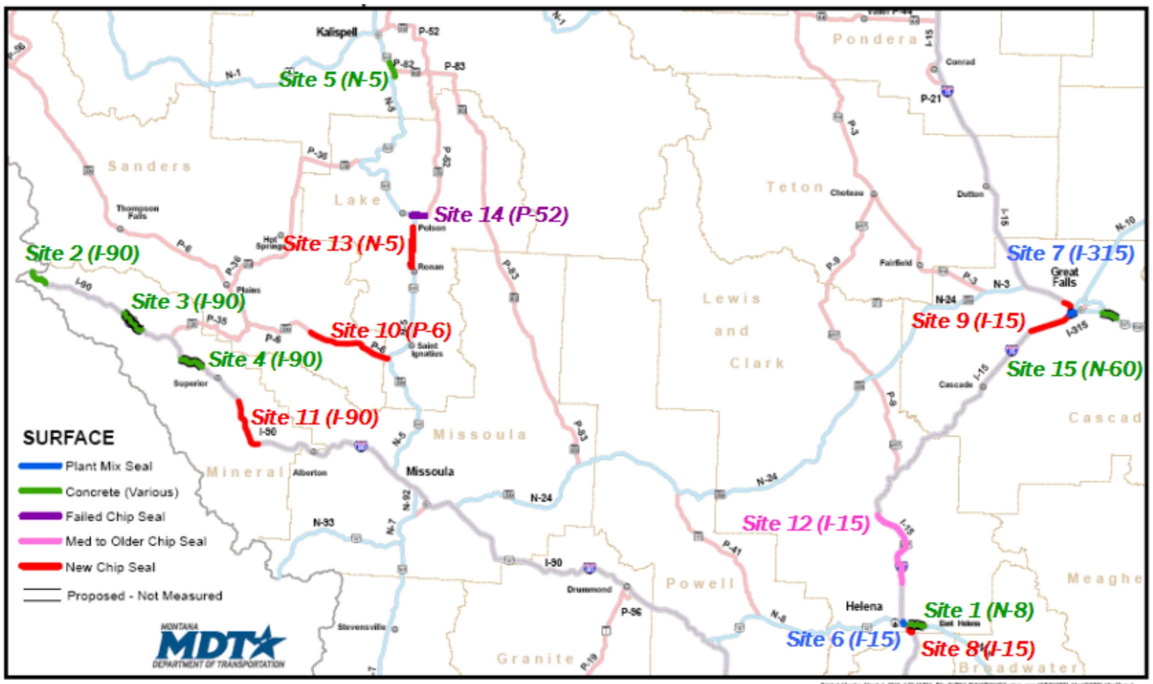

Figure 3. Map of Montana Showing the Test Site Locations

Figure A-2 shows the construction existing at Site 15 at the time of testing.

C. Meteorological Conditions

Measurements were conducted between 10:30 am and 5:00 pm on September 15, 2009, between 10:00 am and 4:00 pm on September 16, 2009, between 10:30 am and 4:00 pm on September 17, 2009, and between 10:30 am and 2:00 pm on September 18, 2009. On testing Day 1, the air temperatures remained in the 65°F to 75°F (18°C to 24°C) range throughout the testing period with clear skies. The air temperature ranged from 59°F to 80°F (15°C to 27°C) on Day 2 with clear skies; the weather on Day 3 was also clear with temperatures ranging from 73°F to 83°F (23°C to 28°C); and Day 4 saw clear skies with temperatures around 75°F (24°C). Barometric pressure was also measured and recorded during testing. Readings were as follows: 920 to 935 hPa on Day 1; 900 to 915 hPa on Day 2; 870 to 975 hPa on Day 3; and 900 hPa on Day 4.

4. RESULTS OF FIELD MEASUREMENTS AND ANALYSIS

Tire/pavement noise measurements were conducted on 10 test sites and a single pavement type each. These included one (1) Transverse Tine PCC pavement, one (1) Burlap Drag PCC pavement, one (1) Plant Mix Seal AC pavement, five (5) New Chip Seal AC pavements, one (1) Medium to Older Chip Seal AC pavement, and one (1) Failed Chip Seal AC pavement.

A. Overall A-Weighted OBSI Levels

Table 2 shows a summary of the test sites and the resultant overall A-weighted sound intensity levels for each site. Averages, by pavement type, are also summarized in Table 2. A comparison of the overall A-weighted sound intensity levels for each test site is shown in Figure 4.

Site Number	Surface Type	OBSI Level, dBA
Site 6 (I-15) **– see Figures A4 & A7**	AC – Plant Mix Seal	100.5
Site 12 (I-15) **– see Figures A4 & A8**	AC – Med to Older Chip Seal	102.0
Site 11 (I-90) **– see Figures A4 & A8**	AC – New Chip Seal	102.1
Site 9 (I-15) **– see Figures A4 & A8**	AC – New Chip Seal	102.2
Site 8 (I-15) **– see Figures A4 & A8**	AC – New Chip Seal	102.6
Site 13 (N-5) **– see Figures A4 & A8**	AC – New Chip Seal	103.3
Site 10 (P-6) **– see Figures A4 & A8**	AC – New Chip Seal	103.3
Site 14 (P-52) **– see Figures A4 & A8**	AC – Failed Chip Seal	104.3
Site 5 (N-5) **– see Figures A3 & A5**	PCC – Burlap Drag	105.5
Site 2 (I-90) **– see Figures A3 & A8**	PCC – Transverse Tine	108.4
Average AC – New Chip Seal		*102.6*
Average All Chip Seals		*102.8*
Average Concrete		*106.9*

