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Quiet Pavement Research: Bridge Deck Tire Noise Report

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Abstract: This report presents the results of tire noise research performed on bridge decks. This work is part of a project that has looked into tire noise on concrete pavements and bridge decks. The objectives of the project are: (a) to identify relationships between tire/pavement noise and variables observed in concrete pavement and bridge decks, (b) to determine trends in noise levels versus age for concrete pavement and bridge decks, and (c) to develop recommendations on surface textures to minimize tire/pavement noise.

A total of 24 bridge sections were included in the study. The evaluation consisted of measuring tire/pavement noise with the OBSI method. The surface type of each section was identified through visual observation, sometimes from the vehicle as no traffic closures were used in this research. Six surface types were observed and tested: diamond ground, transversely tined, transversely broomed, polyester overlay with several different finishes, hot-mix asphalt, and burlap drag.

This report begins by explaining the data collection and data reduction procedures, and then presents the analysis performed on the aggregated results (by surface type, surface age, Year 1–to–Year 2 variation) plus results on pavement–bridge transitions and the effect of bridge joints. A chapter is dedicated to describing the results on each bridge section.

The results indicate that, of the six texture types tested, diamond-ground decks are the quietest, followed by polyester overlays. Bridges in these two groups both had On-board Sound Intensity (SI) levels between 100 and 105 dB(A), respectively. Transversely tined and transversely broomed surfaces were the most commonly used deck surface types included in the study, with most having OBSI levels between 105 and 109 dB(A). The effect of joint slap was found to be negligible in most cases in terms of average OBSI, although joint slap causes very high short-duration noise, on the order of 112 dB(A). On the five bridges where the joint slap could be identified, it was determined that elimination of the joints would reduce the bridge deck noise by only 0.2 to 0.3 dB(A). With respect to trends in noise versus age, the sample size and time series were insufficient to draw strong conclusions. All the sections but one range from 0 to 15 years old, and most have OBSI levels that seemed to increase with age. The oldest section, which has been in service for 44 years, presented an OBSI level of less than 106 dB(A).

Keywords: Bridge deck, tire noise, OBSI

Proposals for implementation: Use diamond grinding and polyester overlays with longitudinal texture on concrete bridges to create quieter surfaces compared with current transverse textures (transverse broomed and transverse tined). Consider project requirements for noise, safety, and cost in implementing this recommendation to reduce bridge deck noise.

Related documents:

- Research Report: UCPRC-RR-2007-03. *Investigation of Noise, Durability, Permeability, and Friction Performance Trends for Asphaltic Pavement Surface Types: First- and Second-Year Results,* by A. Ongel, J. T. Harvey, E. Kohler, Q. Lu, and B. D. Steven. February 2008. FHWA No: CA091200A.
- Summary Report: UCPRC-SR-2008-01. *Investigation of Noise, Durability, Permeability, and Friction Performance Trends for Asphalt Pavement Surface Types: First- and Second-Year Results: Summary Report,* by A. Ongel, J. T. Harvey, E. Kohler, Q. Lu, B. D. Steven, and C. L. Monismith. August 2008. FHWA No.:CA091200B.
- Research Report No.: UCPRC-RR-2007-12. *Acoustical Absorption of Open-Graded, Gap-Graded, and Dense-Graded Asphalt Pavements,* by A. Ongel and E. Kohler (UCPRC) and J. Nelson (WIA). July 2007. FHWA No.:CA111200A.
- Technical Memorandum: UCPRC-TM-2008-07. *State of the Practice in 2006 for Open-Graded Asphalt Mix Design,* by A. Ongel, J. Harvey, and E. Kohler. December 2007. FHWA No.:CA111200B.
- Research Report: UCPRC-RR-2009-01. *Investigation of Noise and Durability Performance Trends for Asphaltic Pavement Surface Types: Three-Year Results,* by Q. Lu, E. Kohler, J. Harvey, and A. Ongel. January 2009. FHWA No.: CA101881A.
- Research Report: UCPRC-RR-2009-07. *Laboratory Evaluation of the Noise and Durability Properties of Asphalt Surface Mixes,* by Q. Lu, P.C. Fu, and J. Harvey. December 2009. FHWA No.: CA121200C
- Research Report: UCPRC-RR-2010-03. *Quieter Pavement Research: Concrete Pavement Tire Noise,* by E. Kohler. June 2010.
- Research Report: UCPRC-RR-2010-05. *Investigation of Noise and Durability Performance Trends for Asphaltic Pavement Surface Types: Four-Year Results,* by Q. Lu, J. Harvey, and R. Wu. April 2011. FHWA No.: CA121200D
- Research Report: UCPRC-TM-2011-01. A Method for Predicting Sound Intensity Noise Levels Using Laboratory Pavement Cores, by C.H. Reyes and J. T. Harvey. November 2010. (In process.)

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DISCLAIMER

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PROJECT OBJECTIVES/PROJECT SUMMARY

This project evaluated tire/pavement noise on rigid pavements and bridge decks in California. The work involved the identification and monitoring of field sections in a study similar to the Quiet Pavement Research (QPR) investigation performed by the University of California Pavement Research Center (UCPRC) on asphalt concrete pavements. The project has three objectives:

1. To identify relationships between the design variables in concrete pavements and bridge decks and tire/pavement noise, covering the majority of surface textures used in California,
2. To determine trends in noise levels versus age for concrete pavement and bridge decks, and
3. To develop recommendations for surface textures that minimize tire/pavement noise.

This report covers all three objectives for bridge decks.

EXECUTIVE SUMMARY

In the early 2000s, the California Department of Transportation (Caltrans) identified a need for research into the acoustics, friction, durability, and related performance properties of pavement surfaces on the state highway network. Consequently, in November 2004, the Caltrans Pavement Standards Team (PST) approved a research project to investigate the tire/pavement noise characteristics and performance properties of existing flexible pavements, including the Department's current open-graded mixes, dense- and gap-graded mixes, and selected experimental mixes.

The initial investigation of flexible pavement surfaces had as its objectives evaluation of the mixes' durability and their comparative effectiveness in increasing safety and reducing noise, determination of the pavement characteristics that affect the tire/pavement noise, and evaluation of the correlation between laboratory sound absorption and tire/pavement sound intensity in the field. The flexible pavement studies have included four years of data collection and analysis to date.

A similar research study for rigid pavements and bridges decks, the latter of which is the subject of this report, was initiated by the Caltrans Quieter Pavement Research Task Group in May 2008.

The quieter concrete bridge deck research study presented in this report was undertaken to determine the acoustic characteristics of the noise generated by tire/pavement interaction on concrete bridge surfaces, and to identify the types and properties of bridge surface textures that would effectively reduce tire/pavement noise. This study has three objectives:

1. To identify relationships between the design variables of concrete bridge surface textures and tire/pavement noise, covering the majority of surface textures used in California,
2. To establish trends in noise levels versus age for concrete bridges, and
3. To develop recommendations for concrete bridge surface textures that minimize tire/pavement noise.

This report covers all three objectives for bridge decks. A separate report presents the reports for concrete pavements.

Measurement and Experiment Plan

A total of 24 bridges were investigated in the study, all of which were located on the state highway network owned and managed by the California Department of Transportation (Caltrans). These bridges were suggested for inclusion by the Division of Structures through the Quieter Pavement Research Task Group. Among the bridges, six surface types were identified: transversely tined, transversely broomed, polyester overlay, diamond ground, burlap drag, and hot-mix asphalt. There were between one and nine sections of each type. It is worth noting that despite the effort put into collecting data on a large number of bridge sections, the number of sections with different surface types was unequal, leading to a study with a nonbalanced factorial that requires more careful analysis for arriving at valid conclusions than one with a balanced factorial.

Transversely tined and transversely broomed are textures applied to fresh concrete. The name "polyester overlay" was used for bridge decks where an overlay material was identified as being different from concrete or hot-mix asphalt. Several finishes were applied to the polyester overlays, which are noted in the analysis for each section. Diamond grinding is a technique used on hardened concrete. Burlap drag is applied to fresh concrete, but in this case the term was used to refer to a deck with old concrete that basically had lost most of whatever original texture it had when constructed. Hot-mix asphalt, also referred to as "asphalt concrete" in this report because Caltrans standard nomenclature changed during the course of the study, corresponds to a bituminous mixture overlaid on the bridge deck.

The data collection spanned two years: In the first year the bridges were selected and evaluated between October 2008 and February 2009, and in the second year they were visited between October 2009 and January 2010.

The study used the OBSI method to measure tire noise measurement. This method has been used on noise projects performed for Caltrans since approximately 2004. At the time this study was performed, a first version of an OBSI standard had been adopted by the American Association of State Route and Transportation Officials (AASHTO) as AASHTO TP-76. In the OBSI method, two sets of microphones, each set consisting of two closely spaced phase-matched microphones, are configured side-by-side. One microphone set (each set is also referred to as a "probe") is placed at the location of the leading edge of the tire/pavement contact patch at a distance of 4 in. (102 mm) from the sidewall and 3 in. (76 mm) from the pavement surface. The second probe is placed at the same distances from the tire and pavement surface at the trailing edge of the tire/pavement contact patch. The distance between the two probes is 8.25 in. (210 mm). The sound intensity is measured in dB and the results are A-weighted and averaged for the leading and trailing-edge positions.

There is no standard method for measuring tire/deck noise on bridges, so a workable data collection procedure had to be devised for this study. This was necessitated by the often short bridge deck pavement test sections under examination. Typical OBSI road pavement noise testing procedures call for recording and analysis of fixed five-second intervals taken at 60 mph (97 km/hr), requiring a minimum test section length of 440 feet (134 m). However, since many bridges are shorter than this minimum length, the five-second recording interval would include pavement surface that is not part of the bridge. To accommodate this method to the shorter test sections, shorter data collection intervals were used in this study. In Year 1, noise data was first collected with three passes at one-second intervals, after which a fourth pass followed where data was collected at 15 millisecond intervals in an attempt to isolate the noise from the bridge joints. During Year 2, an interval of 0.2 seconds was used, which proved to be more suitable for the overall analysis. Afterward, the 1-second and 0.2-second intervals were analyzed to obtain the results for each bridge, and the 15-millisecond single pass was used only for evaluation of joint slap noise.

For the study, a decision was made to have the vehicle operator begin collecting tire/pavement data noise at some distance before entering the bridge and to terminate collection after leaving it so that an approximate difference in tire noise level could be measured between the approach and leave sections of pavement on either side of the bridge including the leave and approach slabs, and the bridge surface itself. A decision was also made to collect data in shorter time intervals and then to post-process it into longer ones. This would allow the identification of bridge joints so their effect on noise could be isolated. In addition to the OBSI testing, the study also included inertial profilometer measurements of both wheelpaths and visual observation of surface type.

Visual observation was necessary for determining the bridge deck surface type. In some cases, bridges were part of heavily trafficked highways which made it impossible to stop and perform a close examination of the bridge surface. In these cases, observations were only made from the moving test vehicle.

For this research, the following adjustments were considered necessary to normalize the results and make them consistent with other OBSI databases delivered to Caltrans (they are discussed in detail in Chapter 2 of the report):

1. Test tire: There were differences in noise response between different Standard Reference Test Tires (SRTT). Several tires were used for this project, and corrections between these tires had to be developed.
2. Sound analyzer: A frequency-by-frequency correction was applied to account for the fact that a new sound analyzer was used for collecting data in Year 2 of the study.

The same approach is being used for the ongoing studies on concrete and asphalt concrete pavement noise.

Results

In this report, the results of On-board Sound Intensity (OBSI) by surface type are presented as three data sets: Year 1 results, Year 2 results, and combined Year 1 and Year 2 results. The sample size changed during the study because two of the 24 sections experienced a change of surface type, from transversely broomed to polyester overlay, and one section was eliminated from the study after Year 1 because the curvature of the bridge made the OBSI results unreliable.

The quietest surface type, when considered as the mean of the OBSI results of sections with the same nominal surface type and from the combined Year 1 and Year 2 data, was found to be the diamond ground. The diamond-ground group presented an average OBSI level of 101.9 dB(A). The polyester overlay deck group was the second quietest with an average OBSI value of 104.4 dB(A). As a group, the transversely tined and transversely broomed surfaces were the loudest, with average OBSI values of 107.2 dB(A) and 106.2 dB(A), respectively. The asphalt concrete section and the burlap drag section were included for reference (102.3 dB[A] and 105.0 dB[A], respectively) because the absence of replicates made it impossible to draw conclusions about these surface types. However, it is expected that results from the asphalt concrete and burlap drag pavements described in other reports can be extrapolated to bridge decks.

The report contains box plots that display the variability of the results for Year 1, Year 2, and both years combined, respectively. In addition, plots of the OBSI spectral contents that compare the OBSI results among the different surface types also appear (these are shown as average spectra for each texture type).

In the report, the plotted OBSI spectral contents show comparisons of the results among the different surface types.

The surface age of all the decks except for one ranged from 0 to 16 years.

The transversely tined decks appear to have a trend indicating an increase in OBSI level with age, although there appear to be decreases between Year 1 and Year 2 measurements on some sections. Because the data points are from bridge decks of different ages rather than a time series of the same bridge decks, it is difficult to estimate a per year increase in noise on transversely tined surfaces. The age of the oldest transversely tined section in the study was 16 years, and the study included a representative sample of this texture.

The transversely broomed surfaces may decrease in noise with time, but the available data was insufficient to confirm this, and there appeared to be decreases between Year 1 and Year 2 measurements on some sections. The oldest transversely broomed section in the study was 10 years old, and there was only a small sample of this texture in the study.

The polyester overlay surface data point at 15 years was louder than the newer surfaces, but it corresponds to the section that was eliminated for being on a curved alignment. The available data suggest an increase in OBSI of about 0.4 dB(A) per year for polyester overlay surfaces, however, the small sample size (four and six sections in Years 1 and 2, respectively) makes it difficult to have much confidence in this statement. The age of the oldest section was six years, after elimination of the section on the curve.

The diamond-ground decks appeared to have an increase in noise level with time, but there is insufficient data to draw a strong conclusion. The age of the oldest was 11 years, and there was only a small sample.

Since there was only one section with a hot-mix asphalt surface and one with a burlap drag surface, no conclusions could be drawn on the effects of age for these surface types. This particular asphalt concrete section had an increase of OBSI of 1.6 dB(A), from 7.3 to 8.2 years of age. Hot-mix asphalt is generally not allowed on bridge decks because of the potential for delamination and pot holes and because asphalt overlays make it difficult for bridge maintenance inspectors to see the condition of the underlying deck. It is important to also note that the burlap drag section had been in service for more than 40 years, and the results of 105.6 and 105.3 dB(A) are well within the midrange of results found for much younger sections with transversely tined surfaces.

The difference in OBSI levels between the bridge deck and that of the approach and leave sections of pavement depends on the type and texture of each surface. It is interesting to note that the first year data showed that on 12 out of 22 sections (55 percent), bridge decks were louder than the adjacent pavement, and the second year showed this same trend on 11 out of 21 sections (52 percent). The transversely tined and transversely broomed decks were all louder than the adjacent pavement. The other bridge deck surfaces (polyester overlay, diamond ground, burlap drag, and asphalt concrete) were all quieter than the adjacent pavement, except for Section QP-149.1. The report includes a figure that presents the difference in tire noise level, defined as bridge OBSI minus pavement OBSI, for each section and for Year 1 and Year 2 data, sorted by surface type.

Only five of the 24 bridges presented a joint “slap” noise level that was high enough to warrant further examination. The effect of bridge joints on the average OBSI level of bridge decks was found to be small, although it causes very high short-duration noise, on the order of 112 dB(A). Because joint slap is a very short-duration spike in noise, it does not have much effect on calculated OBSI. For example, a 112 dB(A) slap noise would have a 0.4 dB(A) effect on the overall noise of a 440-foot section. Detailed plots showing the bridge OBSI level and the joint OBSI level are presented in Chapter 4.

It should be noted, that while this analysis shows that joint slap noise does not significantly increase the calculated overall OBSI level, the short, sharp noise caused by the slap can be perceived as annoying. A method for characterizing the effects of short sharp noise levels in conjunction with the longer-duration noise level from the bridge deck has not been developed.

Conclusions and Recommendations

These conclusions have been drawn from noise measurements on the 24 bridge decks included in this study. It must be remembered that the purpose of this study was to provide an initial investigation of tire/pavement noise on bridge decks, and that the experiment design is not a complete factorial with respect to surface type and age. In addition, there is no established practice for use of the OBSI method for bridge decks, and part of this investigation included experimentation with regard to test method. Hence, the conclusions and recommendations made here must be considered as preliminary.

The following conclusions have been drawn with respect to the identification of relationships between the design variables, in this case the bridge deck surface type and the presence of joints:

- The general order, from noisiest to quietest, of On-board Sound Intensity (OBSI) for the bridge deck surfaces with more than one section in the study was: transversely tined, transversely broomed, polyester overlay, and diamond ground. On-board Sound Intensity (OBSI) levels in the range of 99.2 to 104.2 dB(A) were measured on the four diamond-ground bridges evaluated, with an average of 101.9 dB(A). The polyester overlays were also quieter than the other surface types, with OBSI generally lower than 105.0 dB(A). Transversely tined and transversely broomed textures had the greatest OBSI levels, generally between 105.0 and 109.0 dB(A). Human hearing can generally detect changes in sound intensity greater than 2 to 3 dB(A), which suggests that there is a perceivable difference in noise between bridge decks with transversely tined or transversely broomed surfaces, and the quieter bridges with diamond-ground or polyester overlay surfaces. The results from measurement of one bridge indicate that hot-mix asphalt surfaces can also be quieter than transversely tined or transversely broomed surfaces, although the longevity of the noise benefit from the asphalt surface on the bridge deck was not identified in this study. Hot-mix asphalt is generally not allowed on bridge decks because of the potential for delamination and pot holes and because asphalt overlays make it difficult for bridge maintenance inspectors to see the condition of the underlying deck. The results from one other bridge show that the noise level on the burlap drag surface was near the mean of the transversely broomed sections.
- OBSI one-third octave band spectra had similar distributions, with quieter surfaces generally quieter across all frequencies and noisier surfaces generally noisier across all frequencies. Peak frequencies

(dB[A]) were typically 800 Hz, with a few at 1,000 Hz. Many of the transversely tined and transversely broomed surfaces had a second peak frequency at 1,600 Hz.

- The differences in noise levels between the bridge decks and the pavement before and after the bridge decks varied, with the pavements noisier than the bridge decks in some cases and the opposite in other cases. The transversely tined and transversely broomed decks were all louder than the adjacent pavement. The other bridge deck surfaces (polyester overlay, diamond ground, burlap drag, and asphalt concrete) were all quieter than the adjacent pavement, except for one case.
- Although the effect of joints causes a very high short-duration noise on the order of 112 dB(A), in all cases but one the effect on noise when traveling across the entire bridge deck was found to be less than 0.4 dB(A) in terms of average OBSI. The exception to the 0.4 dB(A) effect noted occurred on the quietest polyester overlay deck (QP-145.1), where a joint effect of 0.5 dB(A) was measured. The joint effect was captured with data collection at 15-msec and 0.2-sec intervals, but currently there is no standard method for assessing joint slap. Additionally, although there is no significant increase in noise from joint slap as measured using the OBSI method, the effect on humans is difficult to judge because there is no methodology for assessing the impact on humans of short, intense noise events like these.

With respect to establishing trends in noise level versus age for different bridge deck surface types, the number of replicate sections was not large enough and the monitoring period was not long enough to establish strong conclusions. The following preliminary statements can be made based on the data that could be collected:

- In general, OBSI levels changed very little over the two years of data collection. Several sections with transverse textures appeared to have a reduction in noise between the Year 1 and Year 2 measurements.
- Noise levels trends on transversely tined decks were not clear. Results from nine such bridges indicated OBSI levels in the range of 103 to 106 dB(A) from sections whose surface had been in service less than five years, while the approximately 15-year old sections evaluated were above 108 dB(A).
- Transversely broomed surfaces about 10 years old had OBSI levels of about 106 dB(A).
- The polyester-overlaid decks were tested on sections six months to six years old, with results of 102 to 106 dB(A). Using the 10 data points that result from combining the Year 1 and Year 2 results, a preliminary estimate could be made that noise increases at a rate of 0.4 dB(A) per year.
- Diamond-ground sections at 10 years of age showed OBSI levels of about 104 dB(A). Younger sections had OBSI levels between 99 and 102 dB(A).
- A section of burlap drag that had been in service for 44 years presented an OBSI level of 106 dB(A), well within the midrange of results found for much younger transversely broomed sections.

Although this study does not include a sufficient number of bridge decks to make recommendations regarding all bridge deck surface types currently used in the state, and does not include sufficient observations to draw strong conclusions regarding the longevity of noise levels, the results indicate that diamond-ground surfaces will provide initial noise reductions that are perceptible to human hearing compared with transversely tined and transversely broomed surfaces, both initially and over at least a 15-year period.

Polyester overlays provide some noise reduction, although not when they are applied as a thin overlay on transversely tined and transversely broomed surfaces where the overlay does not eliminate the underlying texture. However, the limited results from this study indicate that differences in noise levels compared with the transverse textures may not be perceptible to human hearing after approximately 10 years of service. Polyester overlays are typically longitudinally tined or diamond-ground, which may be the primary reason they are quieter than the transversely tined surfaces they are placed on. Both the polyester overlays and the diamond-ground decks were generally quieter than the approach and leave sections pavement before and after the bridges.

It is therefore recommended that diamond-ground surfaces or, as a second option, polyester overlays be used when the minimization of tire/pavement noise on bridge decks is a desirable design feature.

It should be remembered that the frictional properties of diamond-ground versus transversely tined and transversely broomed surfaces were not considered in this study, and should be considered in any decision.

It is recommended that some additional bridge deck surfaces be measured, particularly any older diamond-ground and polyester overlay surfaces that might exist in the state, and that the bridge decks included in this study be monitored for several more years to provide a better estimate of changes in tire/pavement noise over time. Additionally, it would be interesting to investigate whether the lower noise level on polyester overlay decks is the result of the polyester material, or if it is just due to the longitudinally tined finish applied on the overlay.

Although current methods for reducing the effect of joint slap have little effect on the overall OBSI during travel across a bridge deck, it is still recommended that they be used where possible and that the human perception of joint slap be further investigated.

It is recommended that the literature be continually reviewed for updates on standardization of measurement methods for OBSI on bridge decks as additional years of measurements are added to this study.

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1 INTRODUCTION

In the early 2000s, the California Department of Transportation (Caltrans) identified a need for research into the acoustics, friction, durability, and related performance properties of pavement surfaces on the state highway network. Consequently, in November 2004, the Caltrans Pavement Standards Team (PST) approved a research project to investigate the tire/pavement noise characteristics and performance properties of existing flexible pavements, including the Department’s current open-graded mixes, dense- and gap-graded mixes, and selected experimental mixes.

The initial investigation of flexible pavement surfaces was included as Strategic Plan Element (SPE) 4.16 in the Partnered Pavement Research Center (PPRC) contract between the University of California Pavement Research Center and Caltrans, and the research had as its objectives evaluation of the mixes’ durability and their comparative effectiveness in increasing safety and reducing noise, determination of the pavement characteristics that affect tire/pavement noise, and evaluation of the correlation between laboratory sound absorption and tire/pavement sound intensity in the field. PPRC SPE 4.16 included two years of field measurements, and included the measurement of material properties and field performance for a range of climate and traffic-level applications. Third- and fourth-year field measurements of noise, ride quality, macrotexture, and permeability (fourth year only) have been completed since then, as part of PPRC SPE 4.19 and SPE 4.27 respectively.

A similar research study for rigid pavements and bridges decks, the latter of which is the subject of this report, was initiated by the Caltrans Quieter Pavement Research Task Group in May 2008.

The quieter concrete bridge deck research study presented in this report was undertaken to determine the acoustic characteristics of the noise generated by tire/pavement interaction on concrete bridge surfaces, and to identify the types and properties of bridge surface textures that would effectively reduce tire/pavement noise. This study has three objectives:

1. To identify relationships between the design variables of concrete bridge surface textures and tire/pavement noise, covering the majority of surface textures used in California,
2. To establish trends in noise levels versus age for concrete bridges, and
3. To develop recommendations for concrete bridge surface textures that minimize tire/pavement noise.

This report covers all three objectives for bridge decks. A separate report presents the reports for concrete pavements.

2 DATA COLLECTION AND DATA REDUCTION

2.1 Data Collection

Very little research has been performed on tire/pavement noise on bridge decks. Noise data cannot always be collected on bridges in the same way it is on pavements because typical procedures for noise testing call for recording and analysis of fixed five-second intervals taken at 60 mph (97 km/hr), which requires a minimum test section length of 440 feet (134 m) on a road. However, many bridges are shorter than this minimum length and so the resulting data from the five-second recording interval would include surface that is not part of the bridge.

For this study, it was decided to collect tire noise starting on the pavement at some distance before entering the bridge and to terminate the data collection after leaving the bridge, so that the approximate difference in tire noise level could be measured between the approach and leave sections of pavement on either side of the bridge, including the leave and approach slabs, and the bridge surface. A decision was also made to collect data in shorter time intervals and then to post-process it into longer intervals. This also allowed the identification of bridge joints so that their effect on noise could be isolated. Consequently, in most cases data collection began one or two seconds before the noise-collecting vehicle entered the bridge. An alternative data collection option considered was to only collect data on the bridge deck. This approach would have greatly simplified the data analysis, but it would not have provided the additional information about the approach and departure from each bridge.

The study used the OBSI method to measure tire noise. This method has been used on noise projects performed for Caltrans since approximately 2004. At the time this study was performed, a first version of an OBSI standard had been adopted by the American Association of State Route and Transportation Officials (AASHTO) as AASHTO TP-76. In the OBSI method, two sets of microphones, each set consisting of two closely spaced phase-matched microphones, are configured side-by-side. One microphone set (each set also referred to as a "probe") is placed at the location of the leading edge of the tire/pavement contact patch at a distance of 4 in. (102 mm) from the sidewall and 3 in. (76 mm) from the pavement surface. The second probe is placed at the same distances from the tire and pavement surface at the trailing edge of the tire/pavement contact patch. The distance between the two probes is 8.25 in. (210 mm). The sound intensity is measured in dB and the results are A-weighted and averaged for the leading and trailing edge positions.

In addition to the OBSI testing, the study also included inertial profilometer measurements of both wheelpaths and visual observation of surface type. Vehicle speed and surface profile elevation were collected during the profilometer testing, as were photos of the pavement surface at fixed short intervals. Profilometer testing was concurrent with OBSI testing, with data collection for both triggered simultaneously. International Roughness

Index (IRI) was collected for both wheelpaths and macrotexture (mean profile depth [MPD] was measured with the high-speed profilometer spot laser in the right wheelpath, although the spot laser is now generally considered inadequate for accurately determining these properties on directionally textured surfaces. Wider lasers are now generally used for directionally textured surfaces, which removes the effect of the spot laser jumping up and down as it moves in and out of the grooves in the textured surface.

Visual observation was necessary for determining the bridge deck surface type. In some cases, bridges were part of heavily trafficked highways which made it impossible to stop and closely examine the bridge surface. In these cases, observations were only made from the moving test vehicle, which is shown in Figure 2.1.

Figure 2.1: Instrumented vehicle with one set of sound intensity microphones on each side of the tire and an inertial profilometer with spot lasers, including a high-speed spot laser in the right wheelpath.

A total of 24 bridges were included in the study and the data collection spanned two years. In the first year the bridges were selected and evaluated between October 2008 and February 2009; in the second year they were visited between October 2009 and January 2010.

2.2 Data Reduction

A large effort went into data reduction for this project. The OBSI method requires measurement of sound intensity levels in one-third octave bands, ranging from noise centered at 400 Hz to noise centered at 5,000 Hz. These values are obtained at the leading and the trailing edges of the tire contact patch. Three passes are conducted on each test section to account for lateral wander of the vehicle and for deviations from the specified 60 mph (97 km/hr) speed. A resulting noise spectrum is obtained from the results of the three passes, at the two probe locations, which in turn allows for calculation of the overall sound intensity level, the single value most commonly reported for tire/pavement noise.

As mentioned, there is no standard testing method to evaluate bridge deck tire noise. The five-second collection time of the OBSI method used for roadway testing is not completely suitable for bridge decks, and therefore shorter intervals were used in this study. In Year 1, the noise data collection was done first with the three passes at one-second intervals, then a fourth pass was done with data collected at 15 millisecond intervals in an attempt to isolate the noise from the bridge joints. During Year 2, an interval of 0.2 seconds was used instead of the one-second interval used in Year 1, which proved to be more suitable for the overall analysis. The 1-second and 0.2-second intervals were analyzed to obtain the results for each bridge, and the 15 millisecond single pass was used only for evaluation of joint "slap" noise, the noise created by the tire passing over an expansion joint in the bridge deck.

In order to average the sound energy from the OBSI measurements from replicate passes, the following equation was used:

$$Energy\ average = 10 * \log_{10}\left[\frac{1}{n} \times \sum_{i=1}^{n} 10^{\frac{x_i}{10}}\right]$$

Where x_i are the OBSI values being averaged, and n is the number of samples.

An air density adjustment was applied to the direct noise measurements to account for the effect of air density on the speed of sound. The adjustment is calculated from the altitude of the section, and the air temperature, barometric pressure, and relative humidity measured when testing occurred.

There have been improvements to the process of OBSI data collection that have affected every organization conducting this type of testing over the years. For this research, the following adjustments were considered necessary to normalize results and make them consistent with other OBSI databases delivered to Caltrans:

a. Test tire: Although the tires used in both years of data collection were Standard Reference Test Tires (SRTT), the actual test tire was replaced in early November 2009, when the tire was considered "young," to prevent problems associated with testing with an older tire. Through comparisons performed later, linear transformation equations were developed to adjust the results of the Year 1 and Year 2 tires back to the first SRTT used by the UCPRC research team. The transformation equations adjusted the SRTT #2 tire (used in 2008) and SRTT #3 tire (used in 2009), back to the SRTT #1 tire, which was the one first used in the asphalt concrete study. The transformations were applied frequency by frequency, and the overall sound intensity was not calculated from the adjusted spectra but from another linear transformation. The tire correction equations were developed using data from concrete pavements only.

b. Sound analyzer: A frequency-by-frequency correction was applied to account for the fact that a new sound analyzer was used for Year 2 data of this study. Year 1 OBSI data were measured using two Larson Davis two-channel analyzers, while a Sinus Harmonie 4-channel analyzer was used in Year 2. Linear transformation equations were determined using results from field sections tested with both analyzers, and the Larson Davis results were converted to equivalent values for the Sinus Harmonie analyzer. The analyzer correction equations were developed using data from asphalt concrete and concrete pavements. These adjustments are presented in Table 2.1 where A is the intercept and B is the slope of the linear transformation. Also shown is the coefficient of determination R^2.

2.3 Description of the Test Sections

The 24 bridges investigated in this study are located on the state highway network owned and managed by the California Department of Transportation (Caltrans). The bridges included in the study were suggested by the Division of Structures through the Quieter Pavement Research Task Group. The *California Log of Bridges on State Highways* contains information on all the bridges and other highway structures on California's state highway network. The relevant information from this log for the bridges in this study is presented in Table 2.2. Table 2.3 presents additional information such as the lane tested, the surface type or texture, and the date and time each section was visited in the field in Years 1 and 2 of this study. A map with the location of the bridges is presented in Figure 2.2, although not all 24 bridges can be seen due to its scale.

Table 2.1: Spectral and Overall OBSI Correction for Test Tire and Sound Analyzer

Param.	Frequency												Overall
	400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000	
SRTT #2 to SRTT #1													
A	12.92	-4.83	-0.13	-3.61	12.85	2.34	-3.66	-6.17	2.15	-1.35	-0.46	0.97	-20.54
B	0.86	1.05	1	1.03	0.86	0.97	1.03	1.05	0.97	1.01	1	0.99	1.19
R^2	0.58	0.93	0.96	0.95	0.65	0.94	0.95	0.93	0.92	0.95	0.96	0.92	0.94
SRTT #3 to SRTT #1													
A	5.03	-33.53	-16.82	-16.27	-1.01	-1.04	9.1	1.15	0.74	10.46	7.62	2.03	-9.28
B	0.95	1.37	1.18	1.16	1.01	1.01	0.9	0.99	0.99	0.87	0.91	0.97	1.09
R^2	0.75	0.9	0.92	0.95	0.94	0.92	0.96	0.96	0.93	0.93	0.93	0.94	0.96
Analyzer change: Larson Davis to Sinus Harmonie													
A	14.06	0.52	1.39	5.03	-0.28	3.6	2.27	1.7	1.34	1.91	2.33	4.34	2.19
B	0.83	0.99	0.98	0.95	1	0.96	0.97	0.98	0.98	0.98	0.97	0.94	0.98
R^2	0.67	0.95	0.95	0.95	0.97	0.95	0.97	0.96	0.95	0.92	0.92	0.89	0.97

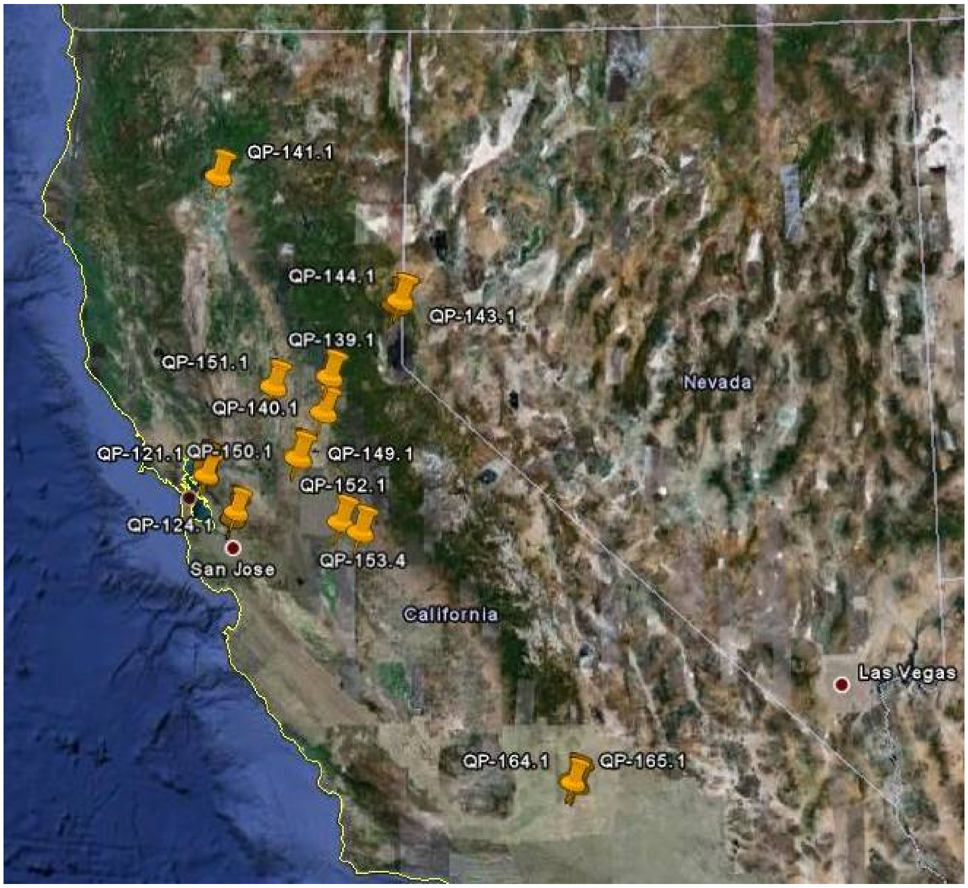

Figure 2.2: Location map of bridge deck sections included in this study.

2.4 Description of Surface Types

Six surface types were identified for this study, and there were between one and nine sections of each type as shown in Table 2.4. Despite the effort put into collecting data in a large number of bridge sections, the number of sections with different surface types was unequal, which led to a nonbalanced factorial that required more careful analysis for arriving at conclusions than if a balanced factorial had been studied.

Transversely tined and transversely broomed are textures applied to fresh concrete. The name “polyester overlay” was used for bridge decks where an overlay material was identified as being different from concrete or asphalt concrete. Diamond grinding is a technique used on hardened concrete. Burlap drag is applied to fresh concrete, but in this case the term was used to refer to a deck with old concrete that basically had lost across the entire bridge deck most of whatever original texture it had when constructed, which may have been burlap drag in many cases. Hot-mix asphalt, also referred to as “asphalt concrete” in this report (Caltrans changed terminology during the course of this study), corresponds to a bituminous mixture overlaid on the bridge deck.

Table 2.2: Bridge Section Information from the *California Log of Bridges on State Routes*

Section ID	Location (District/County/Route/ Direction/Post Mile	Bridge Number	Structure Name	Structure Type	Bridge Length (m)	Number of Spans	Year Built
QP-118.1	04ALA580W47.3	33 0051R	80/580 EL CERRITO SEPARATION	505	643	17	1999
QP-119.1	04ALA580E7.2	33 0051L	EL CERRITO SEPARATION & OH	204 302	643.7	33	1998
QP-120.1	04ALA80E7.0	33 0051R	80/580 EL CERRITO SEPARATION	505	643	17	1999
QP-121.1	04ALA880S32.7L1	33 0616L	5TH & 6TH STREET VIADUCT	505	1138.4	26	1998
QP-122.1	04ALA880S32.7L3	33 0616L	5TH & 6TH STREET VIADUCT	505	1138.4	26	1998
QP-124.1	04ALA262W0.1	33 0270F	WB262-SB880/880 CONNECTOR/SEPA	105	395.5	7	2008
QP-125.1	04SCL237W6.4	37 0244L	GUADALUPE RIVER	201	208.8	23	1994
QP-125.2	04SCL237W6.1	37 0470L	SOUTH ALVISO OVERHEAD	605	133.1	6	1994
QP-125.3	04SCL237W6.9	37 0471L	GREAT AMERICA PARKWAY UC	605	58.8	2	1994
QP-139.1	03ED50E11.2	25 0121	MISSOURI FLAT ROAD	206	55.9	2	2008
QP-140.1	10AMA104W3.6	26 0050	DRY CREEK	205	61.3	3	2005
QP-141.1	02SHA5N6.9	06 0128	SACRAMENTO RIVER	502	188	4	2000
QP-143.1	03NEV80E20.8	17 0013	TRUCKEE RIVER	503	93	3	2004
QP-144.1	03NEV80E21.1	17 0012	TRUCKEE RIVER	503	93	3	2004
QP-145.1	03NEV267S0.4	17 0098	TRUCKEE RIVER BRIDGE & OH	205	465	7	2003
QP-149.1	10SJ4E19.4	29 0309G	N99-W4 CONNECTOR OC	605	208.2	6	1993
QP-150.1	10SJ99N17.8	29 0119	MORMON SLOUGH	201	31.4	4	1949
QP-151.1	03Yol80E11.3	22 0026R	SACRAMENTO RIVER BOH (BRYTE OH)	405	1234.4	22	1971
QP-152.1	10Mer99S31.1	39 0015L	MERCED RIVER	605	115	2	1997
QP-153.4	10Mer99S17.5	39 0010L	BLACK RASCAL CANAL	201	28.4	4	1964
QP-163.1	06Ker58E111.8	50 0495R	KENWATER OVERHEAD	605	77	3	2003
QP-164.1	06Ker58W108.7	50 0497L	LA DWP EAST AQUEDUCT	605	79.6	3	2003
QP-164.2	06Ker58W108.5	50 0494L	LA DWP WEST AQUEDUCT	605	81.4	3	2003
QP-165.1	06Ker58R108.90	50 0496	"ON BUS. ROUTE 58, East of Junction"	605	250	1	2003

Table 2.3: Lane, Surface, and Date/Time of Field Evaluation of Bridge Sections

Section ID	Bridge Number	Lane	Surface Type	Date Time Y1	Date Time Y2
QP-118.1	33 0051R	2 of 2	Diamond ground	10/30/2008 12:13	11/10/2009 11:32
QP-119.1	33 0051L	2 of 2	Transversely tined	11/4/2008 10:52	11/10/2009 12:00
QP-120.1	33 0051R	4 of 4	Diamond ground	11/4/2008 12:15	11/10/2009 12:51
QP-121.1	33 0616L	1 of 3	Transversely broomed (changed to Polyester overlay in Year 2)	11/5/2008 11:02	11/12/2009 10:22
QP-122.1	33 0616L	3 of 3	Transversely broomed (changed to Polyester overlay in Year 2)	11/5/2008 12:21	11/12/2009 11:52
QP-124.1	33 0270F	3 of 3	Transversely broomed	11/6/2008 11:46	11/17/2009 11:55
QP-125.1	37 0244L	3 of 3	Transversely tined	11/6/2008 15:31	11/17/2009 14:31
QP-125.2	37 0470L	3 of 3	Transversely tined	11/6/2008 15:38	11/17/2009 14:36
QP-125.3	37 0471L	3 of 3	Transversely tined	11/6/2008 16:00	11/17/2009 14:53
QP-139.1	25 0121	2 of 2	Transversely tined	11/20/2008 13:59	10/12/2009 13:58
QP-140.1	26 0050	two-lane road	Transversely tined/diamond ground	11/20/2008 16:03	10/12/2009 16:11
QP-141.1	06 0128	2 of 2	Transversely tined	11/21/2008 13:57	9/18/2009 14:16
QP-143.1	17 0013	2 of 2	Polyester overlay	11/25/2008 11:53	9/16/2009 16:51
QP-144.1	17 0012	2 of 2	Polyester overlay	11/25/2008 12:26	9/16/2009 17:18
QP-145.1	17 0098	two-lane road	Polyester overlay (Overlaid again in Year 2)	11/25/2008 14:39	9/17/2009 10:02
QP-149.1	29 0309G	1 of 2 ramps	Polyester overlay (Eliminated from the study due to curvature)	12/4/2008 11:37	Not evaluated
QP-150.1	29 0119	2 of 2	Hot-mix asphalt	12/4/2008 13:07	10/28/2009 15:13
QP-151.1	22 0026R	1 of 3	Longitudinally tined polyester overlay	12/5/2008 10:57	10/12/2009 11:21
QP-152.1	39 0015L	2 of 2	Transversely tined	12/17/2008 12:37	11/13/2009 11:54
QP-153.4	39 0010L	1 of 2	Burlap drag	12/17/2008 15:34	11/13/2009 13:28
QP-163.1	50 0495R	2 of 2	Transversely broomed	2/24/2009 17:15	12/2/2009 14:49
QP-164.1	50 0497L	2 of 2	Diamond ground	2/26/2009 10:41	12/3/2009 9:16
QP-164.2	50 0494L	2 of 2	Transversely tined	2/26/2009 10:41	12/3/2009 9:16
QP-165.1	50 0496	2 of 2	Diamond ground	2/25/2009 17:24	12/2/2009 15:38

Table 2.4: Surface Types and Sections

Surface Type	Number of Sections	Sections
Transversely tined	9	QP-164.2, QP-141.1, QP-152.1, QP-139.1, QP-125.3, QP-125.1, QP-125.2, QP-119.1, and QP-140.1 (Section QP-140.1 is diamond ground as well.)
Transversely broomed	Year 1: 4 Year 2: 2	QP-163.1 and QP-124.1. Sections QP-121.1 and QP-122.1 were transversely broomed only in Year 1.
Polyester overlay	Year 1: 4 Year 2: 6	QP-145.1, QP-144.1, QP-143.1, and QP-151.1 (Section QP-151.1 is longitudinally tined as well). In Year 2, two sections turned into polyester overlay (QP-121.1 and QP-122.1) and one section (QP-145.1) was repaired and had a new polyester overlay surface. One polyester overlay section was initially measured and then eliminated from the study due to its curved alignment (QP-149.1).
Diamond ground	4	QP-165.1, QP-164.1, QP-120.1, and QP-118.1
Burlap drag	1	QP-153.4
Hot-mix asphalt	1	QP-150.1

2.5 Lane Locations of Sections

Table 2.5 lists the section locations, which had varied lane positions: 18 of the 24 were on an outside lane, four were on an inside lane, and two were on two-lane roads.

Table 2.5: Lane Location of Sections

Lane		Number of Sections	
Outside	2 of 2	12	18
	3 of 3	5	
	4 of 4	1	
Inside	1 of 2	2	4
	1 of 3	2	
Two-lane roads		2	2

3 ANALYSIS OF DATA BY BRIDGE DECK SURFACE TYPE

This chapter contains the analysis of aggregated data for each type of bridge deck surface. Chapter 4 will discuss the results from individual bridges.

3.1 Surface Type

The results of On-board Sound Intensity (OBSI) testing by surface type are presented here as three data sets: Year 1 results, Year 2 results, and combined Year 1 and Year 2 results. The sample size changed during the study because two of the 24 sections experienced a change of surface type, from transversely broomed to polyester overlay (QP-121.1 and QP-122.1), and one section (QP-149.1) was eliminated from the study after Year 1 because the curvature of the bridge made the OBSI results unreliable.

The quietest surface type, when considered as the mean of the OBSI results of sections with the same nominal surface type and from the combined Year 1 and Year 2 data, was found to be the diamond ground. The diamond-ground group presented an average OBSI level of 101.9 dB(A). The polyester overlay-deck group was the second quietest with an average OBSI value of 104.4 dB(A). As a group, the transversely-tined and transversely-broomed surfaces were the loudest, with average OBSI values of 107.2 dB(A) and 106.2 dB(A), respectively. The hot-mix asphalt section and the burlap drag section were included for reference (102.3 dB[A] and 105.0 dB[A], respectively) because the absence of replicates made it impossible to draw conclusions about these surface types. However, it is expected that the results from hot-mix asphalt and burlap drag pavements described in other reports can be extrapolated to bridge decks.

Table 3.1 presents the mean overall results by surface type along with sample size.

Table 3.1. Mean OBSI Level by Surface Types and Number of Sections of Each Type

Surface Type	Year 1		Year 2		Combined Years 1 and 2	
	Mean OBSI (dB[A])	Sample Size, n	Mean OBSI (dB[A])	Sample Size, n	Mean OBSI (dB[A])	Sample Size, n
Transversely tined	107.0	9	107.3	9	107.2	18
Transversely broomed	105.8	4	107.1	2	106.2	6
Polyester overlay	103.5	4	104.4	6	104.4	10
Diamond ground	101.5	4	102.3	4	101.9	8
Burlap drag	104.5	1	105.5	1	105.0	2
Hot-mix asphalt	100.7	1	103.9	1	102.3	2

The results by section are presented graphically in Figure 3.1 and Figure 3.2 for Years 1 and 2, respectively. Note that Section QP-149.1 with a polyester overlay surface is shown in Year 1 with a different color than the other polyester overlay sections, but it was not considered in the analysis of aggregated data.

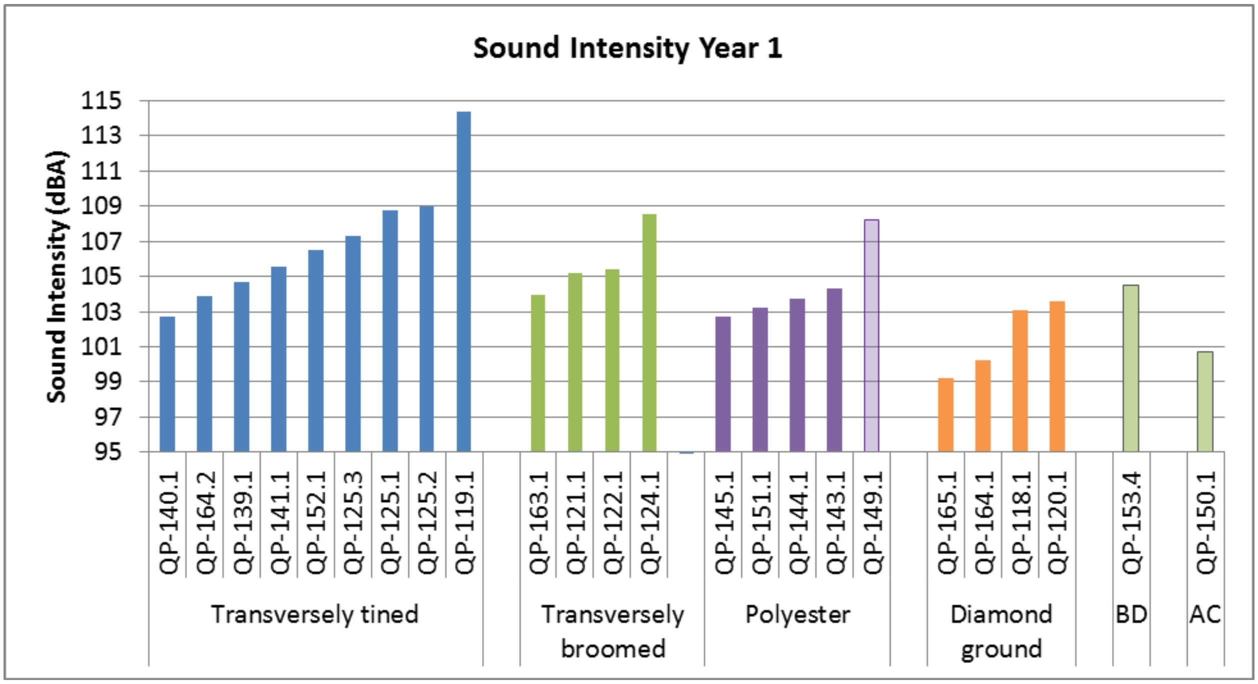

Figure 3.1: OBSI results for each section by surface type, Year 1.

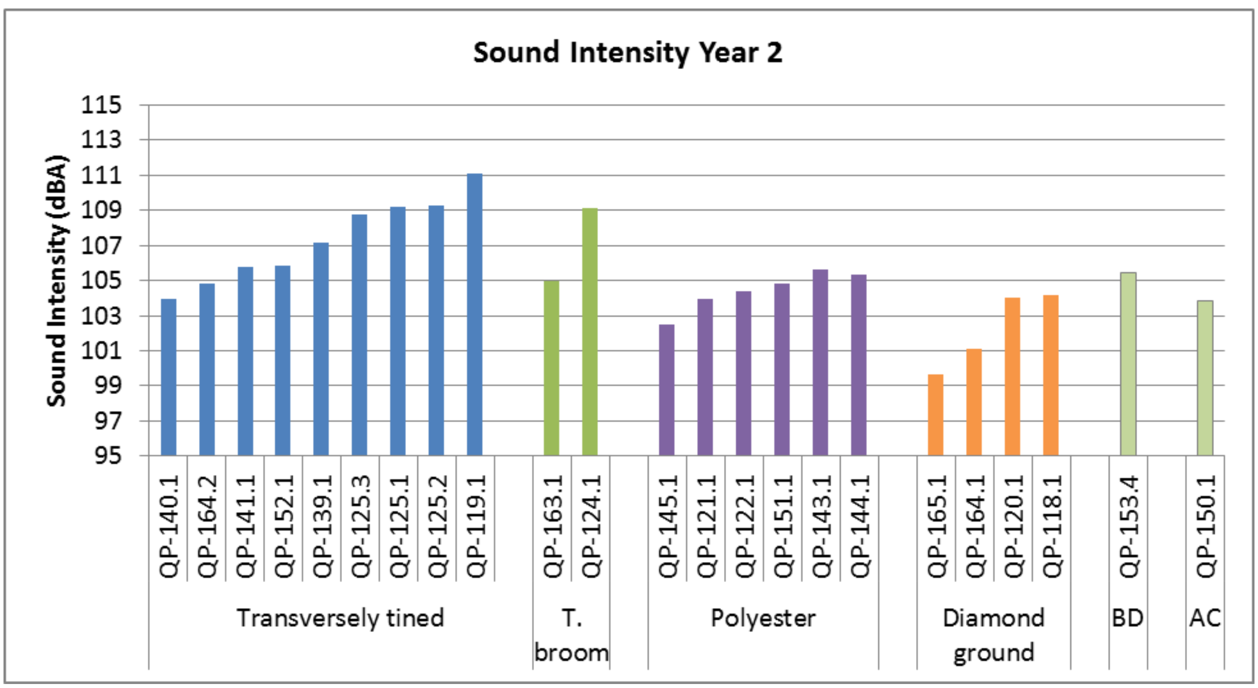

Figure 3.2: OBSI results for each section by surface type, Year 2.

The variability of the results is shown through box plots in Figure 3.3, Figure 3.4, and Figure 3.5 for Year 1, Year 2, and both years combined, respectively. In these plots the maximum and minimum are indicated with lines, and the first and third quartiles are shown as a box.

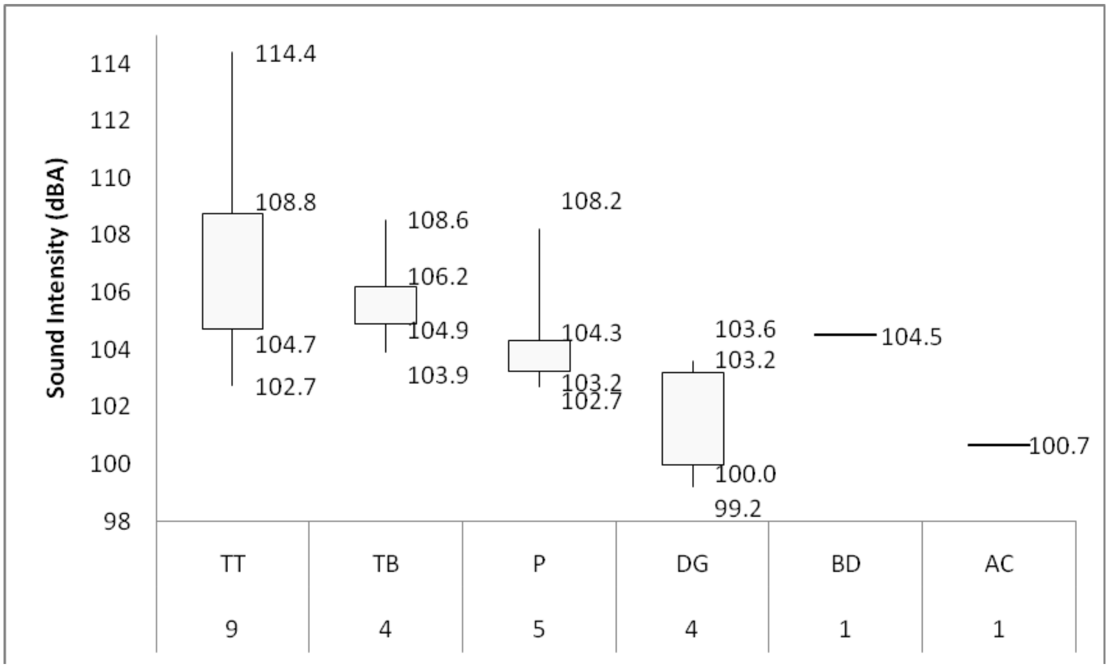

Figure 3.3: Box plots of OBSI results by surface type, Year 1.
(Note: TT is transversely tined, TB is transversely broomed, P is polyester overlay, DG is diamond ground, BD is burlap drag, and AC is hot-mix asphalt [asphalt concrete].)

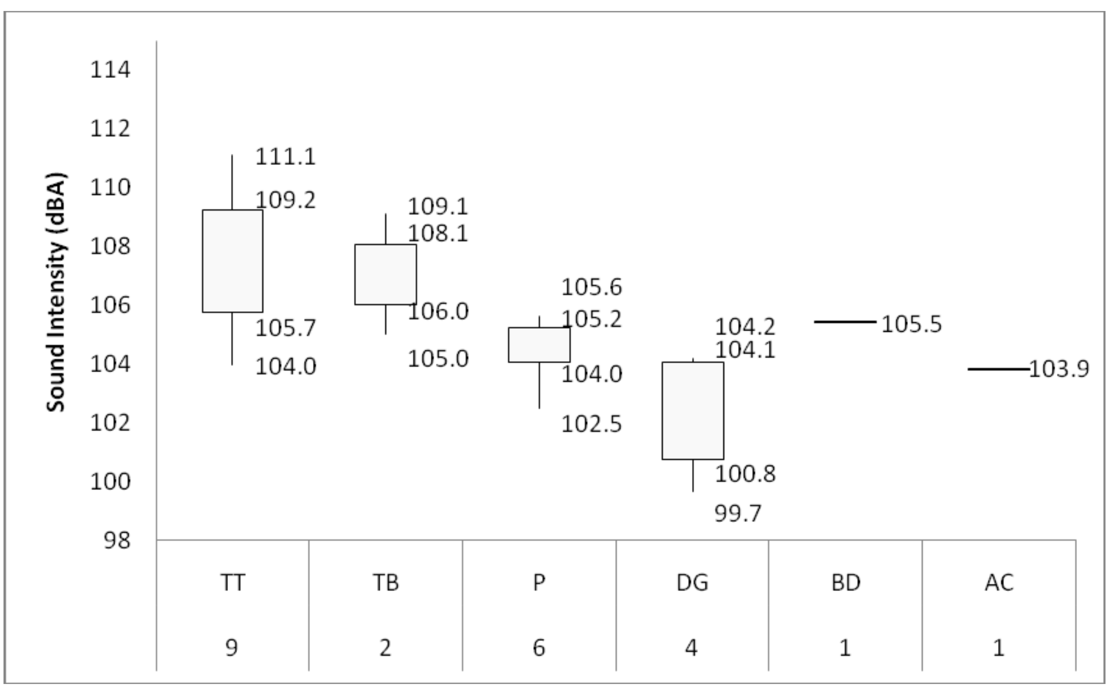

Figure 3.4: Box plots of OBSI results by surface type, Year 2.
(Note: TT is transversely tined, TB is transversely broomed, P is polyester overlay, DG is diamond ground, BD is burlap drag, and AC is hot-mix asphalt [asphalt concrete].)

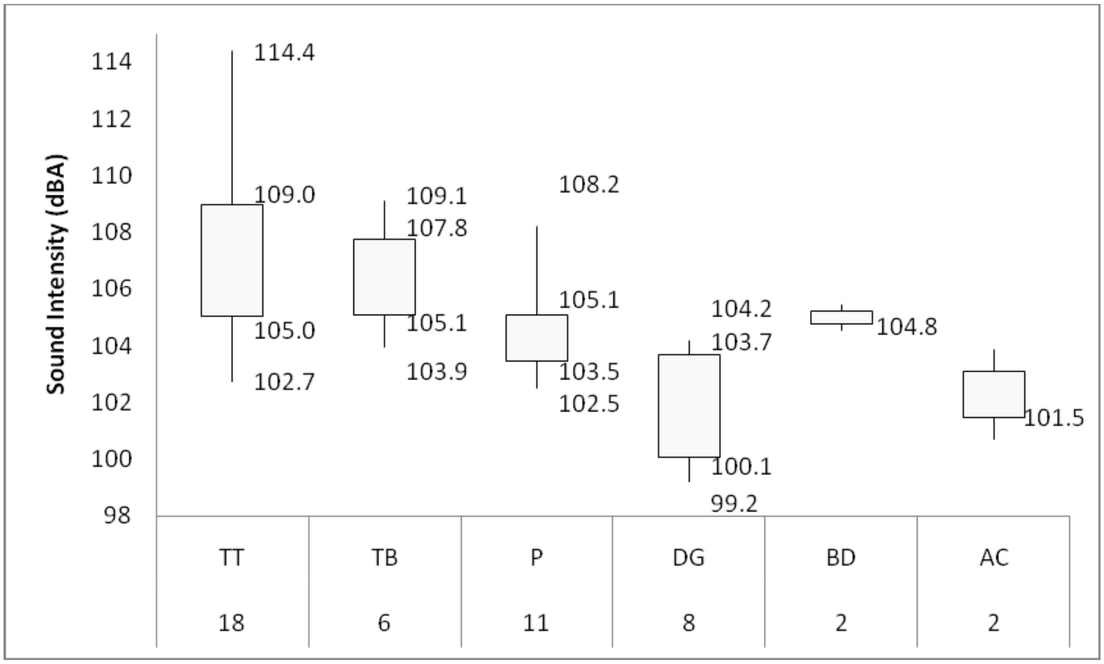

Figure 3.5: Box plots of OBSI results by surface type, Years 1 and 2 combined.
(Note: TT is transversely tined, TB is transversely broomed, P is polyester overlay, DG is diamond ground, BD is burlap drag, and AC is hot-mix asphalt [asphalt concrete].)

The OBSI spectral contents were plotted to compare the OBSI results among the different surface types. After looking at the change of the spectra from Year 1 to Year 2, it was decided that using the average spectra from the two years for each section was adequate for the plots, as presented in Figure 3.6 to Figure 3.9. The surface year is included in the legend for each section.

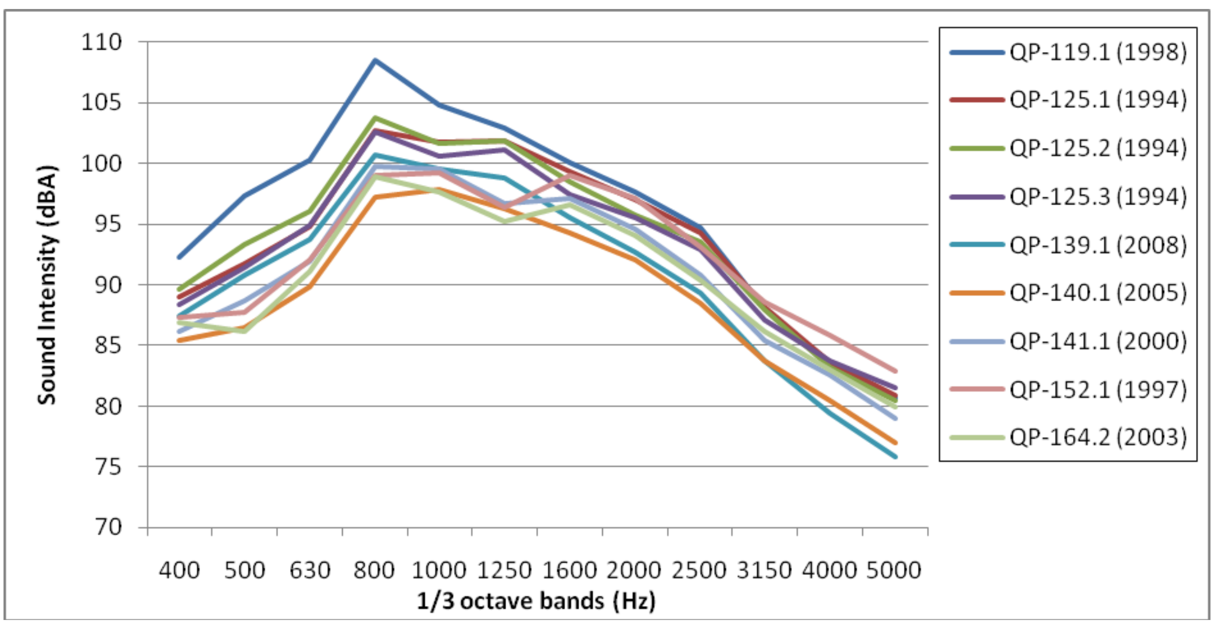

Figure 3.6: OBSI spectral content for transversely tined sections, average of Year 1 and Year 2 data.

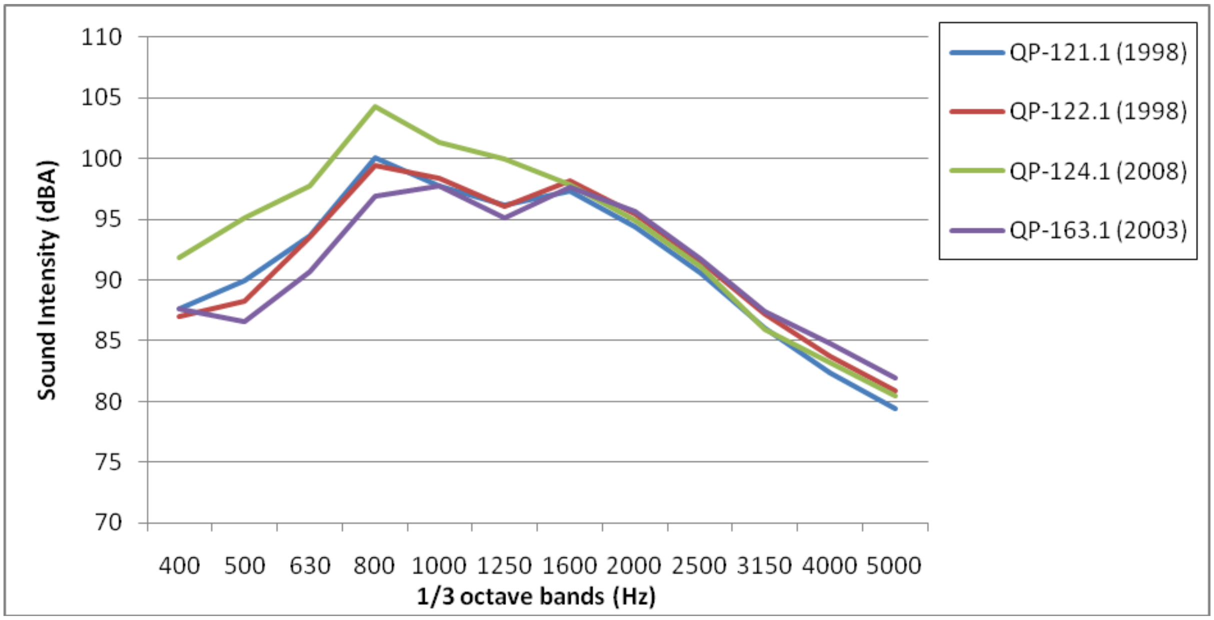

Figure 3.7: OBSI spectral content for transversely broomed sections.

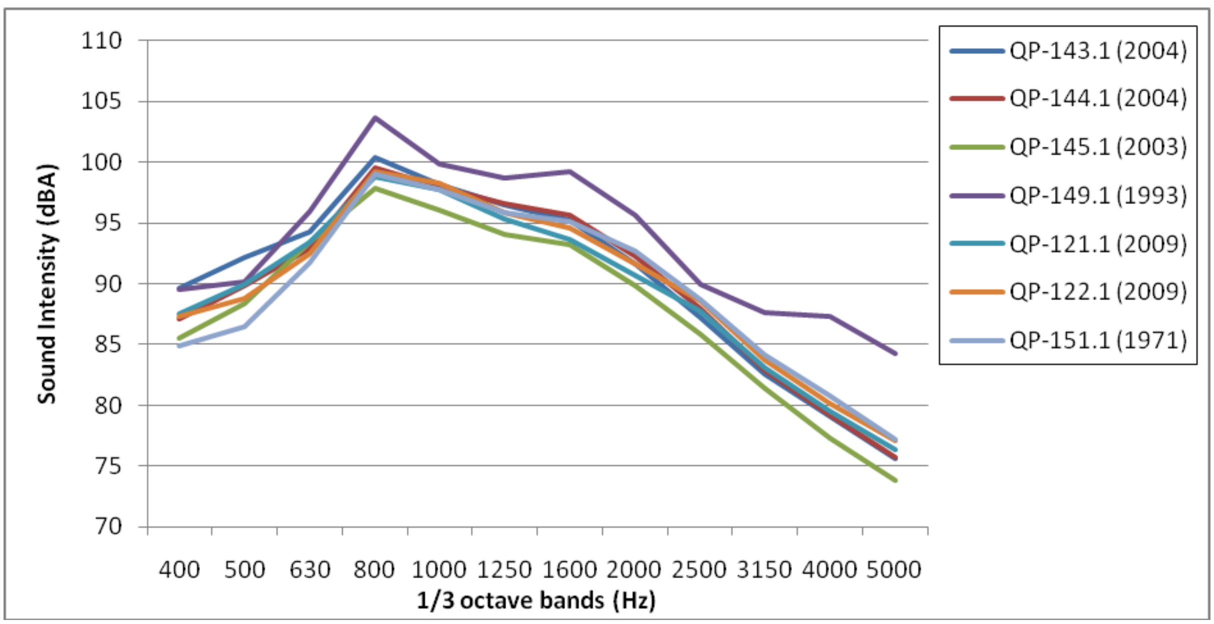

Figure 3.8: OBSI spectral content for polyester overlay sections.

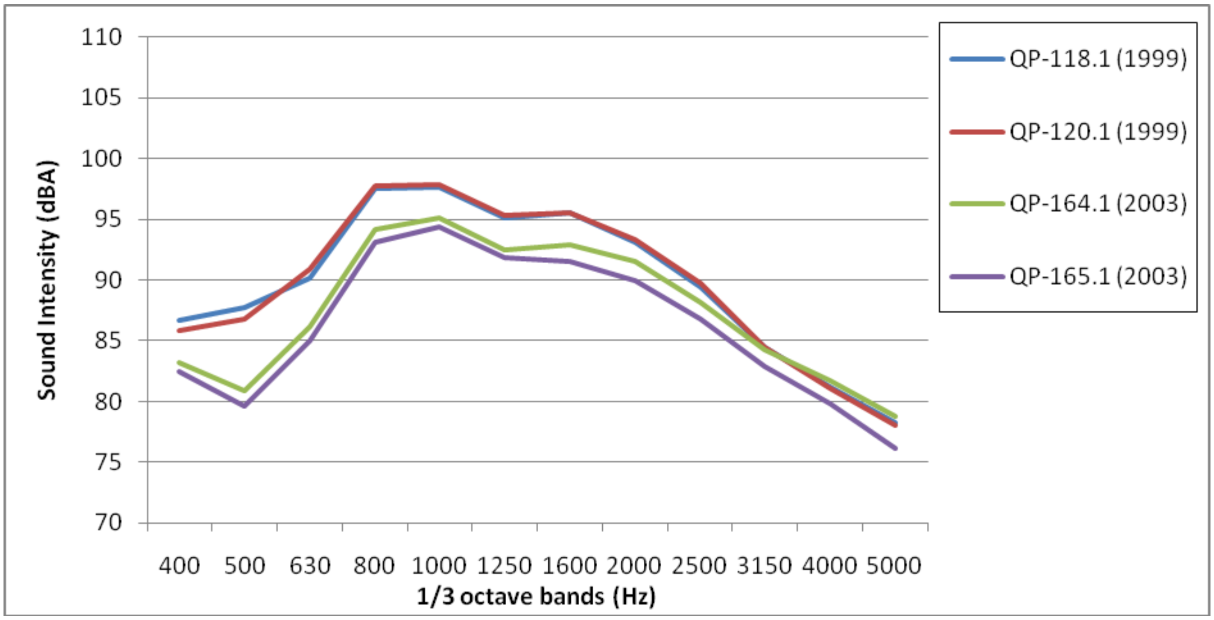

Figure 3.9: OBSI spectral content for diamond ground sections.

To begin the examination of the noise characteristics of bridge deck surface textures in more detail, Figure 3.10 presents the one-third octave sound intensity levels, using the average for each type. Diamond ground had lower levels at frequencies below 1,000 Hz, and is otherwise similar to the AC section collected as a reference. The other surface types are difficult to separate from one another.

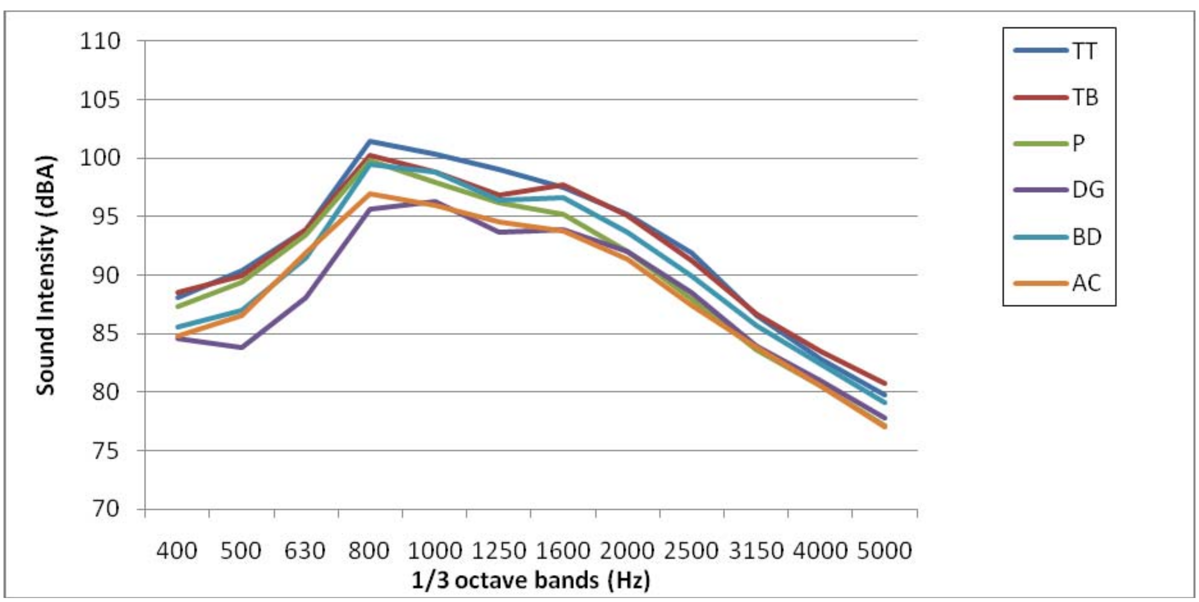

Figure 3.10: Average OBSI spectra of all surface types.
(Note: TT is transversely tined, TB is transversely broomed, P is polyester overlay, DG is diamond ground, BD is burlap drag, and AC is hot-mix asphalt [asphalt concrete].)

Because an average spectrum is just a mathematical construction of a fictitious average section, it is convenient to include in the plots the actual spectra for the sections with the highest and lowest OBSI for each texture type. This is presented in Figure 3.11.

The results of Figure 3.11 are summarized in Table 3.2.

3.2 Surface Age

The testing date and the year of last construction were utilized to determine the age of the bridge deck surfaces. The date of last construction was assumed to be June 30 of the year in which the deck was built, ground, or overlaid. Results for both Year 1 and Year 2 were used in the analysis of noise level versus age.

Table 3.3 presents the year of construction of the structure (Construction Year [Constr. Year]) and the year of the last treatment of the surface (Surface Year [Surf. Year]), and the corresponding age (since the Surface Year) and OBSI level for all sections, sorted by surface type.

The surface age of all the decks but one ranged from 0 to 16 years. The exception was QP-153.4, which the records indicate has not been ground or overlaid since its construction in 1964, making it 44.7 years old at the time of Year 2 testing. Its age made this deck particularly valuable since the Caltrans online data[1] indicate that the most common ages for bridge decks in the network are between 36 to 40 and 41 to 45 years.

Figure 3.12 presents the results of OBSI level versus deck surface age for transversely tined surfaces. The points with a black marker line correspond to Year 1 and those with a red marker line correspond to Year 2. The same black-and-red line code is used in the plots in Figure 3.13 through Figure 3.17. Figure 3.13 presents the OBSI results for transversely broomed deck surfaces. Figure 3.14 shows the results for polyester overlay decks, Figure 3.15 shows them for diamond-ground decks, and Figure 3.16 shows them for hot-mix asphalt and burlap drag surfaces.

The transversely tined decks appear to have a trend indicating an increase in OBSI level with age, although one bridge (QP-119.1) showed a decrease in noise between the Year 1 and Year 2 measurements. Because the data points are from bridge decks of different ages rather than a time series of the same bridge decks, it is difficult to estimate a per year increase in noise on transversely tined surfaces. As will be seen later in the assessment of individual bridge decks (Chapter 4), there may not be a causal relationship between age and noise. Instead, the very small sample of bridges may include several older bridges with aggressive transverse textures and/or poor concrete finishing, and younger bridges with less aggressive textures and better finishing.

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[1] California State Bridge Deck Area by Age, *www.dot.ca.gov/hq/structur/strmaint/agegroup.pdf.*

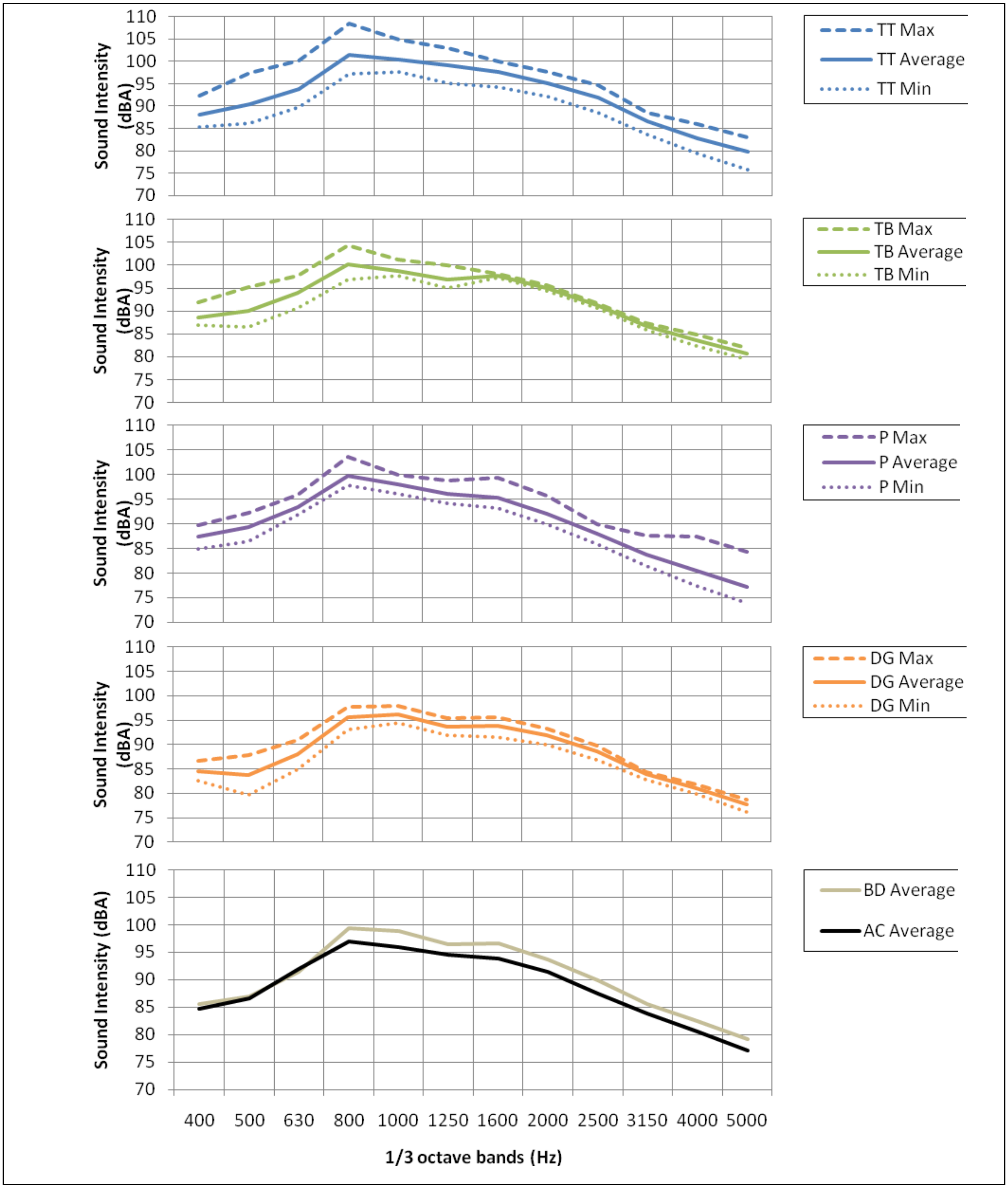


Figure 3.11: Comparison of OBSI spectral content of bridge decks with different surface types.
(Note: TT is transversely tined, TB is transversely broomed, P is polyester overlay, DG is diamond ground, BD is burlap drag, and AC is hot-mix asphalt [asphalt concrete].)

Table 3.2. Sound Intensity in One-Third Octaves of Sections

Surf. Type		One-Third Octave Center Frequencies											
		400	500	630	800	1,000	1,250	1,600	2,000	2,500	3,150	4,000	5,000
TT	Max	92.3	97.3	100.3	108.5	104.8	102.9	100.1	97.6	94.6	88.6	85.9	82.9
	Avg	88.1	90.4	93.9	101.5	100.3	99.0	97.5	95.2	91.9	86.6	82.8	79.8
	Min	85.4	86.1	89.8	97.2	97.7	95.2	94.2	92.1	88.5	83.7	79.4	75.8
TB	Max	91.8	95.1	97.7	104.3	101.3	100.0	98.1	95.6	91.8	87.4	84.8	81.9
	Avg	88.5	90.0	93.9	100.2	98.8	96.8	97.7	95.1	91.2	86.7	83.5	80.7
	Min	87.0	86.5	90.6	96.9	97.8	95.1	97.3	94.4	90.5	85.9	82.4	79.4
P	Max	89.7	92.2	95.9	103.7	99.9	98.7	99.3	95.6	90.0	87.6	87.3	84.3
	Avg	87.4	89.4	93.5	99.8	98.0	96.1	95.2	92.1	88.0	83.6	80.5	77.2
	Min	84.9	86.5	91.7	97.8	96.1	94.1	93.2	89.9	85.9	81.4	77.3	73.8
DG	Max	86.6	87.8	90.9	97.8	97.8	95.3	95.6	93.3	89.7	84.4	81.8	78.8
	Avg	84.5	83.8	88.1	95.6	96.3	93.7	93.9	92.0	88.5	84.0	81.0	77.8
	Min	82.5	79.7	85.0	93.1	94.4	91.9	91.5	89.9	86.8	82.8	79.8	76.1
BD	Avg	85.5	87.0	91.4	99.4	98.8	96.4	96.6	93.7	89.9	85.6	82.4	79.2
AC	Avg	84.8	86.6	91.9	97.0	95.9	94.5	93.8	91.4	87.4	83.8	80.5	77.0

Table 3.3: Deck Surface Age and OBSI Level Results (Sorted by Surface Type)

Section ID	Surf. Type	Constr. Year	Surf. Year	Age by Y1 (years)	Age by Y2 (years)	OBSI Year 1 (dB[A])	OBSI Year 2 (dB[A])
QP-140.1	TT/DG	2005	2005	3.3	4.2	102.7	104.0
QP-139.1	TT	2008	2008	0.4	1.3	104.7	107.2
QP-164.2	TT	2003	2003	5.6	6.3	103.9	104.9
QP-141.1	TT	2000	2000	8.3	9.1	105.6	105.7
QP-119.1	TT	1998	1998	10.2	11.2	114.4	111.1
QP-152.1	TT	1997	1997	11.3	12.2	106.5	105.8
QP-125.1	TT	1994	1994	14.1	15.2	108.8	109.2
QP-125.2	TT	1994	1994	14.1	15.2	109.0	109.3
QP-125.3	TT	1994	1994	14.1	15.2	107.3	108.8
QP-124.1	TB	2008	2008	0.3	1.4	108.6	109.1
QP-163.1	TB	2003	2003	5.6	6.3	103.9	105.0
QP-121.1	TB*	1998	1998	10.2	-	105.2	
QP-122.1	TB*	1998	1998	10.2	-	105.4	
QP-121.1	P**	1998	2009	-	0.5		103.9
QP-122.1	P**	1998	2009	-	0.5		104.4
QP-143.1	P	2004	2004	4.3	5.1	104.3	105.6
QP-144.1	P	2004	2004	4.3	5.1	103.7	105.4
QP-145.1	P*	2003	2003	5.3	-	102.7	
QP-145.1	P**	2003	2009	-	0.5		102.5
QP-149.1	P	1993	1993	15.2	n/a	108.2	
QP-151.1	LT-P	1971	2006	2.4	3.2	103.2	104.8
QP-164.1	DG	2003	2003	5.6	6.3	100.2	101.1
QP-165.1	DG	2003	2006	2.6	3.4	99.2	99.7
QP-118.1	DG	1999	1999	9.2	10.2	103.1	104.2
QP-120.1	DG	1999	1999	9.0	10.0	103.6	104.0
QP-153.4	BD	1964	1964	43.8	44.7	104.5	105.5
QP-150.1	AC	1949	2001	7.3	8.2	100.7	103.9

* Only Year 1; ** only Year 2

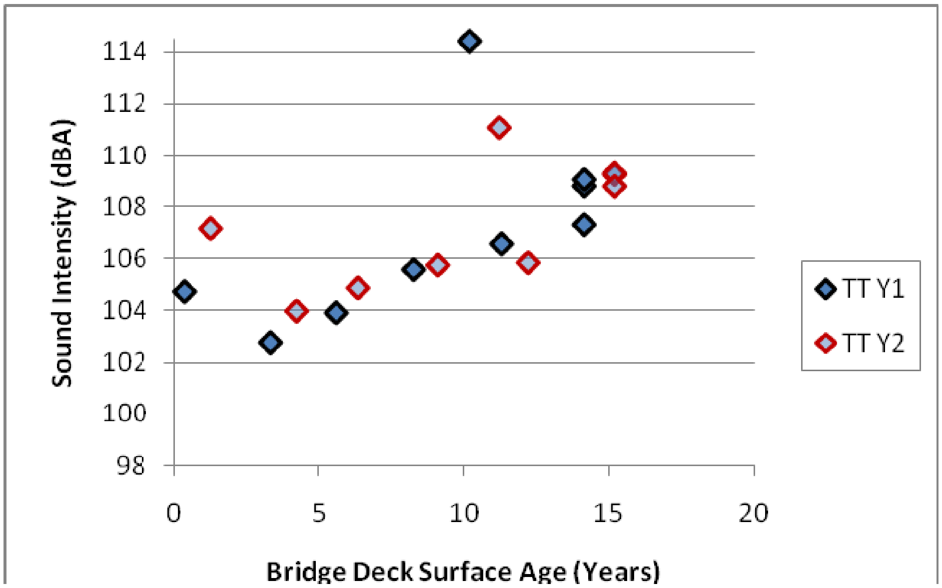


Figure 3.12: Plot of OBSI versus surface age, transversely tined surfaces.

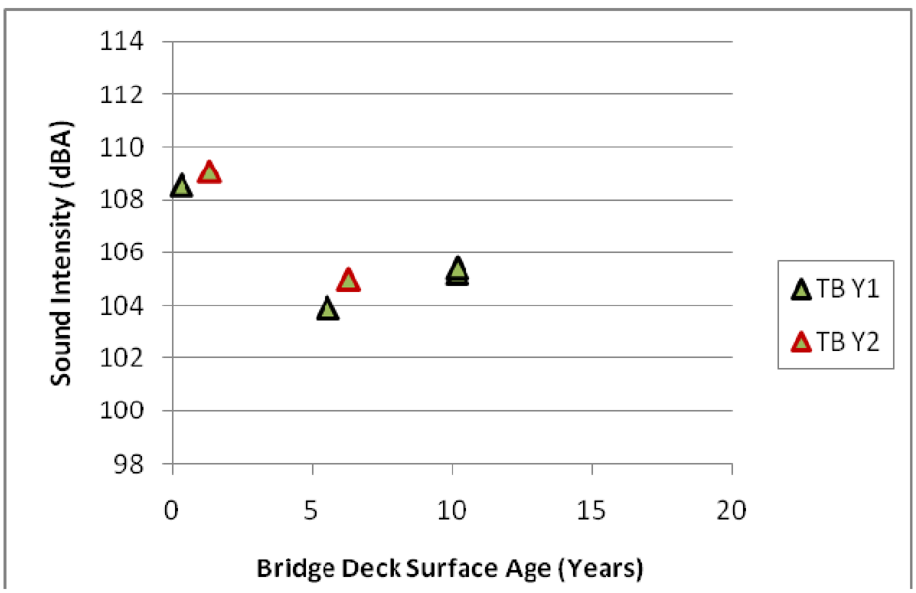


Figure 3.13: Plot of OBSI versus surface age, transversely broomed surfaces.

The transversely broomed surfaces may decrease in noise with time, but the available data is insufficient to confirm this. Sections QP-121.1 and QP-122.1 were overlaid with polyester material by the time of the second year of testing.

The polyester overlay surface data point at 15 years is louder than the newer surfaces, but corresponds to the section that was eliminated for being on a curved alignment. The available data suggest an increase in OBSI of about 0.4 dB(A) per year for polyester overlay surfaces, however, the small sample size (four and six sections in Years 1 and 2, respectively) makes it difficult to have much confidence in this statement.

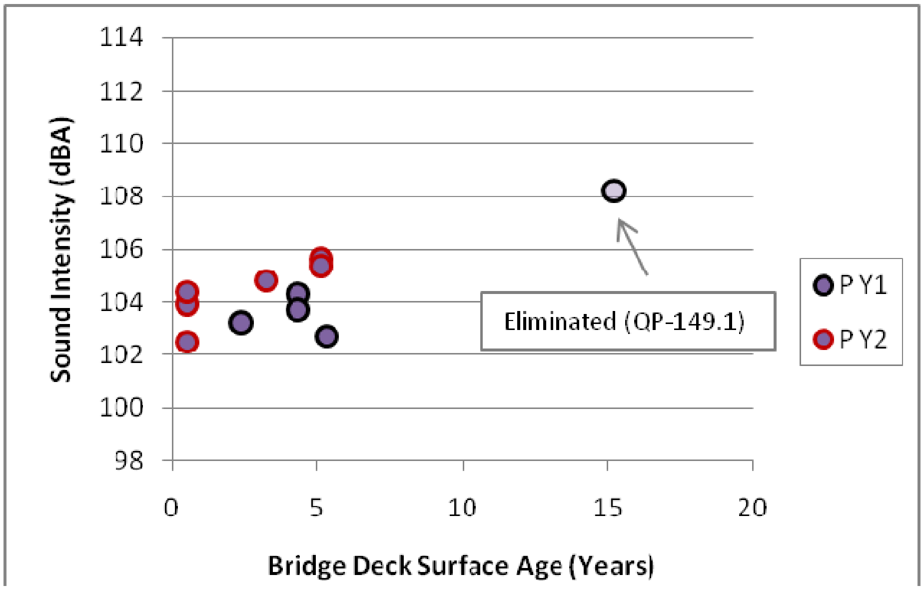


Figure 3.14: Plot of OBSI versus surface age, polyester overlay surfaces.

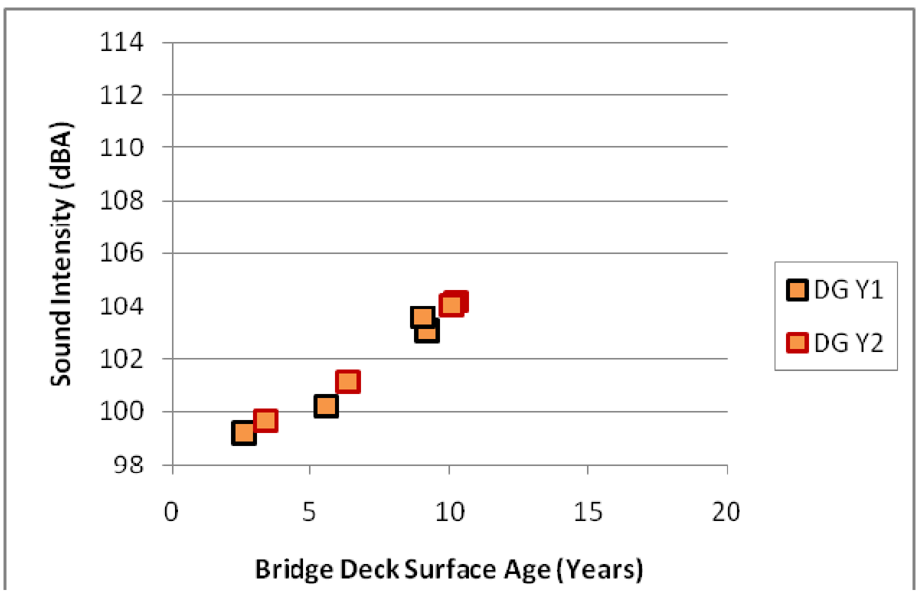


Figure 3.15: Plot of OBSI versus surface age, diamond-ground surfaces.

The diamond-ground decks appear to have an increase in noise level with time, but there is insufficient data to draw a strong conclusion.

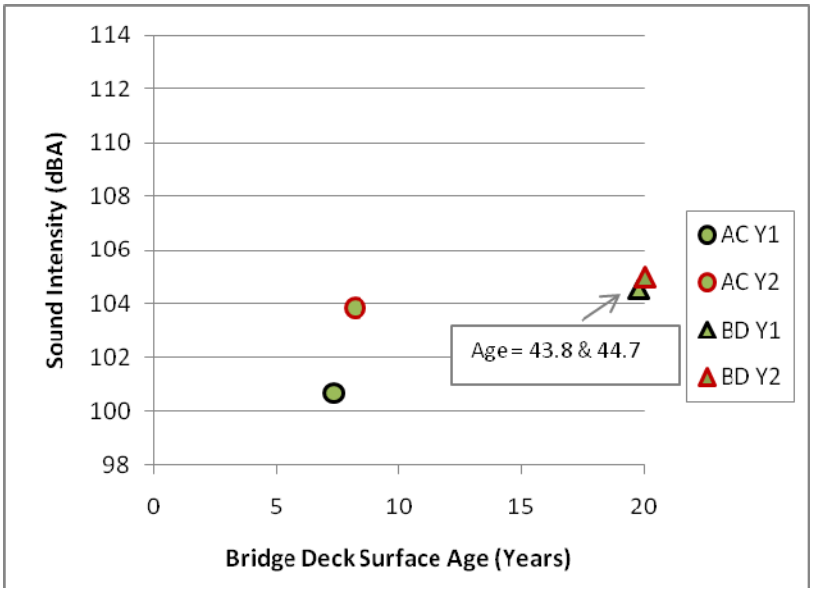


Figure 3.16: Plot of OBSI versus surface age, hot-mix asphalt and burlap drag concrete surfaces.
(Horizontal scale was preserved for clarity).

With only one section with a hot-mix an asphalt surface and one with a burlap drag surface, no conclusions can be drawn on the effects of age for these surface types. This particular asphalt concrete section had an increase of OBSI of 1.6 dB(A), from 7.3 to 8.2 years of age. It is important to also note that the burlap drag section has been in service for more than 40 years, and the results of 105.6 and 105.3 dB(A) are well within the midrange of results found for much younger transversely tined sections.

Figure 3.17 shows the OBSI level results versus age for all sections, regardless of surface type.

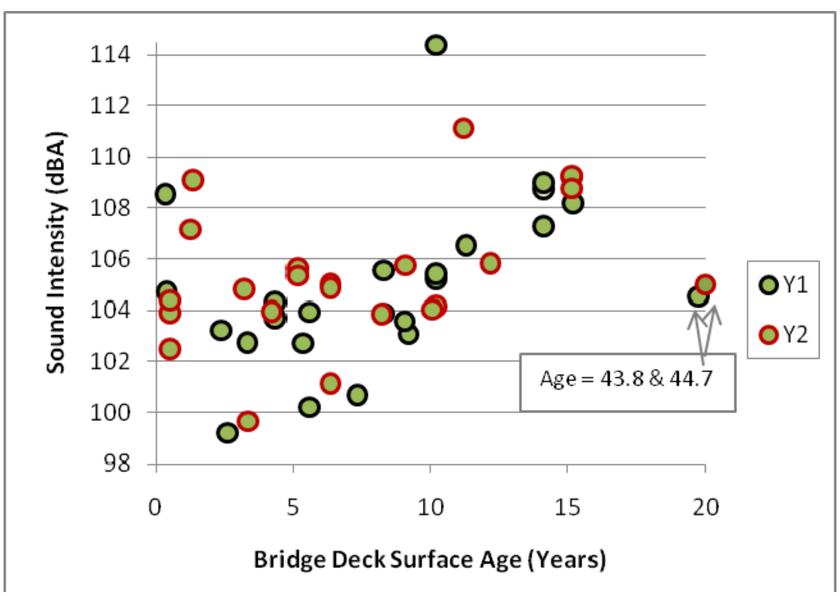


Figure 3.17: Plot of OBSI versus surface age, all surface types combined.