Table 2. Summary of Test Sections and Overall A-Weighed Sound Intensity Levels

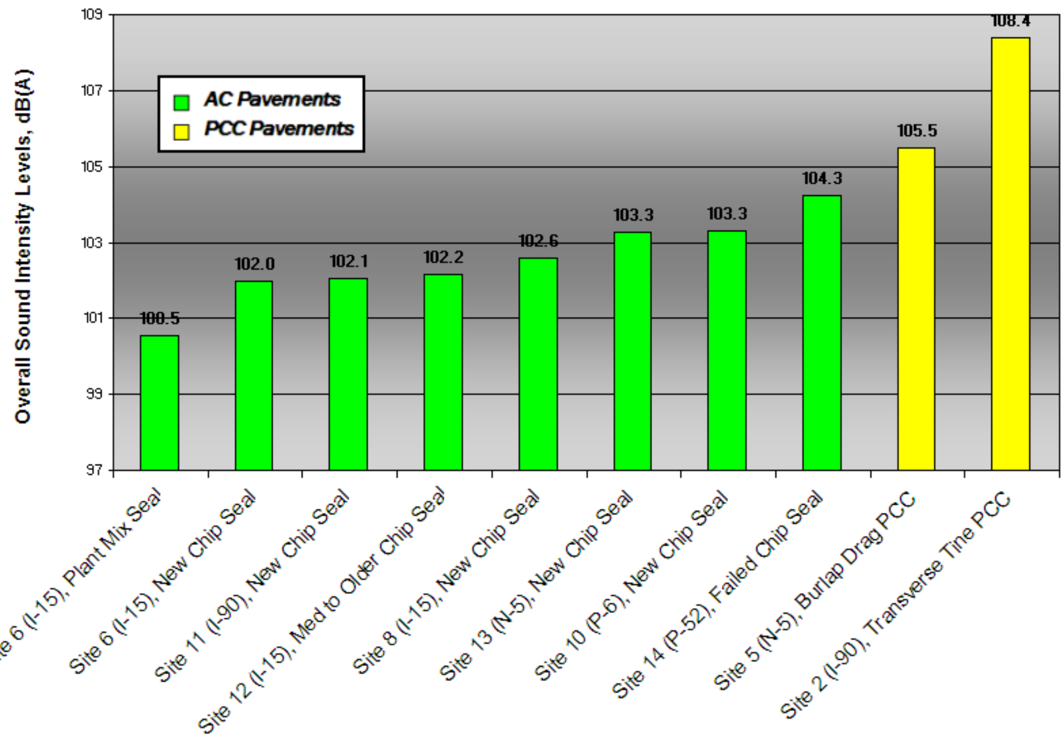

Figure 4. A-Weighted Tire/Pavement Sound Intensity Levels

As indicated in Table 2 and Figure 4, the PCC sections were on average 6.4 dBA higher than the Plant Mix section and 4.1 dBA higher than the Chip Seal sections. The transverse tine PCC segment along Site 2 (I-90) resulted in the highest overall level of

108.4 dBA. The highest AC pavement was the Failed Chip Seal measured at Site 14 (P-52), which had an overall noise level of 104.3 dBA; however, this level was only 1 dBA greater than the overall noise level measured on the New Chip Seal pavement at Site 10 (P-6).

Figures 5 and 6 show comparisons of the resulting overall A-Weighted sound intensity noise levels of the Montana sites compared with other PCC and AC pavements in California, Arizona, Ohio, Iowa, Kansas, Minnesota, and Alabama. All data shown was measured at 60 mph using the SRTT test tire. The Montana test sites are indicated in red.

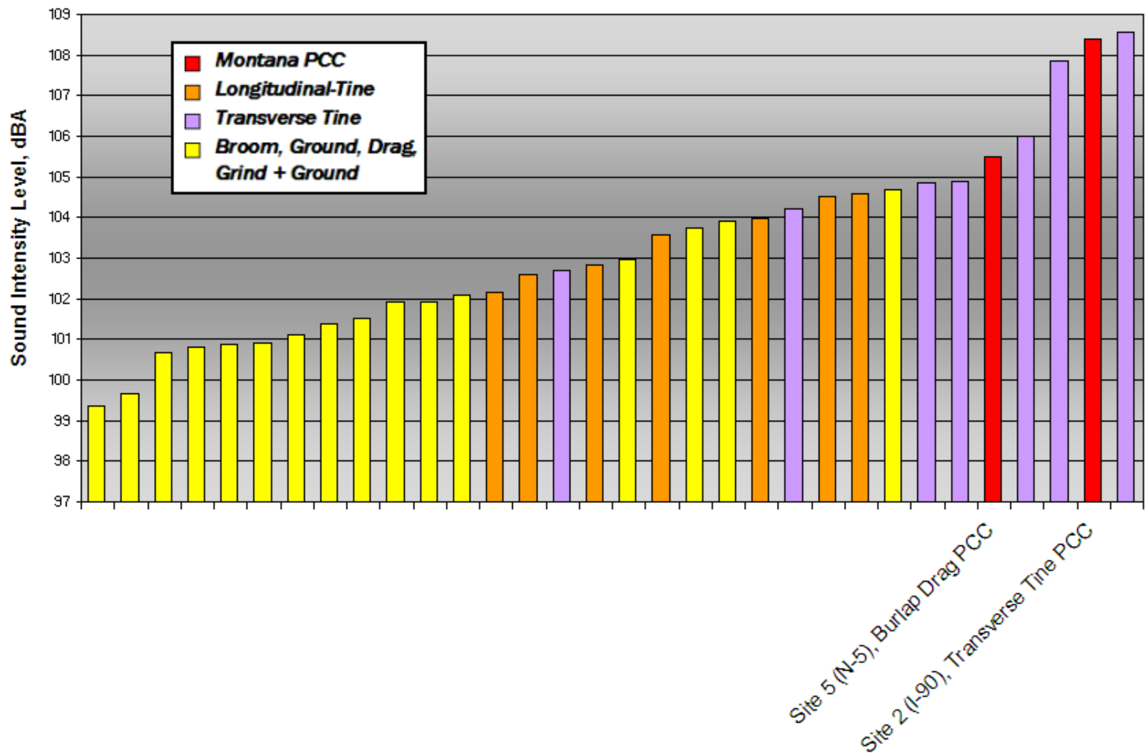

Figure 5. Overall A-Weighted OBSI Levels for PCC Pavements, 60 mph

From Figure 5, the broom, ground, and drag PCC pavements from each state shown result in the lower overall noise levels. Longitudinal tine PCC make up the mid-range of the pavements, and transverse tine PCC pavements produce the upper-range shown in Figure 5. The transverse tine PCC pavement from Montana test Site 2 (I-90) produced one of the highest levels and was virtually identical to the transverse tine PCC located along I-70 in Ohio. As shown above, Site 2 (I-90) and Site 5 (N-5) have overall levels of 108.4 dBA and 105.5 dBA, respectively. According to the state of Montana Department of Transportation (MDT) specifications, concrete pavement textures are to be random spaced transverse tine followed by a burlap drag finish. The Site 5 (N-5) segment, which was laid in 2000, would be consistent with this specification; however, the older Site 2 (I-90), which was laid in 1976, was laid prior to the specification update and follows the guidelines for the original specification of regular transverse tine PCC. However, given the state-wide usage of studded snow tires in Montana, the original texturing has likely little bearing on the current pavement texture. Experience in Washington State, which also allows the use of studded snow tires, is that applied texture is typically lost within 2 to 4 years[2]. This is further evidenced by the photograph in Figure A-1d of the Appendix that displays no evidence of the original transverse tining. Although not photographically documented, it is suspected that the Site 5 (N-5) surface has also lost its original burlap drag texture based on the WSDOT experience. Burlap drag textured PCC surface are typically more in the range of 100 to 102 dBA, with a highest level of 103.7 dBA measured on an older section of the roadway in California. The levels at Site 5 (N-5) are actually more in the range of those that have been measured on SR 520 in Seattle that was also a stud damaged surface devoid of its original texture. This surface produced levels in the range from 106.1 to 106.9 dBA. In considering the performance of the PCC at Site 2 (I-90) and Site 5 (N-5), these probably should not be considered to be representative of the texturing by which they are identified, but rather as unique to themselves.