3.3 Year 1 to Year 2 Variation

Twenty sections have OBSI data in both Year 1 and in Year 2 that can be used for comparison. The average Year 2 OBSI level for these 20 sections is 1.2 dB(A) louder than for Year 1, but if the burlap drag and the hot-mix asphalt sections are excluded, the other four surface types have an average annual increase of 0.7 dB(A). OBSI decreased in two sections, both transversely tined. Table 3.4 shows the details of the variations from Year 1 to Year 2 for each section, as well as by surface type.

Table 3.4: Change in OBSI Level from Year 1 to Year 2 by Section and by Surface Type

Section ID	Surface Type	OBSI Year 1 (dB[A])	OBSI Year 2 (dB[A])	Increase (dB[A])	Decrease (dB[A])	Average By Surface Type		
						Year 1	Year 2	Diff.
QP-140.1	TT/DG	102.7	104.0	1.2		107.0	107.3	0.3
QP-139.1	TT	104.7	107.2	2.5				
QP-164.2	TT	103.9	104.9	1.0				
QP-141.1	TT	105.6	105.7	0.2				
QP-119.1	TT	114.4	111.1		-3.3			
QP-152.1	TT	106.5	105.8		-0.7			
QP-125.1	TT	108.8	109.2	0.5				
QP-125.2	TT	109.0	109.3	0.3				
QP-125.3	TT	107.3	108.8	1.5				
QP-124.1	TB	108.6	109.1	0.6		106.2	107.1	0.8
QP-163.1	TB	103.9	105.0	1.1				
QP-143.1	P	104.3	105.6	1.3		103.7	105.3	1.5
QP-144.1	P	103.7	105.4	1.7				
QP-151.1	LT-P	103.2	104.8	1.6				
QP-164.1	DG	100.2	101.1	0.9		101.5	102.3	0.7
QP-165.1	DG	99.2	99.7	0.5				
QP-118.1	DG	103.1	104.2	1.1				
QP-120.1	DG	103.6	104.0	0.5				
QP-153.4	BD	104.5	105.5	0.9		104.5	105.5	0.9
QP-150.1	AC	100.7	103.9	3.2		100.7	103.9	3.2

The greatest increase occurred in Section QP-150.1, a hot-mix asphalt overlay, which had a measured increase of 3.2 dB(A). The greatest decrease, 3.3 dB(A), occurred on a transversely tined surface, Section QP-119.1. There seems to be no change in the surface to explain such a great difference, but 3.3 dB(A) is a large change from one year to the next.

Although the reduction in noise may be due to continued wearing down of the tining, the fact that this bridge deck was approximately 10 years old suggests that most of the wearing down should have occurred previously.

A thorough investigation was performed to rule out errors in the measurement or in the analysis, with the following review of the results.

- Variation of +/–1.0 dB(A) are commonly attributed to variability in the measurement method, and 10 out of the 20 sections compared presented changes in that range. The NCHRP 630 report *(1)* indicates that 0.8 dB(A) can be considered as the measurement uncertainty, based on consecutive runs with "no changes in the fixture configuration or measurement protocol."
- Even though a different sound analyzer was used in Year 2, there is no reason to believe that this is the cause of the decrease. The manufacturer specifications of the new unit meet the requirements necessary for sound intensity measurement. Validation in the laboratory using controlled noise sources led to the conclusion that it was acceptable to replace the old units, and a set of small adjustments by frequency were established based on field evaluation. These adjustments allow for spectra comparison, and the effect of replacing the analyzer unit on the measured OBSI was found to be minor.
- The analysis interval for the sound intensity signals was different in Year 1 and Year 2. The recommendation received by the researchers was not to try to process signals in time intervals less than 1 second. Year 2 signals were processed at 0.2 second, which allowed for a more precise identification of the start and end points for the data analysis.
- On most bridges it was possible to measure the OBSI level for the approach and leave sections, consisting of pavement before and/or after the bridge and the approach and leave slabs. The approach and leave sections of pavement showed an average increase of 1.6 dB(A).

In conclusion, the results appear to be correct for QP-119.1.

3.4 Pavement–Bridge Transition

The noise level of a bridge deck is not necessarily similar to that of the highway pavements adjacent to it. In this study, the noise level on the leave and approach transition pavement was measured continuously for all but two bridges (the exceptions were Sections QP-121.1 and QP-122.1).

The difference in OBSI level between the bridge deck and that of the adjacent pavement depends on the type and texture of each surface. It is interesting to note that the first-year data showed that on 12 out of 22 sections (55 percent), bridge decks were louder than the adjacent pavement, and the second year showed this same trend on 11 out of 21 sections (52 percent). The transversely tined and transversely broomed decks were all louder than the adjacent pavement. The other bridge deck surfaces (polyester overlay, diamond ground, burlap drag, and asphalt concrete) were all quieter than the adjacent pavement, except for Section QP-149.1. Figure 3.18

presents the difference in *tire noise level,* defined as bridge OBSI minus pavement OBSI, for each section and for Year 1 and Year 2 data, sorted by surface type.

Chapter 4 includes plots of the OBSI levels before, on, and after the bridge as measured in Year 1 (one pass at 15-msec intervals, and 3 passes at 1-sec intervals) and in Year 2 (3 passes at 0.2-sec intervals).

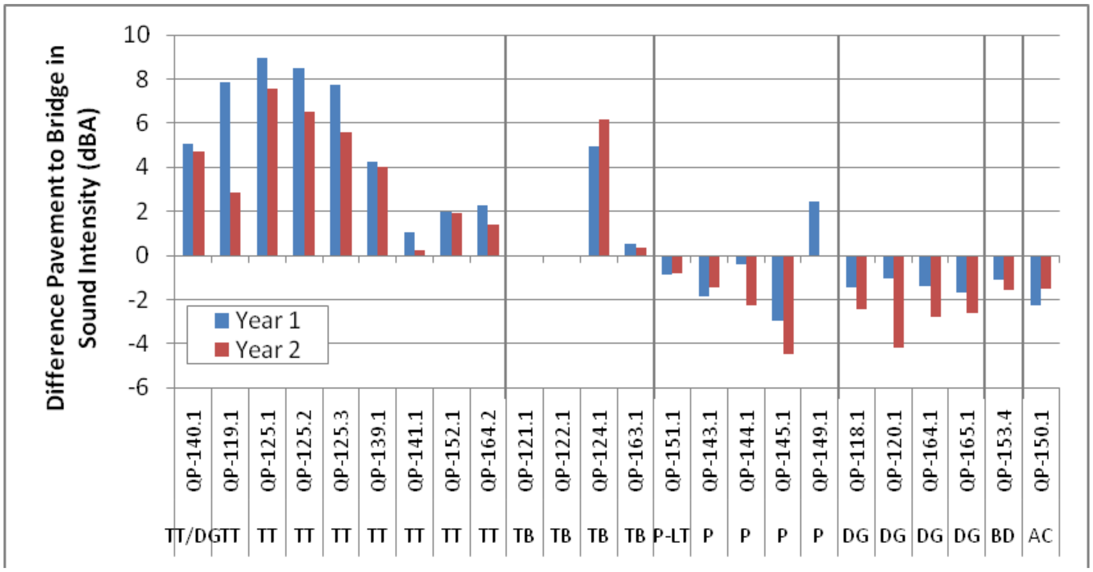


Figure 3.18: Difference in OBSI level between pavement and bridge for each section.
(Note: TT is transversely tined, TB is transversely broomed, P is polyester overlay, DG is diamond ground, BD is burlap drag, and AC is hot-mix asphalt [asphalt concrete].)

3.5 Effect of Bridge Joints

The effect of bridge joints on the OBSI level of bridge decks was found to be small. Only five of the 24 bridges presented a joint "slap" noise level that was high enough to warrant further examination.

Before looking at the results, it is useful to examine the theoretical effect of a "noise spike." For example, consider a 440-ft (134-m) road with a surface that creates an OBSI level of 100.0 dB(A) that is perfectly homogeneous throughout the section (i.e., all values, at any time interval, are exactly 100.0 dB[A]). If an artificial 112 dB(A) slap noise that lasts for a fraction of a second is added to this section, the noise could potentially be "heard" over a 3-ft (0.91-m) segment of the road. This means that there is a short event creating a higher noise level that lasts the equivalent of 3 feet or 0.034 seconds, if traveling at 60 mph (97 km/hr).

However, the effect of slap noise events, such as the vehicle's passage over a joint, is controlled by both the duration of the event and its magnitude. The OBSI of the slap noise when measured at intervals shorter than the duration of the effect created (in this case 0.034 seconds) would be 112 dB(A) (see Figure 3.19); however when included in a one-second interval (see Figure 3.20), its OBSI is only measured as 101.8 dB(A) because the 100.0 dB(A) surface largely controls the overall noise level if any of it is included in the time interval. For the five-second average normally used for OBSI measurement, the slap noise would cause an increase from 100.0 to 100.4 dB(A). This means that a 112 dB(A) slap noise would have a 0.4 dB(A) effect on the overall noise of a 440-ft section. (The averages here are taken as energy averages, as explained in Section 2.2.)

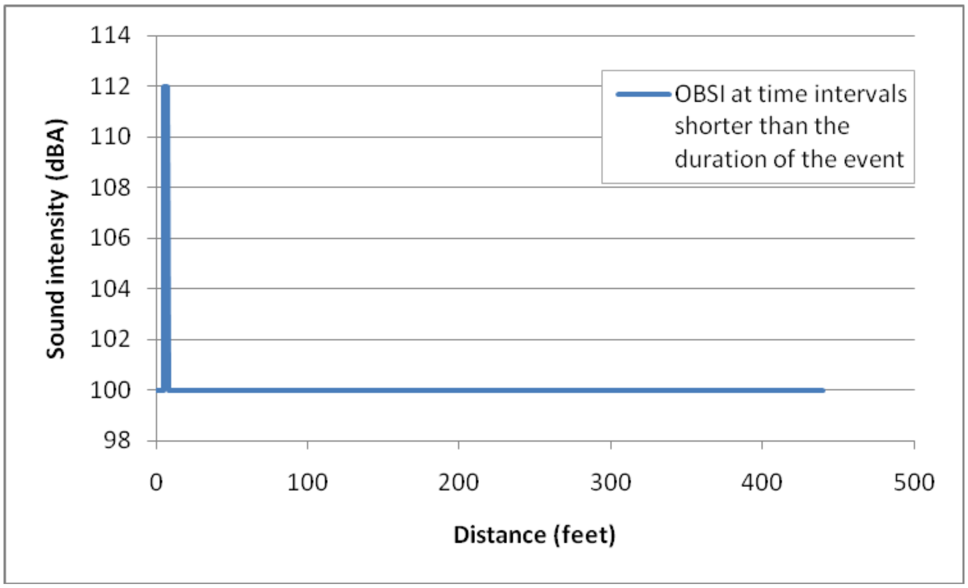


Figure 3.19: Theoretical slap noise of 112 dB(A) and 3-ft (0.91-m) duration on a 100 dB(A) surface.

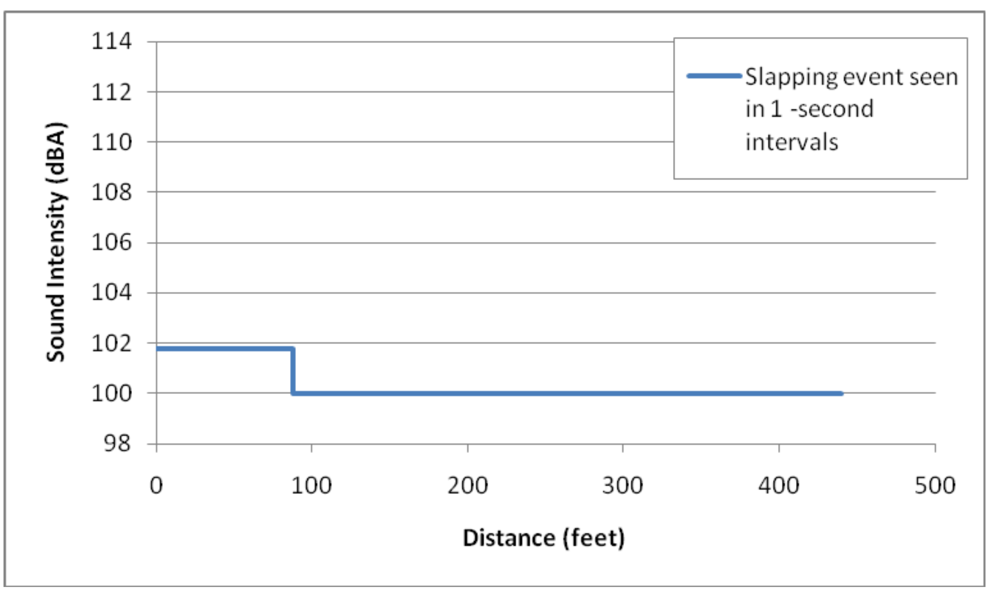


Figure 3.20: Effect of a single 112 dB(A) slap event expressed in a 1-sec interval.

The effect of joint slap noise events, such as occurs when a tire rolls over a joint, is controlled by the duration of the event and its magnitude. The above example used a 112 dB(A) event that lasted for an assumed 3 feet. Figure 3.21 shows the effect of events of 104, 108, and 112 dB(A), lasting between 0.5 and 4 feet (0.15 and 1.2 m). Based on the results from this study, the bridge joints seem to fall within this range of possible effects.

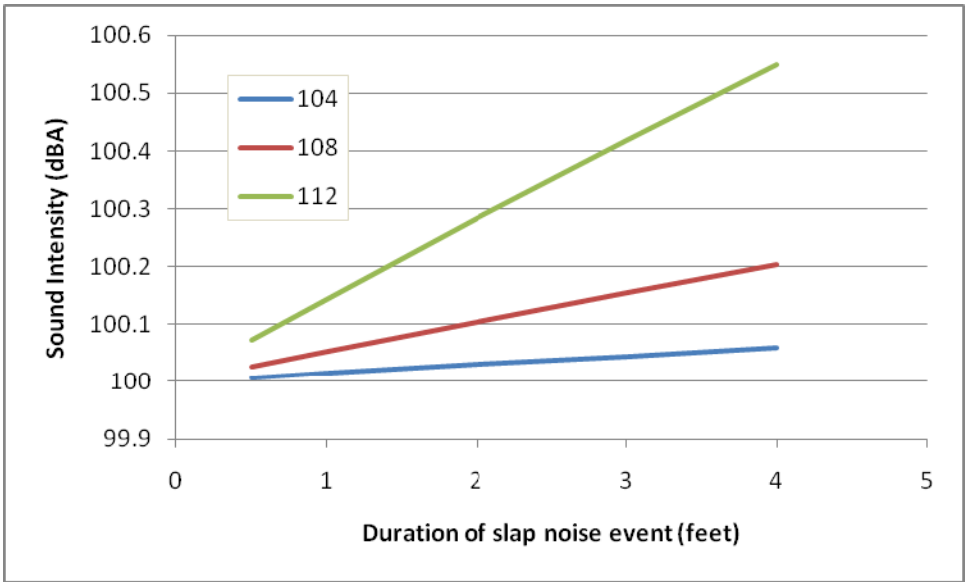


Figure 3.21: Effect of a single slap event of 104, 108, or 112 dB(A) on a 440-ft long surface with an OBSI level of 100 dB(A).

Like the pavement–bridge comparison, the joint effect is relative because it not only depends on the type and condition of the joint, but also on the OBSI level of the bridge deck itself. While the joint effect on a quiet bridge might be perceived, the same slap noise might go unnoticed if the OBSI level of the bridge deck is higher.

The theoretical example presented above was loosely based on the results obtained on Section QP-145.1. The noise slap from the end joints and the central joint are clearly visible in the 0.2-sec interval plot shown in Figure 3.22. Even when looking at the single 15-msec pass measurement from Year 1, the slap noise seems to be at 112 dB(A), which corresponds to what was measured at 0.2-sec intervals. In this case the bridge was long enough to allow measurement of 17.8 sec of OBSI data on the bridge itself, plus the data on the pavement before and after the bridge.

When the slap noise is included, this bridge deck presented an OBSI level of 102.6 dB(A). If the three joints were removed, the approximate OBSI level would be 102.1 dB(A). It is important to realize that the effect of joint slap can at this point only be defined as approximate, as there are no standards on how to measure these short-duration events. In this study, the results of joint slap in Year 1 were obtained using 1-sec intervals, and in

Year 2 they were obtained using 0.2-sec intervals. Figure 3.22 shows the OBSI level measured in Section QP-145.1, including the tire noise on the pavements immediately before and after the bridge, on the bridge deck between joints, and on the joints.

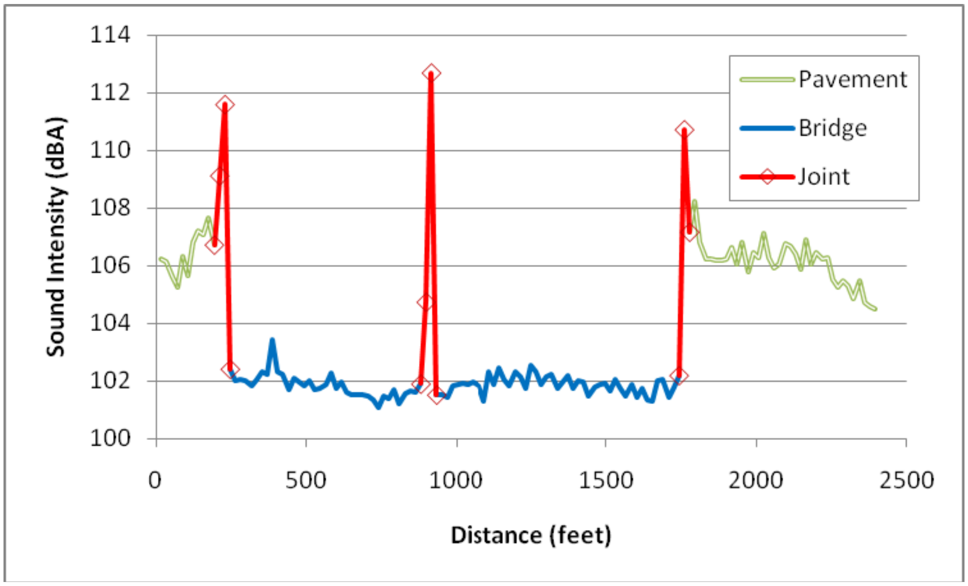


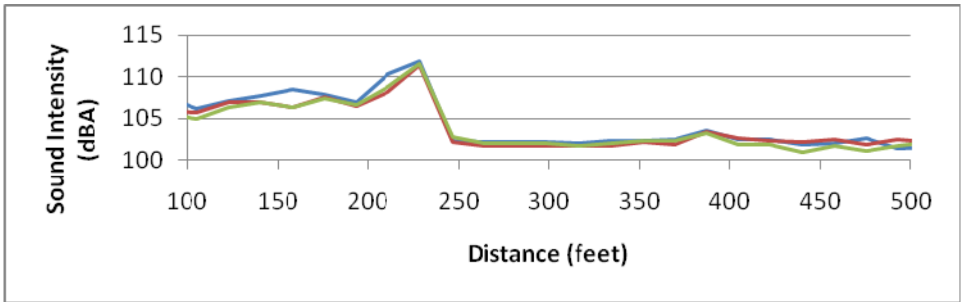
Figure 3.22: Example of joint slap noise and approach and leave pavement noise from Section QP-145.1 (1,000 ft = 305 m).

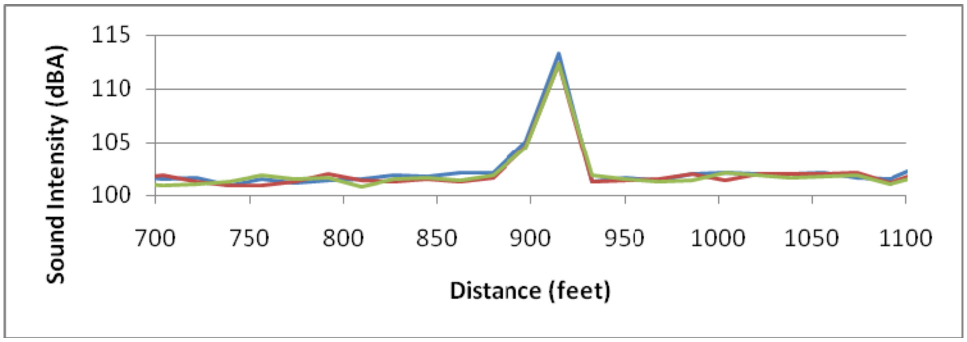
It is also interesting to note that the three passes yielded highly repeatable results, both in terms of OBSI level and with respect to the location of the joints. Figure 3.23 shows the three passes on the three joints of this bridge. Similar results were observed on all bridges.

The five bridges where a difference in overall OBSI was observed when the joint effect was removed are presented in Table 3.5. The effect of joints accounts for a 0.5 dB(A) difference for one bridge, while the range for the rest of the cases is 0.2 to 0.4 dB(A). As mentioned, these effects are only estimates because there is no standard or accepted method to account for joint slap. For each of these sections, detailed plots showing the bridge OBSI level and the joint OBSI level are presented in Chapter 4 (plots similar to Figure 3.22).

Figure 3.24 shows example pictures of the bridge joints measured as part of this study.

It should be noted, that while this analysis shows that joint slap noise does not significantly increase the calculated overall OBSI level, the short, sharp noise caused by the slap can be perceived as annoying. A method for characterizing the effects of short sharp noise levels in conjunction with the longer duration noise level from the bridge deck has not been developed.





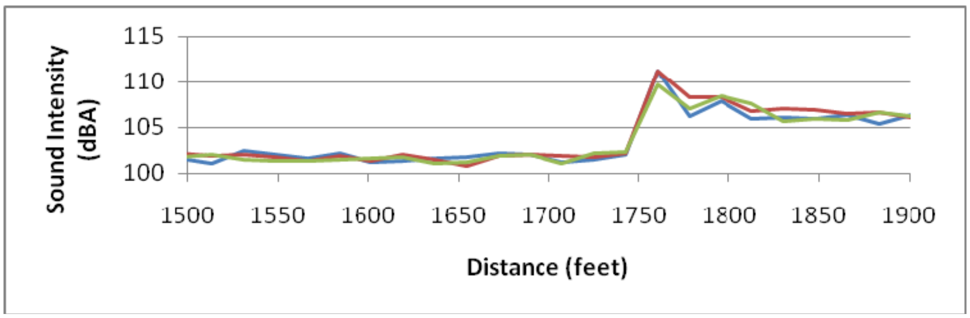


Figure 3.23: Three repeat passes at the beginning, central, and ending joint of Section QP-145.1.

Table 3.5: Effect of Joint on OBSI Level on Bridges with Noticeable Effect

Section	Surf. Type	Year	Bridge (with Joints)	Bridge (without Joints)	Approximate Difference of Removing Joints (dB[A] Reduction)
QP-118.1	DG	Year 1	103.1	102.9	0.2
QP-118.1	DG	Year 2	104.2	103.9	0.2
QP-120.1	DG	Year 1	103.6	103.2	0.4
QP-120.1	DG	Year 2	104.0	103.8	0.3
QP-121.1	TB	Year 1	105.2	105.0	0.3
QP-121.1	TB	Year 2	103.9	103.7	0.2
QP-122.1	TB	Year 1	105.4	105.0	0.4
QP-122.1	TB	Year 2	104.4	104.2	0.2
QP-145.1	P	Year 1	102.7	102.4	0.3
QP-145.1	P	Year 2	102.5	102.0	0.5

Section QP-145.1

Section QP-124.1

Section QP-143.1

Section QP-151.1

Figure 3.24: Examples of bridge joints included in this study.

4 ANALYSIS OF INDIVIDUAL BRIDGES

This chapter provides a description of each bridge in the study. As noted earlier, in Year 1 there were three passes of the sound car conducted with OBSI measurements at 1-sec intervals and one pass at 15-msec intervals. In Year 2 there were three passes conducted at 0.2-sec intervals. The following three plots are shown for each bridge: (a) the 15-msec single pass in Year 1, (b) the three passes at 1-sec intervals in Year 1, and (c) the three passes at 0.2-sec intervals in Year 2. In some cases the elevation profile is included, which shows as clear spikes the locations where the profilometer laser beam penetrated into the joints.

End joints were not always included as part of the bridge, depending upon whether the noise result seemed to have been affected by the short segment of pavement corresponding to the approach or leave slab.

4.1 Section QP-118.1 on Bridge Number 33 0051R at 04ALA580W47.3

Section QP-118.1 is on Bridge Number 33 0051R, which separates eastbound I-80 and westbound I-580 in Albany in Alameda County. The deck was classified as diamond ground, and had been treated with methacrylate in 2008. The pavement before and after the bridge is asphalt concrete. In addition to the joints at the beginning and at the end of the bridge, there are two intermediate joints, identifiable in the noise trace at 0.2 sec and with the surface elevation data that was obtained from the profilometer. These two joints are located approximately 510 and 930 ft (155 and 284 m) from the beginning of the measurement.

Table 4.1: OBSI Results (dB[A]) Section QP-118.1

	Bridge	Bridge without Joints	Pavement
Year 1	103.1	102.9	104.5
Year 2	104.2	103.9	106.6

Figure 4.1: Transition from the pavement to the approach slab on Section QP-118.1.

Figure 4.2: Surface and joint on Section QP-118.1.

Figure 4.3: Detailed surface texture on Section QP-118.1.

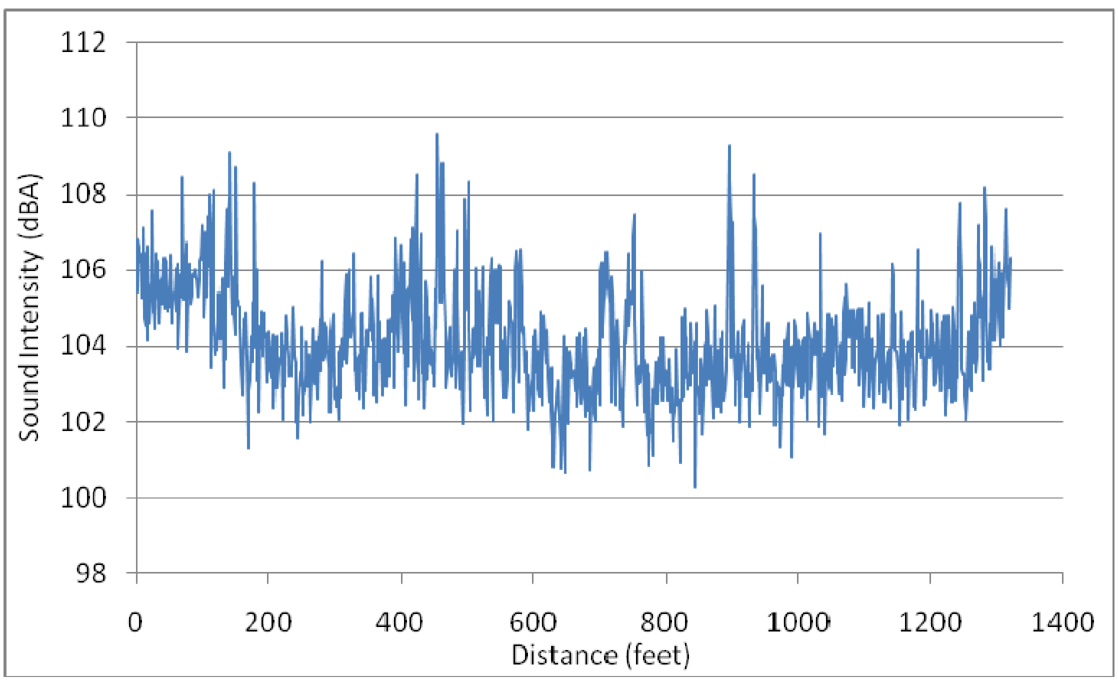


Figure 4.4: OBSI level in 15-msec intervals of Section QP-118.1 obtained in Year 1.

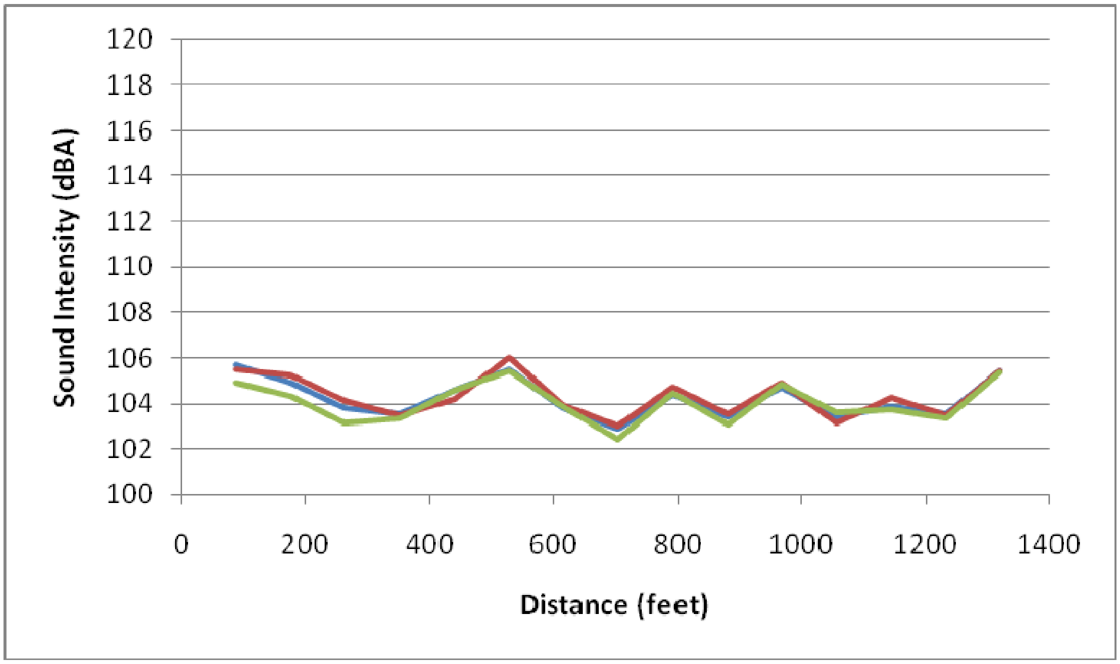


Figure 4.5: OBSI levels in 1-sec intervals of Section QP-118, Year 1, three passes.

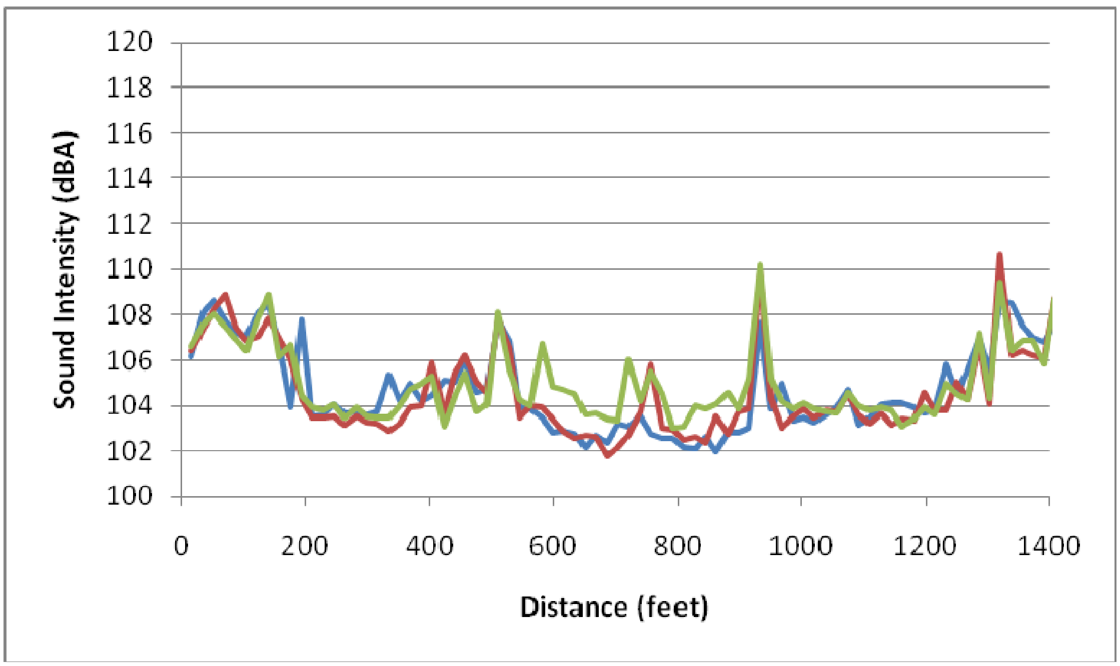


Figure 4.6: OBSI level in 0.2-sec intervals of Section QP-118.1, Year 2, three passes.

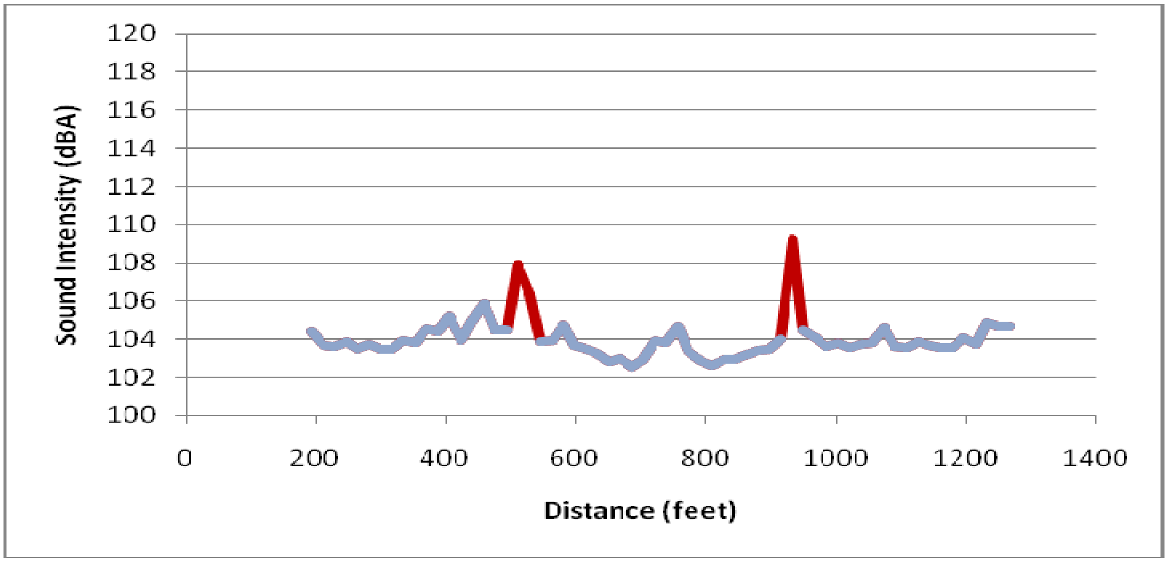


Figure 4.7: OBSI level in 0.2-sec intervals of Section QP-118.1, the bridge only, Year 2, average of three passes, highlighted joints.

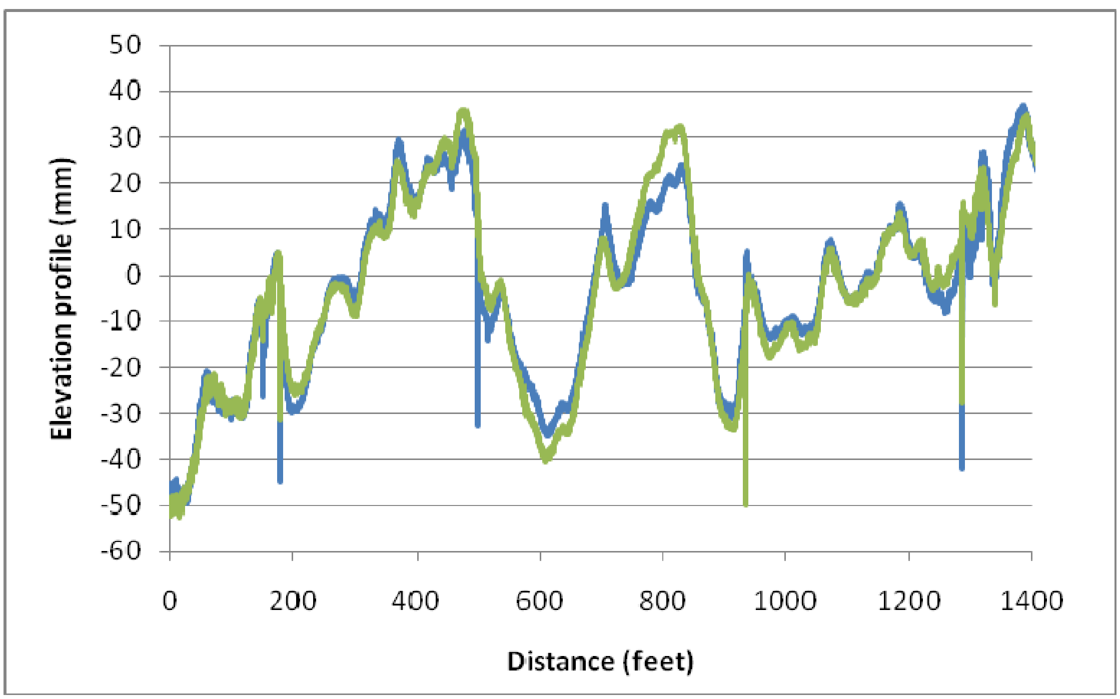


Figure 4.8: Elevation profile of Section QP-118.1.

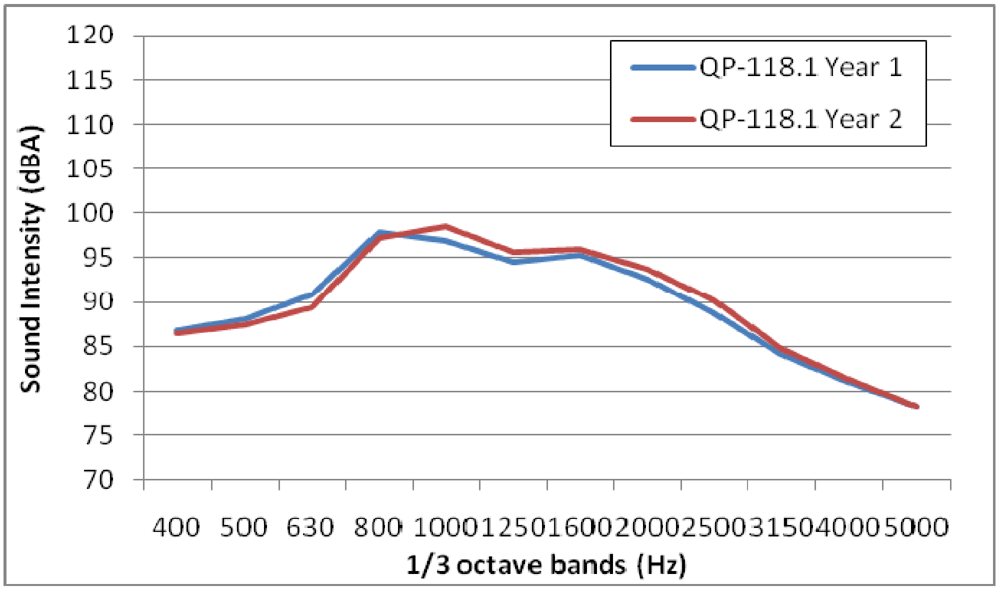


Figure 4.9: OBSI spectra of Section QP-118, Year 1 and Year 2.

4.2 Section QP-119.1 on Bridge Number 33 0051L at 04ALA580E7.2

Section QP-119.1 is on Bridge Number 33 0051L which transitions eastbound I-580 to westbound I-80 in Albany in Alameda County. This heavily textured transversely tined surface (see Figure 4.10 through Figure 4.12) is very loud and in fact had the highest OBSI of the study. It can be seen in Figure 4.12 that along with its heavy transversely tined texture, the bridge deck is also poorly finished and the poor finish likely contributes further to the noise.

In Year 1 its OBSI level was 114.4 dB(A), but in Year 2 its OBSI was 3.3 dB(A) lower, at 111. 1 dB(A). Close inspection of the texture did not reveal changes from one year to the next, but the spectra (Figure 4.18) show that the differences are in the low and middle frequencies. The results of the three passes in each year indicate that the runs within each year are similar. The results also show similar patterns between the two years with regard to the approaches and different parts of the bridge; however, the results for the second year are consistently lower across each section of the approaches and bridge, which eliminates the possibility that the driver took a different wheelpath in the second year. It is recommended that these results be treated with caution and reconsidered after the third year of data is collected.

Table 4.2: OBSI Results (dB[A]) Section QP-119.1

	Bridge	Bridge without Joints	Pavement
Year 1	114.4	114.4	106.6
Year 2	111.1	111.1	108.2

Figure 4.10: Beginning of Section QP-119.1.

Figure 4.11: Surface on Section QP-119.1.

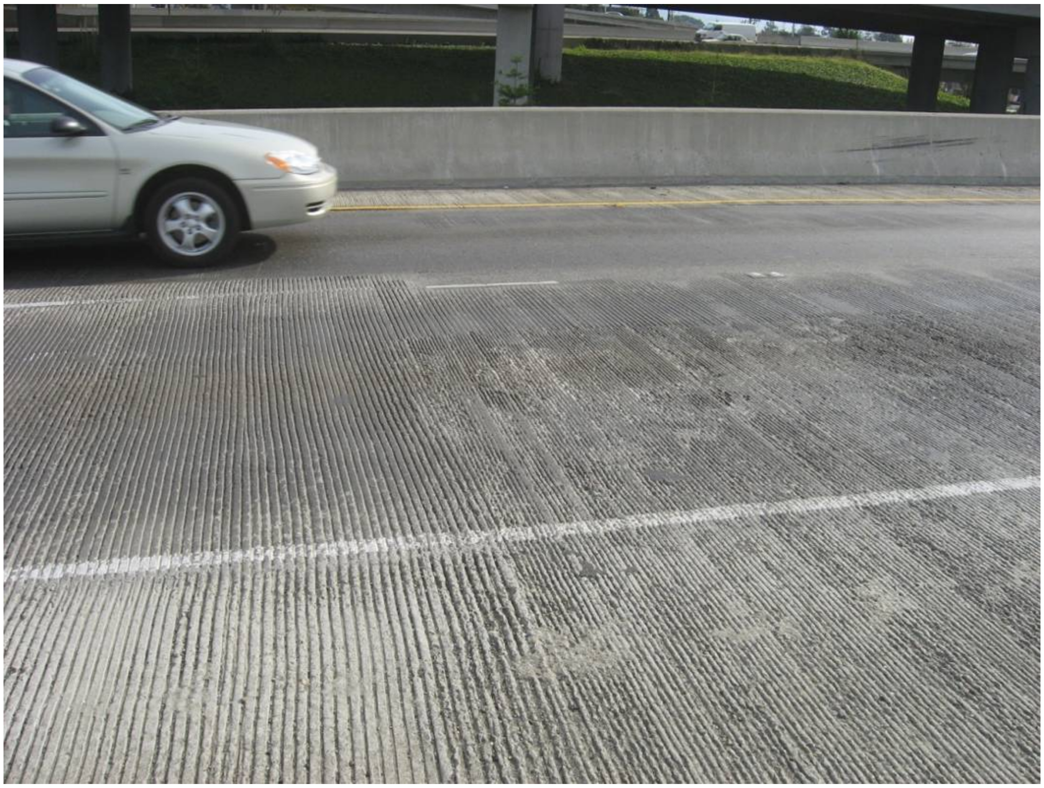


Figure 4.12: Close-up of texture on Section QP-119.1.

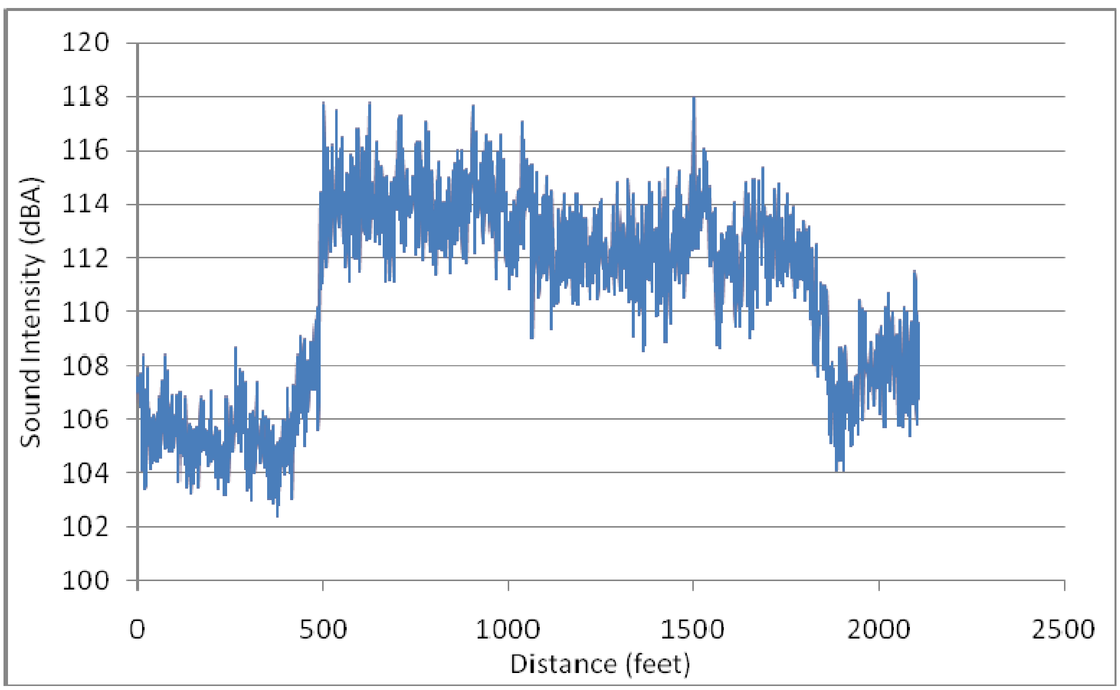


Figure 4.13: OBSI level in 15-msec intervals of Section QP-119.1, Year 1.

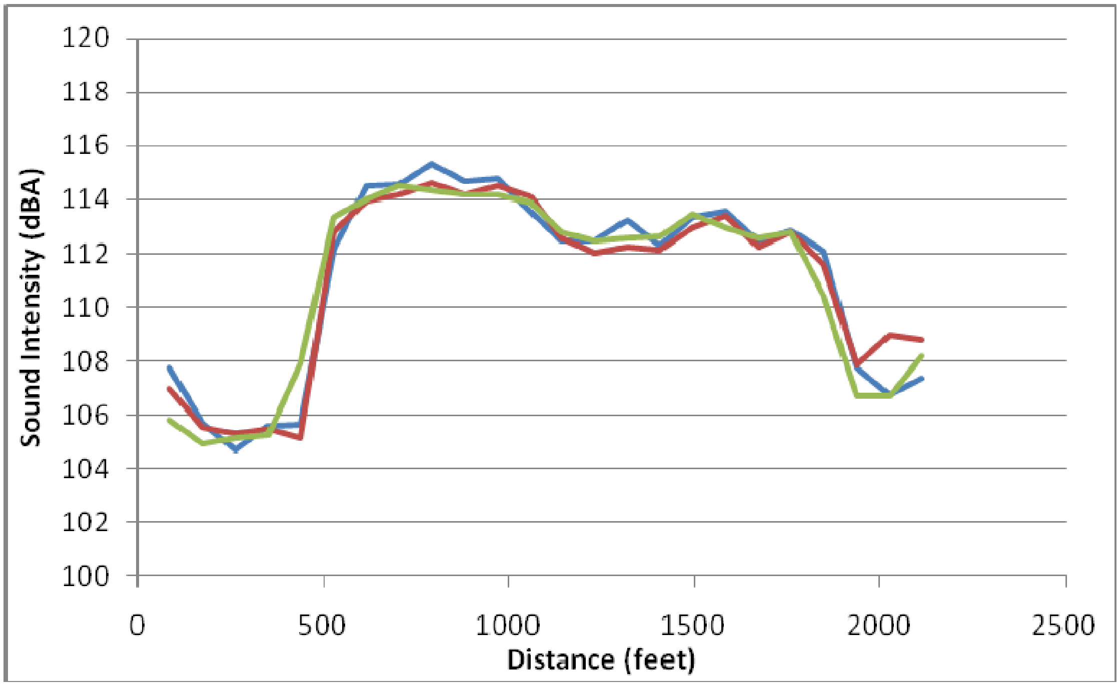


Figure 4.14: OBSI level in 1-sec intervals of Section QP-119.1, Year 1, three passes.

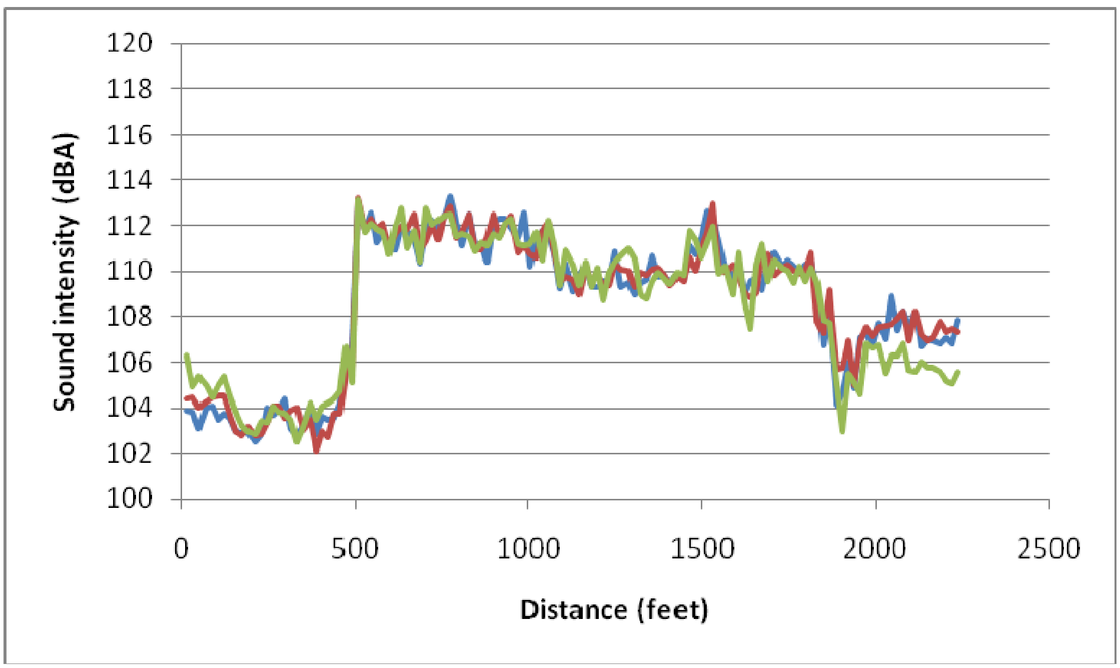


Figure 4.15: OBSI level in 0.2-sec intervals of Section QP-119.1, Year 2, three passes.

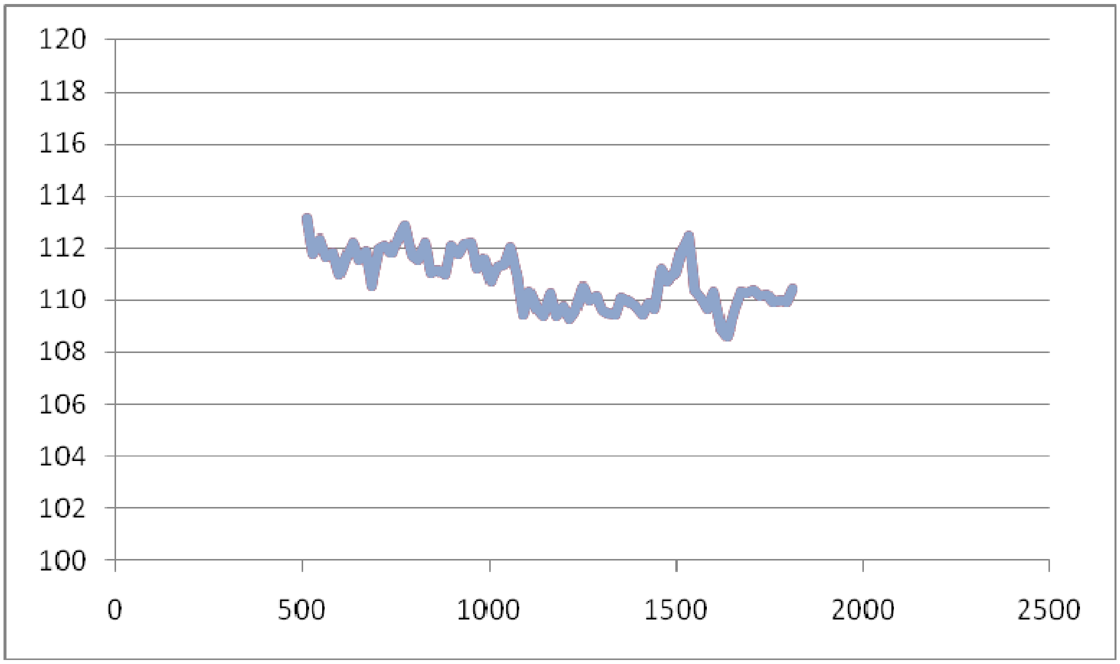


Figure 4.16: OBSI level in 0.2-sec intervals of Section QP-119.1, the bridge only, Year 2, average of three passes.

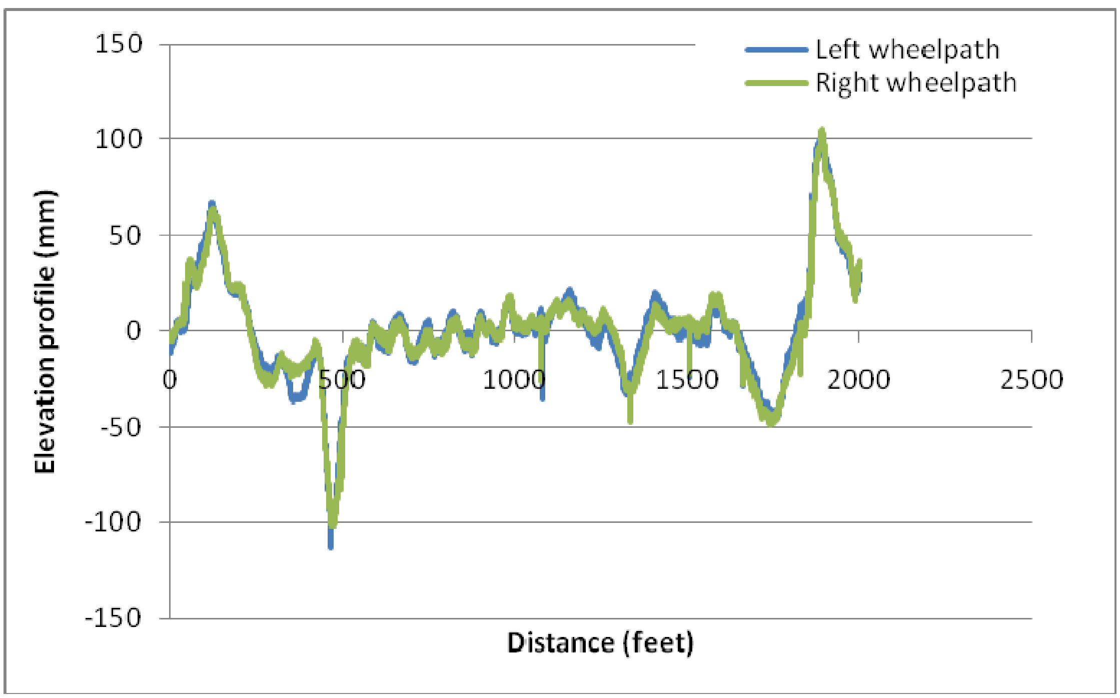


Figure 4.17: Elevation profile of Section QP-119.1.

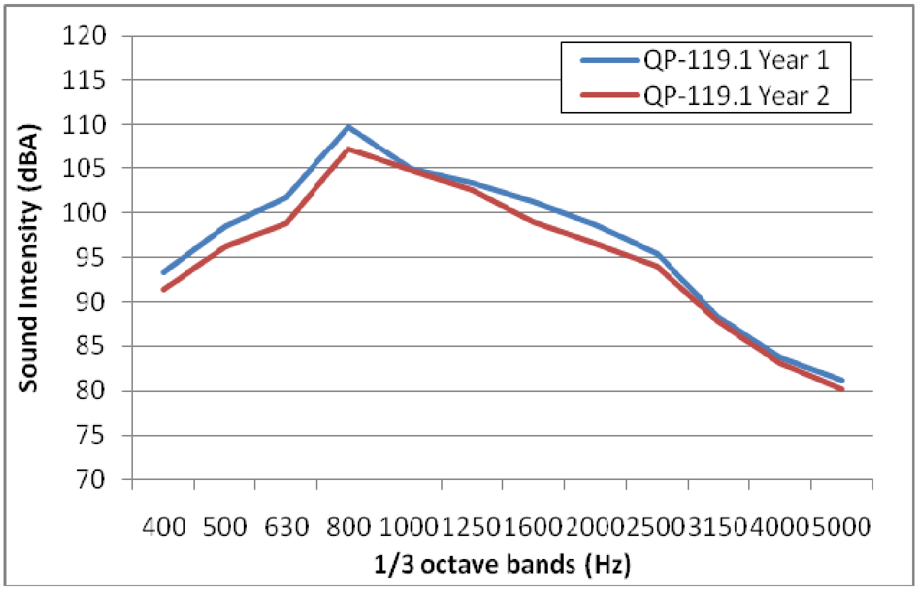


Figure 4.18: OBSI spectra of Section QP-119.1, Year 1 and Year 2.

4.3 Section QP-120.1 on Bridge Number 33 0051R at 04ALA80E7.0

Section QP-120.1 on Bridge Number 33 0051R is located on I-80 in Albany, parallel to the bridge containing Section QP-118.1. The bridge transitions from an asphalt concrete pavement to a diamond-ground deck. Without the joint this bridge would be 0.2 to 0.3 dB(A) quieter, but even with the joints the OBSI is lower than the pavements before and after it.

Table 4.3: OBSI Results (dB[A]), Section QP-120.1

	Bridge	Bridge without Joints	Pavement
Year 1	103.6	103.2	104.6
Year 2	104.0	103.8	108.2

Figure 4.19: Beginning of Section QP-120.1.

Figure 4.20: Surface and joint on Section QP-120.1.

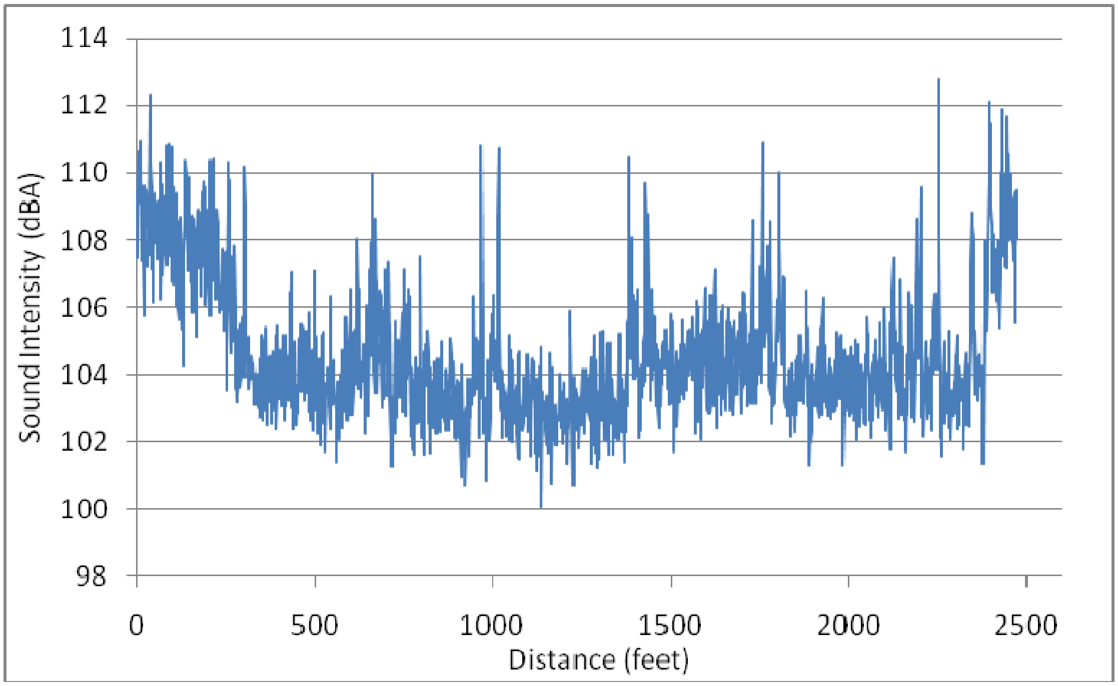


Figure 4.21: OBSI level in 15-msec intervals of Section QP-120.1, obtained in Year 1.

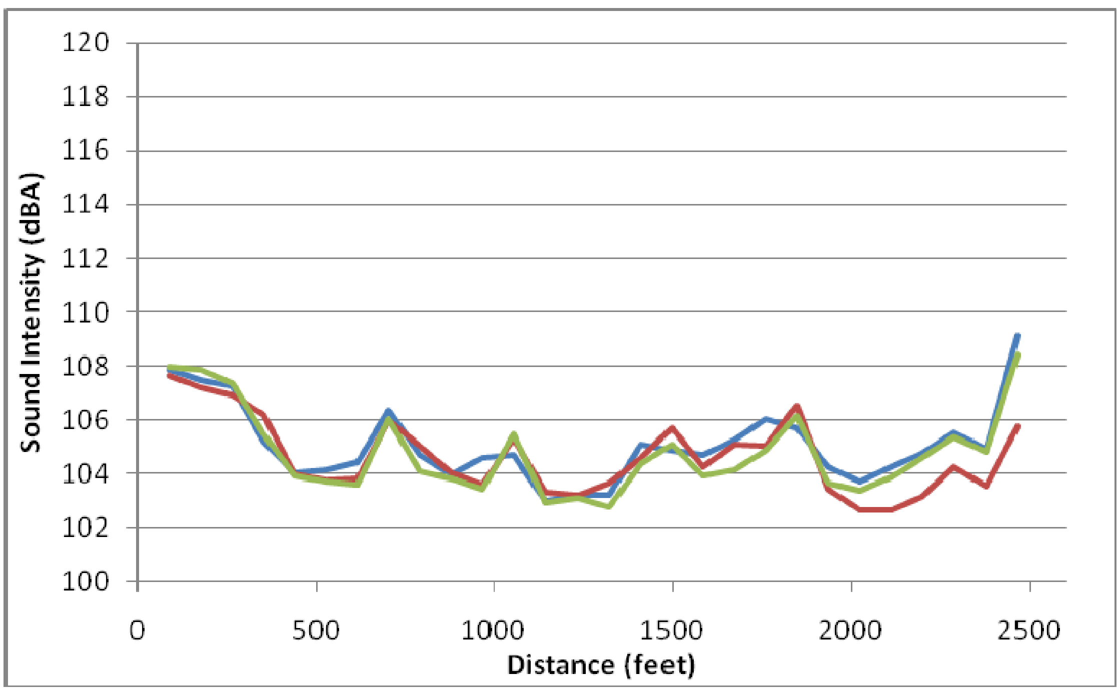


Figure 4.22: OBSI level in 1-sec intervals of Section QP-120.1, Year 1, three passes.

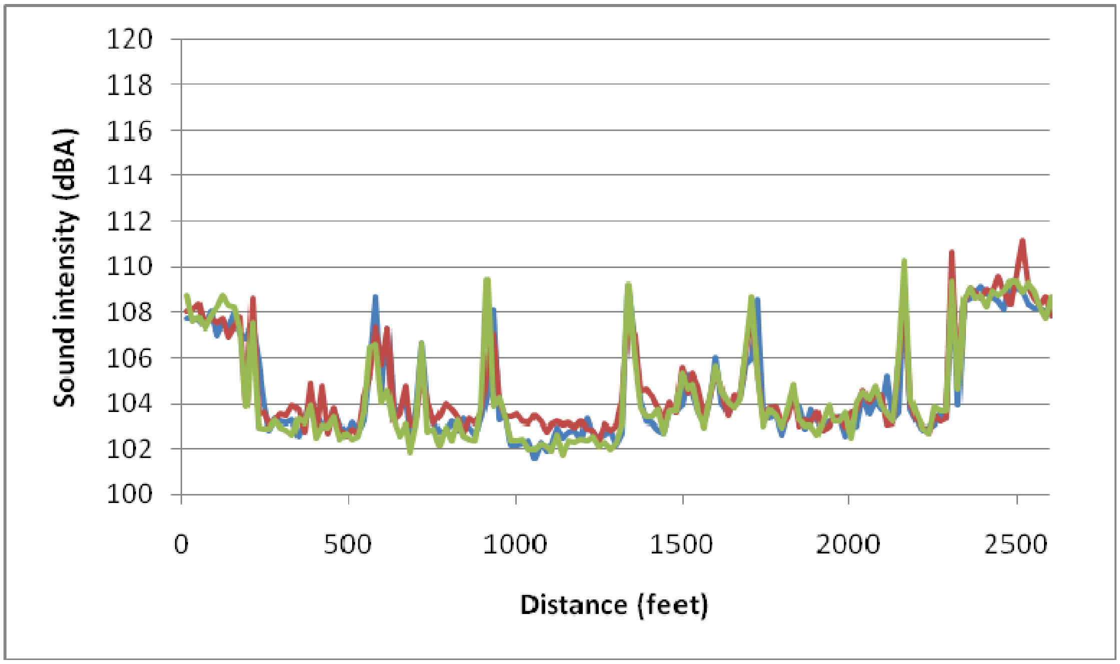


Figure 4.23: OBSI level in 0.2-sec intervals of Section QP-120.1, Year 2, three passes.

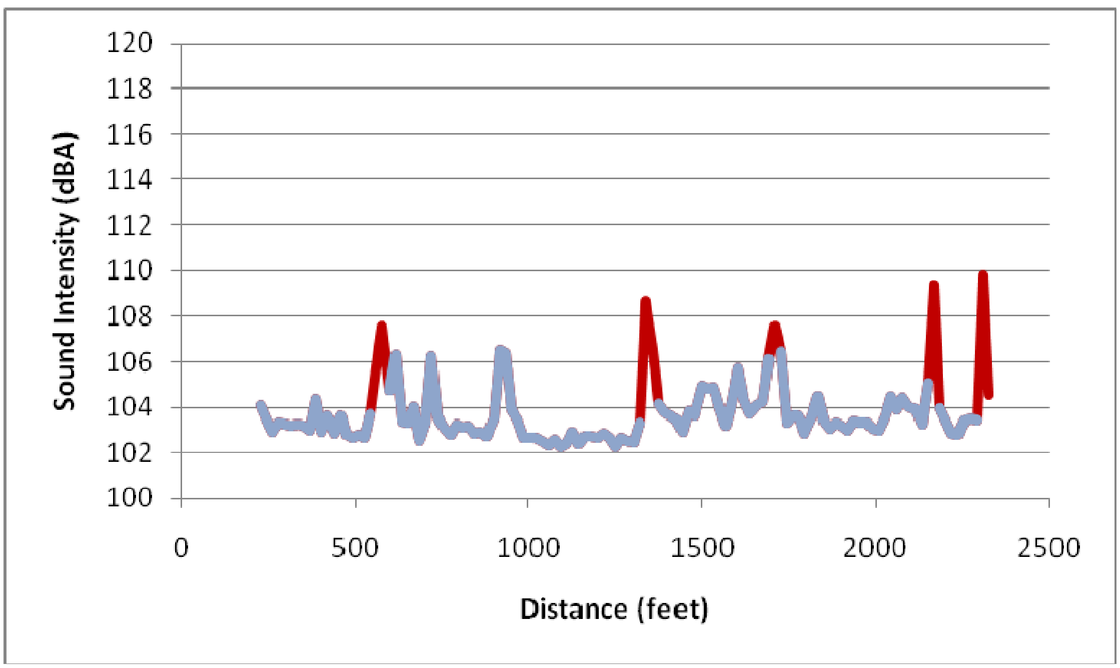


Figure 4.24: OBSI level in 0.2-sec intervals of Section QP-120.1, the bridge only, Year 2, average of three passes, highlighted joints.

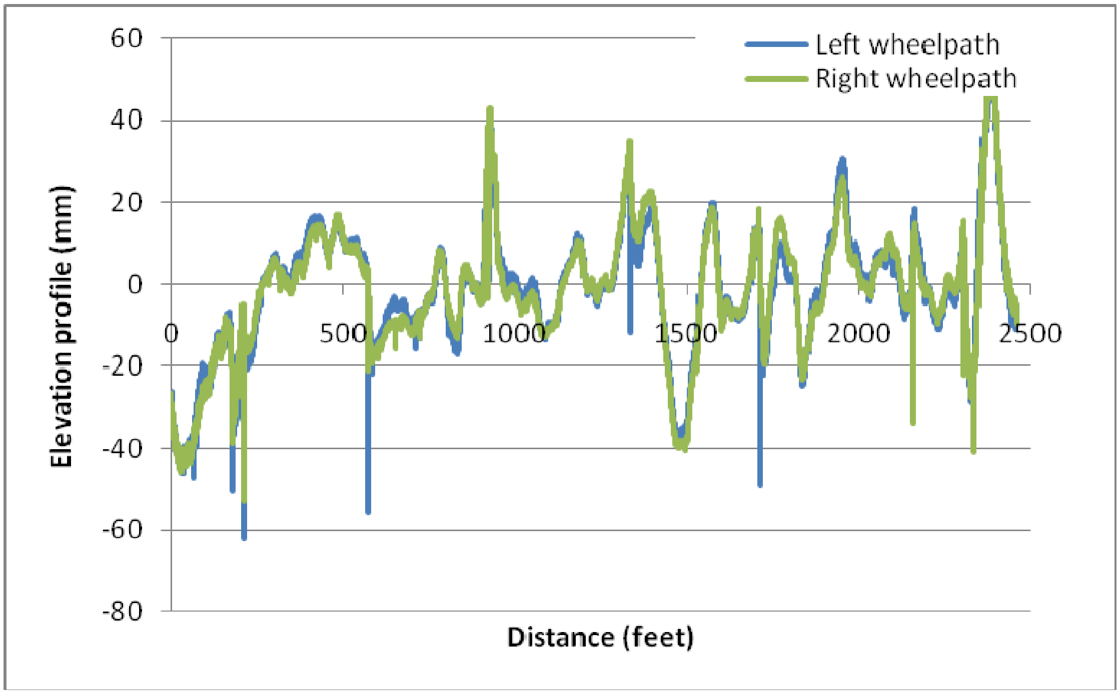


Figure 4.25: Elevation profile of Section QP-120.1.

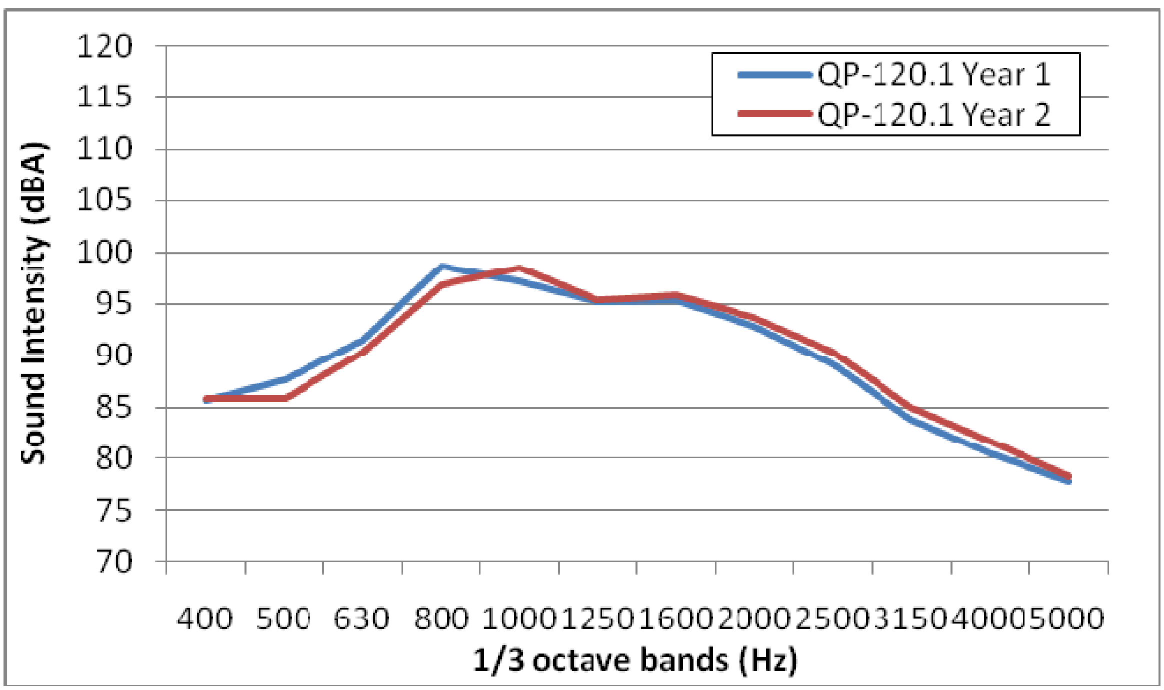


Figure 4.26: OBSI spectra of Section QP-120.1, Year 1 and Year 2.

4.4 Section QP-121.1 on Bridge Number 33 0616L at 04ALA880S32.7L1

Section QP-121.1 is on Bridge Number 33 0616L, which is located in Oakland and is nearly three quarters of a mile long. This section is in Lane 1, and Section QP 122.1 is in the same direction on the same bridge in Lane 3. Although Sections QP-121.1 and 122.1 are both part of this bridge, they were considered separately in the study because different levels of wear, probably due to truck traffic, were found on the transversely broomed textures in Lane 1 (inside lane, Section 121.1) and Lane 3 (outside lane, Section 122.1 [see Section 4.5 of this report]). To facilitate data collection, an offset between the two sections was configured to allow for the test vehicle to shift lanes and collect data from both sections in one pass.

As the entire set of measurements was taken on the bridge, there are no results presented for the pavement sections before or after the bridge. Two clearly marked joints were identified. The surface had been diamond ground near the joints. A polyester overlay was applied on this bridge between Year 1 and Year 2, changing the surface type. This new surfacing caused a reduction of 1.3 dB(A) in OBSI level. The reduction was observed at the high frequencies.

Table 4.4: OBSI Results (dB[A]) Section QP-121.1

	Bridge	Bridge without Joints	Pavement
Year 1	105.2	105.0	n/a
Year 2	103.9	103.7	n/a

Figure 4.27: Surface and first measured joint on Section QP-121.1.

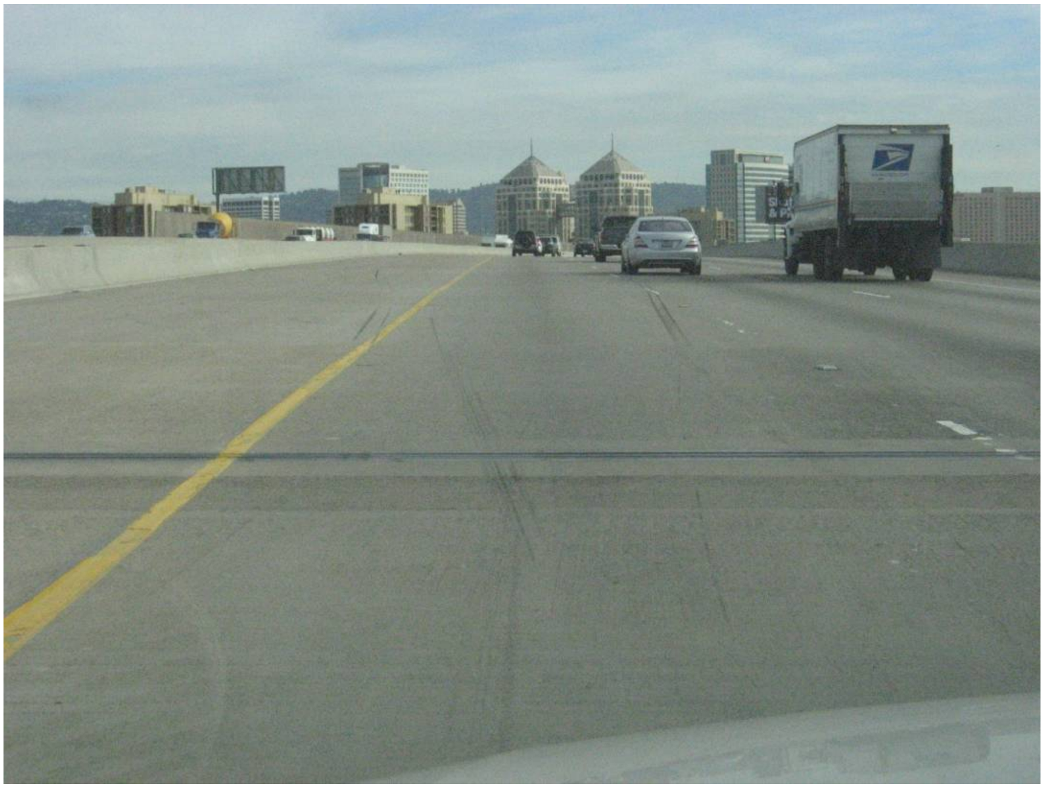


Figure 4.28: Surface and second measured joint of Section QP-121.1.

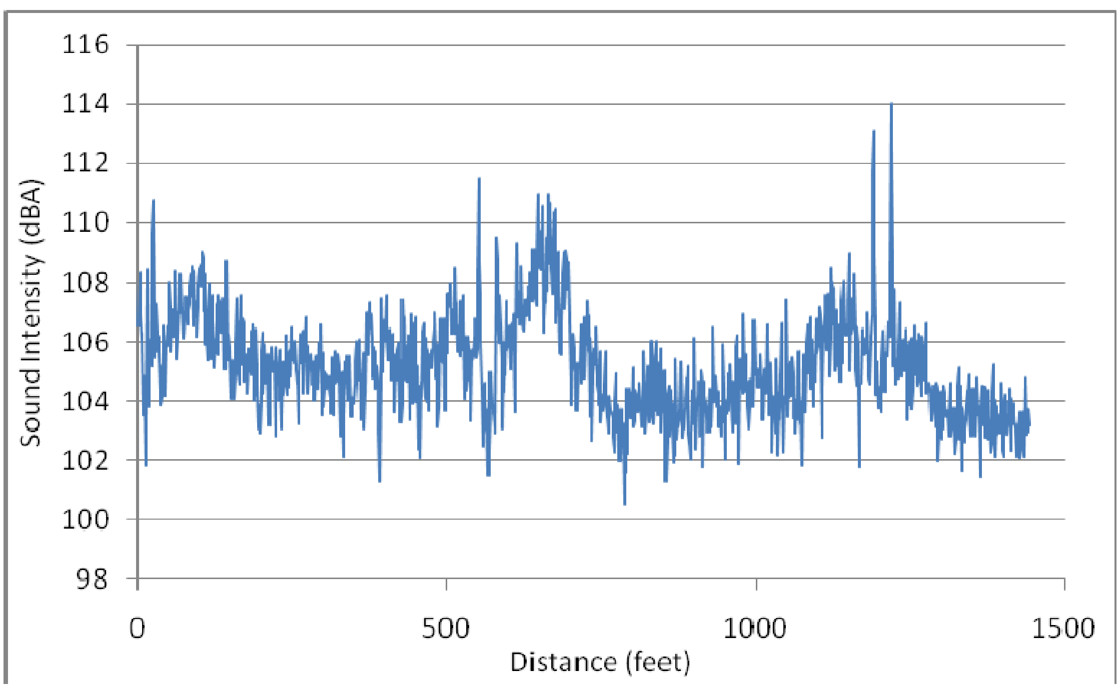


Figure 4.29: OBSI level in 15-msec intervals of Section QP-121.1, obtained in Year 1.

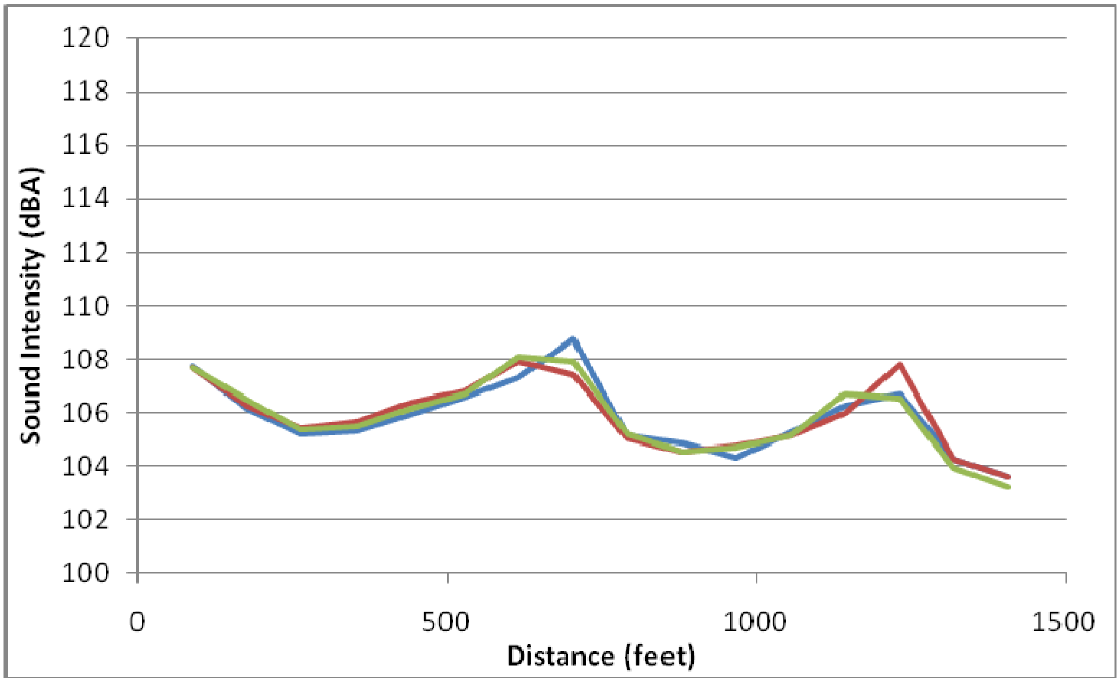


Figure 4.30: OBSI level in 1-sec intervals of Section QP-121.1, Year 1, three passes.

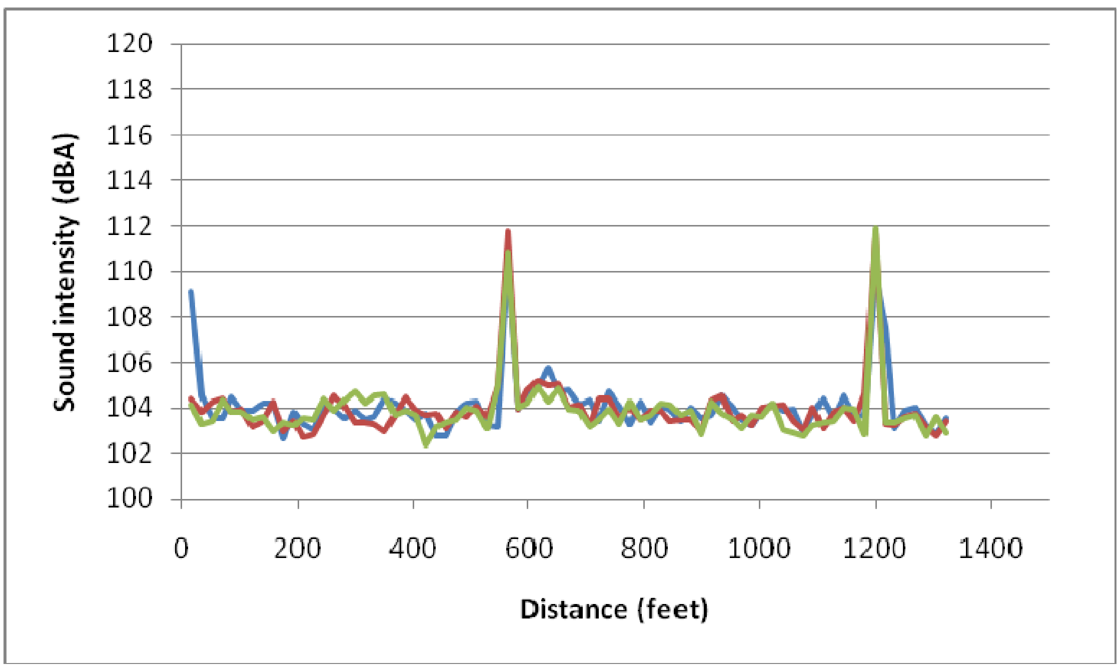


Figure 4.31: OBSI level in 0.2-sec intervals of Section QP-121.1, Year 2, three passes.

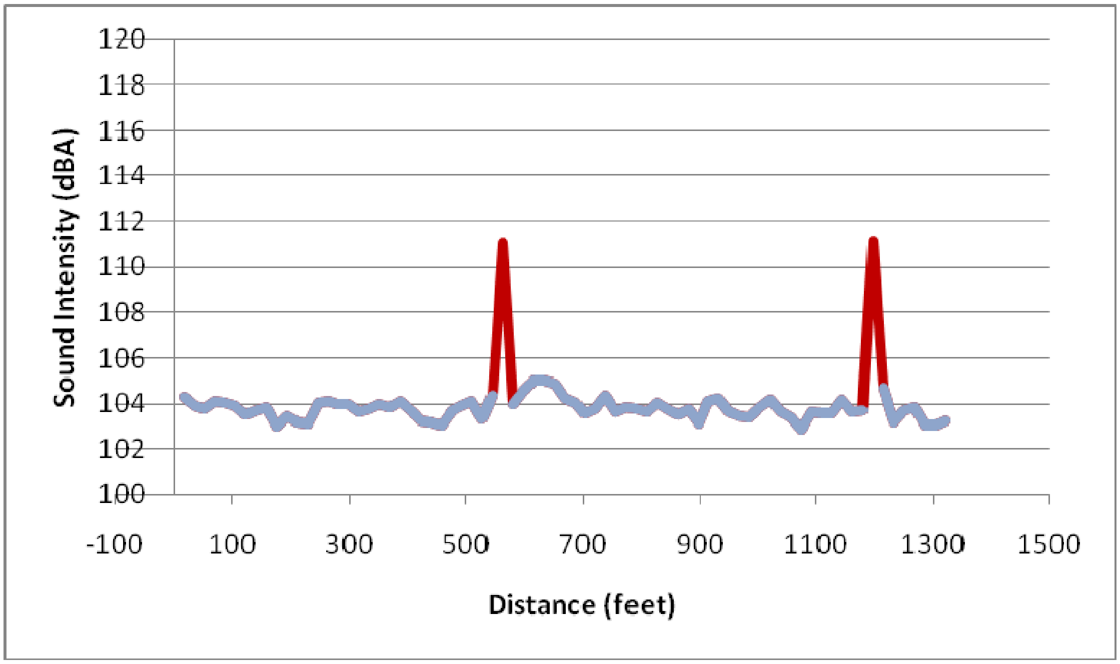


Figure 4.32: OBSI level in 0.2-sec intervals of Section QP-121.1, the bridge only, Year 2, average of three passes, joints highlighted.

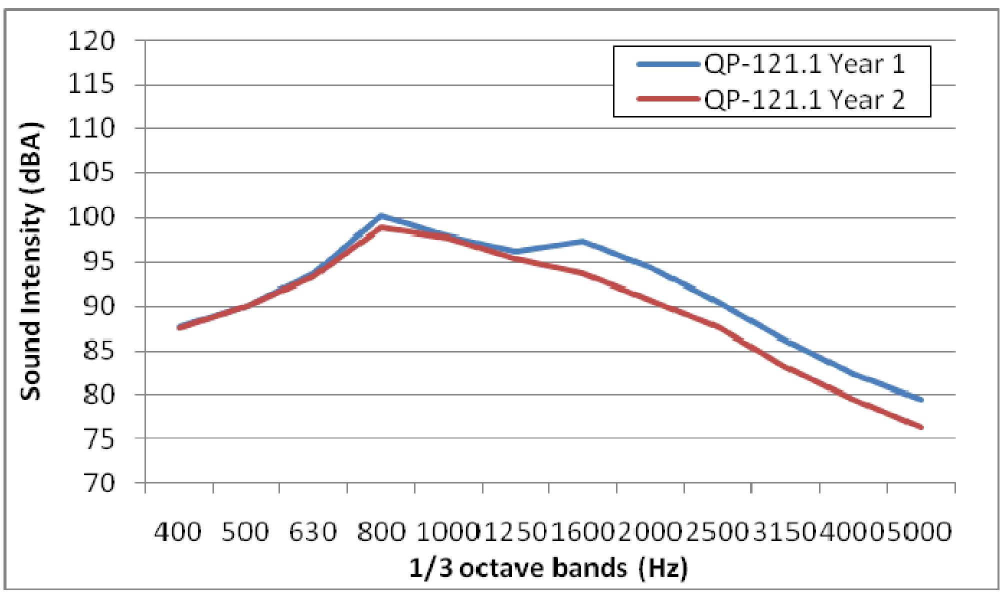


Figure 4.33: OBSI spectra of Section QP-121.1, Year 1 and Year 2.

4.5 Section QP-122.1 on Bridge Number 33 0616L at 04ALA880S32.7L3

Section QP-122.1 is near Section QP-121.1 (see Section 4.4 of this report) and is also on Bridge Number 33 0616L, but in Lane 3 rather than Lane 1. In the first year the transversely broomed texture was shallower than in Section QP-121.1, probably due to truck traffic. By the second year this section had been overlaid with polyester, which reduced its OBSI level, primarily by reducing the noise at the higher frequencies.

There are two clear joints on this section, and without them the OBSI level changed approximately 0.4 dB(A). Data from Years 1 and 2 indicate that OBSI in Lane 3 is 0.2 dB(A) higher than in Lane 1.

Table 4.5: OBSI Results (dB[A]) Section QP-122.1

	Bridge	Bridge without Joints	Pavement
Year 1	105.4	105.0	n/a
Year 2	104.4	104.2	n/a

Figure 4.34: Beginning of Section QP-122.1.

Figure 4.35: Surface and joint on Section QP-122.1.

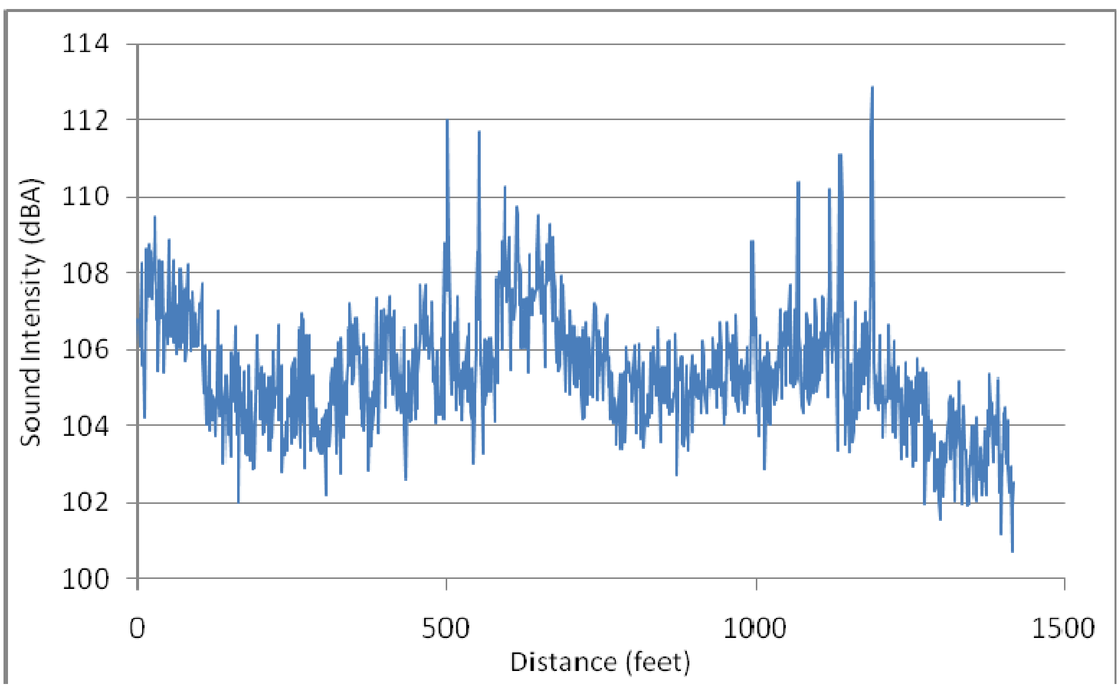


Figure 4.36: OBSI level in 15-msec intervals of Section QP-122.1, obtained in Year 1.

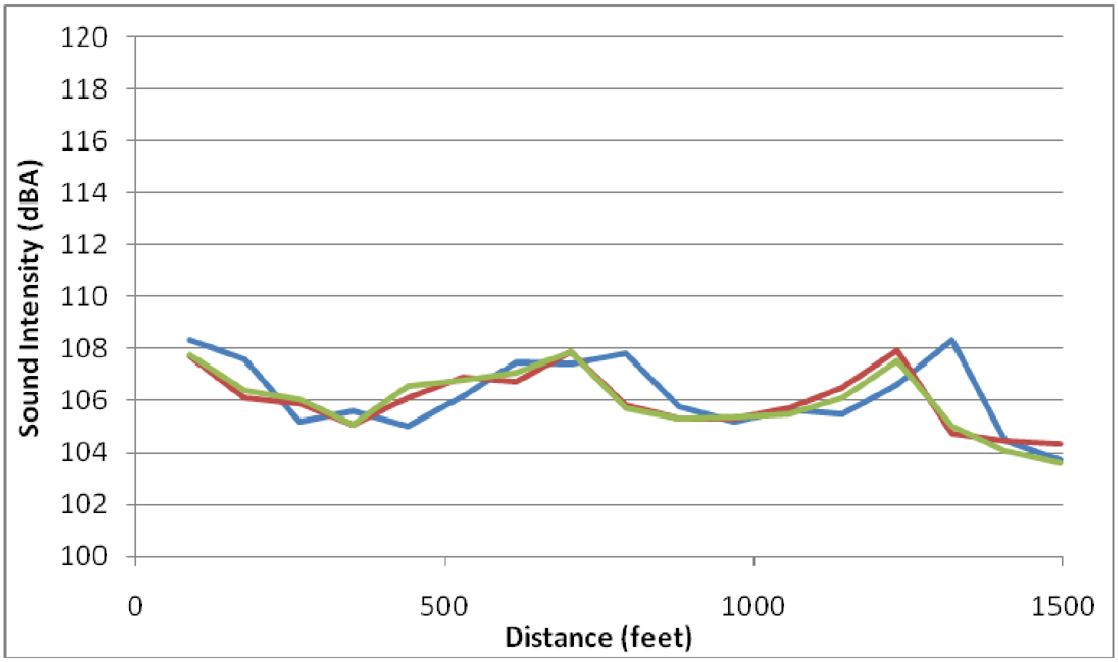


Figure 4.37: OBSI level in 1-sec intervals of Section QP-122.1, Year 1, three passes.