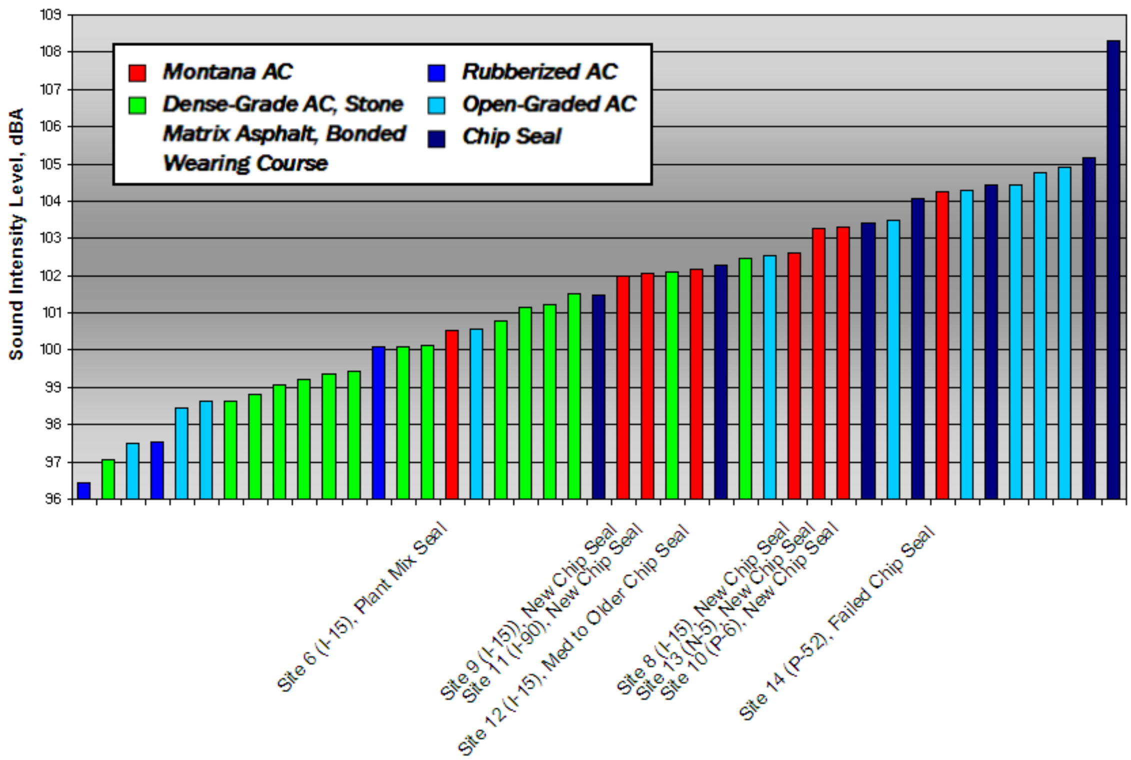

Figure 6. Overall A-Weighted OBSI Levels for AC Pavements, 60 mph

In general, the RAC and DGAC pavements yield overall noise levels in the lower range of all AC pavements shown in Figure 6. The mid- to upper range of overall noise levels consists of Chip Seal pavements. The New Chip Seal and Medium to Older Chip Seal pavement segments in Montana fell into the lower range of Chip Seals shown in Figure 6. The overall noise levels range from 102.0 to 103.3 dBA, which was about the same as the Chip Seal pavement measured at the General Motors Mesa Proving Ground in Arizona. The Failed Chip Seal pavement at Site 14 (P-52) measured an overall noise level of 104.3 dBA. This measurement was louder than the Chip Seal pavement at the Hyundai-Kia

[2] Personal communication, Tim Sexton, Washington State Department of Transportation

Test Track in California, which was 104.1 dBA, and quieter than the Chip Seal pavement along SR 521 in Ohio, which was 104.4 dBA. The Plant Mix Seal falls approximately in the middle of the DGAC pavements and is about 2.0 dBA lower in level than the average of the Chip Seal pavements.

B. Third Octave Band Levels

Figure 7 shows the spectra for both of the PCC pavements measured at sites Site 5 (N-5) and Site 2 (I-90). As shown by the overall levels above, the PCC pavements were, on average, higher than the Chip Seal pavements by approximately 4.1 dBA. The segment for Site 5 (N-5) shows similarities to Site 2 (I-90) in the lower frequency range but has significantly lower levels at frequencies above 800 Hz. In these frequencies, both pavements are about 10 dB higher in level than typical burlap drag or ground surfaces re-enforcing the conclusion that stud/chain damage and the resultant increase in surface roughness is a major factor in the performance of these pavements. Above 800 Hz, the levels for Site 2 (I-90) become 3 to 6 dB higher than Site 5 (N-5). The magnitude and range in the levels between these two pavements is similar to that observed for the range of pavements in the OBSI data base and maybe be due aging effects for the much older Site 2 (I-90) pavement.

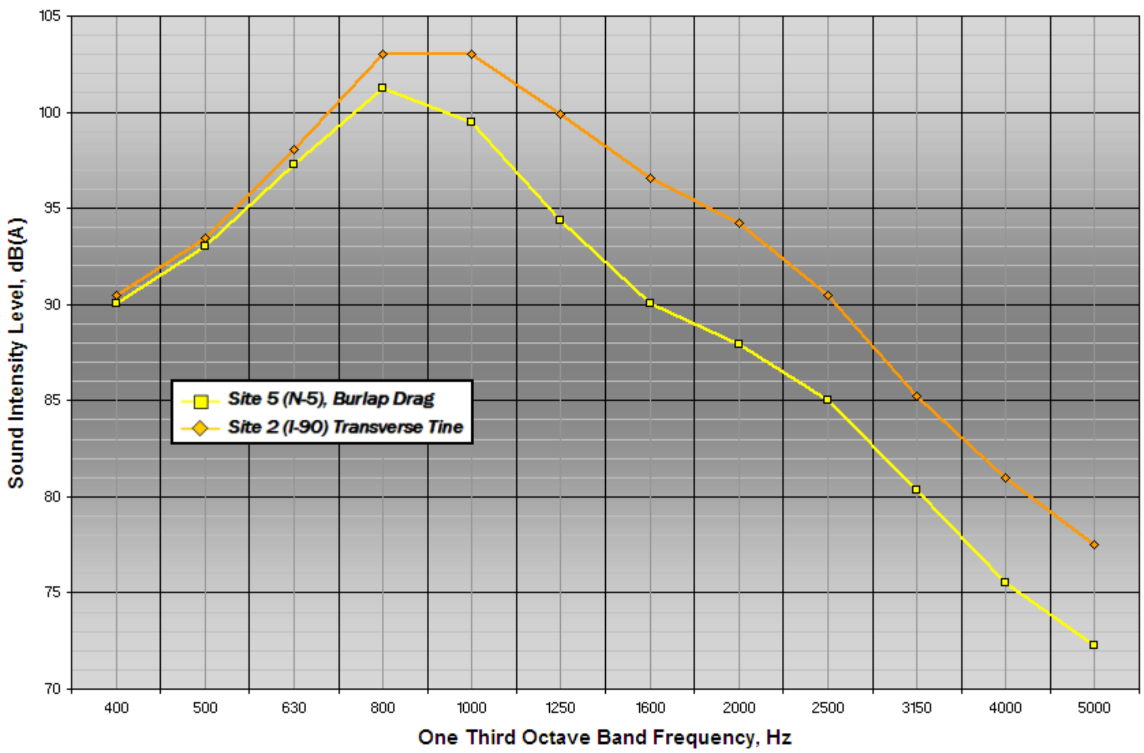

Figure 7. One-Third Octave Band Levels for PCC Pavements

The spectra for all the chip seal AC pavements and the plant mix seal pavement are shown in Figure 8. The plant mix seal segment is in the low to mid-range of spectral levels at frequency bands below 800 Hz and is the quietest pavement at frequency bands above 800 Hz, averaging approximately 3.3 dBA quieter than the chip seal pavements. For each test segment with chip seal pavement, raised levels exist in the range from 800 to 1000 Hz. The peak levels are at 800 Hz for the following chip seal segments: Site 9 (I-15), Site 11 (I-90), Site 10 (P-6), and Site 14 (P-52). For the segments along Site 8 (I-15) and Site 12 (I-15), the peak levels are at 1000 Hz. The failed chip seal segment, which is Site 14 (P-52), is in the mid- to high range of spectra for frequency bands below 800 Hz, but above 800 Hz, Site 14 (P-52) shows the highest levels, averaging approximately 2.2 dBA higher than the other chip seal segments. The quietest segment at the lower frequencies is the medium to older chip seal pavement Site 12 (I-15). Site 12 (I-15) averages approximately 1.9 dBA quieter in this frequency range than the new chip seal pavements and is 2.7 dBA quieter than the failed chip seal. At the higher frequencies, however, Site 12 (I-15) is among the segments with the highest spectral levels, being an average 0.7 dBA higher than the new chip seal pavements and 1.6 dBA quieter than Site 14 (P-52). On average, the new chip seal segments fall within the mid-range of spectral levels throughout Figure 8. However, at the lower frequencies, Site 10 (P-6) and Site 13 (N-5) are slightly higher than the other new chip seal pavements, with a standard deviation of 1.2 dBA; at frequencies above 1000 Hz, all the new chip seal segments remain within 0.6 dBA of each other.