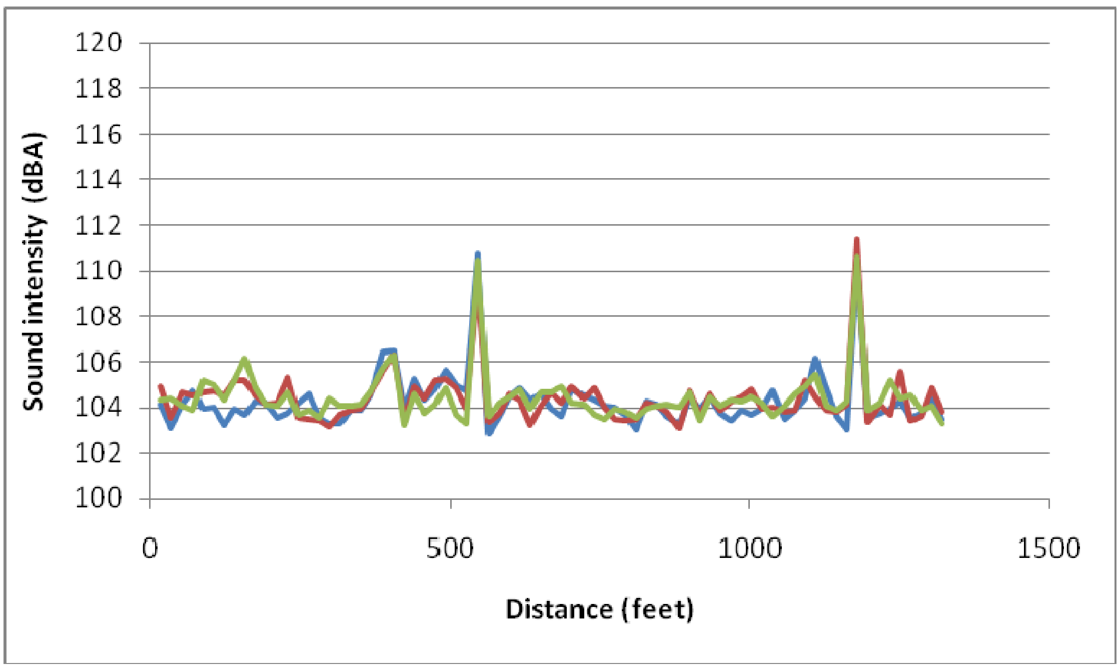


Figure 4.38: OBSI level in 0.2-sec intervals of Section QP-122.1, Year 2, three passes.

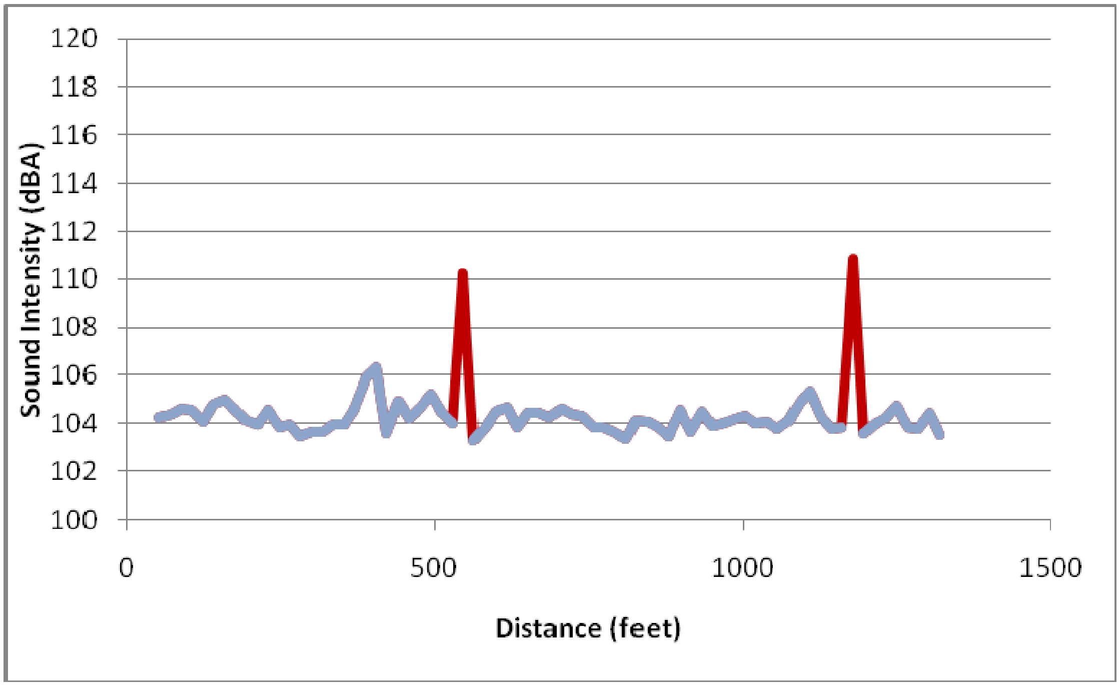


Figure 4.39: OBSI level in 0.2-sec intervals of Section QP-122.1, the bridge only, Year 2, average of three passes, highlighted joints.

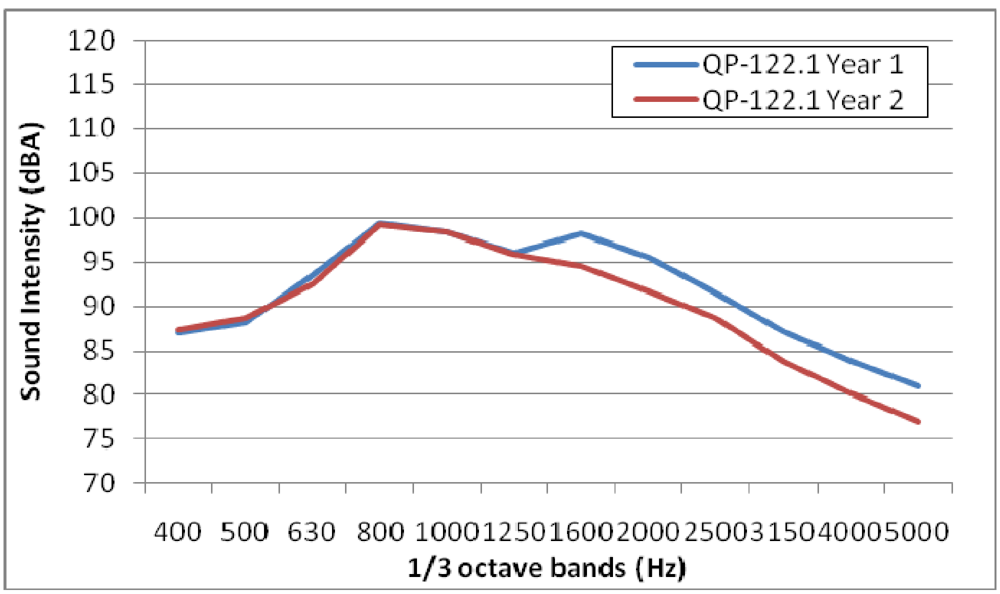


Figure 4.40: OBSI spectra of Section QP-122.1, Year 1 and Year 2.

4.6 Section QP-124.1 on Bridge Number 37 0244L at 04ALA262W0.1

Section QP-124.1 is located on Bridge Number 37 0244L, which connects I-680 to I-880 between Fremont and Milpitas. The measured section transitions from asphalt concrete pavement to a transversely broomed deck. It can be seen in Figure 4.43 that the transversely broomed texture is aggressive and has a relatively poor finish, although not as poor a finish as Section 119.1 (Figure 4.12). No joint slap noise was identified, but the diamond-ground segments at the joints are visible in the 0.2-sec OBSI plots. Despite the drop in overall noise level from Year 1 to Year 2, the spectra are very similar. It is worth noting that this section is in a curve.

Table 4.6: OBSI Results (dB[A]) Section QP-124.1

	Bridge	Bridge without Joints	Pavement
Year 1	108.6	108.6	103.6
Year 2	109.1	109.1	102.9

Figure 4.41: Beginning of Section QP-124.1.

Figure 4.42: OBSI Surface and diamond-ground segments near joints on Section QP-124.1.

Figure 4.43: Detail of surface and joint on Section QP-124.1.

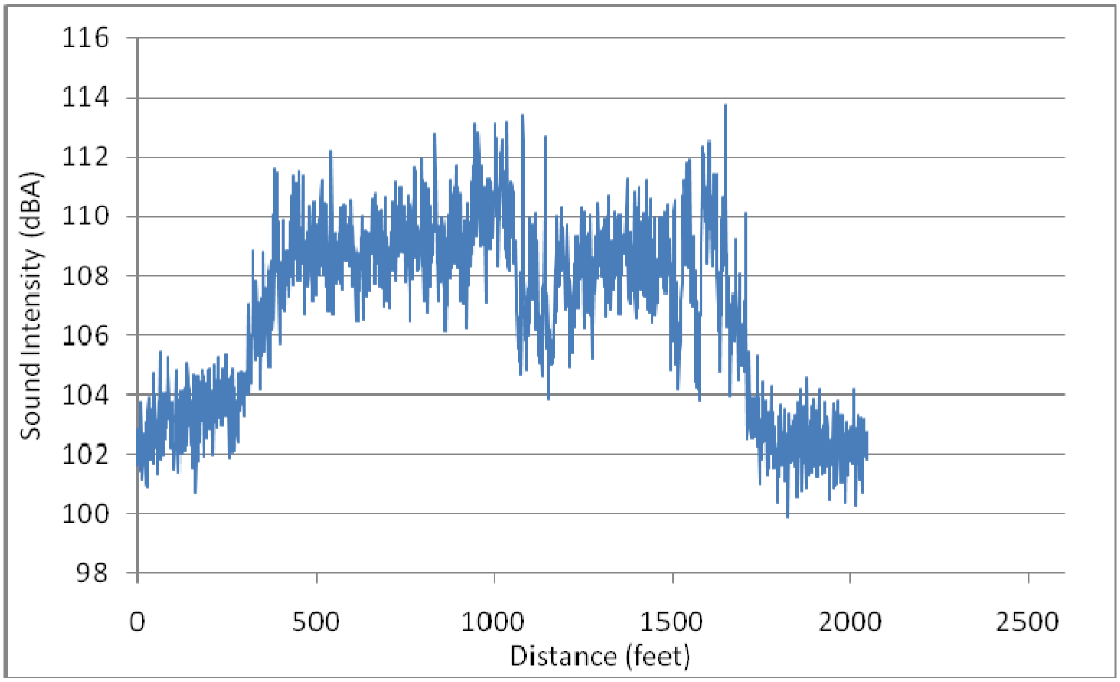


Figure 4.44: OBSI level in 15-msec intervals of Section QP-124.1, obtained in Year 1.

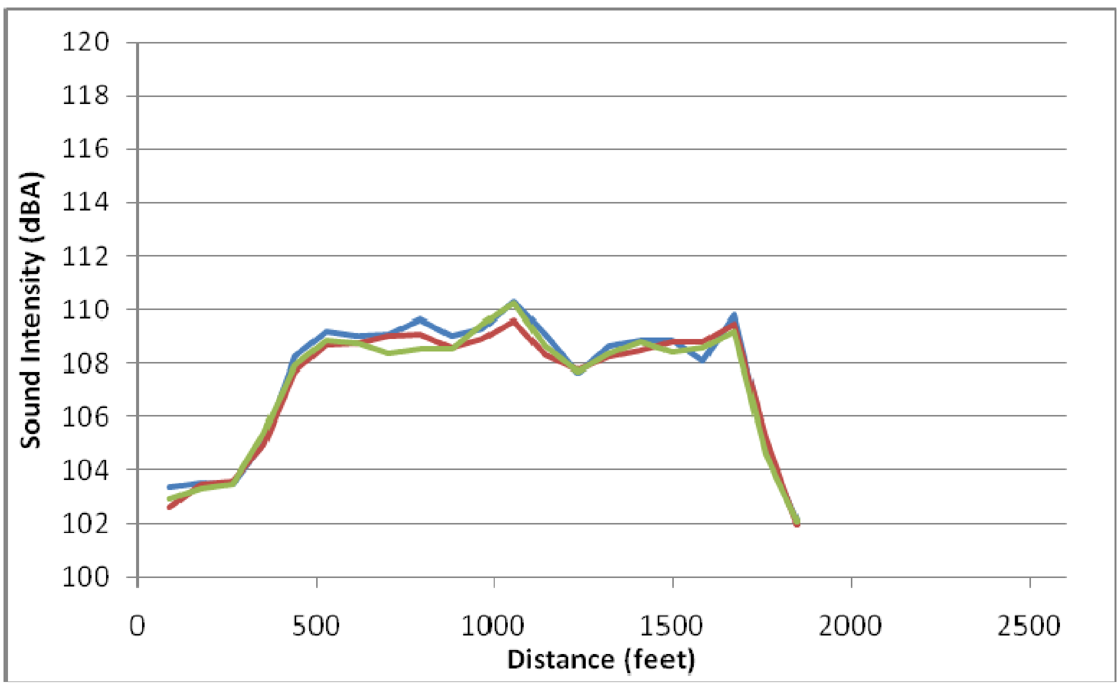


Figure 4.45: OBSI level in 1-sec intervals of Section QP-124.1, Year 1, three passes.

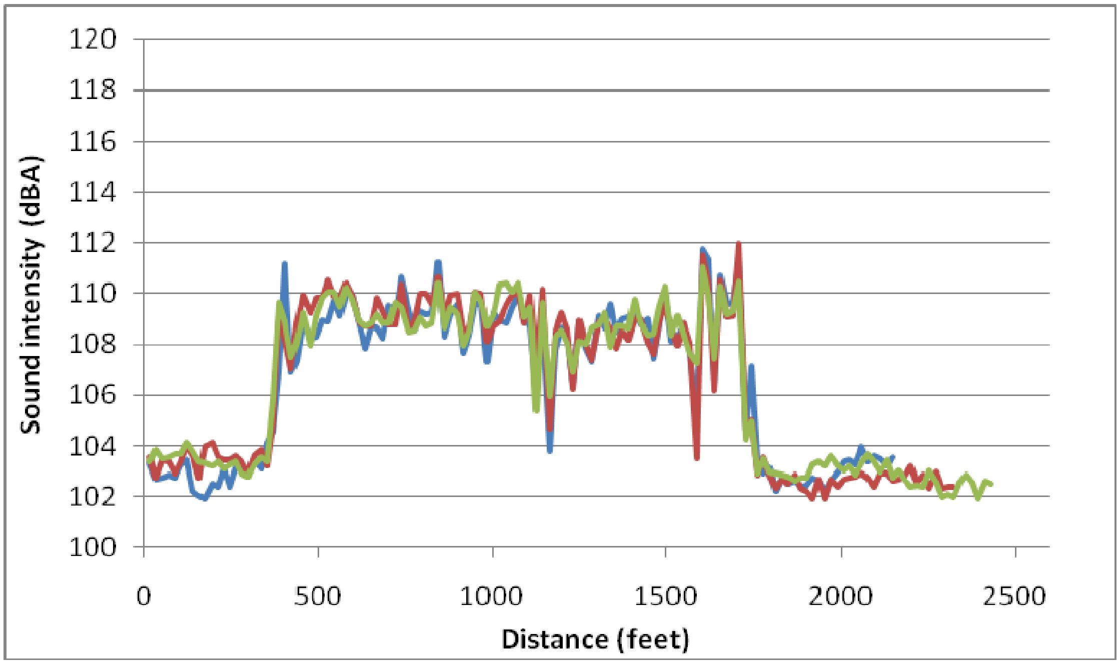


Figure 4.46: OBSI level in 0.2-sec intervals of Section QP-124.1, Year 2, three passes.

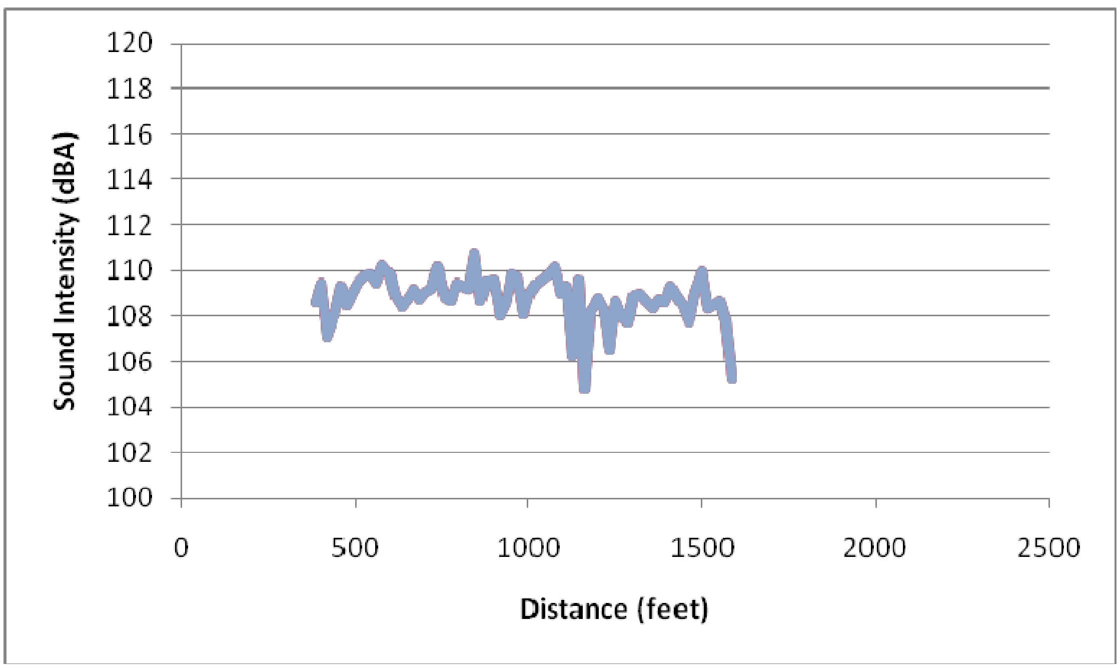


Figure 4.47: OBSI level in 0.2-sec intervals of Section QP-124.1, the bridge only, Year 2, average of three passes, no joints to highlight.

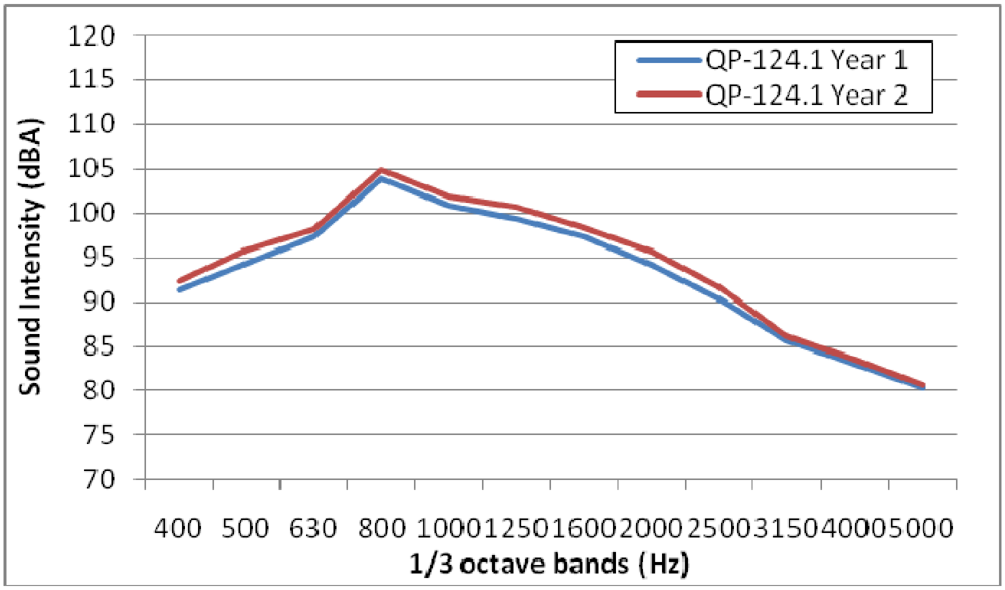


Figure 4.48: OBSI spectra of Section QP-124.1, Year 1 and Year 2.

4.7 Sections QP-125.1, QP-125.2, and QP-125.3 on Bridge Numbers 37 0244L, 37 0470L, and 37 0471L at 04SCL237W6.2, 04SCL237W5.8, and 04SCL237W5.5

Sections QP-125.1, QP-125.2, and QP-125.3 are on Bridge Numbers 37 0244L, 37 0470L, and 37 0471L, which are near the city of Santa Clara, CA, approximately a quarter of a mile apart from one another. The pavement before, after, and between the bridges is asphalt concrete, and the bridge deck surface is transversely tined. There was no effect from joints.

Table 4.7: OBSI Results (dB[A]) Section QP-125.1

	Bridge	Bridge without Joints	Pavement
Year 1	109.3	109.3	101.6
Year 2	108.8	108.8	101.9

Table 4.8: OBSI Results (dB[A]) Section QP-125.2

	Bridge	Bridge without Joints	Pavement
Year 1	109.0	109.0	100.5
Year 2	109.3	109.3	102.8

Table 4.9: OBSI Results (dB[A]) Section QP-125.3

	Bridge	Bridge without Joints	Pavement
Year 1	107.3	107.3	99.6
Year 2	108.8	108.8	103.2

Figure 4.49: Beginning of Section QP-125.1.

Figure 4.50: Beginning of Section QP-125.2.

Figure 4.51: Beginning of Section QP-125.3.

The three sections are shown together in each of the following plots (Figure 4.52 through Figure 4.54) along with the pavements before, after, and between them.

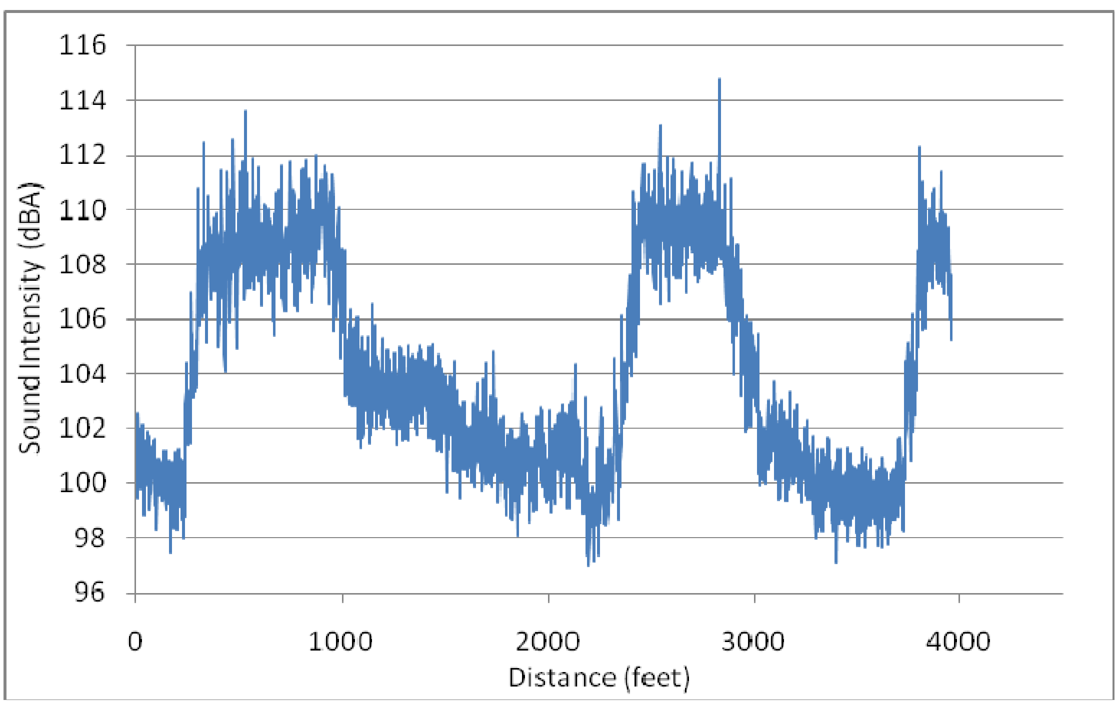


Figure 4.52: OBSI level in 15-msec intervals of Sections QP-125.1, QP125.2, and QP-125.3 obtained in Year 1.

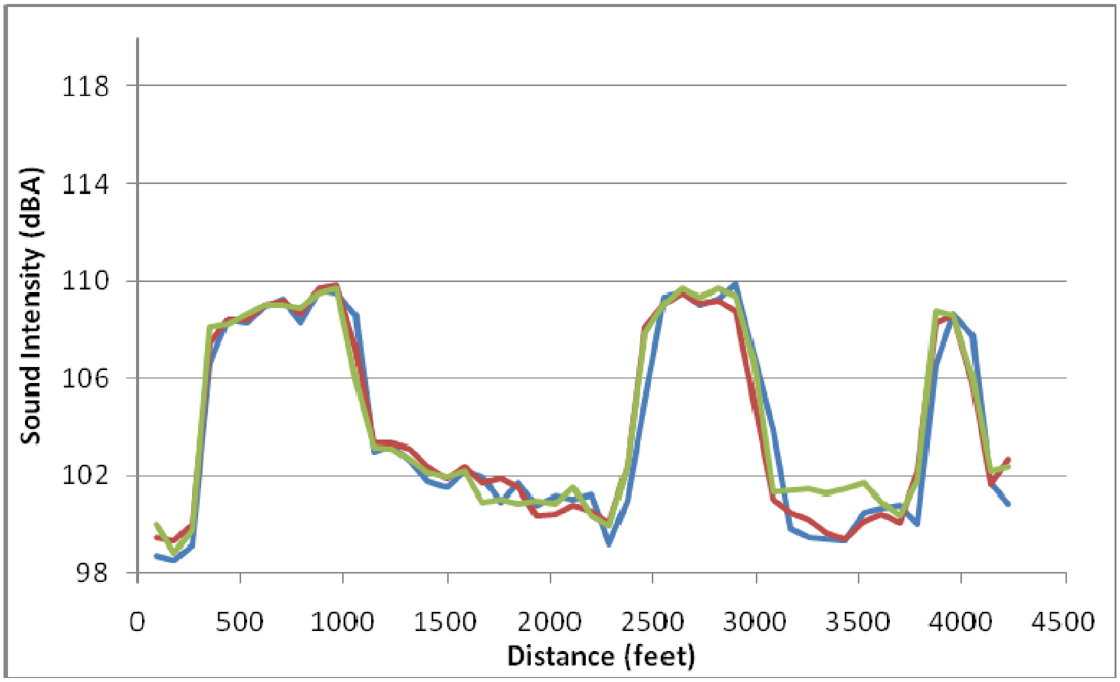


Figure 4.53: OBSI level in 1-sec intervals of Sections QP-125, Year 1, three passes.

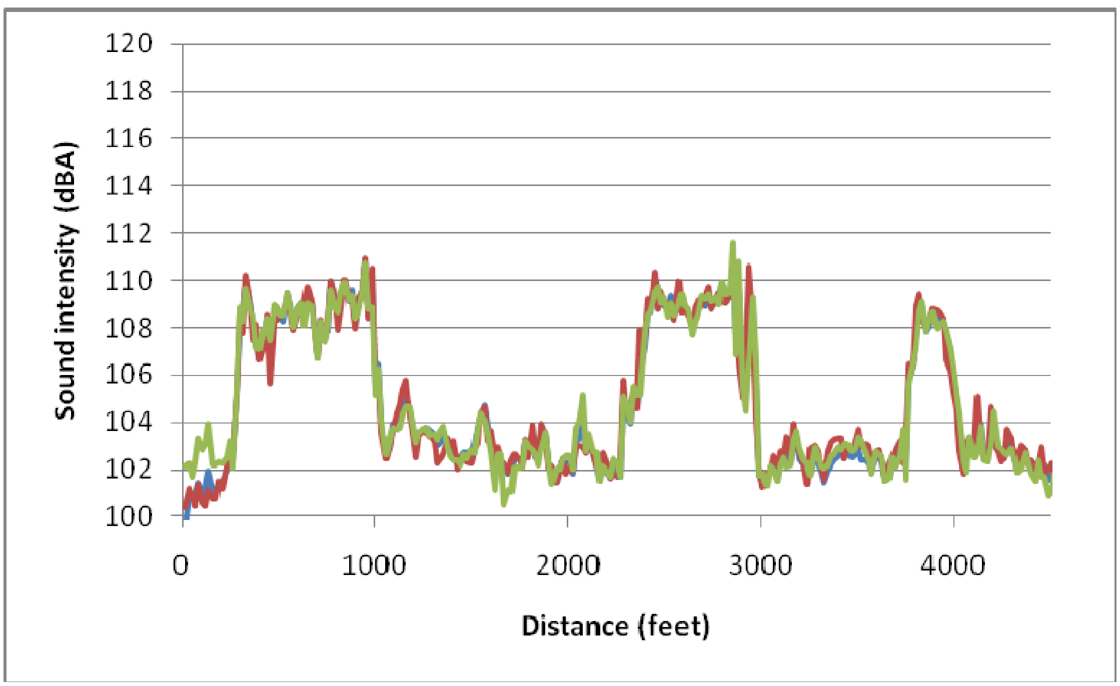


Figure 4.54: OBSI level in 0.2-sec intervals of Sections QP-125, Year 2, three passes.

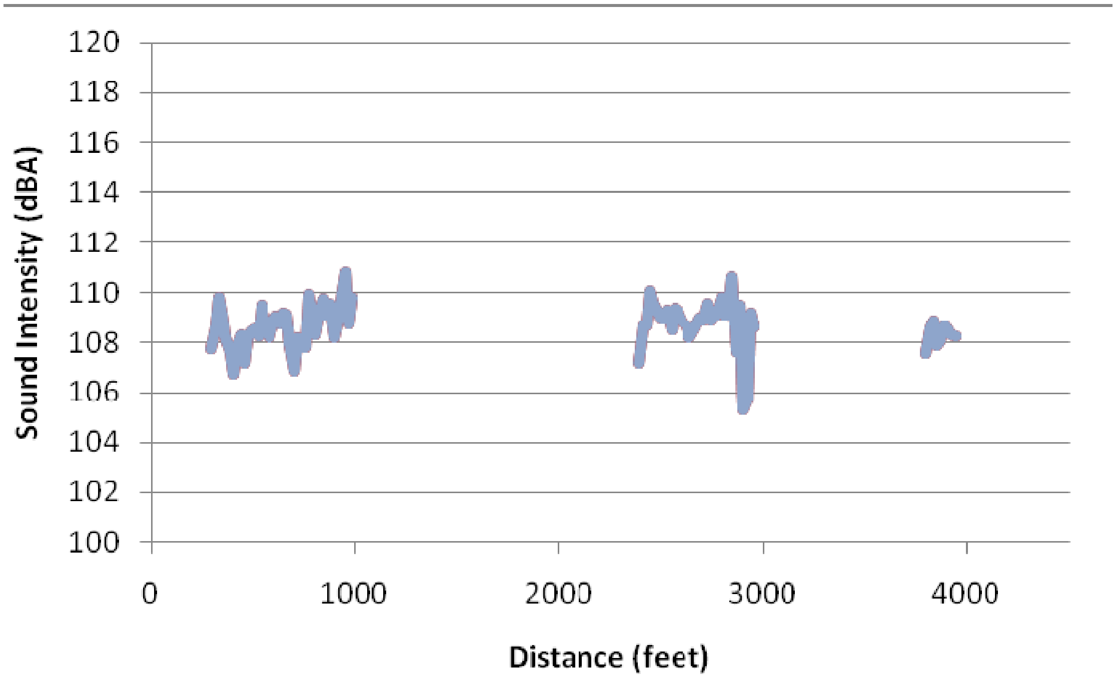


Figure 4.55: OBSI level in 0.2-sec intervals of Sections QP-125, the bridges only, Year 2, average of three passes, no joints to highlight.

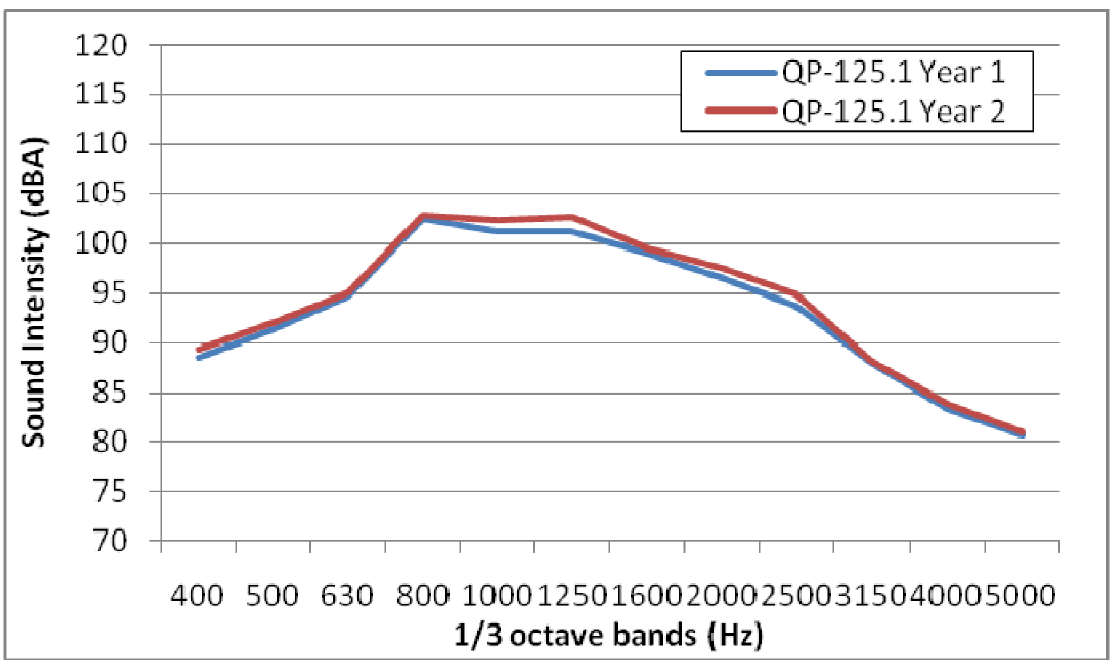


Figure 4.56: OBSI spectra of Section QP-125.1, Year 1 and Year 2.

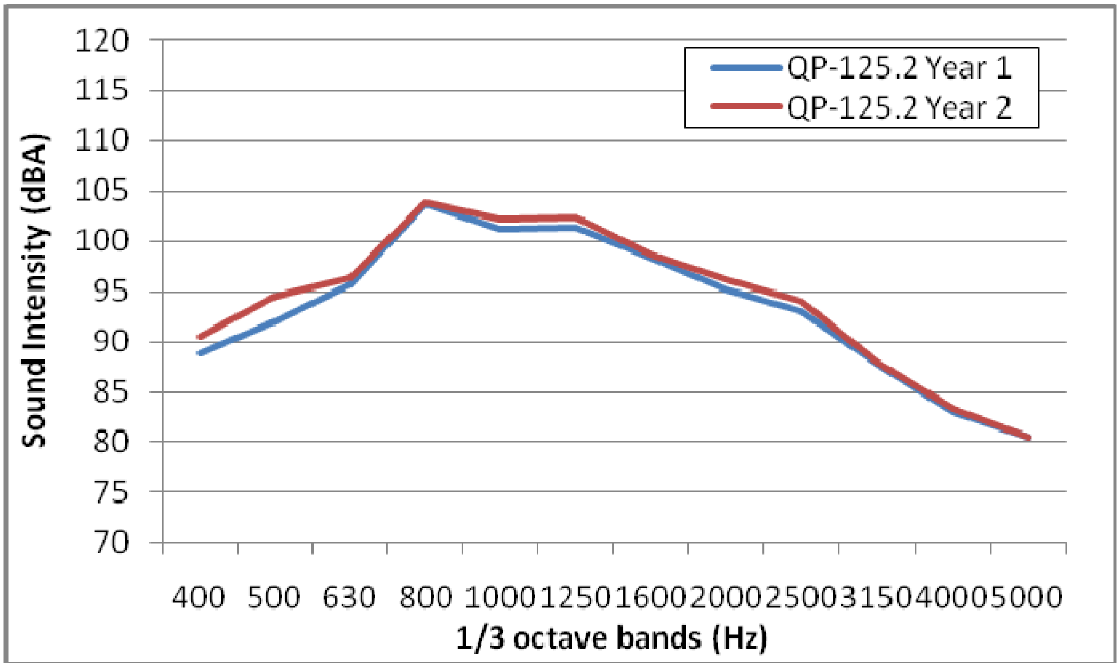


Figure 4.57: OBSI spectra of Section QP-125.2, Year 1 and Year 2.

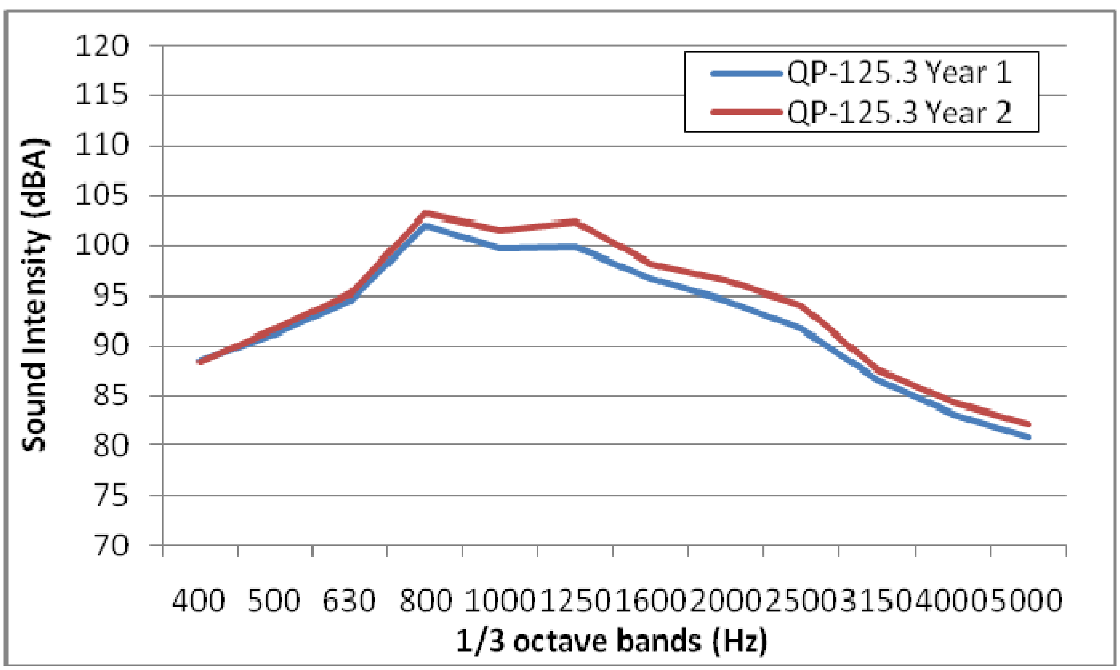


Figure 4.58: OBSI spectra of Section QP-125.3, Year 1 and Year 2.

4.8 Section QP-139.1 on Bridge Number 25 0121 at 03ED50E11.2

Section QP-139.1 in on Bridge Number 25 0121 on US 50 in El Dorado County. The bridge was opened in 2008 shortly after the beginning of this study. The section transitions from a hot-mix asphalt pavement to a skewed transversely tined bridge deck. There was no effect from joints.

Table 4.10: OBSI Results (dB[A]) Section QP-139.1

	Bridge	Bridge without Joints	Pavement
Year 1	104.7	104.7	100.4
Year 2	107.2	107.2	103.2

Figure 4.59: Beginning of Section QP-139.1.

Figure 4.60: Transition pavement, Section QP-139.1.

Figure 4.61: Back view on Section QP-139.1.

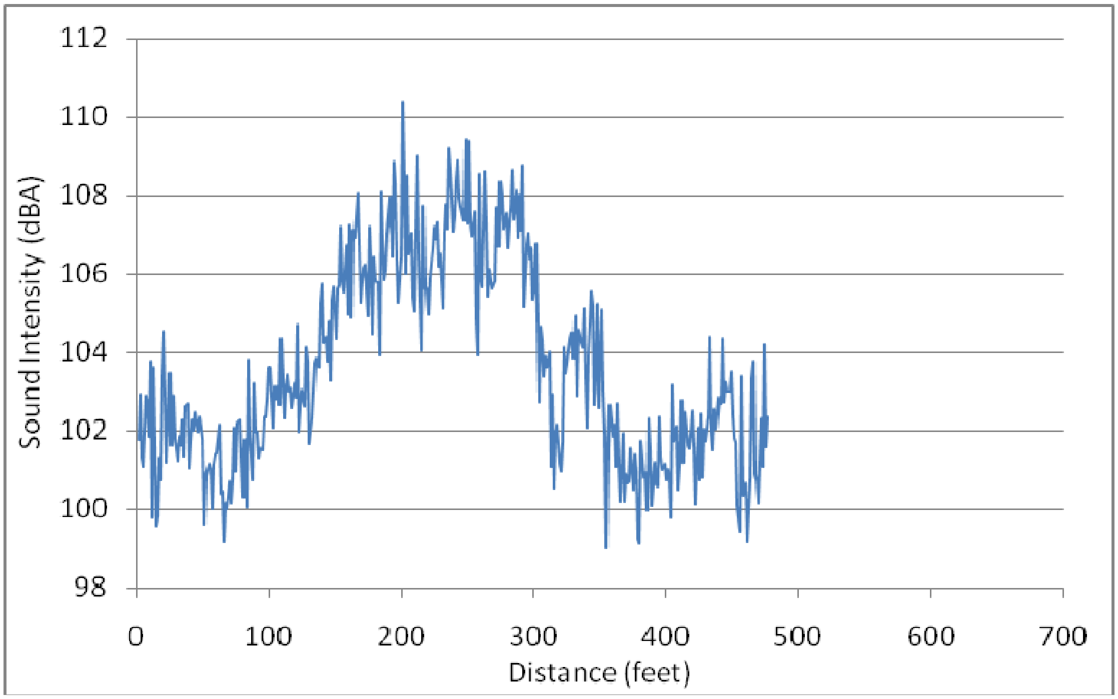


Figure 4.62: OBSI level in 15-msec intervals of Section QP-139.1, obtained in Year 1.

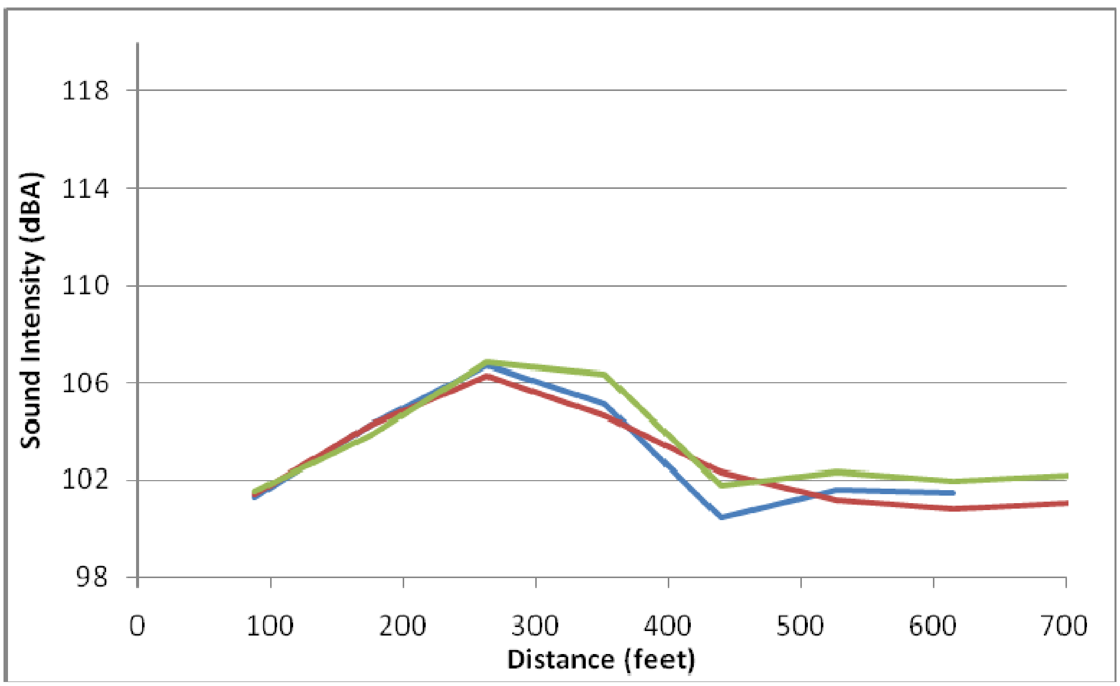


Figure 4.63: OBSI level in 1-sec intervals of Section QP-139.1, Year 1, three passes.

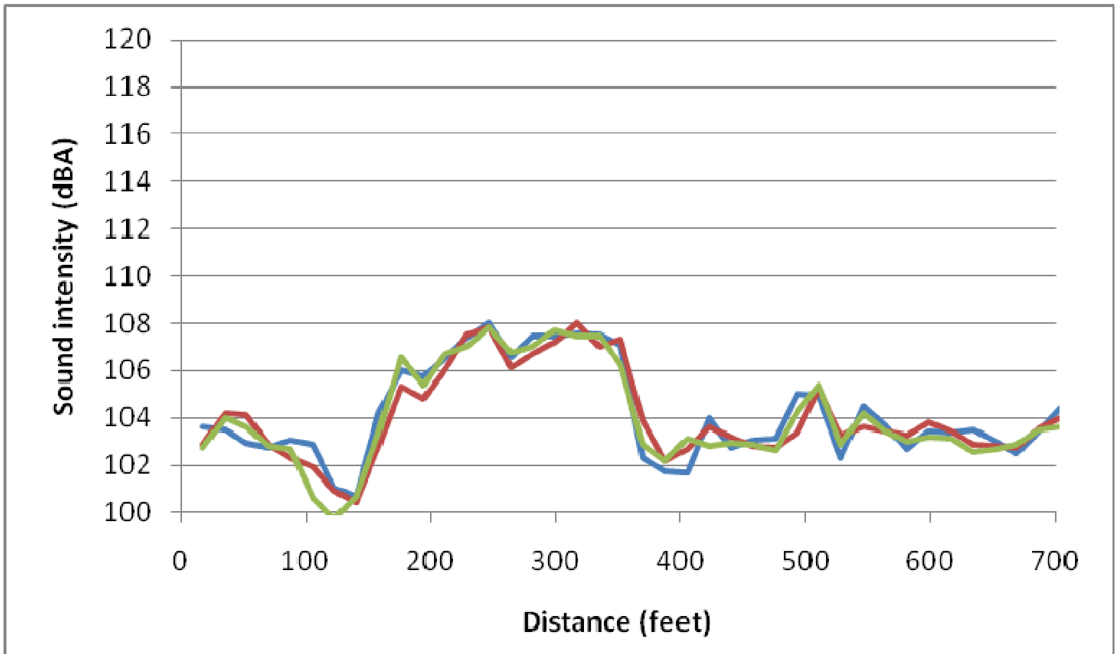


Figure 4.64: OBSI level in 0.2-sec intervals of Section QP-139.1, Year 2, three passes.

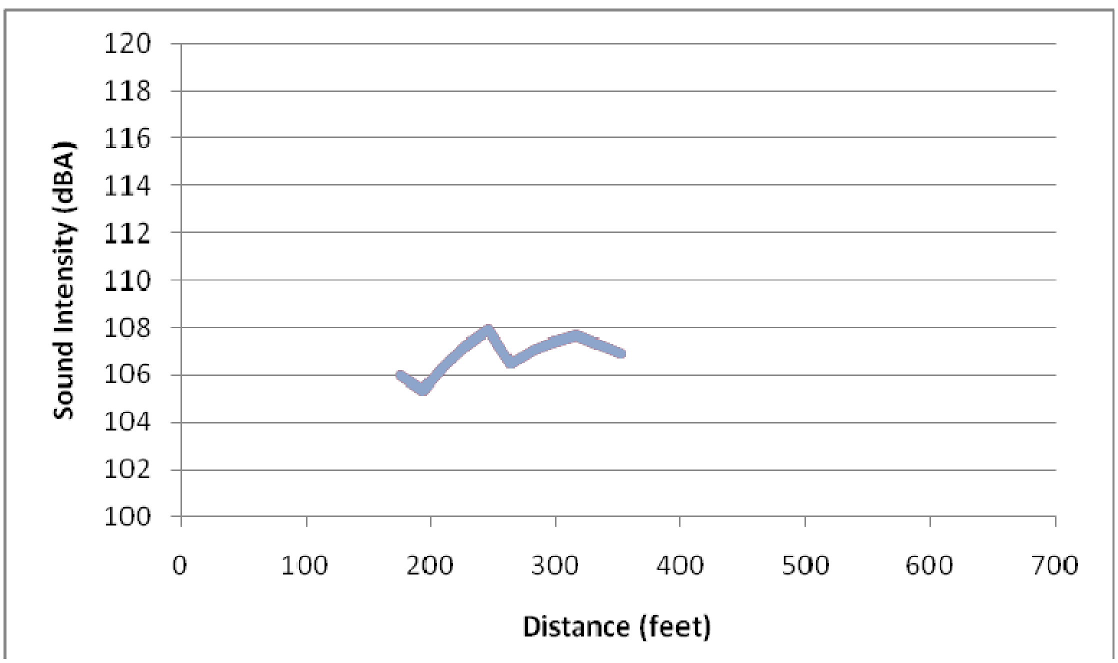


Figure 4.65: OBSI level in 0.2-sec intervals of Section QP-139.1, the bridge only, Year 2, average of three passes.

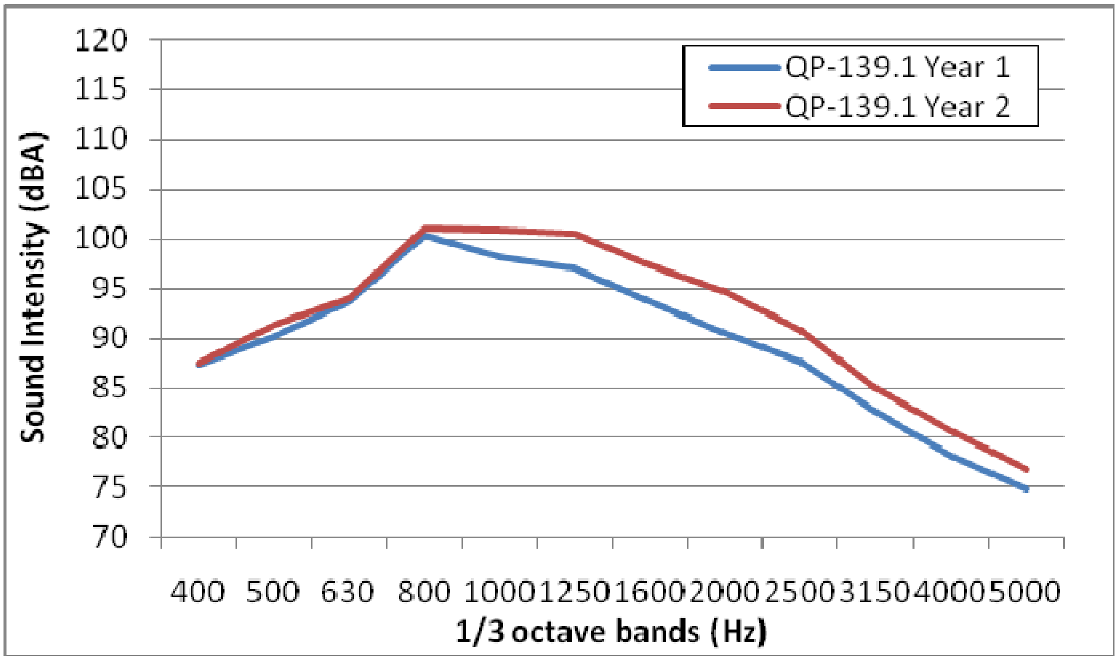


Figure 4.66: OBSI spectra of Section QP-139.1, Year 1 and Year 2.

4.9 Section QP-140.1 on Bridge Number 26 0050 at 10AMA104W3.6

Section QP-140.1 is on Bridge Number 26 0050, which is located in a rural area in Amador County. The highway transitions from an asphalt concrete pavement to a transversely tined bridge deck, but approximately 50 percent of its surface was diamond ground. There was no effect from joints.

Table 4.11: OBSI Results (dB[A]) Section QP 140.1

	Bridge	Bridge without Joints	Pavement
Year 1	102.7	102.7	97.7
Year 2	104.0	104.0	99.2

Figure 4.67: Beginning of Section QP-140.1.

Figure 4.68: Surface and joint on Section QP-140.1.

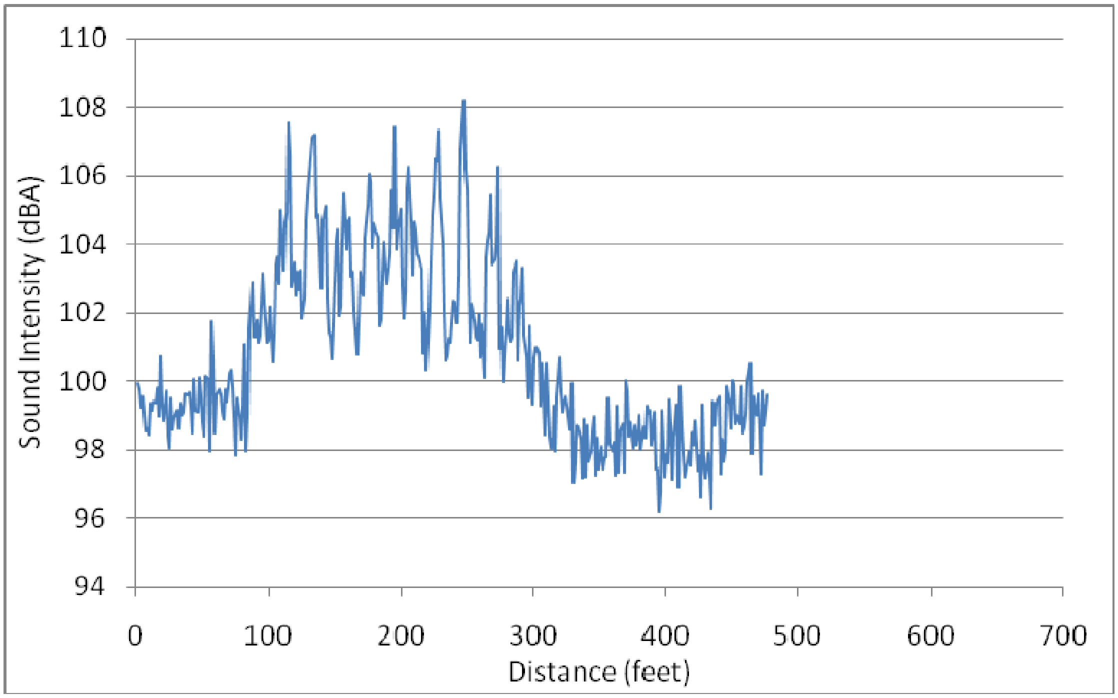


Figure 4.69: OBSI level in 15-msec intervals of Section QP-140.1, obtained in Year 1.

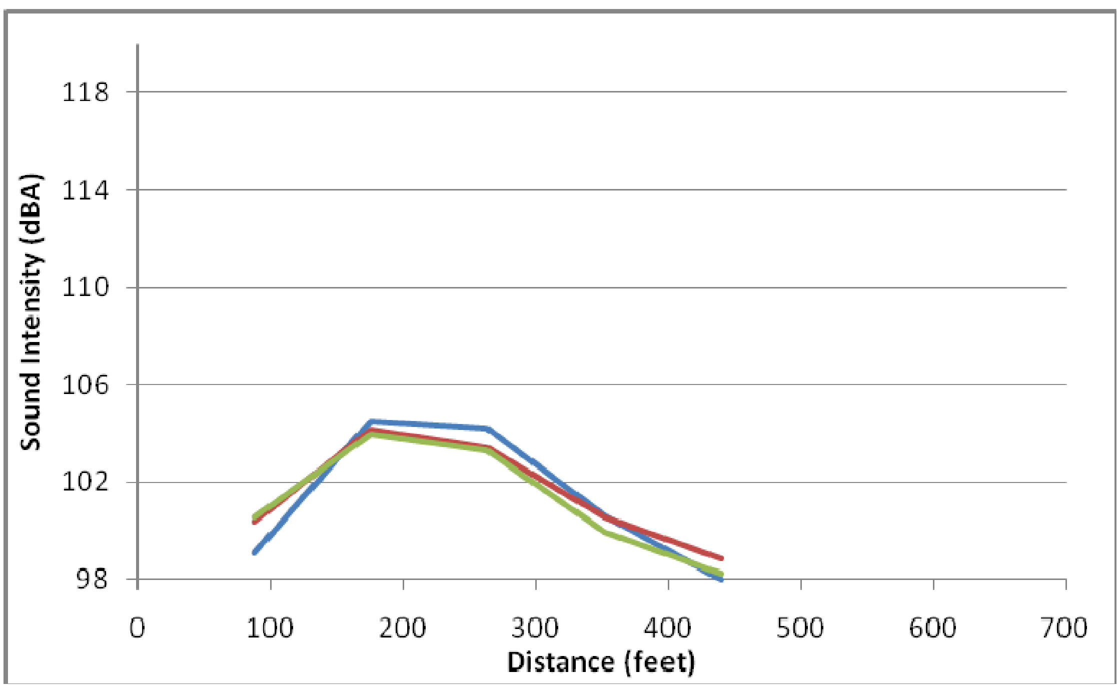


Figure 4.70: OBSI level in 1-sec intervals of Section QP-140.1, Year 1, three passes.

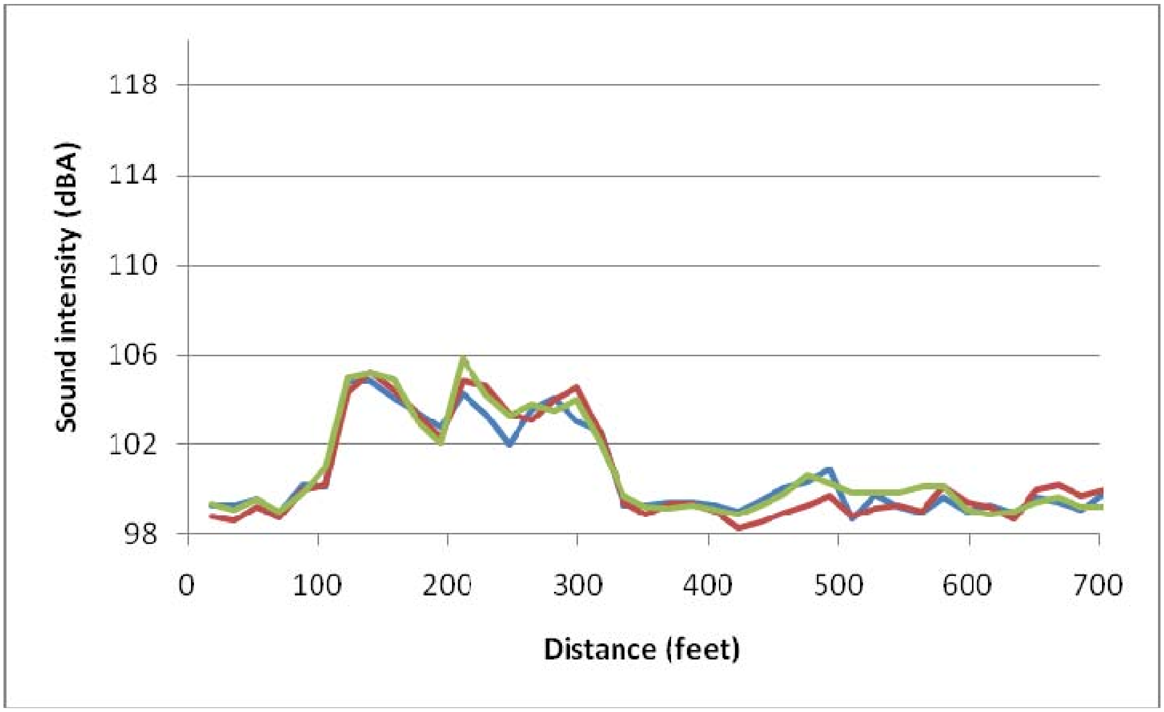


Figure 4.71: OBSI level in 0.2-sec intervals of Section QP-140.1, Year 2, three passes.

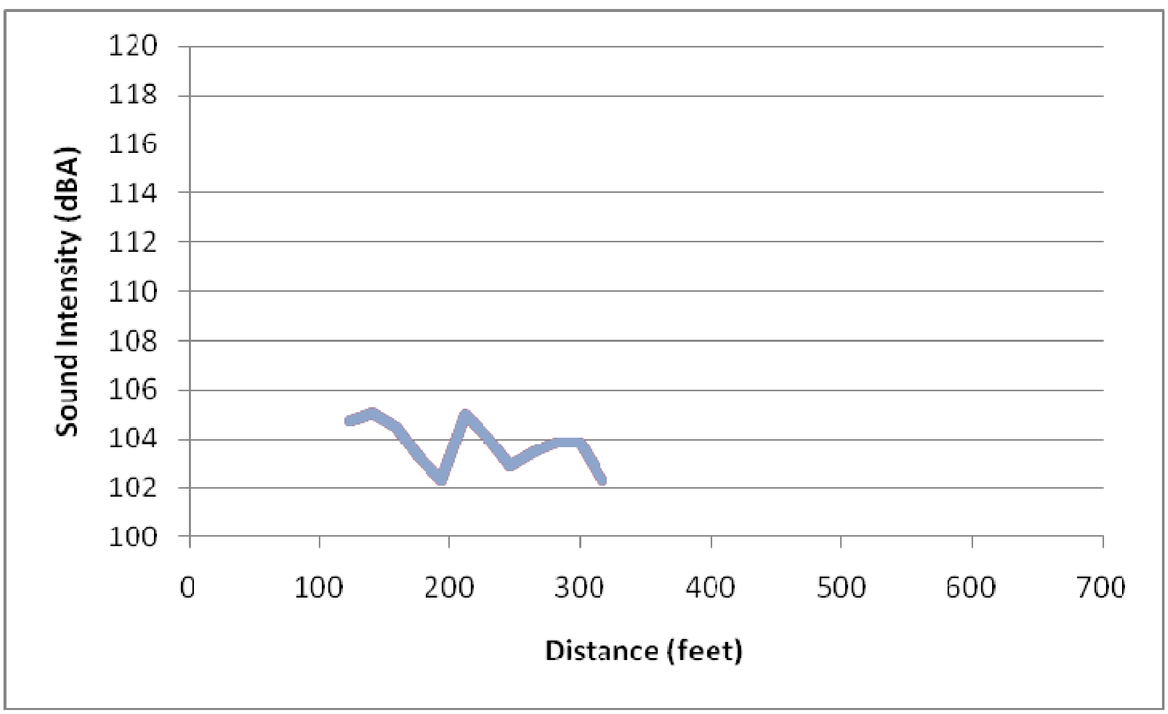


Figure 4.72: OBSI level in 0.2-sec intervals of Section QP-140.1, the bridge only, Year 2, average of three passes.

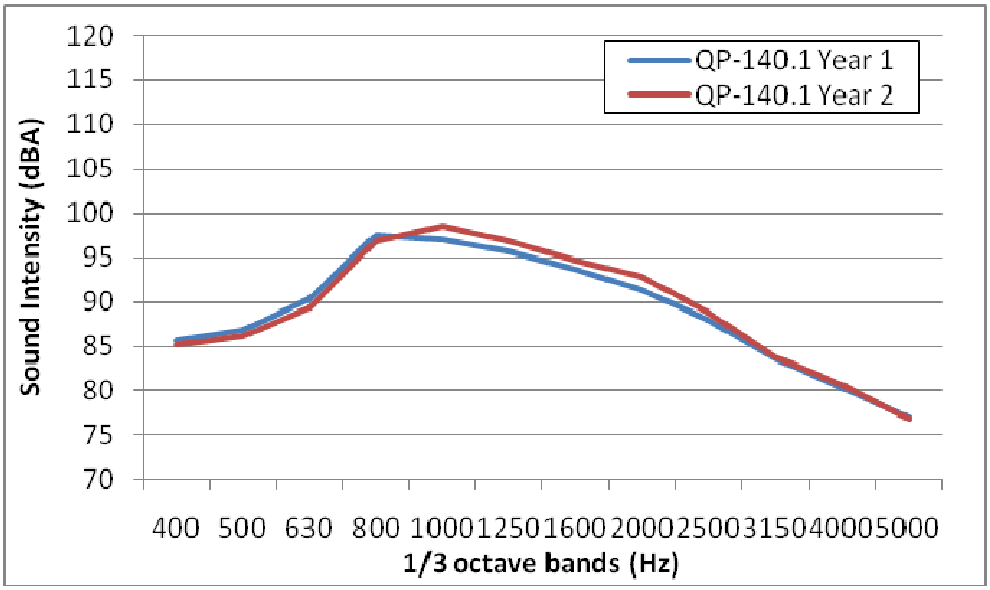


Figure 4.73: OBSI spectra of Section QP-140.1, Year 1 and Year 2.

4.10 Section QP-141.1 on Bridge Number 06 0128 at 02SHA5N6.9

Section QP-141.1, which is on Bridge Number 06 0128, is located on I-5 eight miles south of Redding, and has a particular transverse-tining texture pattern that is clearly visible on the shoulder. However, the pattern has worn out in the wheelpaths on the bridge deck. Changes in the test car's lateral position relative to the wheelpaths from one pass to another caused variability in the noise results. This can be seen in Figure 4.78**,** where the vehicle position for the first pass was different from that of the second and third passes, resulting in different tire/pavement noise. There was no effect from joints.

Table 4.12: OBSI Results (dB[A]) Section QP-141.1

	Bridge	Bridge without Joints	Pavement
Year 1	105.6	105.6	104.5
Year 2	105.7	105.7	105.5

Figure 4.74: Beginning of Section QP-141.1.

Figure 4.75: Texture difference in the wheelpath and the rest of bridge deck on Section QP-141.1.

Figure 4.76: Close up view of wheelpath texture in the wheelpaths and overall view of Section QP-141.1.

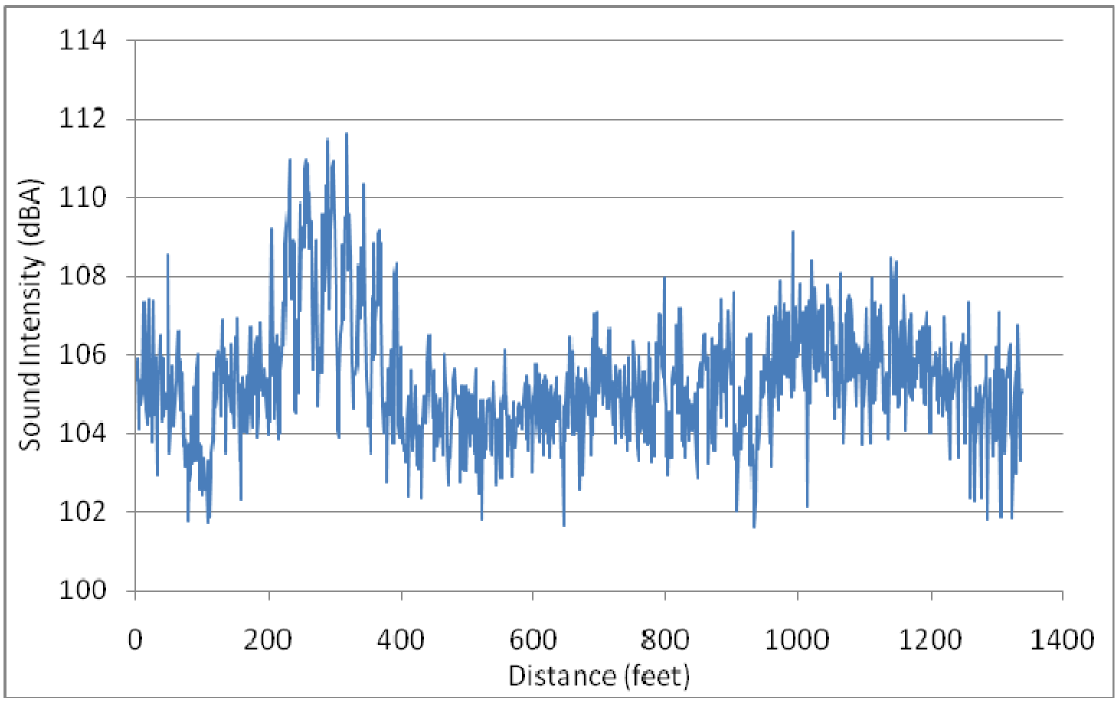


Figure 4.77: OBSI level in 15-msec intervals of Section QP-141.1, obtained in Year 1.

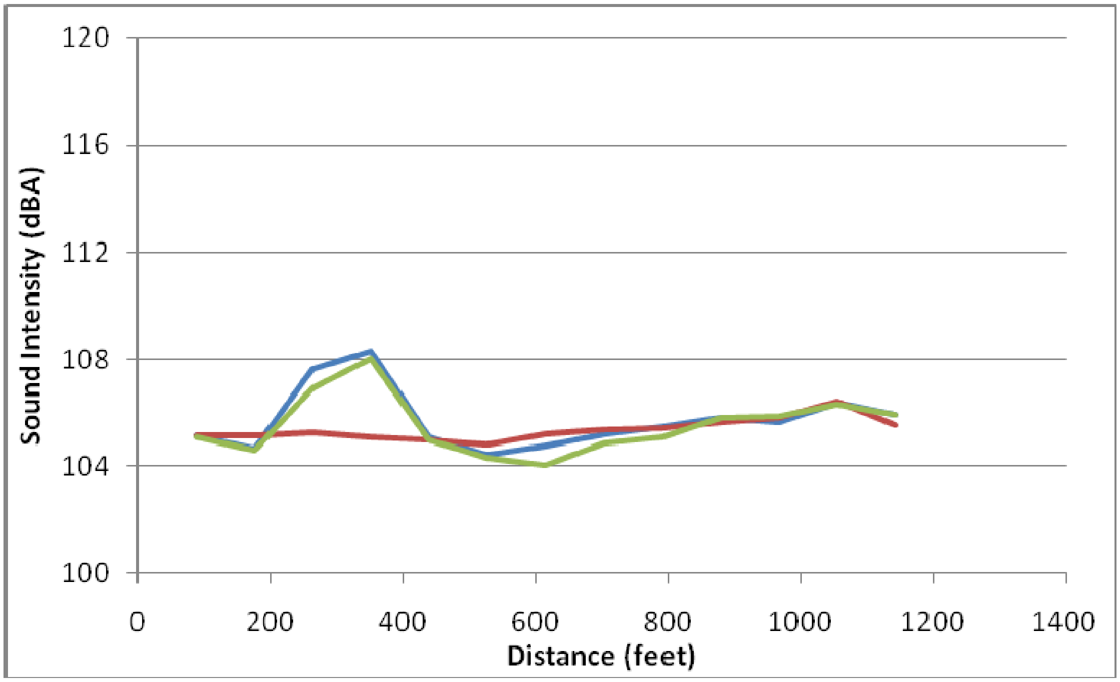


Figure 4.78: OBSI level in 1-sec intervals of Section QP-141.1, Year 1, three passes, with first pass in red and passes two and three in green and blue, respectively.
(Note: differences between first and second/third passes due to different vehicle positions and different texture in the wheelpaths compared to out of the wheelpaths).

The following sequence shows the lateral positions as recorded by the automatic camera. In Year 2, the first pass was to the right of passes 2 and 3. This is reflected in Figure 4.80, as the blue line shows higher OBSI levels for the first pass that is out of the wheelpath and therefore running over the tining that has not been worn down by traffic.

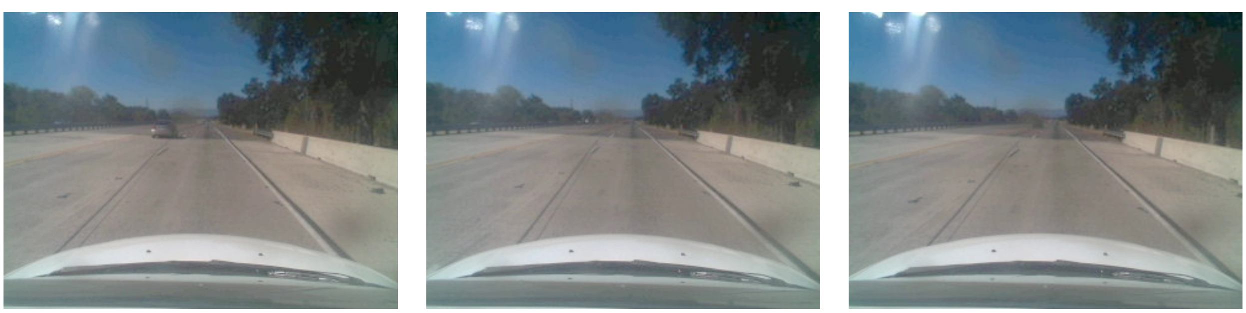


Figure 4.79: Variability in lateral position of the test vehicle on Section QP-141.1 from pass to pass.

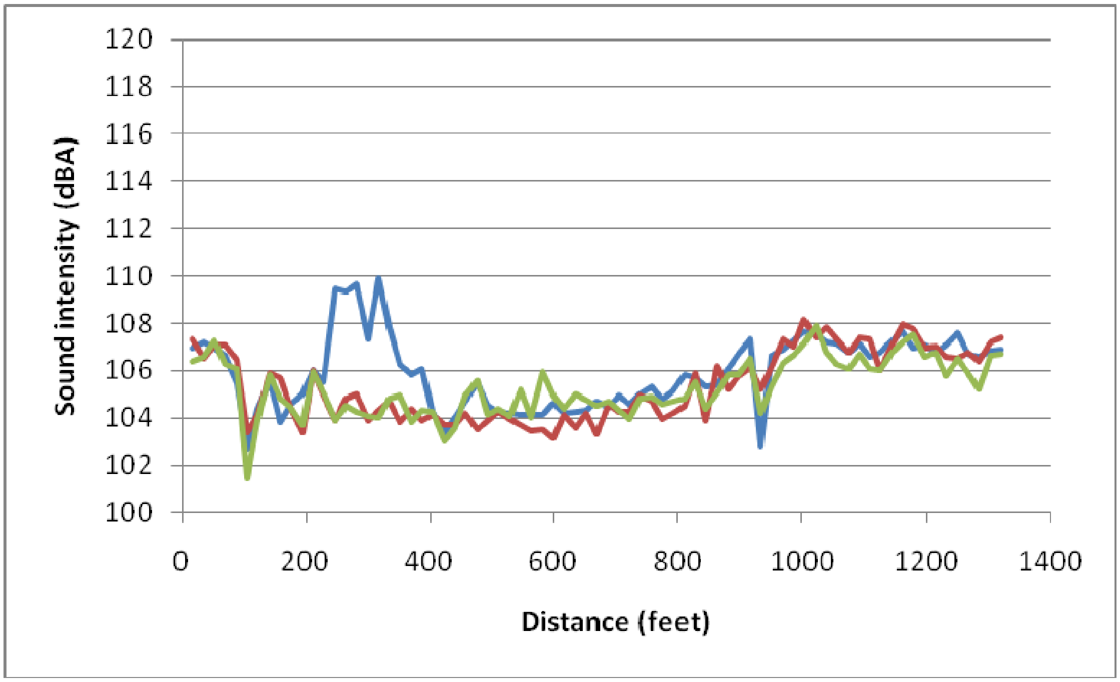


Figure 4.80: OBSI level in 0.2-sec intervals of Section QP-141.1 Year 2, three passes.
Note: first pass (blue) out of the wheelpath, second and third passes (red and green) in the wheelpath.

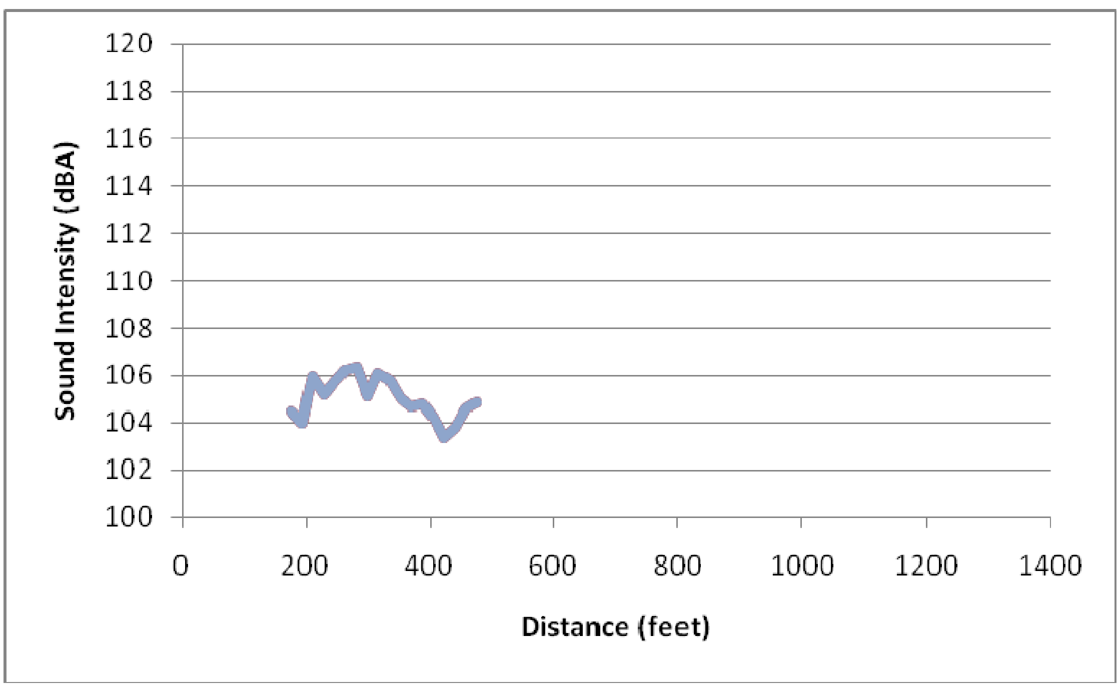


Figure 4.81: OBSI level in 0.2-sec intervals of Section QP-141.1, the bridge only, Year 2, average of three passes.

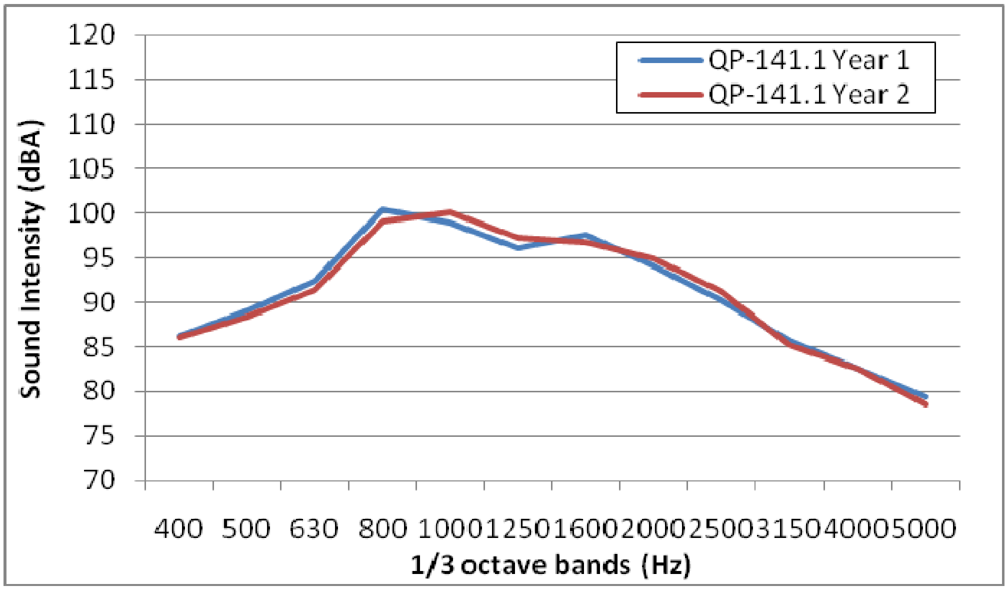


Figure 4.82: OBSI spectra of Section QP-141.1, Year 1 and Year 2.

4.11 Section QP-143.1 on Bridge Number 17 0013 at 03NEV80E20.8

Section QP-143.1, on Bridge Number 17 0013, is located on I-80 east of Truckee. The freeway transitions from concrete pavement to a polyester-overlaid bridge deck. There was no effect from joints. The bridge deck is about 1.7 dB(A) quieter than the surrounding pavement (1.9 and 1. 5 dB[A] in Years 1 and 2 respectively). This bridge is in an area that receives snow and is therefore subject to winter maintenance which may accelerate damage to the deck.

Table 4.13: OBSI Results (dB[A]) Section QP-143.1

	Bridge	Bridge without Joints	Pavement
Year 1	104.3	104.3	106.2
Year 2	105.6	105.0	107.1

Figure 4.83: Beginning of Section QP-143.1 (right side of photo).

Figure 4.84: Surface of Section QP-143.1.

Figure 4.85: Joint on Section QP-143.1.

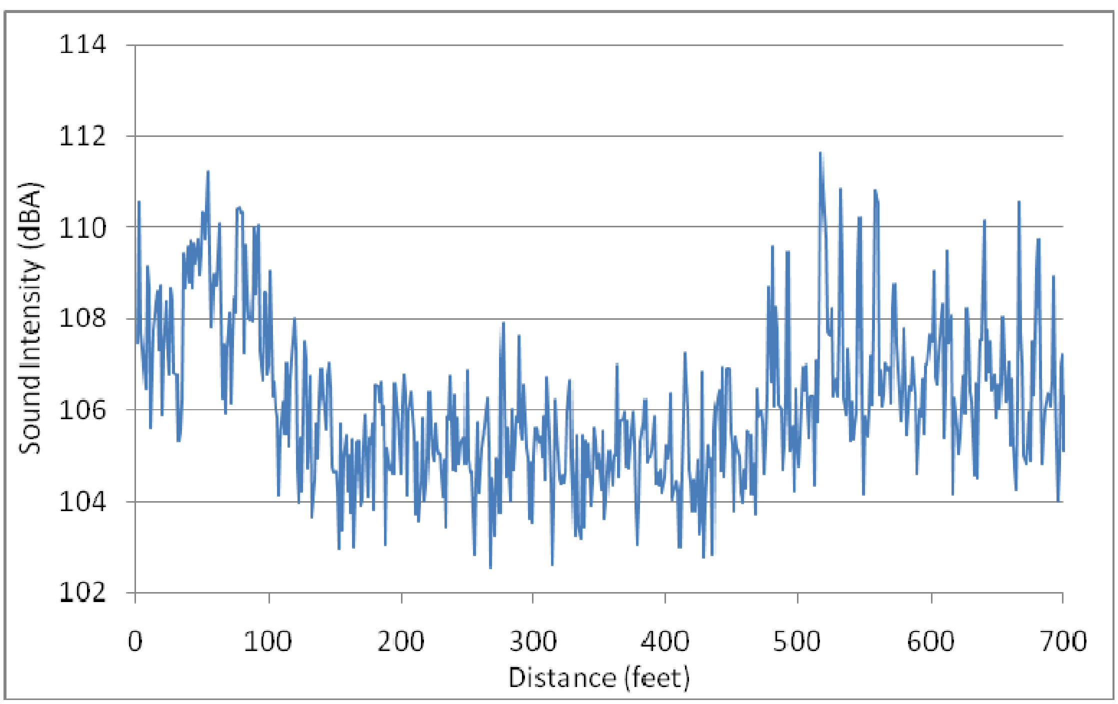


Figure 4.86: OBSI level in 15-msec intervals of Section QP-143.1, obtained in Year 1.

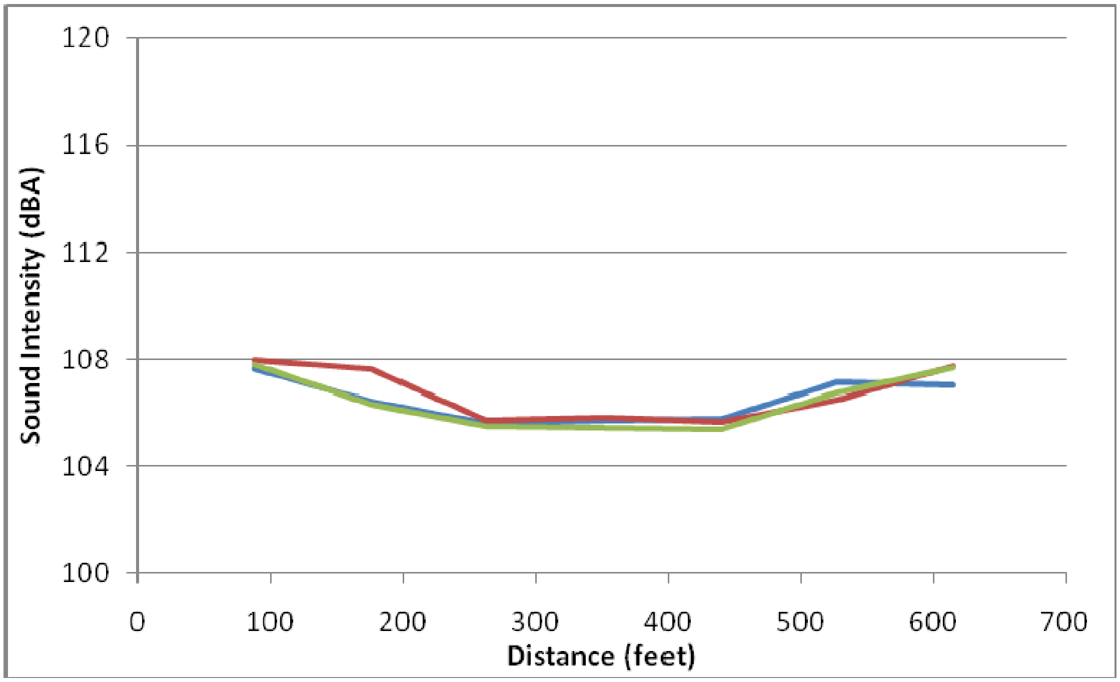


Figure 4.87: OBSI level in 1-sec intervals of Section QP-143.1, Year 1, three passes.

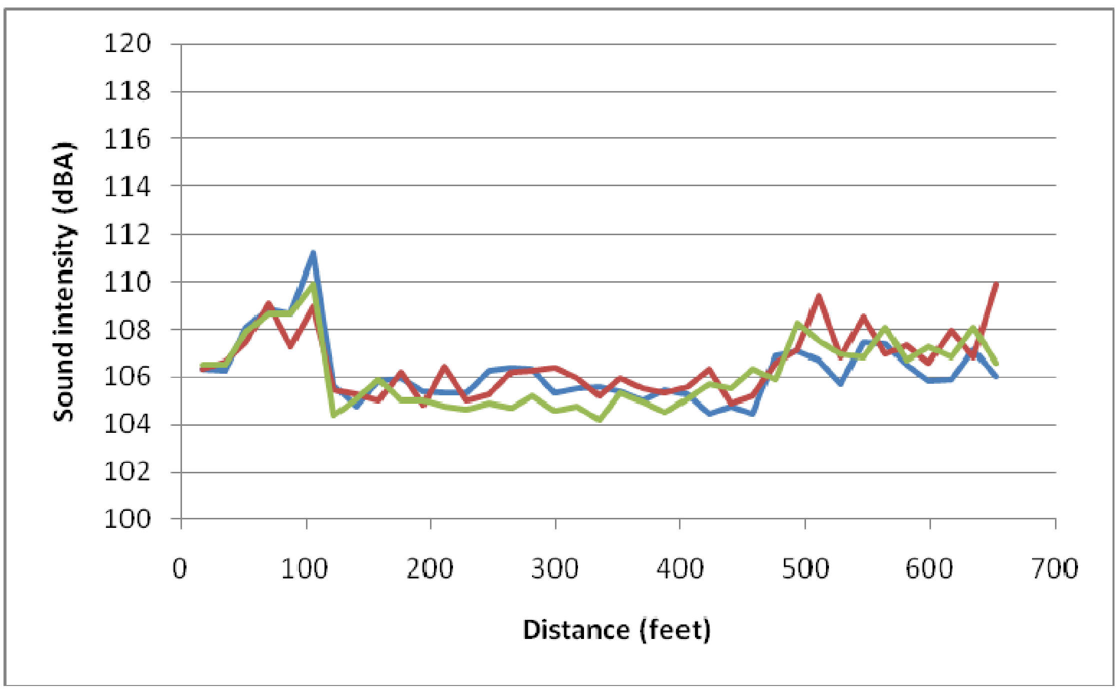


Figure 4.88: OBSI level in 0.2-sec intervals of Section QP-143.1, Year 2, three passes.

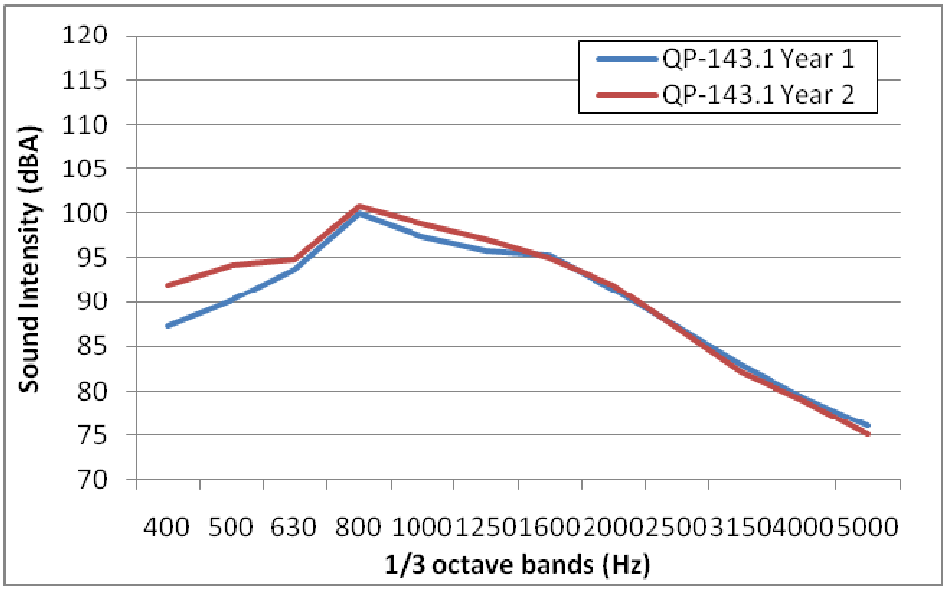


Figure 4.89: OBSI spectra of Section QP-143.1, Year 1 and Year 2.

4.12 Section QP-144.1 on Bridge Number 17 0012 at 03NEV80E21.1

Section QP-144.1 is on Bridge Number 17 0012, which is on I-80 near Truckee and transitions from concrete pavement to a deck with a polyester overlay that has a longitudinally tined finish. It is located a quarter mile east of Section QP-143.1. The effect of joints was not were excluded from the overall OBSI calculations because they had no effect on it. This bridge also has concrete pavement before and after it that is noisier than the bridge deck. This bridge is in an area that receives snow and is therefore subject to winter maintenance which may accelerate damage to the deck.

Table 4.14: OBSI Results (dB[A]) Section QP-144.1

	Bridge	Bridge without Joints	Pavement
Year 1	103.7	103.7	104.1
Year 2	105.4	105.4	107.6

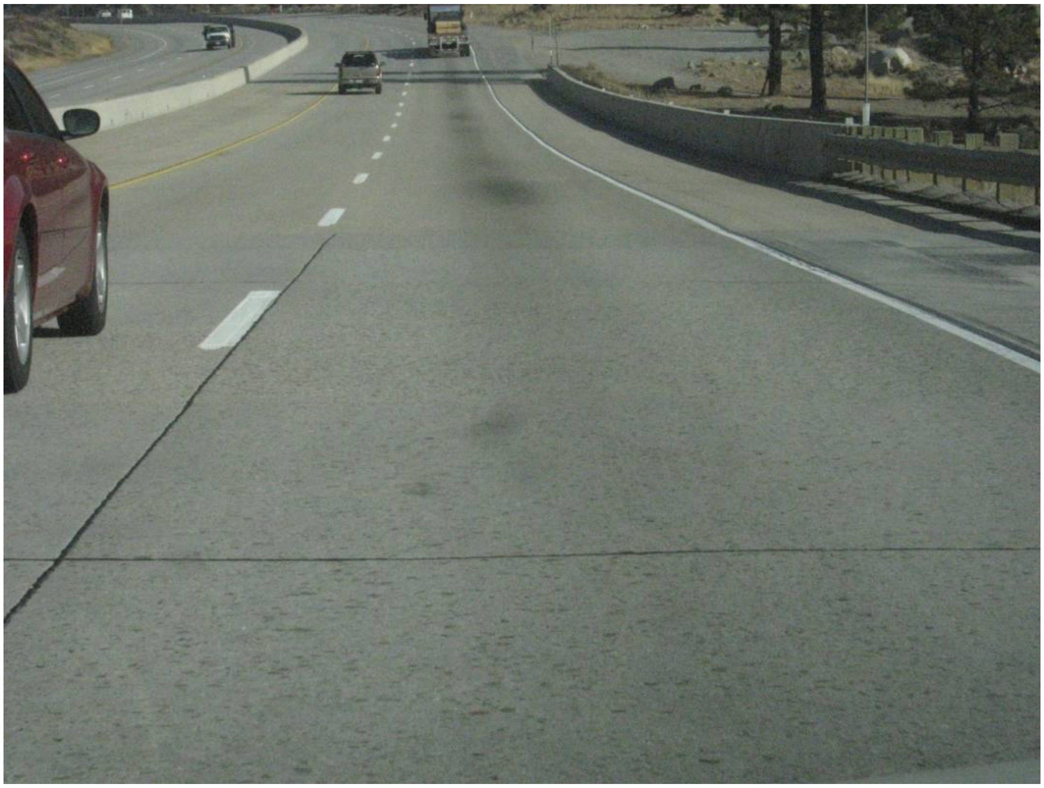


Figure 4.90: Beginning of Section QP-144.1.

Figure 4.91: Pavement–bridge transition on Section QP-144.1 (right side of photo).

Figure 4.92: Joint on Section QP-144.1.