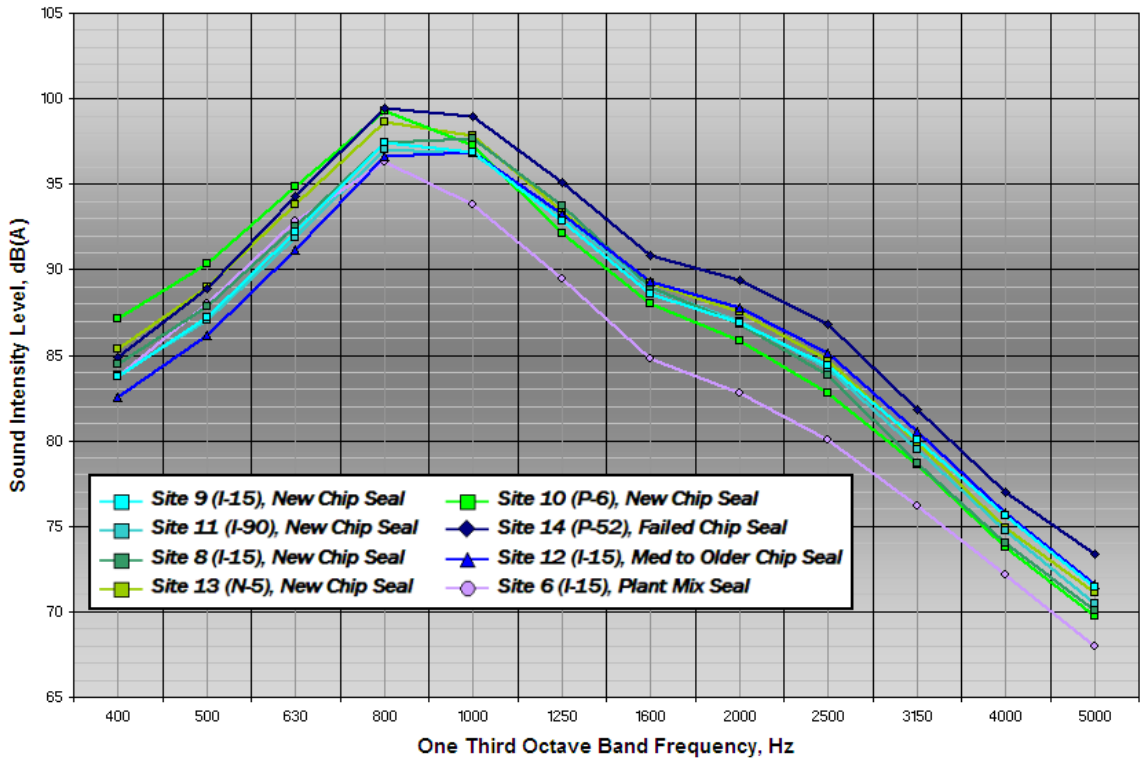

Figure 8. One-Third Octave Band Levels for AC Pavements

C. Effects of Meteorological Conditions

Previous studies have been conducted to investigate the possible adjustment factors applied to sound intensity levels to account for temperature and barometric pressure effects[3]. The following formula is used to calculate the temperature correction term:

[3] Gade, S., "Sound Intensity," Technical Review, No. 3, 1982.

$$\Delta L_{temp} = +10\log_{10}\left(\frac{T}{T_o}\right),\ T_o = 273K \qquad (1)$$

The temperature measured at the time of testing is the T input value. Similarly, the pressure correction term is calculated as follows:

$$\Delta L_{press} = -10\log_{10}\left(\frac{p}{p_o}\right),\ p_o = 1013.25hPa \qquad (2)$$

The barometric pressure measured at the time of testing is the p input value. Table 3 shows the temperature and pressure correction terms calculated from the measured inputs. Since the average correction term is within 1 dB, both the temperature and pressure effects did not have a strong effect on the noise levels, and therefore, were not applied to the measurements.

Site Number	Temperature, ^{o}F (^{o}C)	Pressure, hPa	Correction Term, dB
Site 6 (I-15)	83^{o}F (28^{o}C)	870 hPa	0.8
Site 9 (I-15)	73^{o}F (23^{o}C)	875 hPa	0.7
Site 11 (I-90)	80^{o}F (27^{o}C)	915 hPa	0.5
Site 12 (I-15)	83^{o}F (28^{o}C)	870 hPa	0.8
Site 8 (I-15)	83^{o}F (28^{o}C)	870 hPa	0.8
Site 13 (N-5)	70^{o}F (21^{o}C)	920 hPa	0.4
Site 10 (P-6)	75^{o}F (24^{o}C)	935 hPa	0.4
Site 14 (P-52)	68^{o}F (20^{o}C)	925 hPa	0.4
Site 5 (N-5)	65^{o}F (18^{o}C)	925 hPa	0.4
Site 2 (I-90)	59^{o}F (15^{o}C)	900 hPa	0.4
Average			*0.6*

Table 3. Summary of Temperatures Measured During Testing and the Calculated Correction Terms

5. CONCLUSION

Tire/pavement noise measurements were conducted on 10 test sites and a single pavement type each. These included one (1) Transverse Tine PCC pavement, one (1) Burlap Drag PCC pavement, one (1) Plant Mix Seal AC pavement, five (5) New Chip Seal AC pavements, one (1) Medium to Older Chip Seal AC pavement, and one (1) Failed Chip Seal AC pavement. Principal findings developed from this data set are as follows:

1. Overall average sound intensity level for the new chip seal AC pavements, which consist of Site 8 (I-15), Site 9 (I-15), Site 11 (I-90), Site 13 (N-5), and Site 10 (P-6), were within the mid- to upper range of AC pavements measured in California, Arizona, Ohio, Iowa, Kansas, Minnesota, and Alabama. Overall levels were, on average, about 1.6 dBA lower than the failed chip seal pavement and 4.3 dBA lower than the PCC segments.

2. Overall average sound intensity levels for the medium to older chip seal pavement, which is Site 12 (I-15), was in the lower to mid-range of Montana pavements but in the mid- to upper range of AC pavements measured in the other states included in the comparison figures. The average overall level of 102 dBA is approximately 2.3 dBA lower than the failed chip seal pavement and 4.9 dBA lower than the PCC segments.