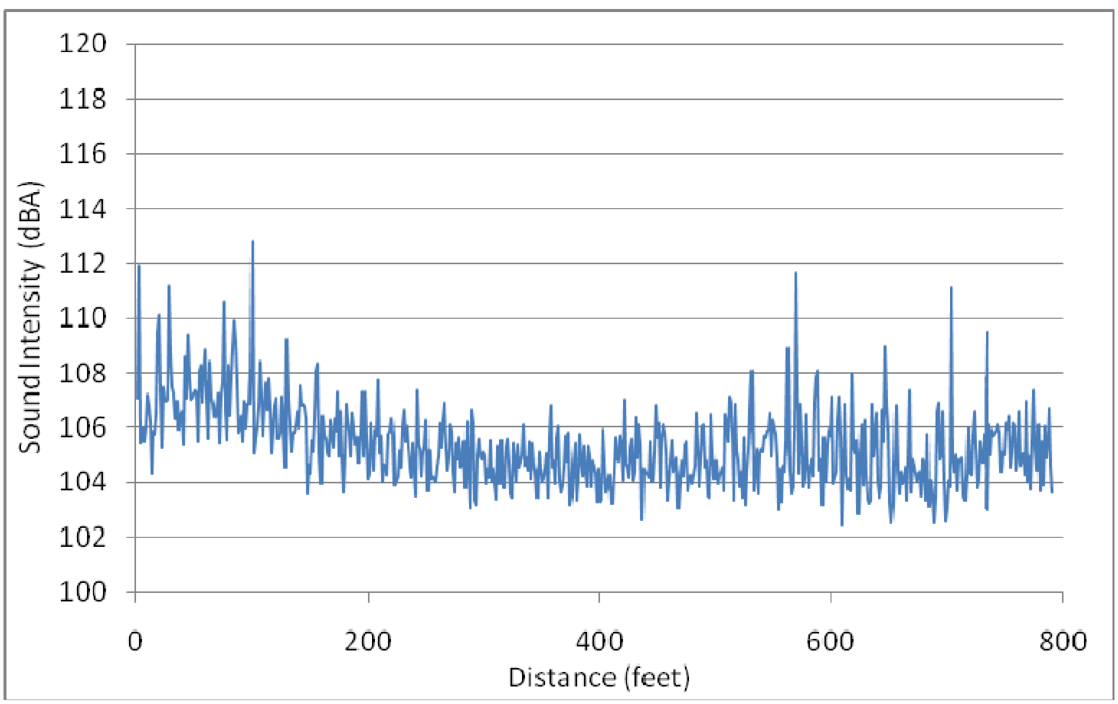


Figure 4.93: OBSI level in 15-msec intervals of Section QP-144.1, obtained in Year 1.

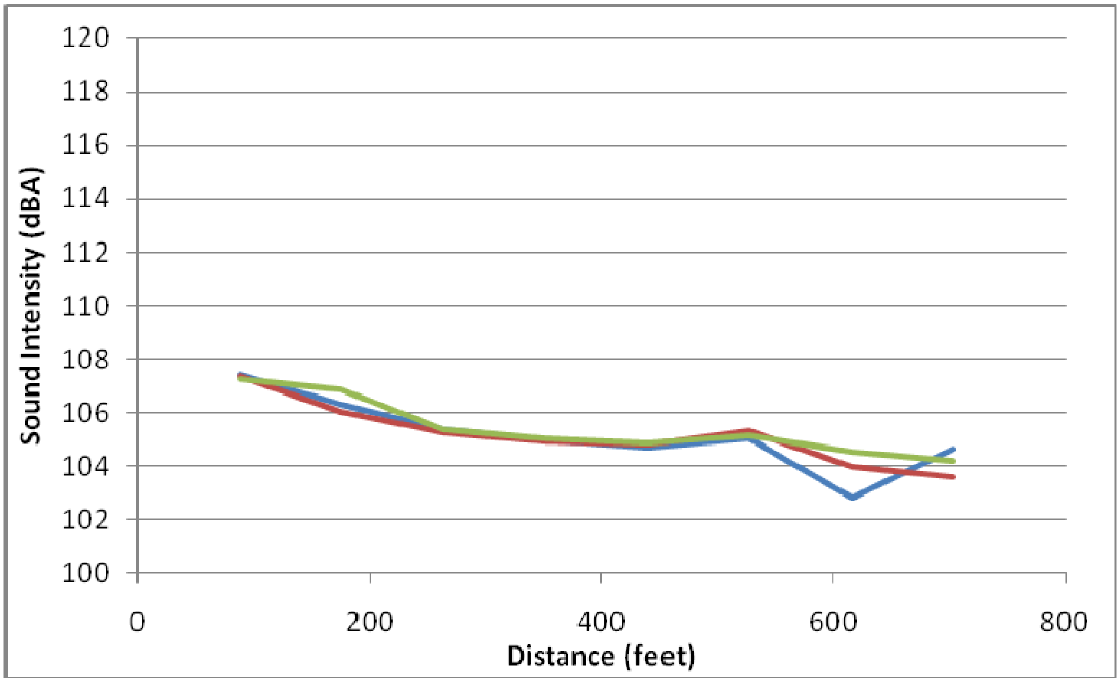


Figure 4.94: OBSI level in 1-sec intervals of Section QP-144.1, Year 1, three passes.

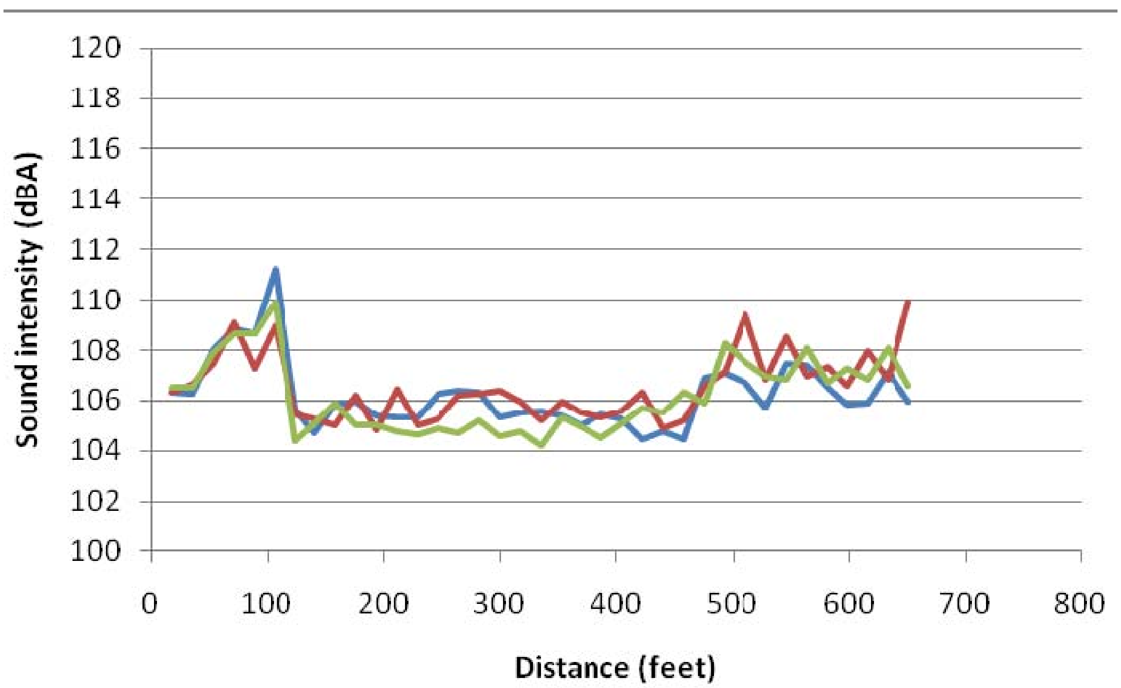


Figure 4.95: OBSI level in 0.2-sec intervals of Section QP-144.1, Year 2, three passes.

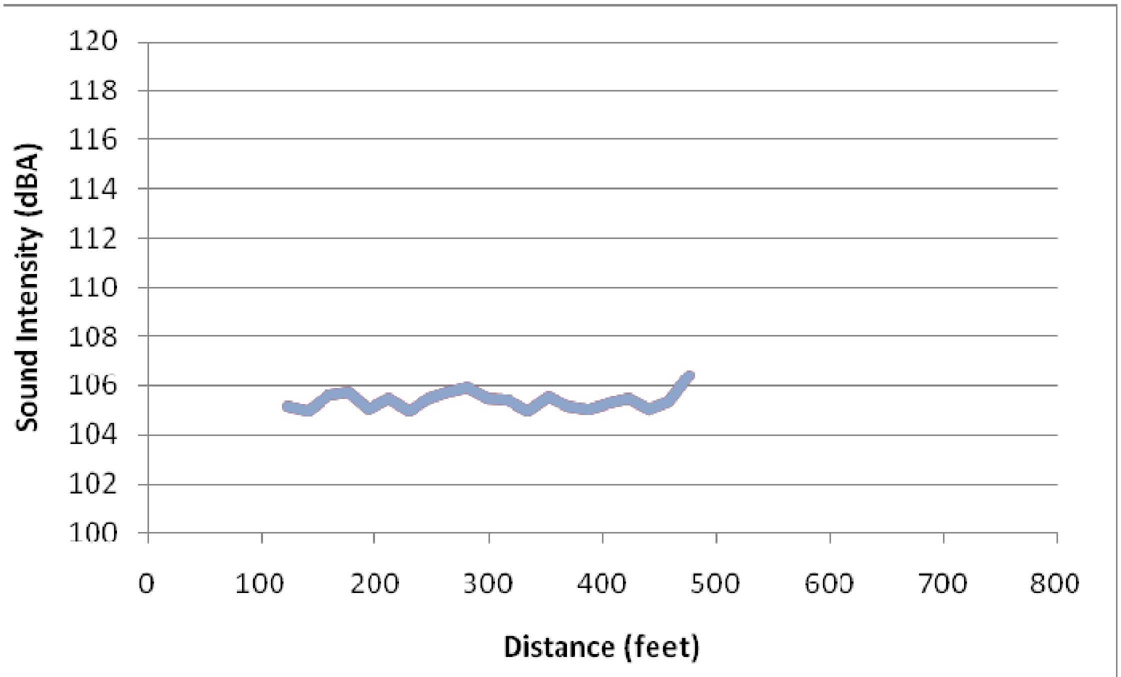


Figure 4.96: OBSI level in 0.2-sec intervals of Section QP-144.1, the bridge only, Year 2, average of three passes.

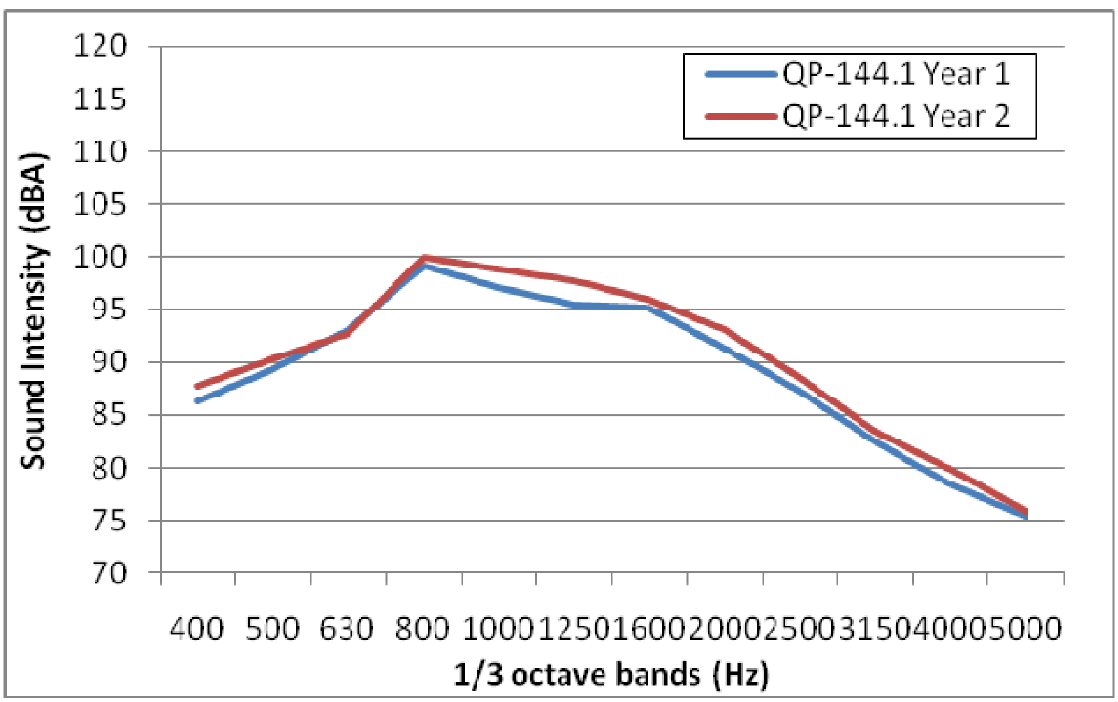


Figure 4.97: OBSI spectra of Section QP-144.1, Year 1 and Year 2.

4.13 Section QP-145.1 on Bridge Number 17 0098 at 03NEV267S0.4

Section QP-145.1 on Bridge Number 17 0098 is located on I-80 near Truckee. It is a polyester-overlaid deck that was overlaid in 2003 and again in 2009. The three joints were clearly noted, and the bridge was quieter than the adjacent concrete pavement. Using Year 1 data, the bridge was 3.0 dB(A) quieter than the pavement, and using Year 2 data, it the bridge was 4.5 dB(A) quieter. Even though the end joints and the center joint both generated a clear slap noise that reached about 113 dB(A), their effect on the bridge's overall OBSI level was minor, on the order of 0.3 to 0.5 dB(A). This bridge is in an area that receives snow and is therefore subject to winter maintenance which may accelerate damage to the deck.

Table 4.15: OBSI Results (dB[A]) Section QP-145.1

	Bridge	Bridge without Joints	Pavement
Year 1	102.7	102.4	105.7
Year 2	102.5	102.0	107.0

Figure 4.98: Beginning of Section QP-145.1 (right side of photos), Year 1 (left) and Year 2 (right).

Figure 4.99: Surface and joint on Section QP-145.1.

Figure 4.100: Detail of joint on Section QP-145.1.

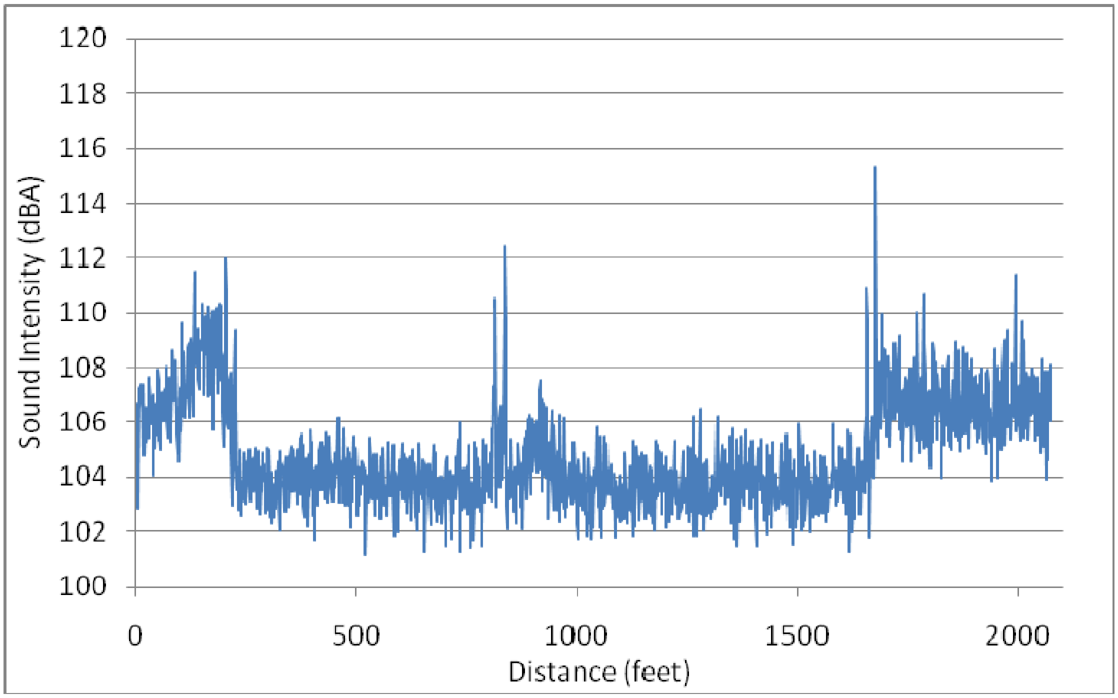


Figure 4.101: OBSI level in 15-msec intervals of Section QP-145.1, obtained in Year 1.

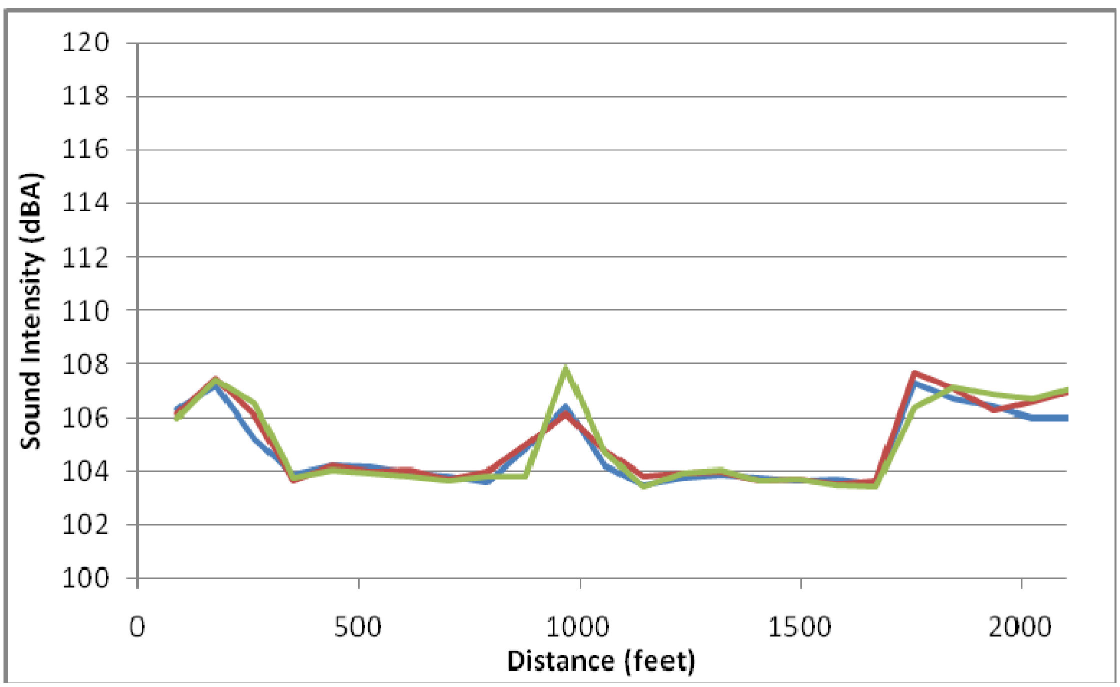


Figure 4.102: OBSI level in 1-sec intervals of Section QP-145.1, Year 1, three passes.

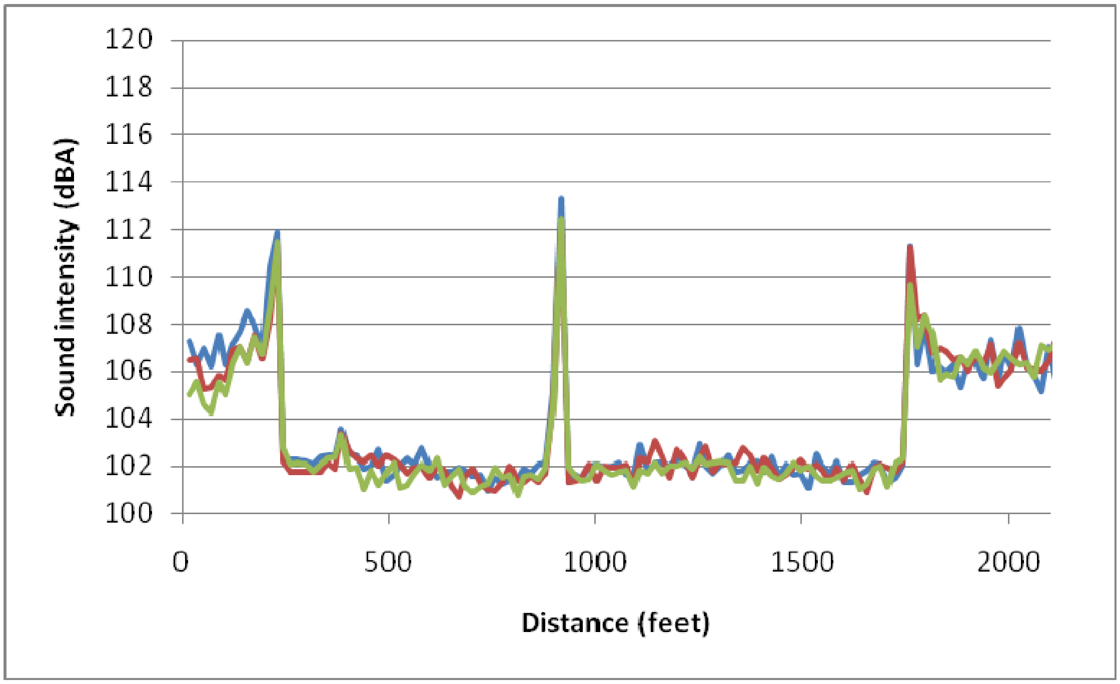


Figure 4.103: OBSI level in 0.2-sec intervals of Section QP-145.1, Year 2, three passes.

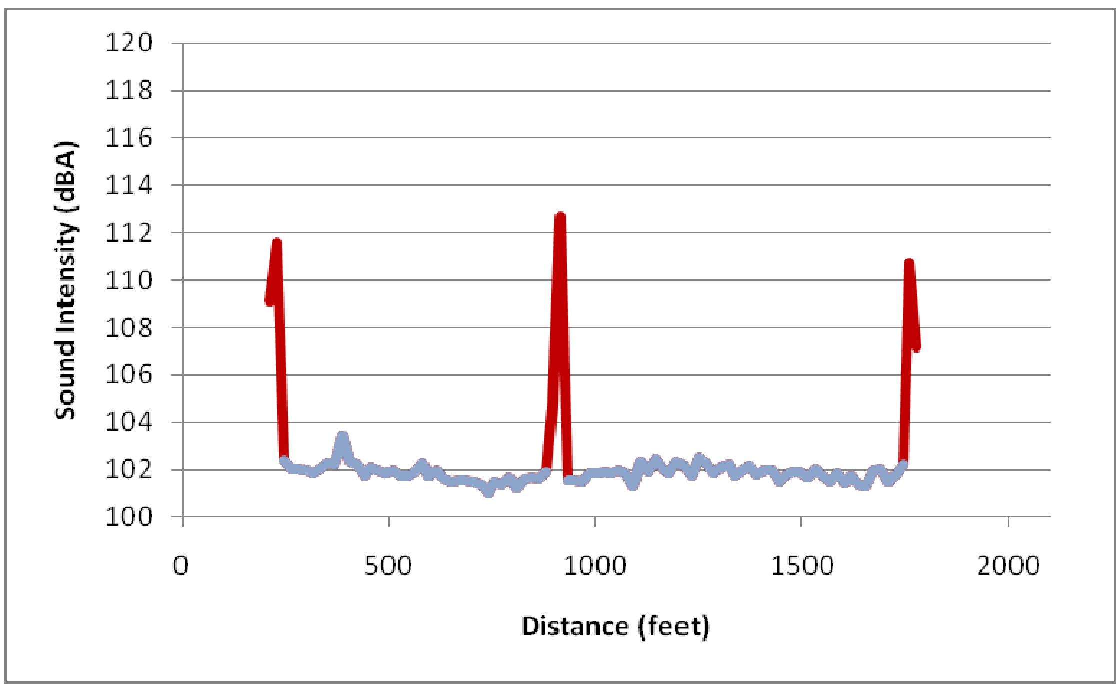


Figure 4.104: OBSI level in 0.2-sec intervals of Section QP-145.1, the bridge only, Year 2, average of three passes, highlighted joints.

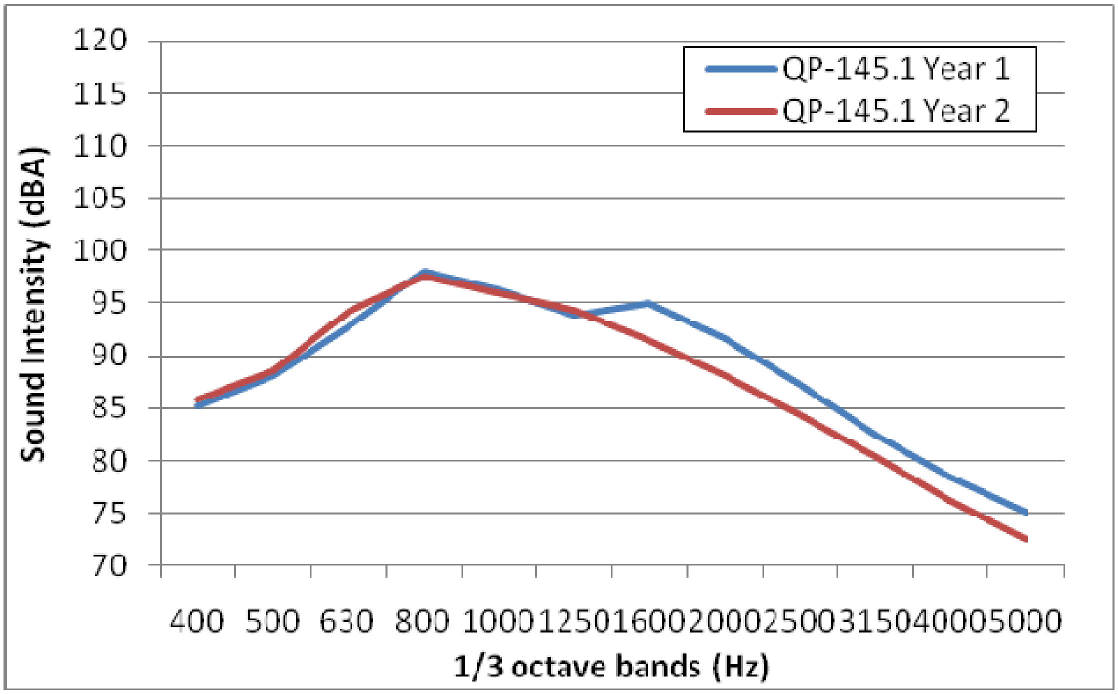


Figure 4.105: OBSI spectra of Section QP-145.1, Years 1 and 2.

4.14 Section QP-149.1 on Bridge Number 29 0309G at 10SJ4E19.4

Section QP-149.1 is on Bridge Number 29 0309G, which connects State Route 4 to State Route 99 southbound near Stockton. The section transitions from longitudinally tined concrete pavement to pavement that appears to be a polyester overlay deck, but which may be a methacrylate treatment. The deck appeared to have been overlaid with a thin polyester layer, because the original transversely tined surface was still "visible"—as indicated by the high OBSI level, which was about 2.5 dB(A) higher than the concrete pavement before and after the bridge. Year 1 data only is available as it appeared that the section had been resurfaced before second year data could be collected, making it unsuitable for evaluation. There was no effect from joints.

Table 4.16: OBSI Results (dB[A]) Section QP-149.1

	Bridge	Bridge without Joints	Pavement
Year 1	108.2	108.2	105.7
Year 2	n/a	n/a	n/a

Figure 4.106: Beginning of Section QP-149.1.

Figure 4.107: Surface of Section QP-149.1.

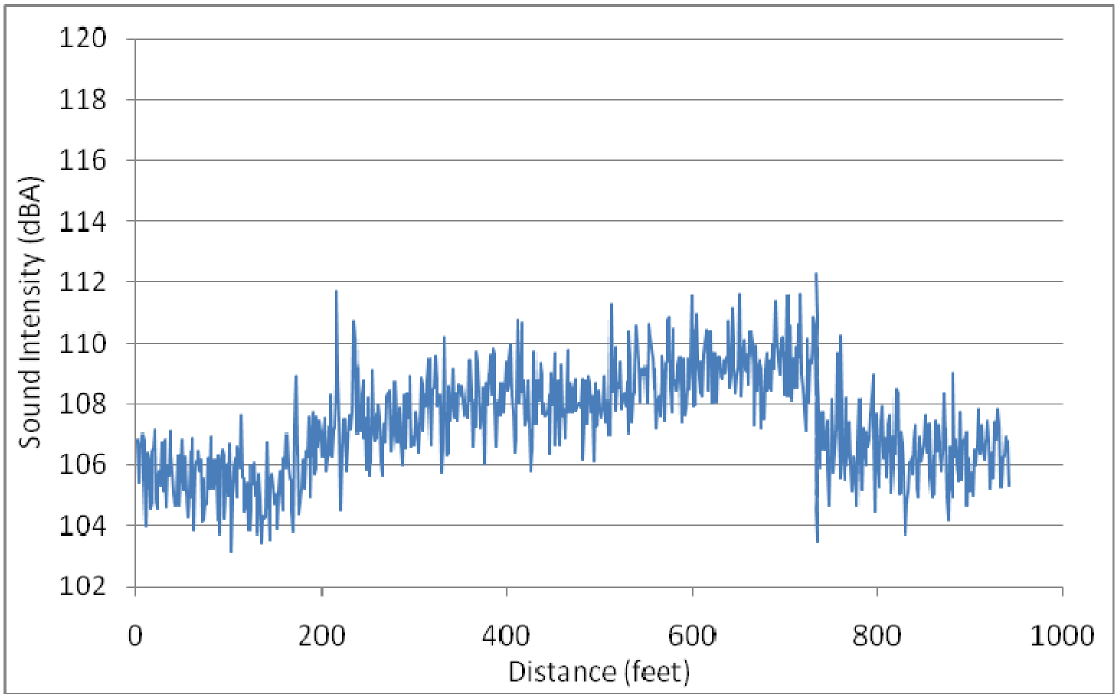


Figure 4.108: OBSI level in 15-msec intervals of Section QP-149.1, obtained in Year 1.

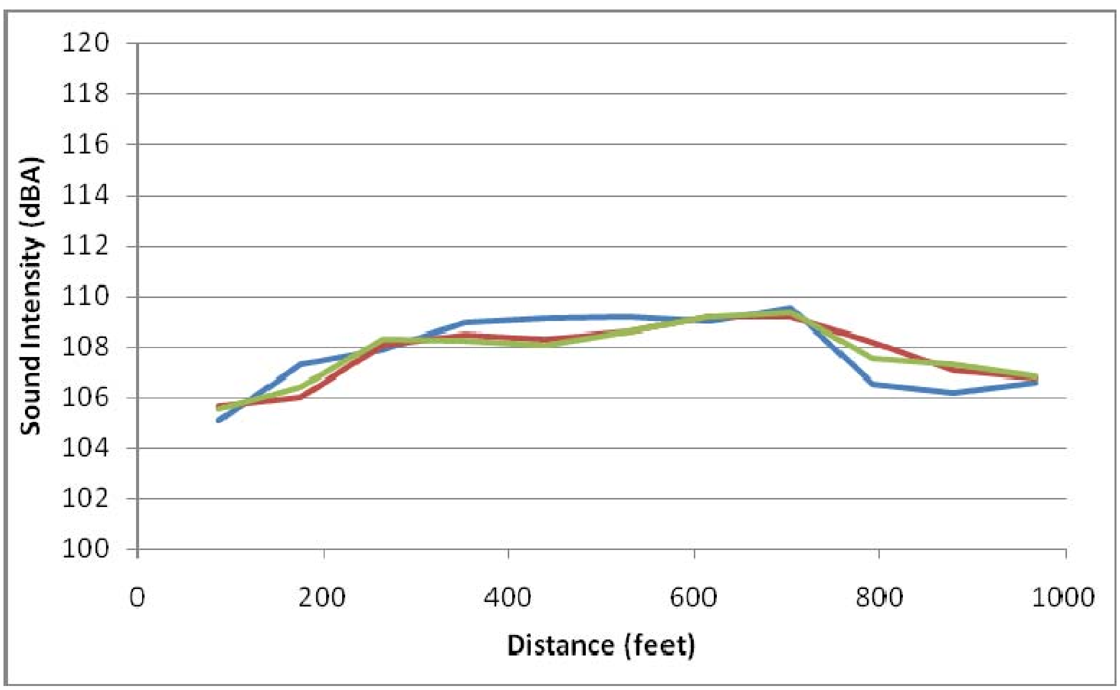


Figure 4.109: OBSI level in 1-sec intervals of Section QP-149.1, Year 1, three passes.

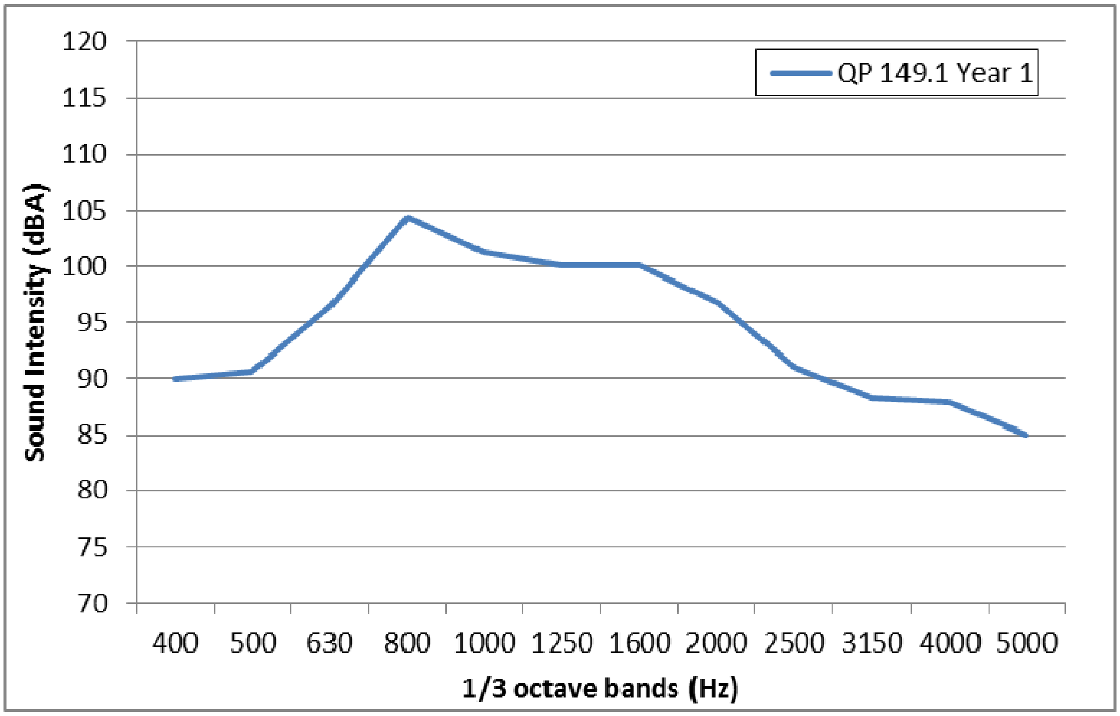


Figure 4.110: OBSI spectra of Section QP-149.1, Year 1 only.

4.15 Section QP-150.1 on Bridge Number 29 0119 at 10SJ99N17.8

Section QP-150.1 on Bridge Number 29 0119 is located on State Route 99 south of Stockton. There was no effect from joints, as they had just been filled with crack sealant. The spectra from Year 1 to Year 2, as well as the overall level, show an increase in overall noise level of 3.2 dB(A) from Year 1 to Year 2 that seems to confirm that the deck surface is not a polyester overlay as originally thought. Instead, the surface is thought to be a hot-mix asphalt overlay with a different mix than the asphalt concrete pavement before and after the bridge that has gotten noisier over one year. There is no other apparent explanation for the large changed between the two years.

Table 4.17: OBSI Results (dB[A]) Section QP-150.1

	Bridge	Bridge without Joints	Pavement
Year 1	100.7	100.7	103.0
Year 2	103.9	103.9	105.4

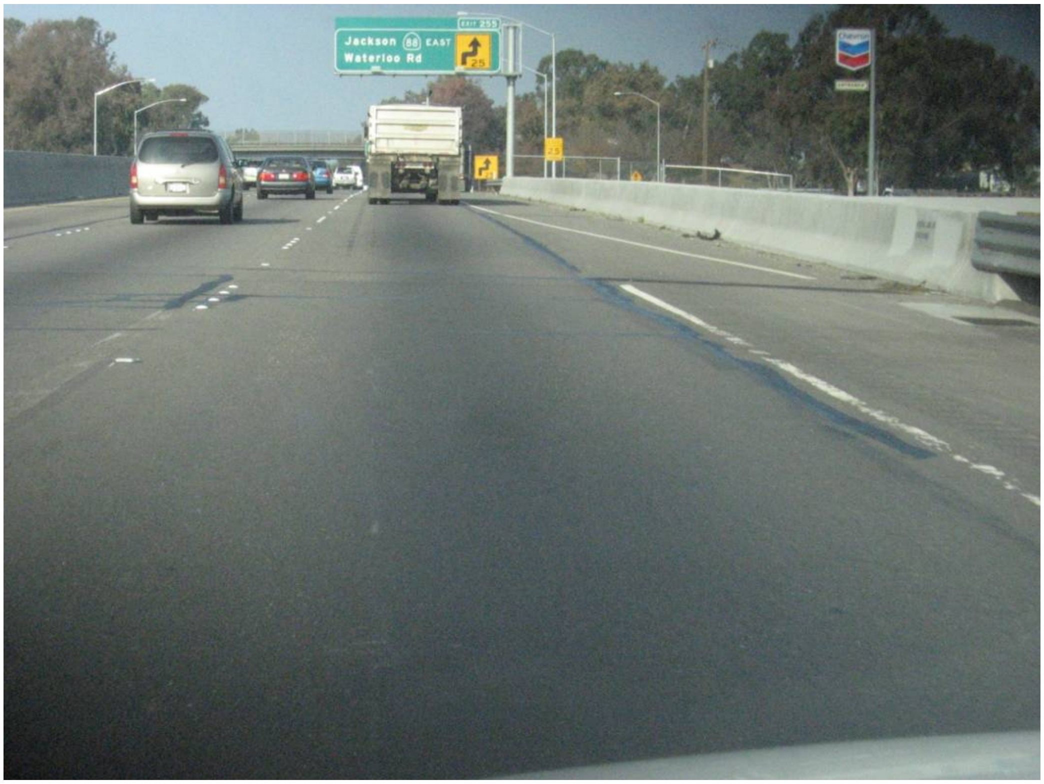


Figure 4.111: Beginning of Section QP-150.1.

Figure 4.112: Surface and joint on Section QP-150.1.

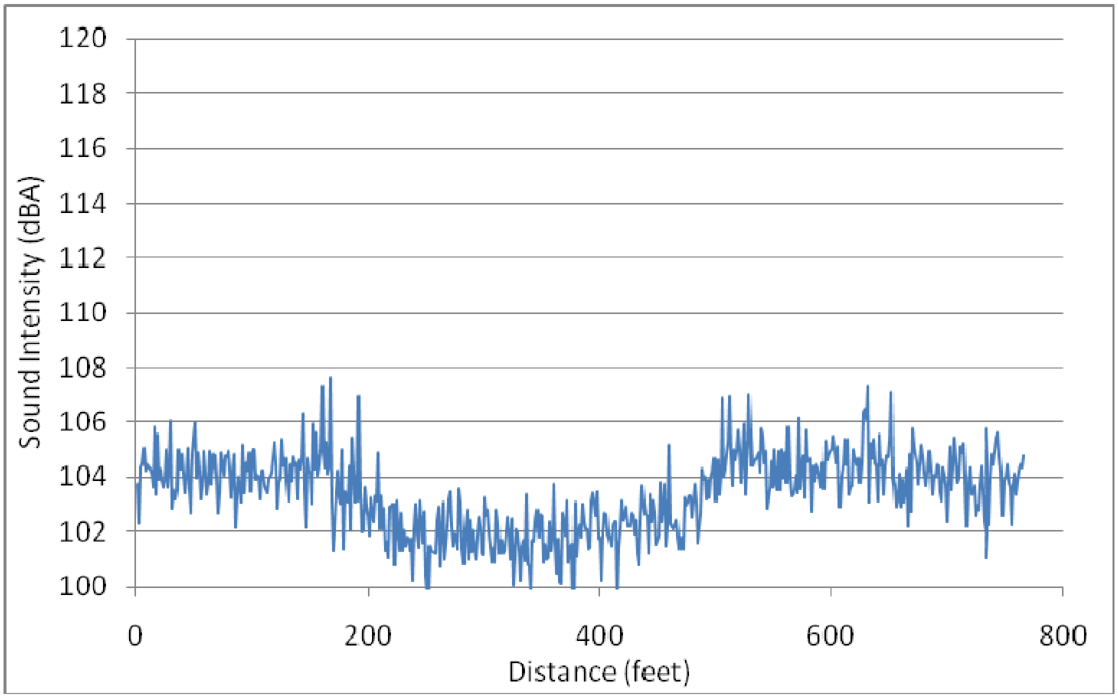


Figure 4.113: OBSI level in 15-msec intervals of Section QP-150.1, obtained in Year 1.

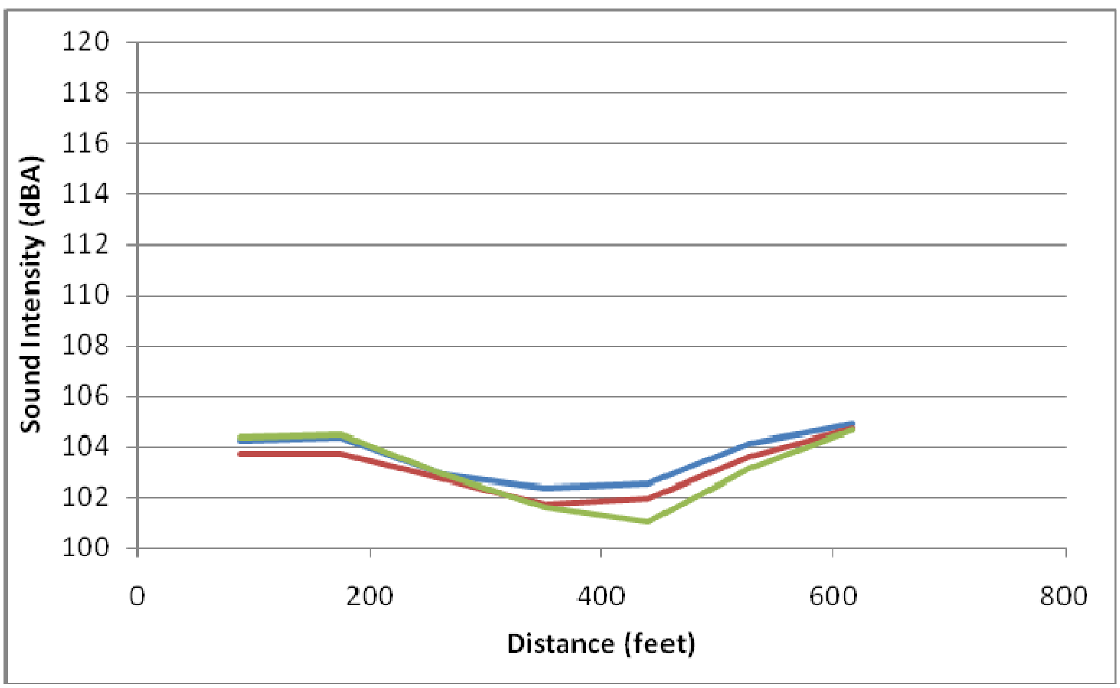


Figure 4.114: OBSI level in 1-sec intervals of Section QP-150.1, Year 1, three passes.

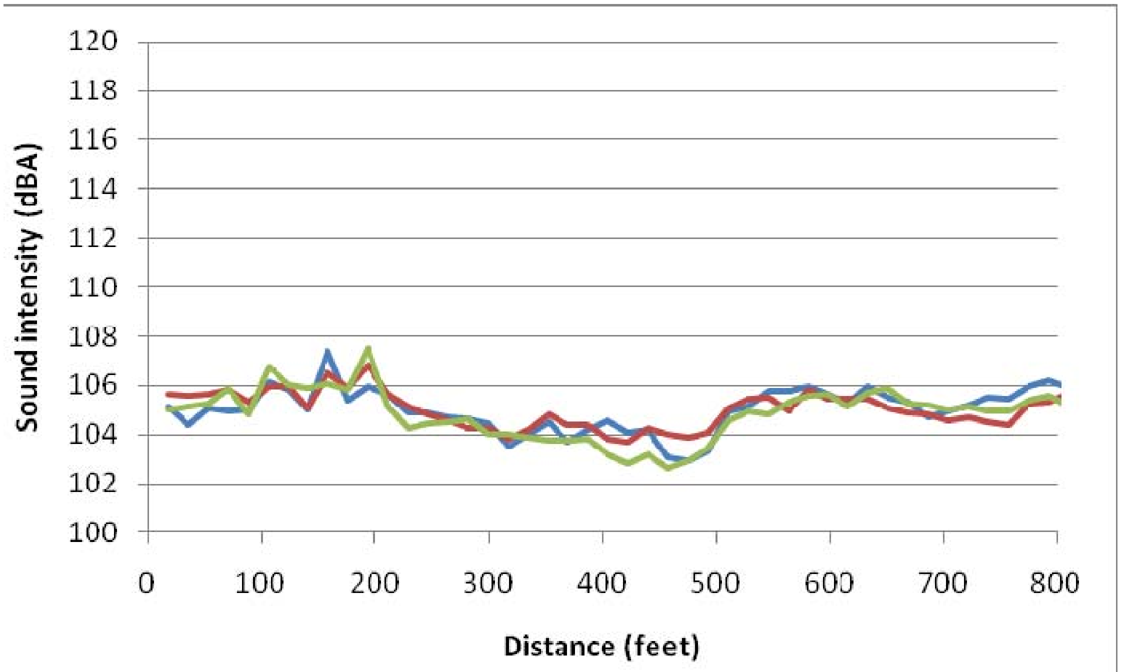


Figure 4.115: OBSI level in 0.2-sec intervals of Section QP-150.1, Year 2, three passes.

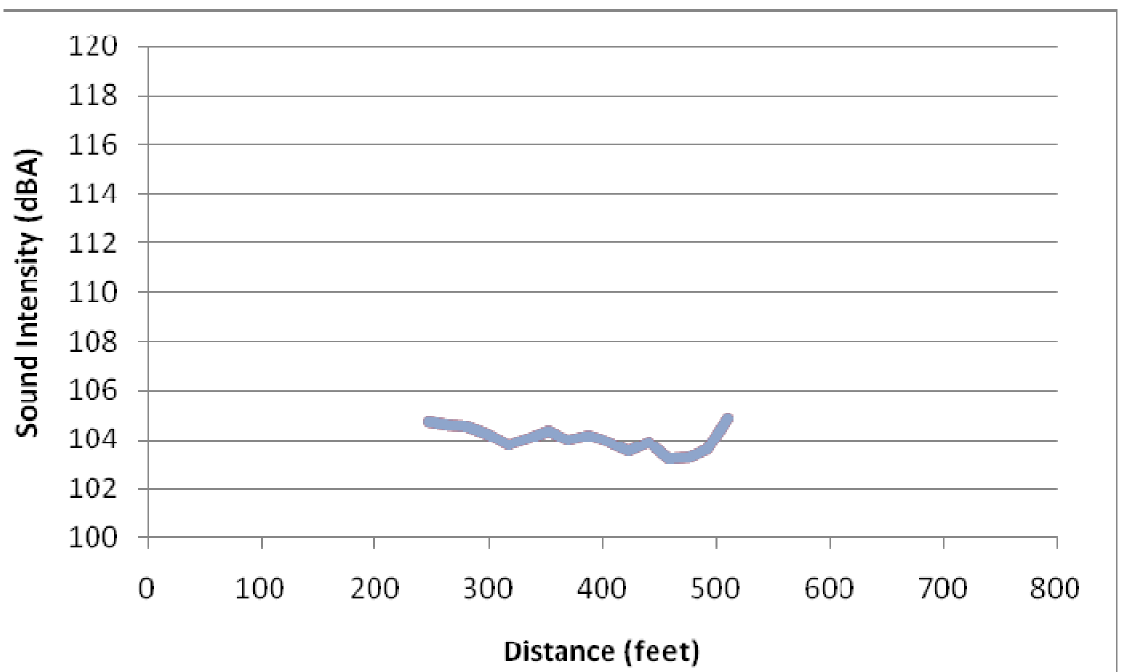


Figure 4.116: OBSI level in 0.2-sec intervals of Section QP-150.1, the bridge only, Year 2, average of three passes.