3. The segment of failed chip seal pavement, which is Site 14 (P-52), had the highest overall level of all Montana AC pavements and was within the upper range of overall levels when compared to similar pavements in California, Arizona, Ohio, Iowa, Kansas, Minnesota, and Alabama. On average, the PCC segments in Montana were approximately 2.3 dBA higher than the failed AC segment at Site 14 (P-52).

4. The two PCC pavements tested at Site 5 (N-5) and at Site 2 (I-90), were in the upper range of all PCC pavements measured in California, Arizona, Ohio, Iowa, Kansas, Minnesota, and Alabama. The overall noise levels were 105.5 dBA and 108.4 dBA, respectively.

5. The plant mix seal, which is denoted as Site 6 (I-15), has spectral levels that fall within the lower to mid-range of AC pavements for frequencies below 800 Hz. Above 800 Hz, however, the plant mix seal averages approximately 3.6 dBA lower than all other AC segments.

6. On average, the new chip seal pavements are within the mid-range of spectral levels throughout the frequency band range. However, the standard deviation of 0.6 dBA at the frequency bands greater than 800 Hz is significantly better than the standard deviation of 1.2 dBA at the frequency bands below 800 Hz.

7. The spectrum for the medium to older chip seal pavement, as compared to the other AC segments, has the lowest levels for frequency bands less than 800 Hz. From 1250 Hz and greater, the medium to older chip seal pavement is among the highest segments.

8. For frequency bands less than 800 Hz, the failed chip seal segment, which is Site 14 (P-52), is in the mid- to upper spectral level range. Above 800 Hz, however, Site 14 (P-52) has the highest spectral levels, averaging approximately 2.2 dBA higher than the other chip seal segments.

9. At frequencies below 800 Hz, Site 2 (I-90) is an average 0.6 dBA higher than Site 5 (N-5), but at frequencies above 800 Hz, the average difference is 5 dBA. In comparison to other PCC surfaces, higher levels in the lower frequencies for both pavements is likely due to increased roughness, presumably due to studded snow tire and snow chain usage. The higher frequency differences may be due to the relative age of the two surfaces.

6. APPENDIX

(a) Site 12 (I-15), Medium to Older Chip Seal

(b) Site 13 (N-5), New Chip Seal

(c) Site 14 (P-52), Failed Chip Seal

(d) Site 2 (I-90), Transverse Tine PCC

Figure A1. Photos of Test Pavements


(a) Roadway Construction

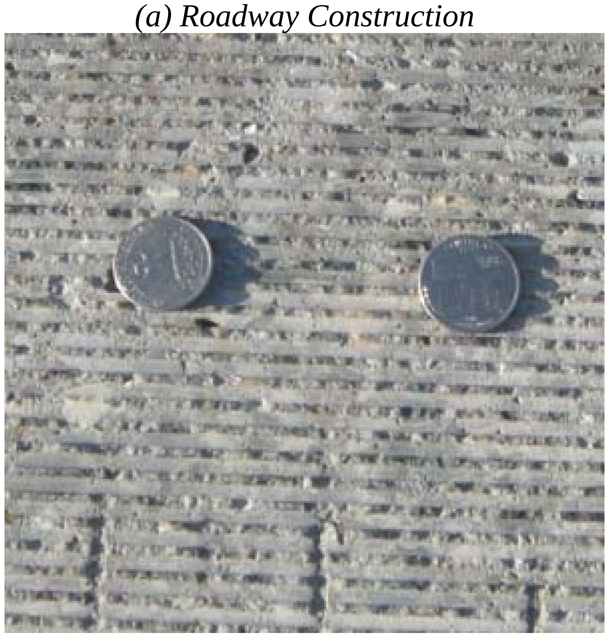
(b) Existing Pavement

Figure A2. Site 15 (N-60) Test Site Photos

***due to existing construction, testing did not occur at Site 15 (N-60)**

	Site	Lane	Direction	Overall Level	Average Overall Level
Burlap Drag	Site 5 (N-5)	Right	NB	105.6	105.5
		Right	SB	105.4	
Transverse Tine	Site 2 (I-90)	Right	WB	109.1	108.4
		Left	WB	107.7	

Table A1. PCC Overall OBSI Levels Sorted By Lane and Direction

	Site	Lane	Direction	Overall Level	Average Overall Level
Plant Mix Seal	Site 6 (I-15)	Right	NB	101.9	101.5
			SB	101.1	
		Left	NB	99.7	99.5
			SB	99.3	
Med to Older Chip Seal	Site 12 (I-15)	Right	NB	101.8	102.1
			SB	102.3	
		Left	NB	101.8	101.9
			SB	102.0	
New Chip Seal	Site 8 (I-15)	Right	NB	102.8	102.9
			SB	102.9	
		Left	NB	102.4	102.4
			SB	102.3	
	Site 9 (I-15)	Right	NB	102.4	102.5
			SB	102.5	
		Left	NB	102.1	101.9
			SB	101.7	
	Site 10 (P-6)	Right	NB	103.3	103.3
			SB	103.3	
	Site 11 (I-90)	Right	EB	102.6	102.5
			WB	102.3	
		Left	EB	101.6	101.7
			WB	101.7	
	Site 13 (N-5)	Right	NB	103.4	103.5
			SB	103.5	
		Left	NB	103.1	103.1
			SB	103.1	
Failed Chip Seal	Site 14 (P-52)	Right	EB	104.1	104.3
			WB	104.4	

Table A2. AC Overall OBSI Levels Sorted By Lane and Direction

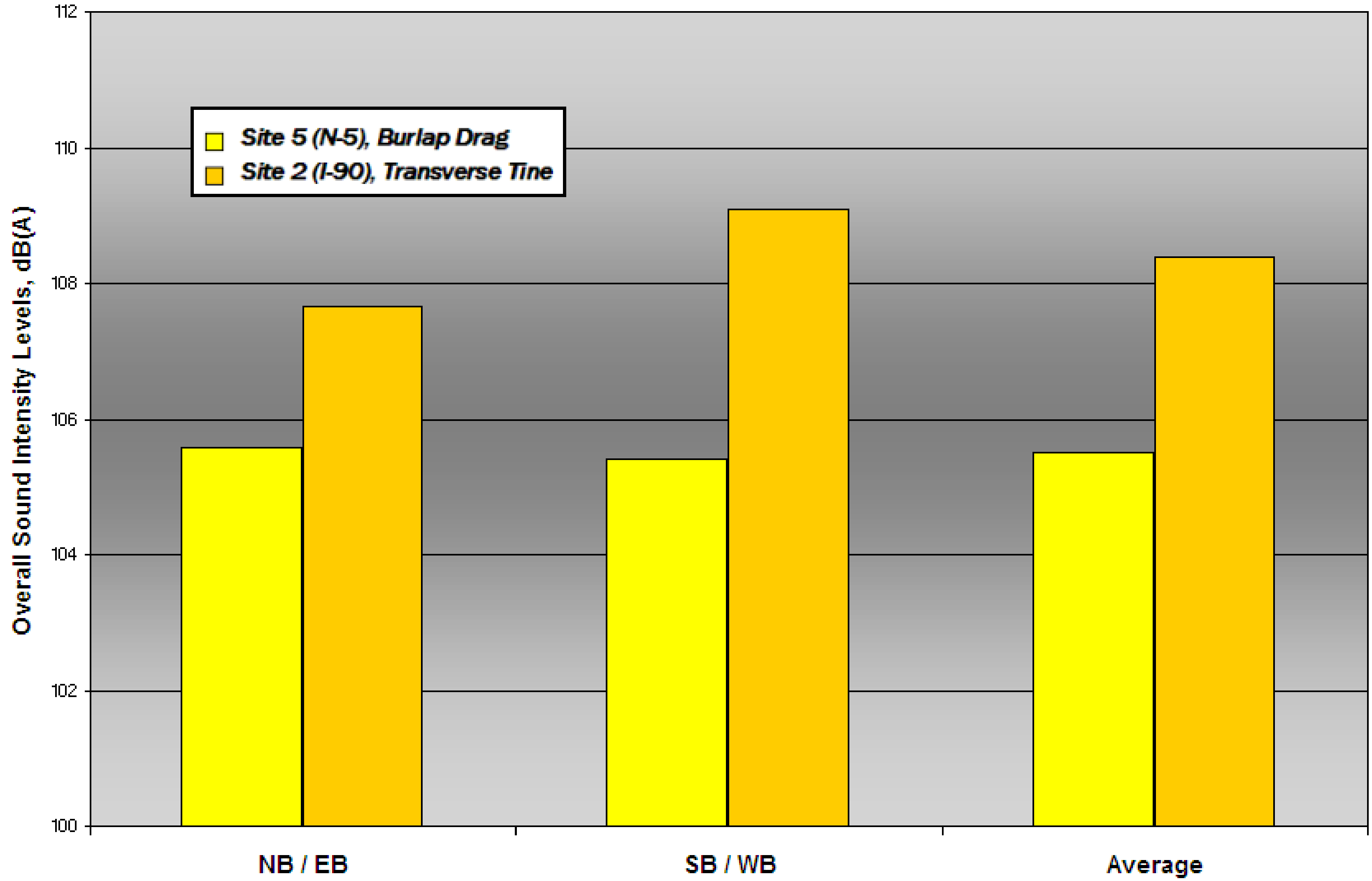

Figure A3. Overall A-Weighted OBSI Levels for PCC Pavements in Each Direction, 60 mph

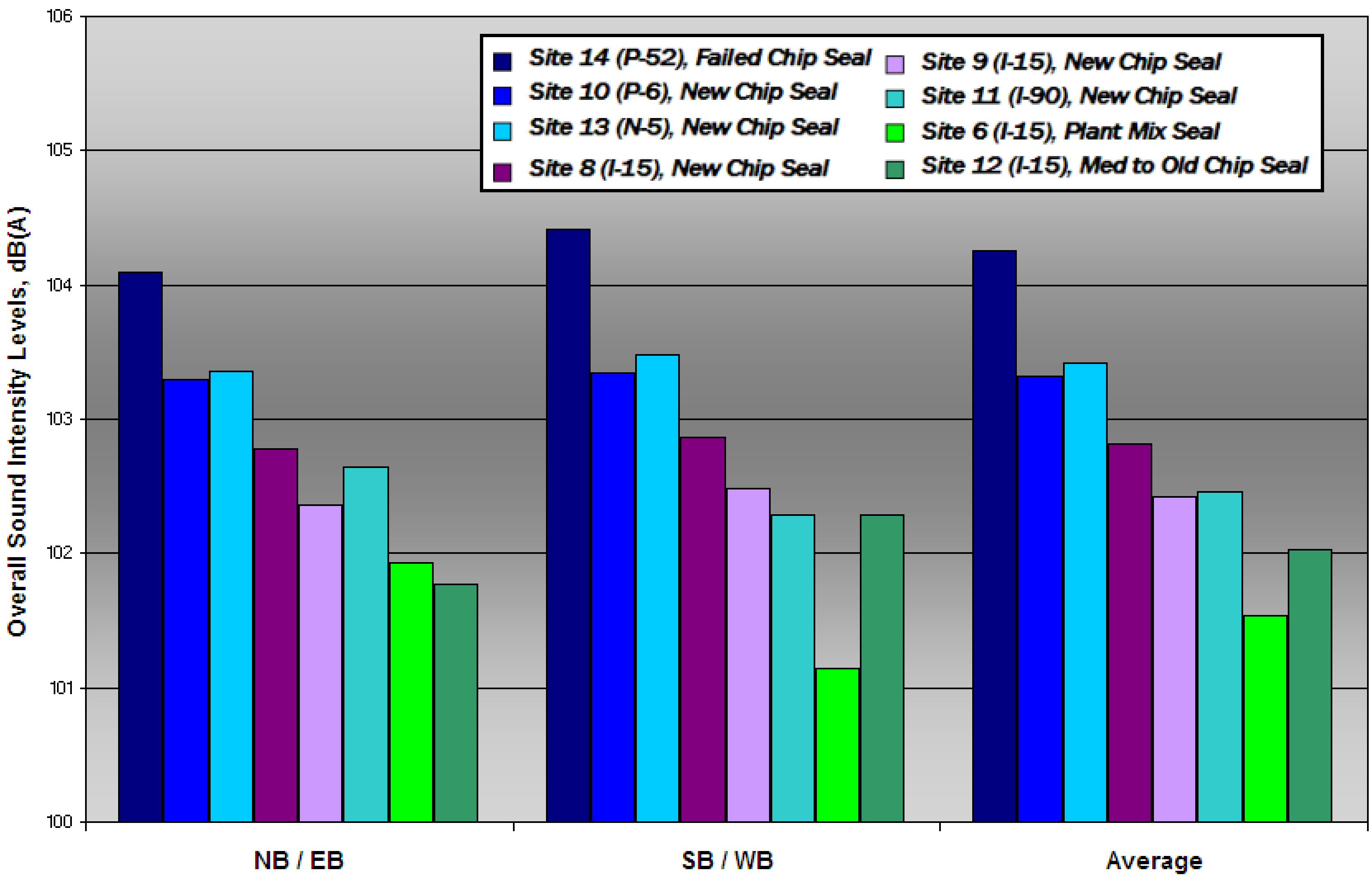

Figure A4. Overall A-Weighted OBSI Levels for AC Pavements in Each Direction, 60 mph

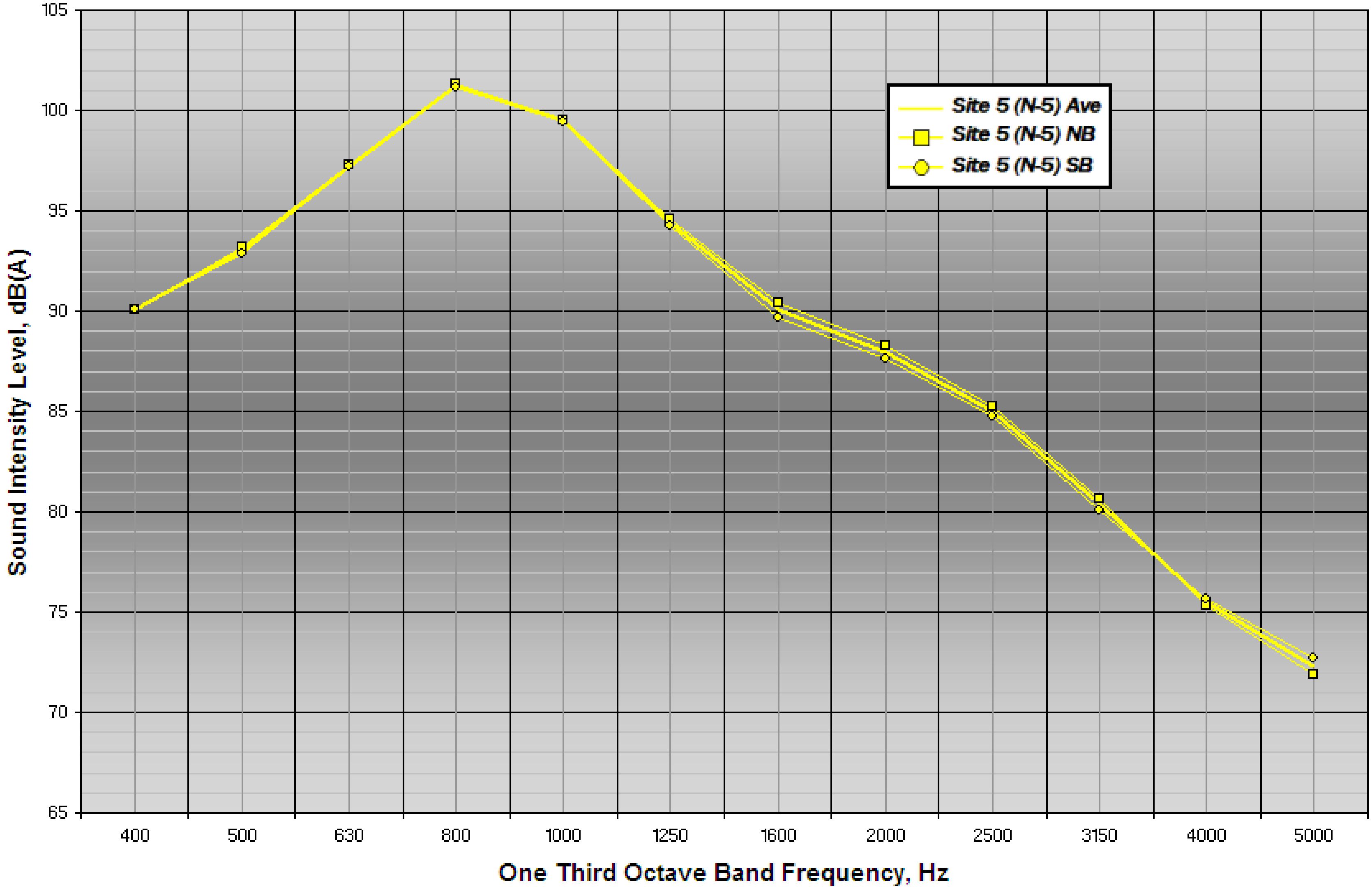

Figure A5. One-Third Octave Band Levels for Site 5 (N-5), Burlap Drag PCC Pavement in NB & SB Directions

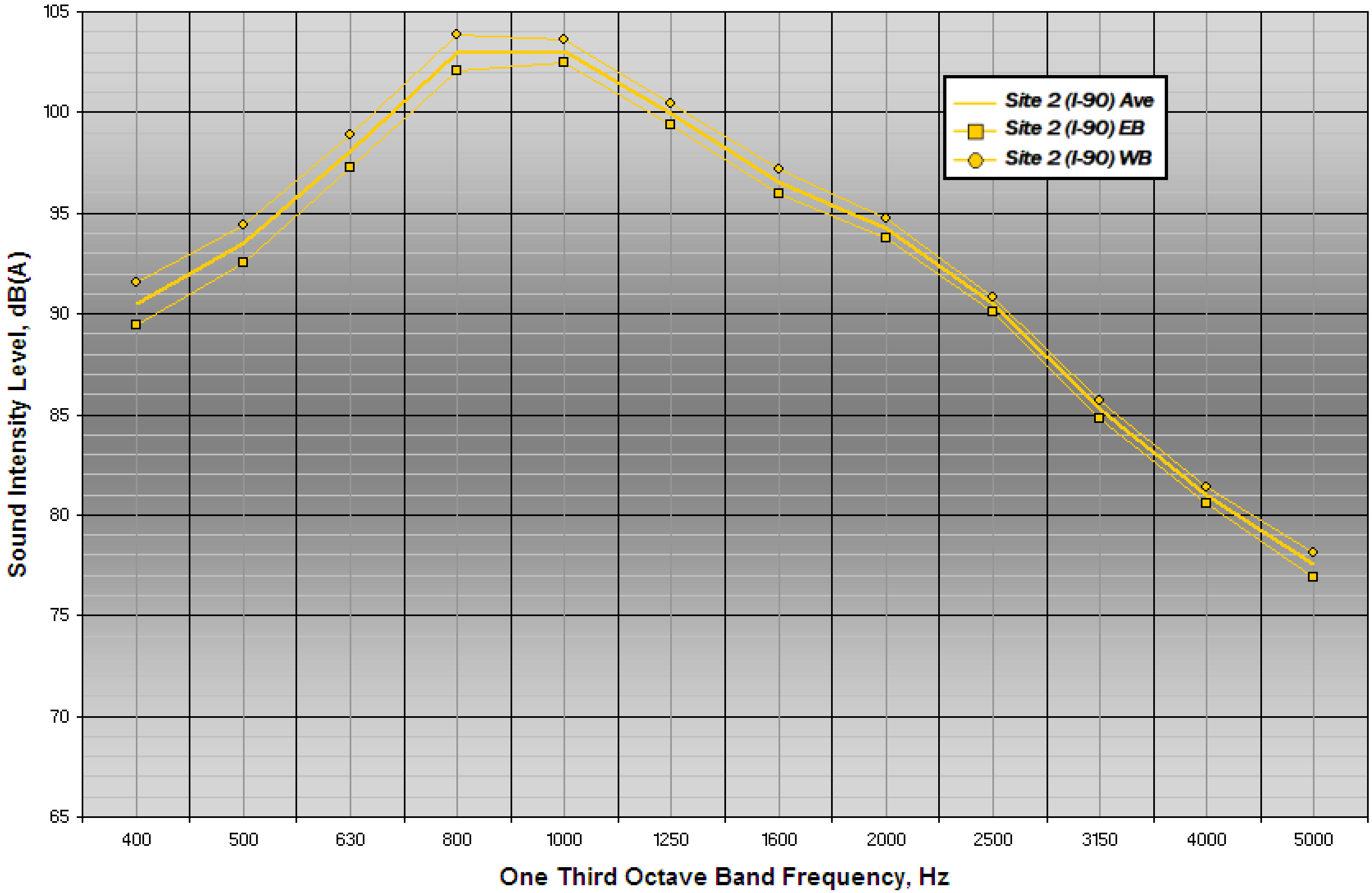

Figure A6. One-Third Octave Band Levels for Site 2 (I-90), Transverse Tine PCC Pavement in EB & WB Directions

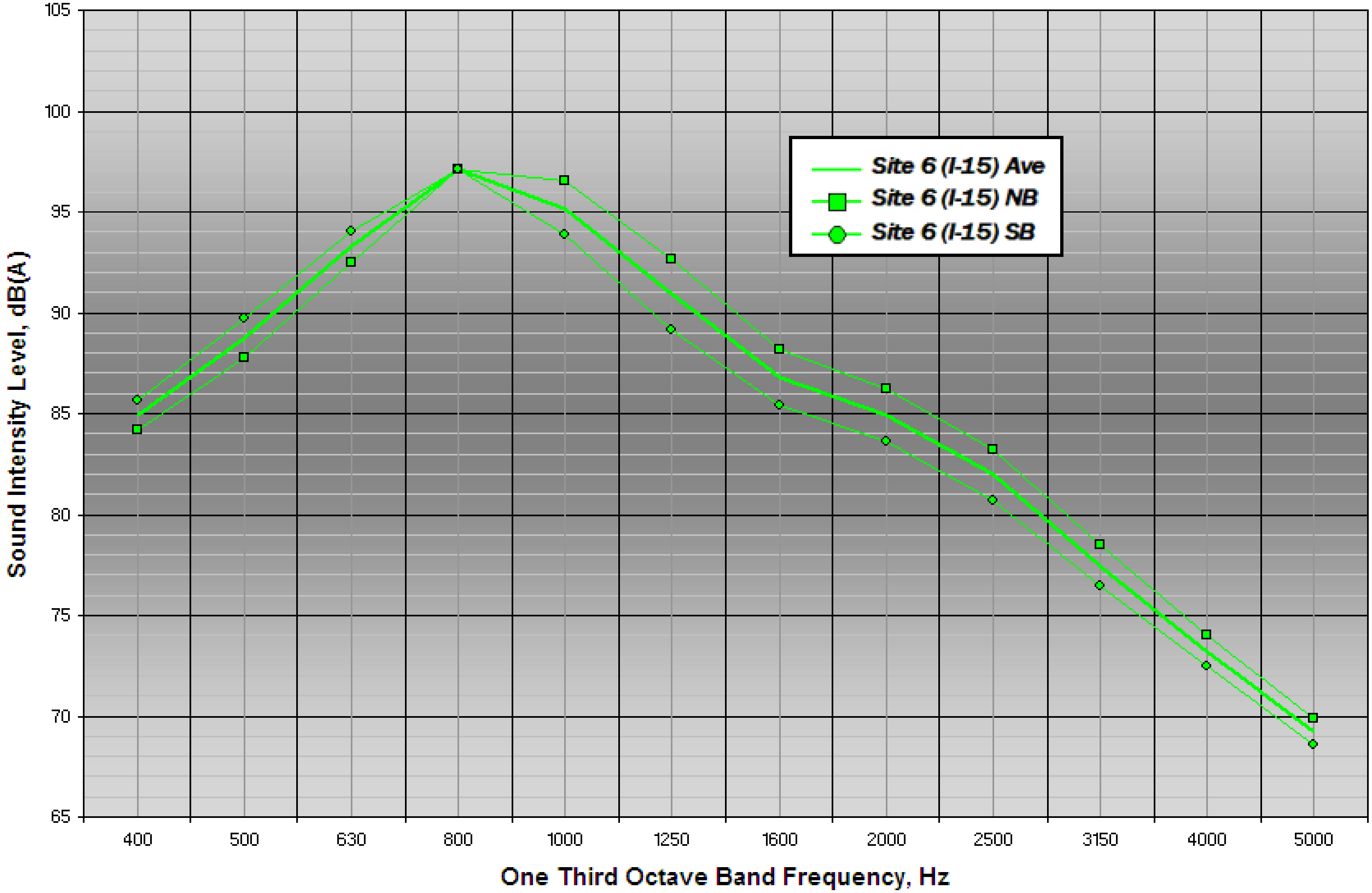

Figure A7. One-Third Octave Band Levels for Site 6 (I-15), Plant Mix Seal AC Pavement in NB & SB Directions

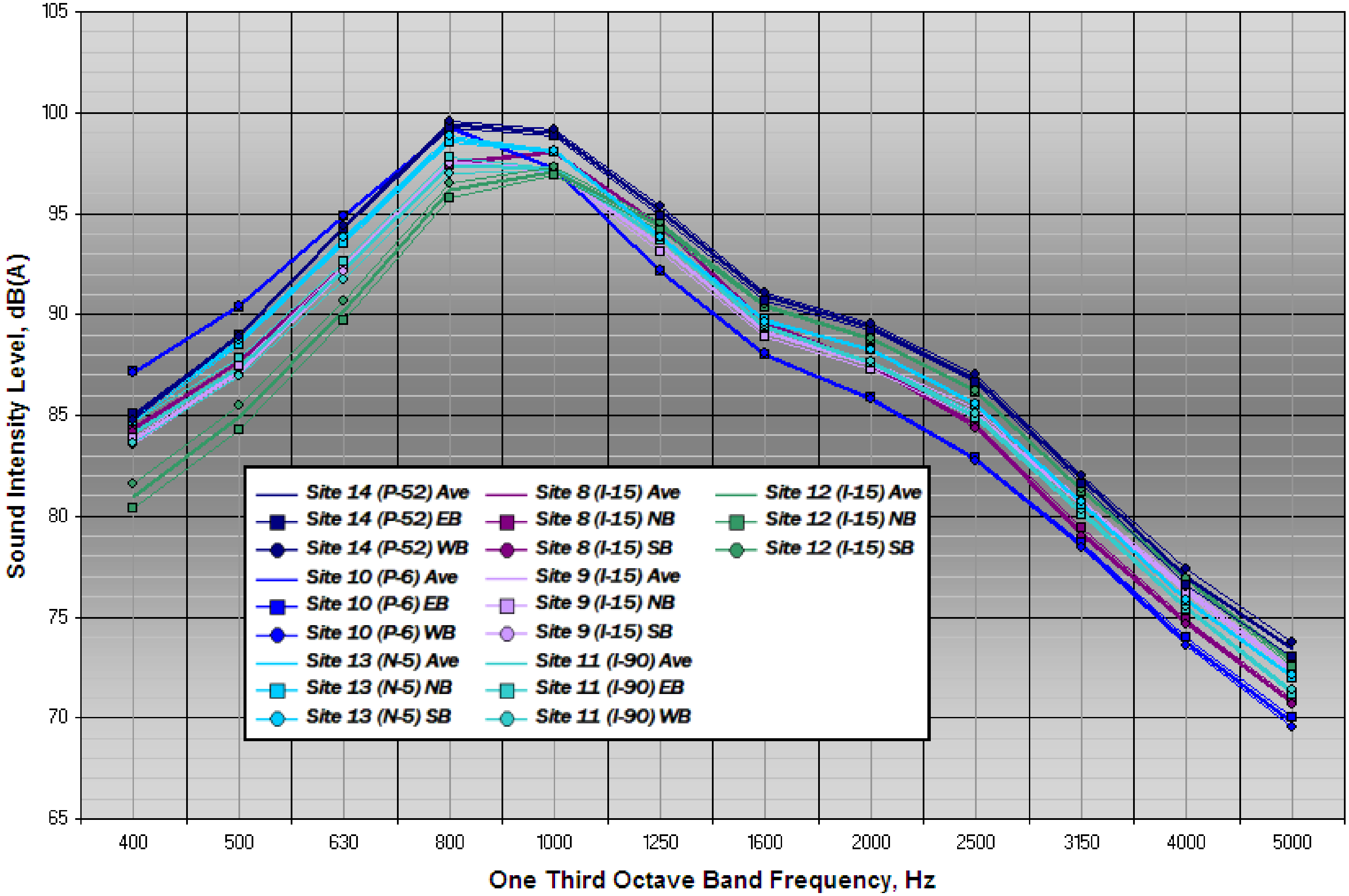

Figure A8. One-Third Octave Band Levels for All Chip Seal AC Pavements in Each Direction