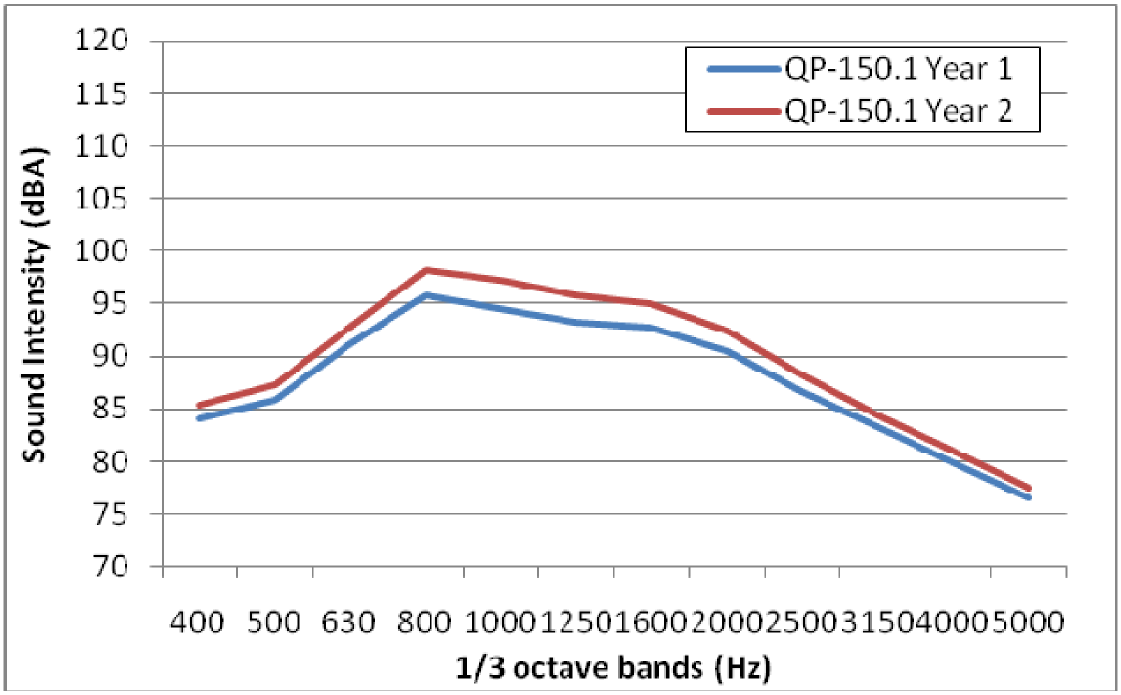


Figure 4.117: OBSI spectra of Section QP-150.1, Year 1 and Year 2.

4.16 Section QP-151.1 on Bridge Number 22 0026R at 03Yol80E11.3

Section QP-151.1 is on Bridge Number 22 0026R, which is on I-80 where it crosses the Sacramento River north of Sacramento. The bridge is 4,050-ft (1,235-m) long (the longest in this study) and its surface is a longitudinally tined polyester overlay. Noise was measured at the adjacent concrete pavement at the end of the bridge and it was found to be nearly 1.0 dB(A) louder than the bridge itself. Rather than eliminating the clearly identifiable bridge joints from the analysis, the central portion of this long bridge was taken as the "bridge part." Note that the surface material and texture are the same in areas where there are slap noise–generating joints and in the central area where there are none. There is approximately 1,970 ft (601 m) between the typical joints (see joint in Figure 4.119) at the center of the bridge, and in this region there are four special joints (see Figure 4.120) that are unidentifiable in the noise data and therefore considered as "quiet joints."

Table 4.18: OBSI Results (dB[A]) Section QP-151.1

	Bridge	Bridge without Joints	Pavement
Year 1	103.2	103.2	104.1
Year 2	104.8	104.8	105.6

Figure 4.118: Beginning of Section QP-151.1.

Figure 4.119: Surface and typical joint on Section QP-151.1.

Figure 4.120: Surface and special longer span joints (one of four) on Section QP-151.1.

Figure 4.121: Detail of longitudinal texture on polyester overlay deck on Section QP-151.1.

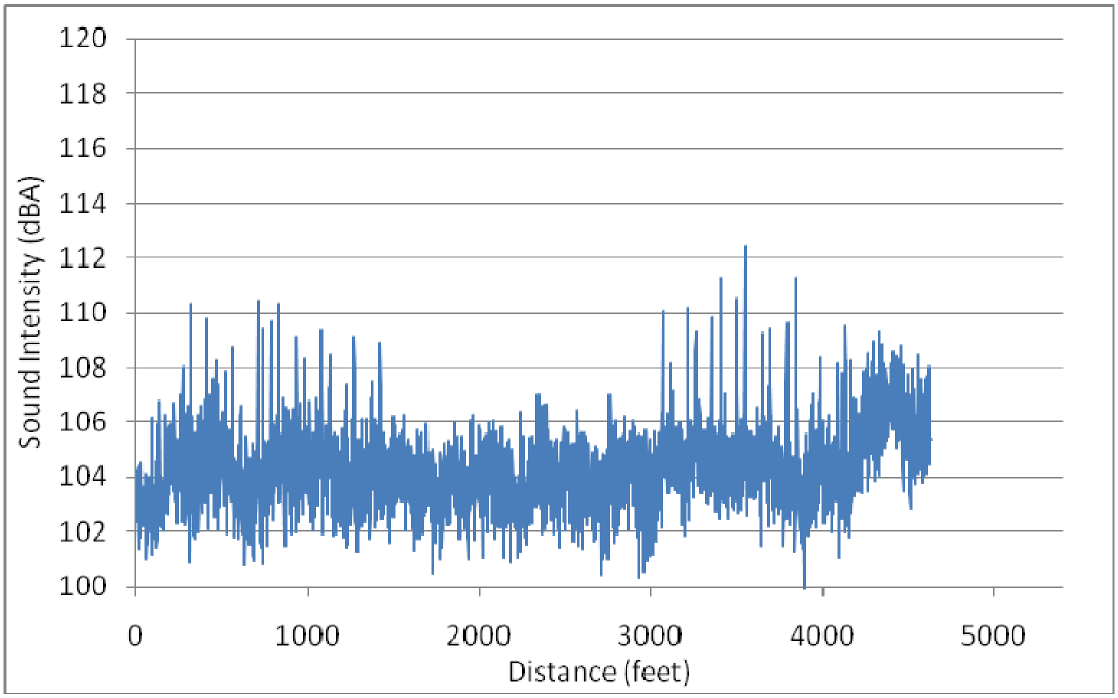


Figure 4.122: OBSI level in 15-msec intervals of Section QP-151.1, obtained in Year 1.

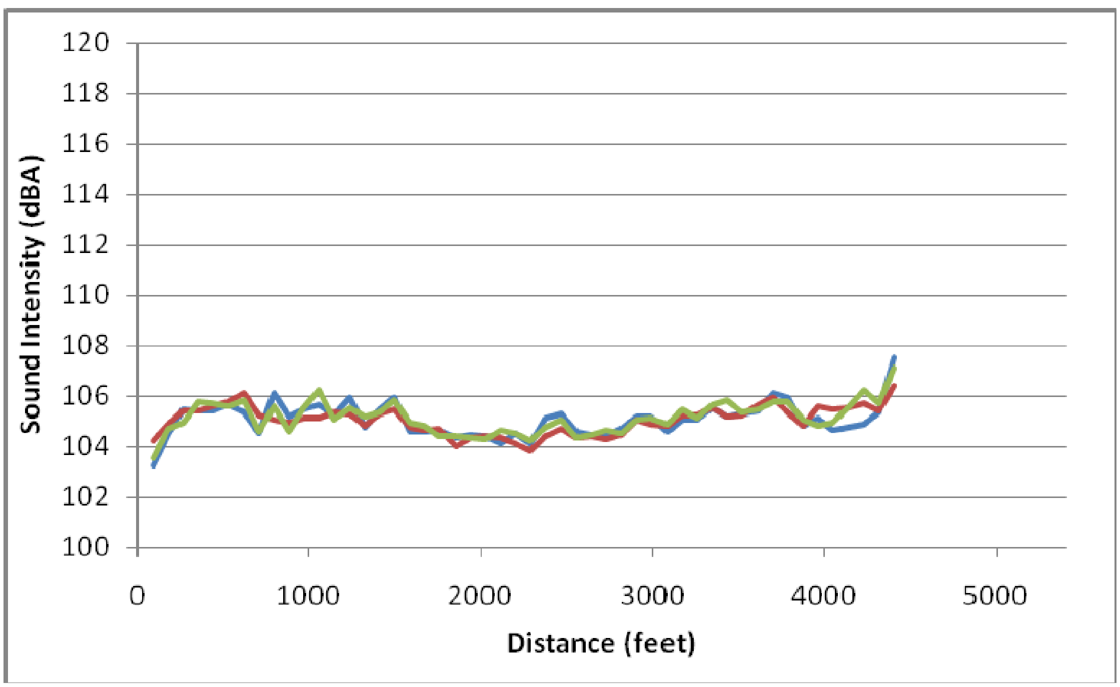


Figure 4.123: OBSI level in 1-sec intervals of Section QP-151.1, Year 1, three passes.

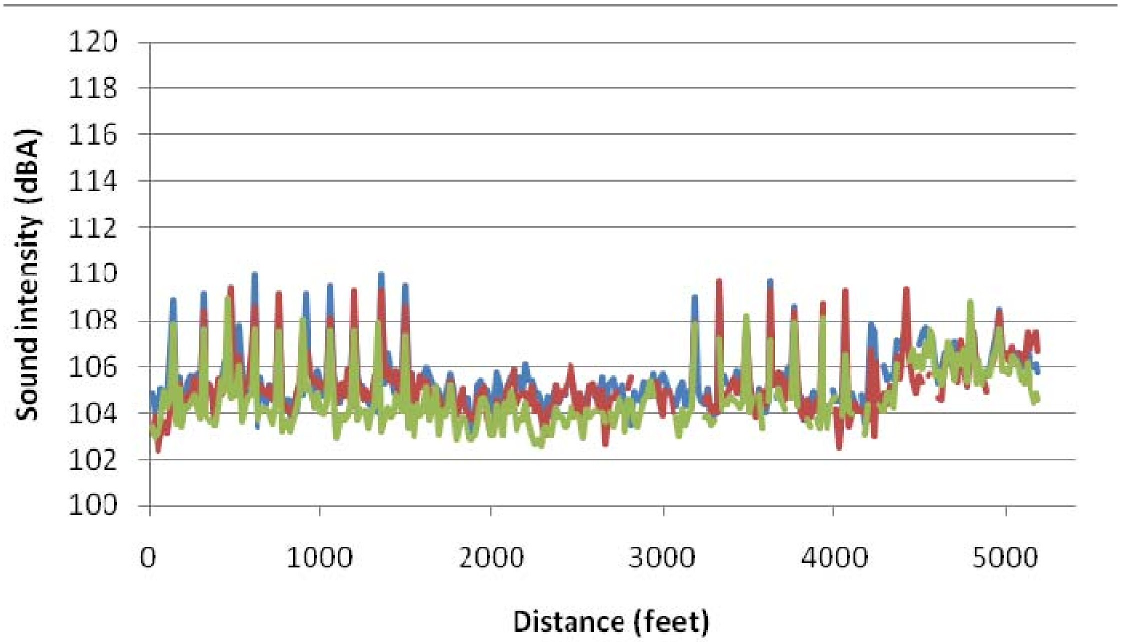


Figure 4.124: OBSI level in 0.2-sec intervals of Section QP-151.1, Year 2, three passes. (Note joint slap in concrete pavement before and after the bridge.)

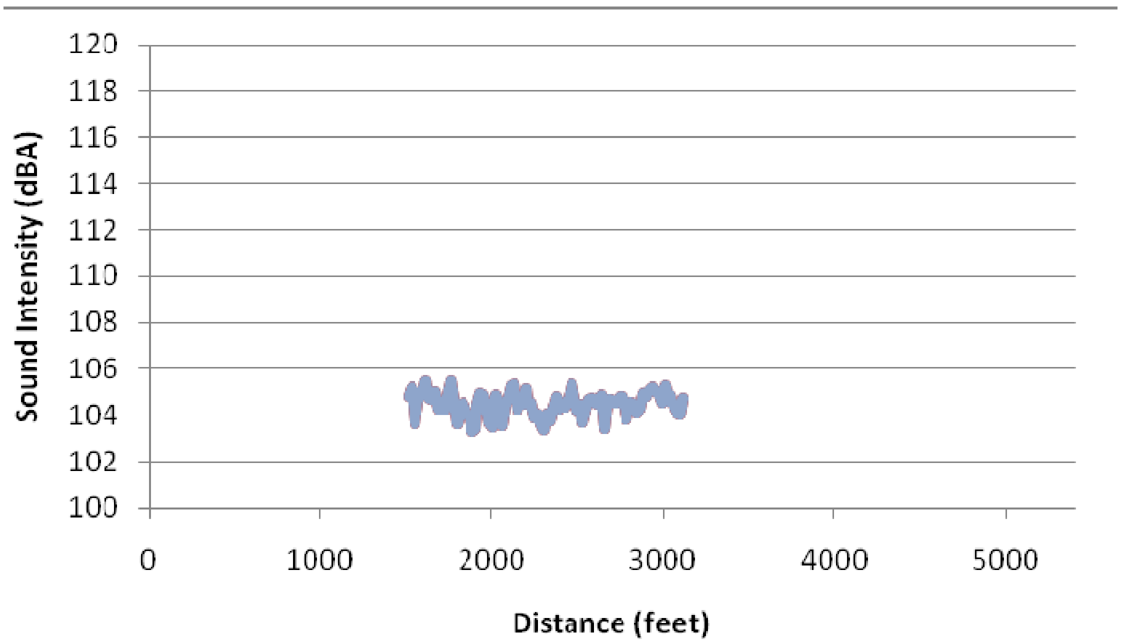


Figure 4.125: OBSI level in 0.2-sec intervals of Section QP-151.1, central part of the bridge only, Year 2, average of three passes.

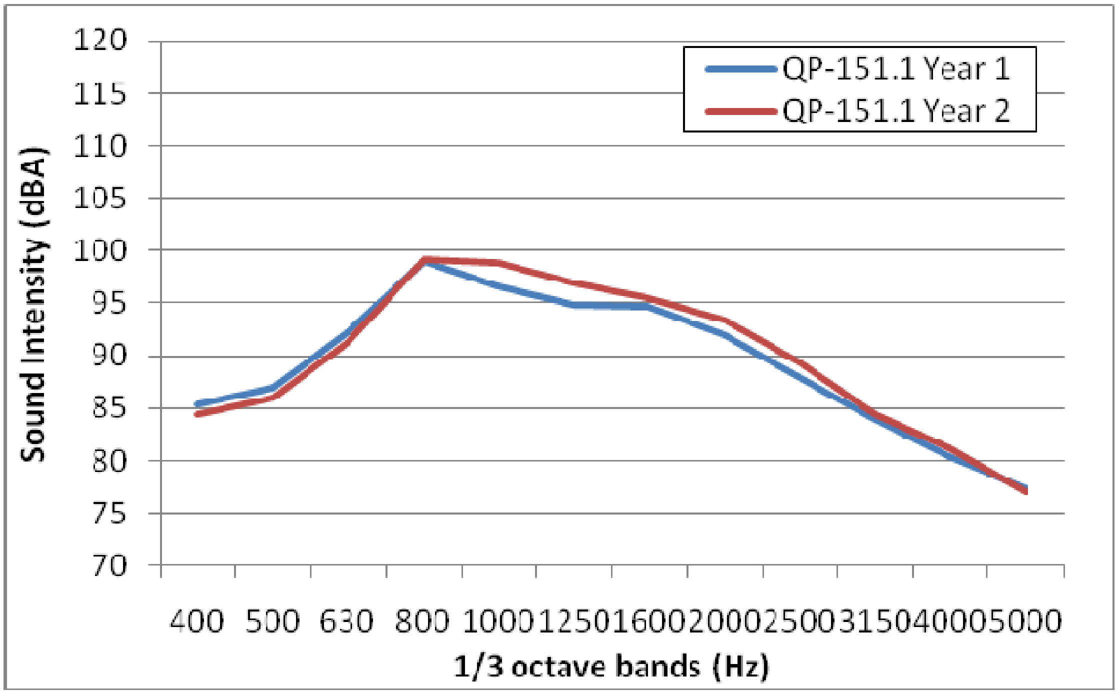


Figure 4.126: OBSI spectra of Section QP-151.1, Year 1 and Year 2.

4.17 Section QP-152.1 on Bridge Number 39 0015L at 10Mer99S31.1

Section QP-152.1 is on Bridge Number 39 0015L, which is on State Route 99 in Merced County and transitions from concrete pavement to a transversely tined deck. It is a single-span bridge and the surface near the joints was diamond ground. There was no effect from joints. The OBSI level in Year 2 decreased by 0.7 dB(A) on the bridge with respect to the Year 1 results, with a similar reduction on the pavement. The surface was the same in both years, as verified pictorially. No explanation was found for this important decrease in OBSI level. The atmospheric conditions were very similar in both years, and the calibration of the microphones did not show any abnormality. It will be important to see OBSI measurements in the following years to help determine whether the repeated measurements are closer to the first year or the second year values.

Table 4.19: OBSI Results (dB[A]) Section QP-152.1

	Bridge	Bridge without Joints	Pavement
Year 1	106.5	106.5	104.6
Year 2	105.8	105.8	103.9

Figure 4.127: Beginning of Section QP-152.1 with diamond-ground surface near the joint.

Figure 4.128: Surface and joint on Section QP-152.1.

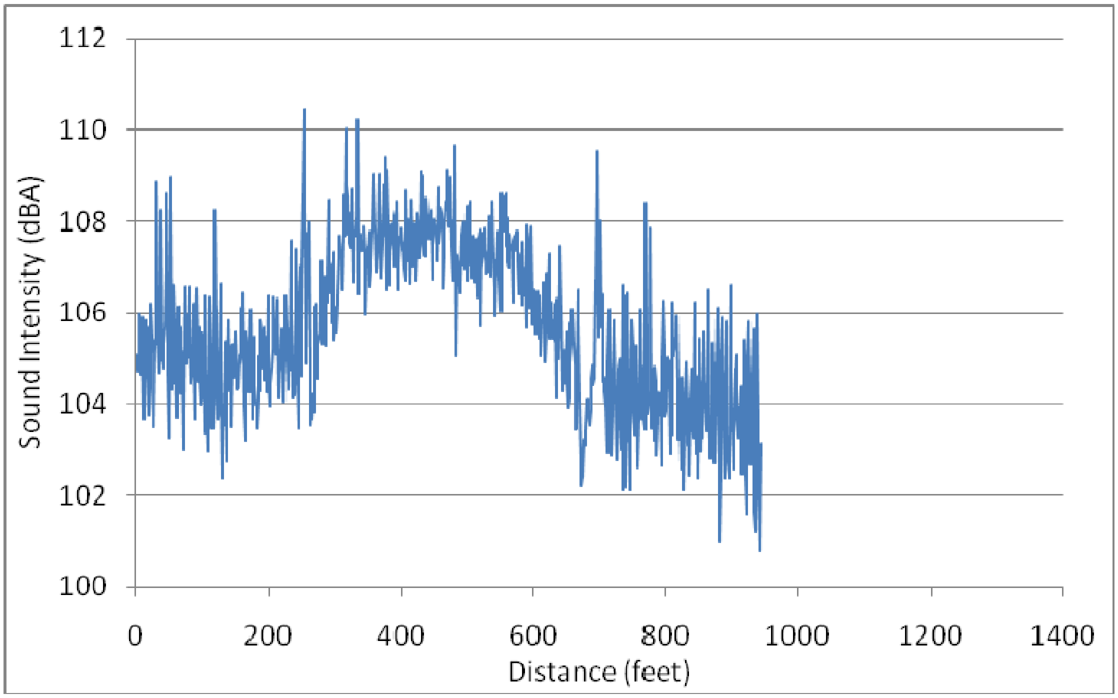


Figure 4.129: OBSI level in 15-msec intervals of Section QP-152.1, obtained in Year 1.

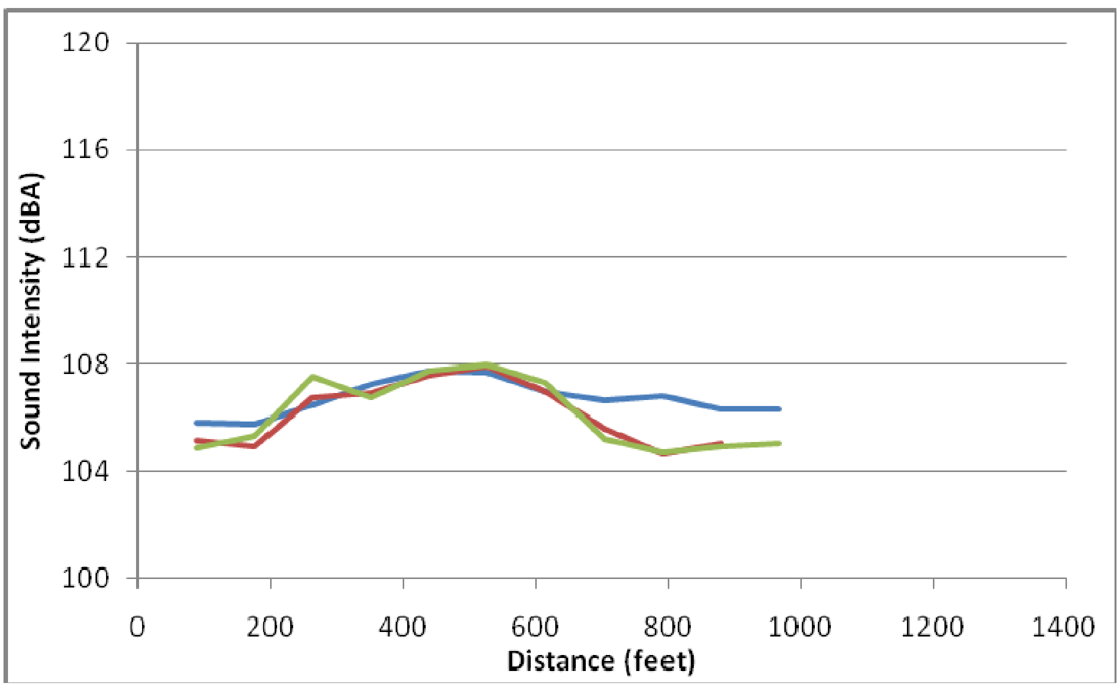


Figure 4.130: OBSI level in 1-sec intervals of Section QP-152.1, Year 1, three passes.

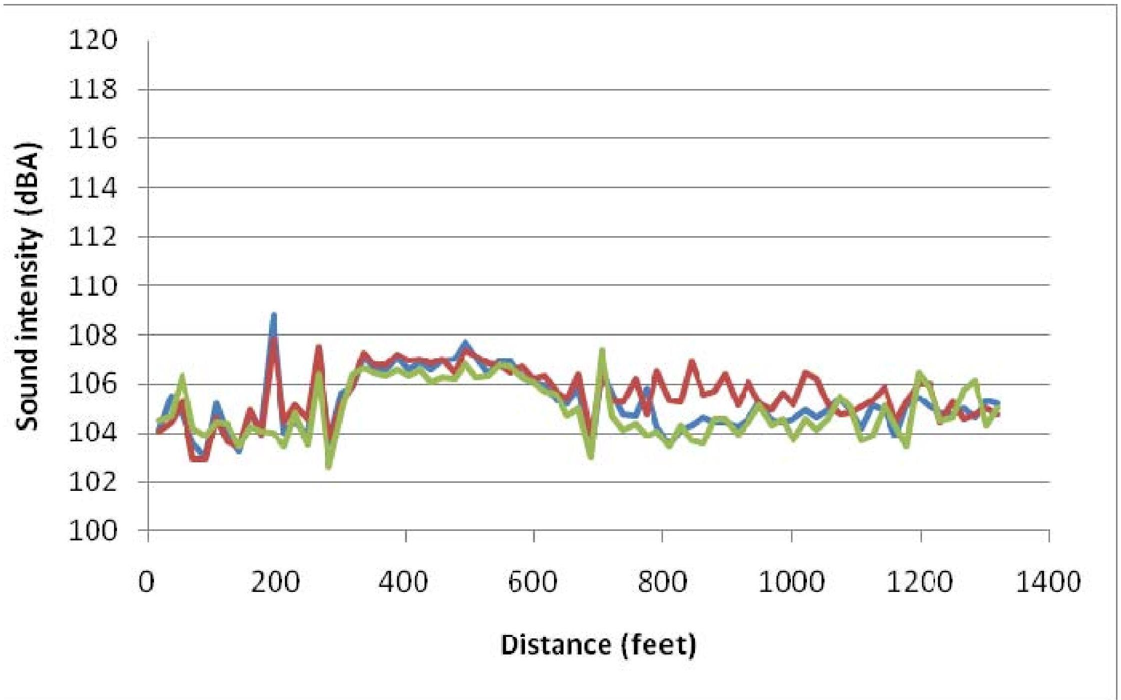


Figure 4.131: OBSI level in 0.2-sec intervals of Section QP-152.1, Year 2, three passes.

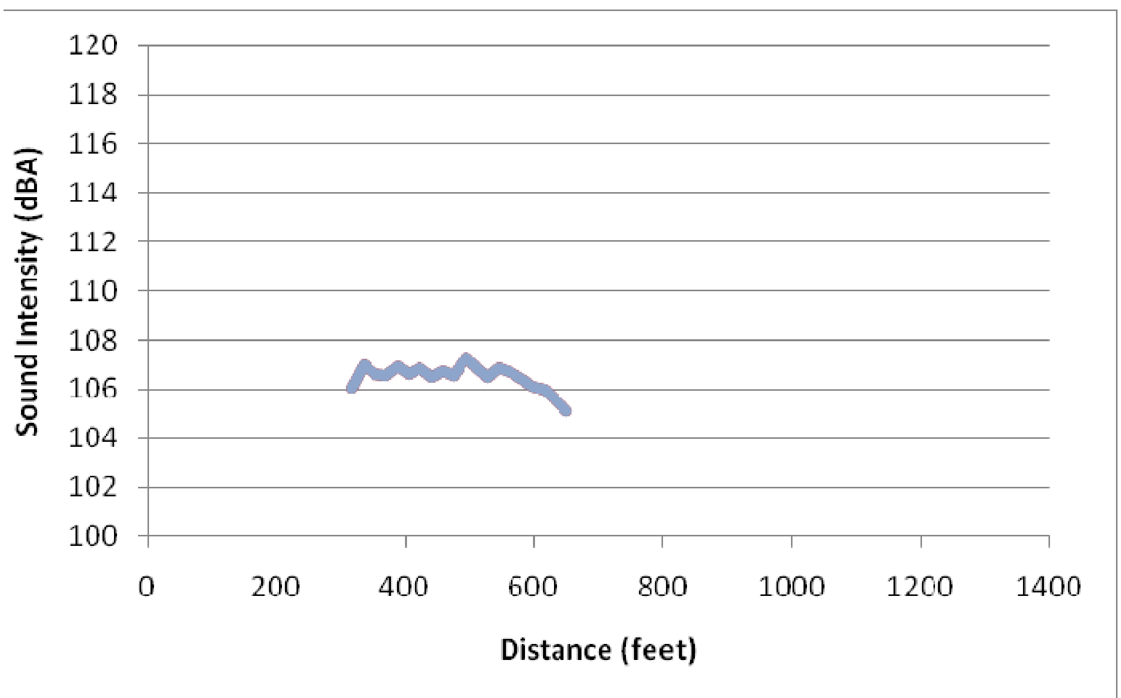


Figure 4.132: OBSI level in 0.2-sec intervals of Section QP-152.1, bridge only, Year 2, average of three passes.

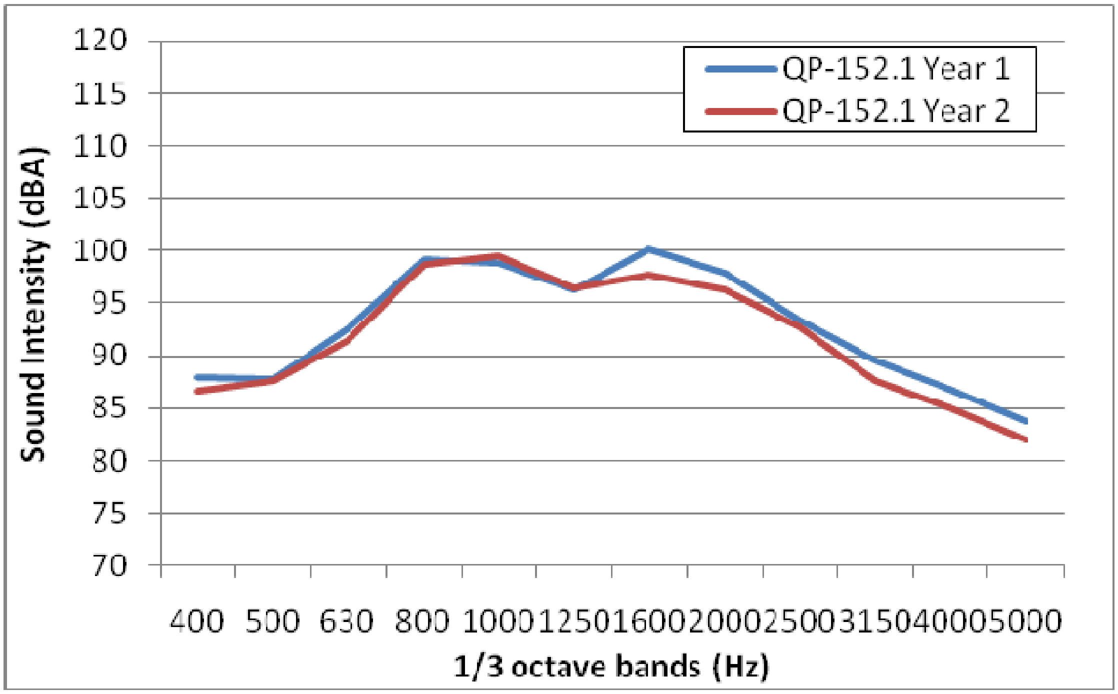


Figure 4.133: OBSI spectra of Section QP-152.1, Year 1 and Year 2.

4.18 Section QP-153.4 on Bridge Number 39 0010L at 10Mer99S17.5

Section QP-153.4, on Bridge Number 39 0010L, is on State Route 99 in Merced County and is located at the end of a set of concrete pavement study sections (QP-153.1, 153.2, and 153.3). The section transitions from diamond-grooved concrete pavement into a bridge deck with no texture that was classified as burlap drag. The bridge is only 93 feet long (the shortest in the study). The deck is slightly quieter than the adjacent pavement.

Table 4.20: OBSI Results (dB[A]) Section QP-153.4

	Bridge	Bridge without Joints	Pavement
Year 1	104.5	104.5	105.6
Year 2	105.5	105.5	107.0

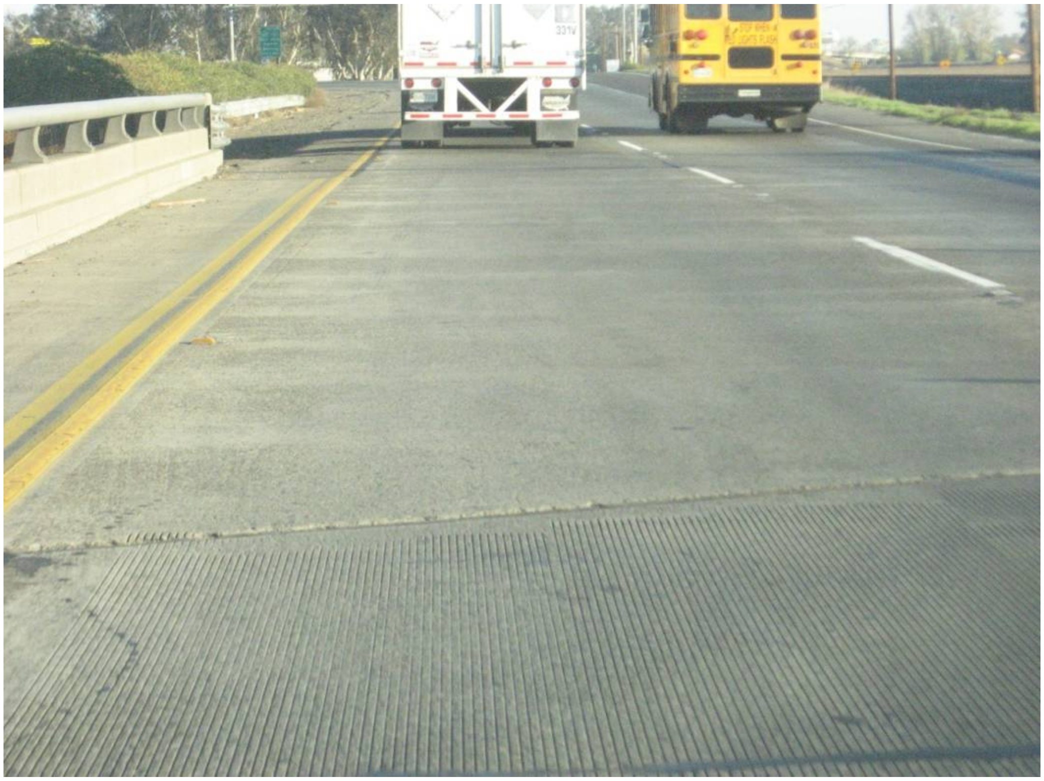


Figure 4.134: Beginning of Section QP-153.4.

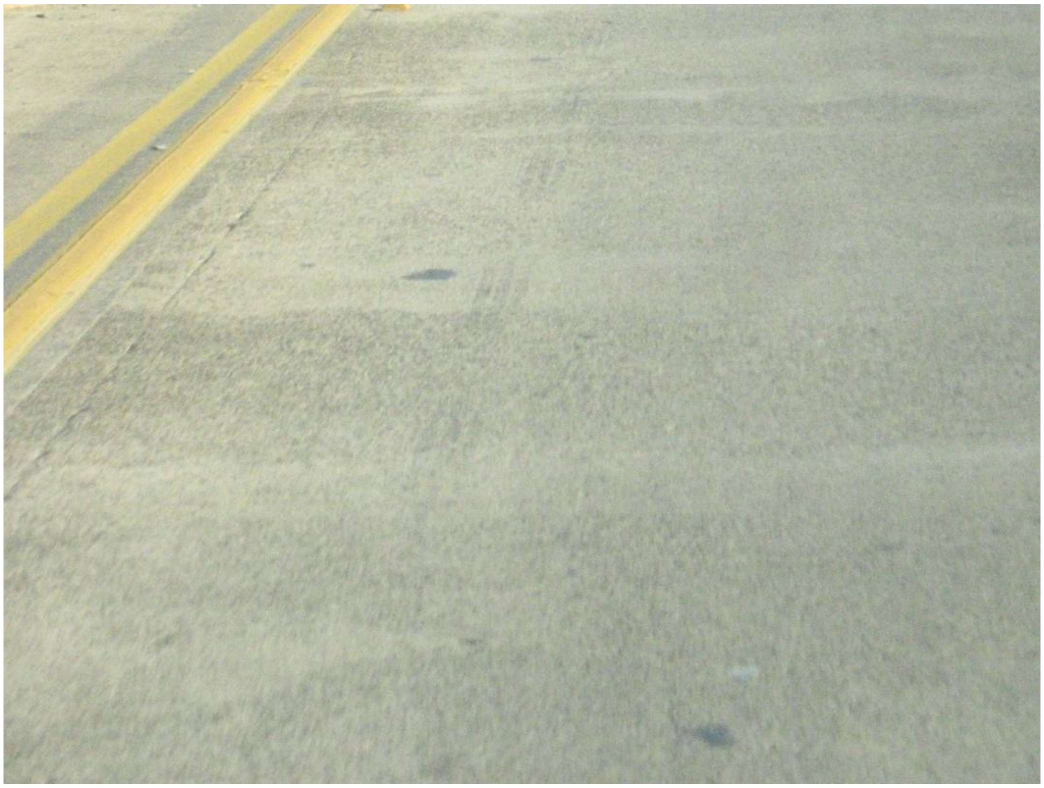


Figure 4.135: Surface texture on Section QP-153.4.

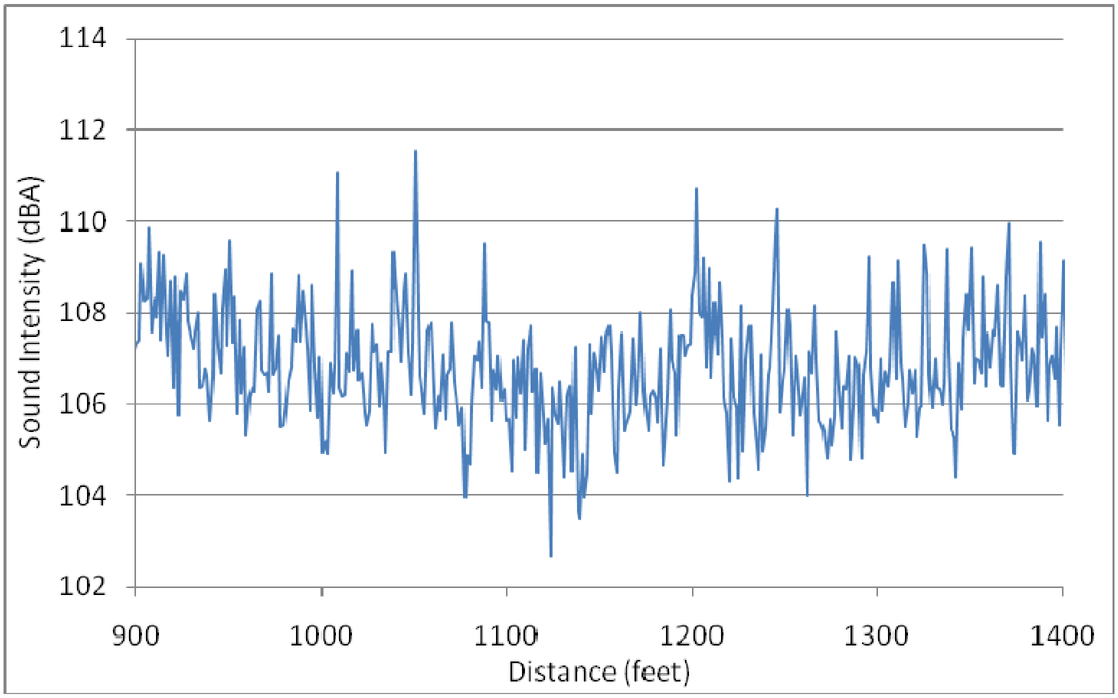


Figure 4.136: OBSI level in 15-msec intervals of Section QP-153.4, obtained in Year 1.

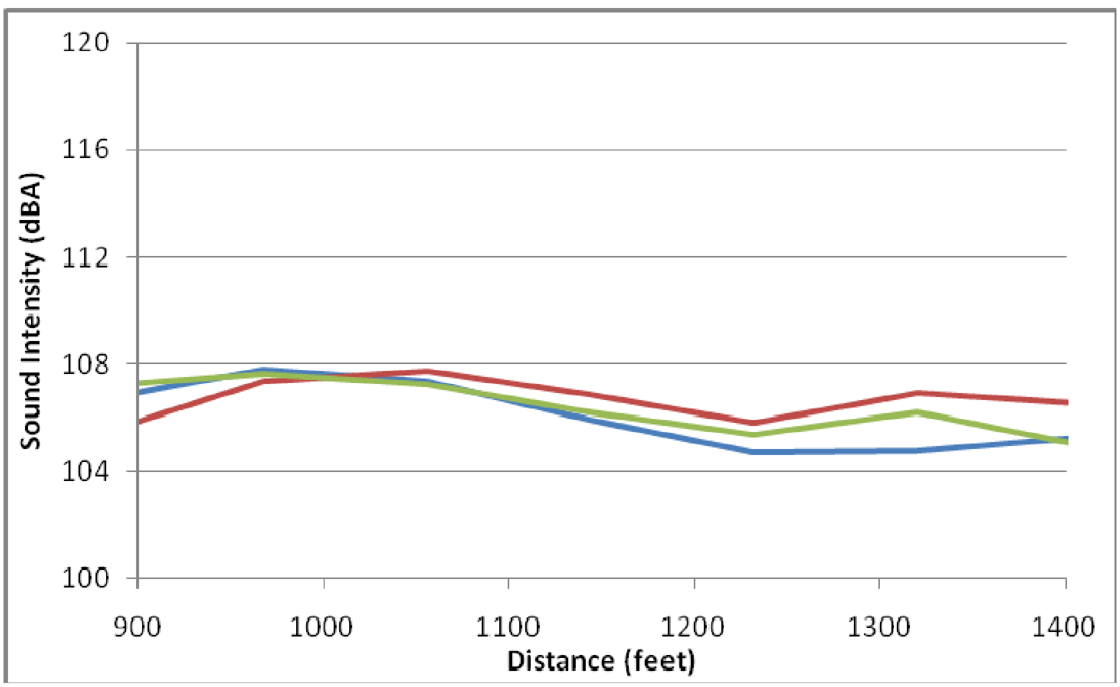


Figure 4.137: OBSI level in 1-sec intervals of Section QP-153.4, Year 1, three passes.

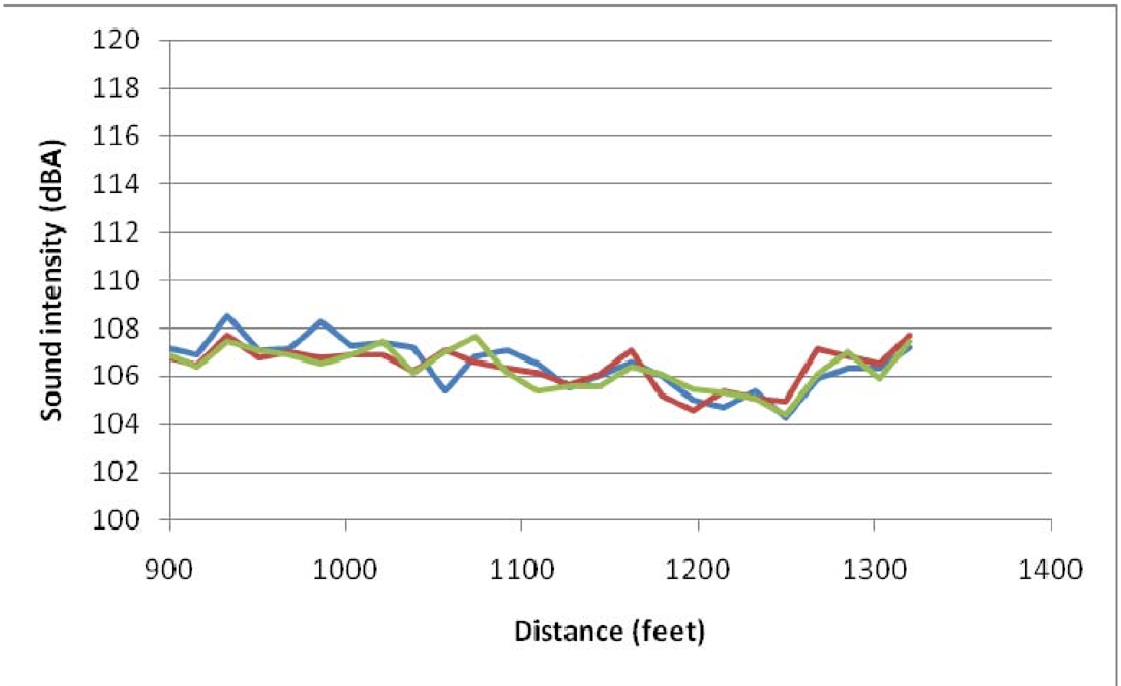


Figure 4.138: OBSI level in 0.2-sec intervals of Section QP-153.4, Year 2, three passes.

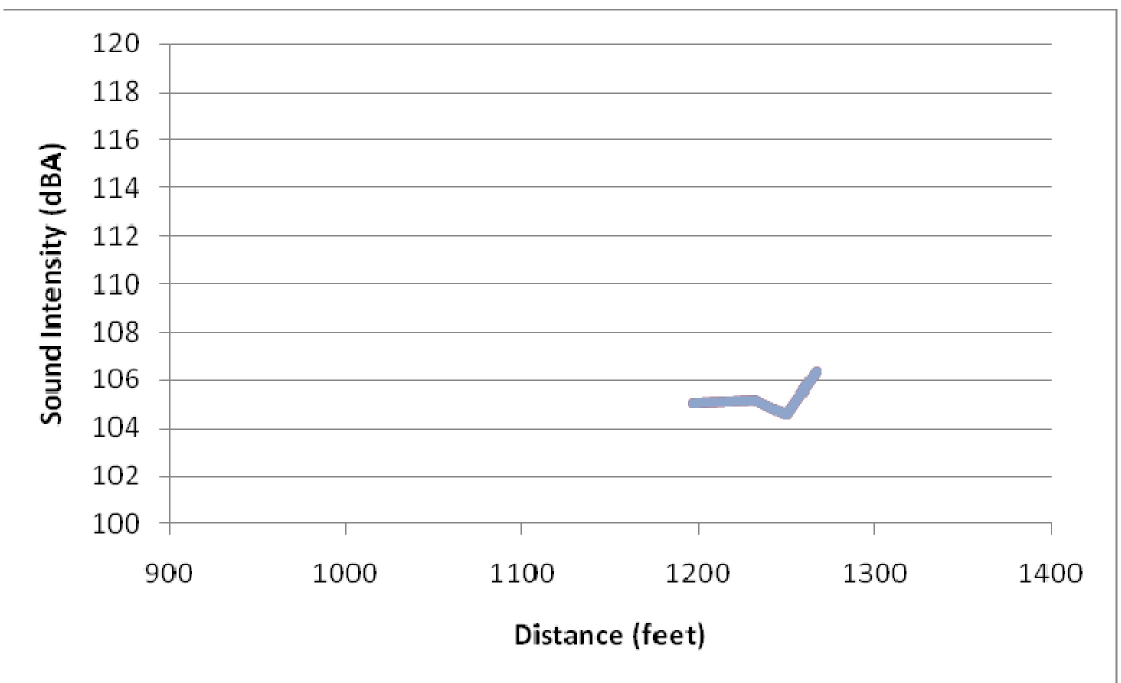


Figure 4.139: OBSI level in 0.2-sec intervals of Section QP-153.4, bridge only, Year 2, average of three passes.

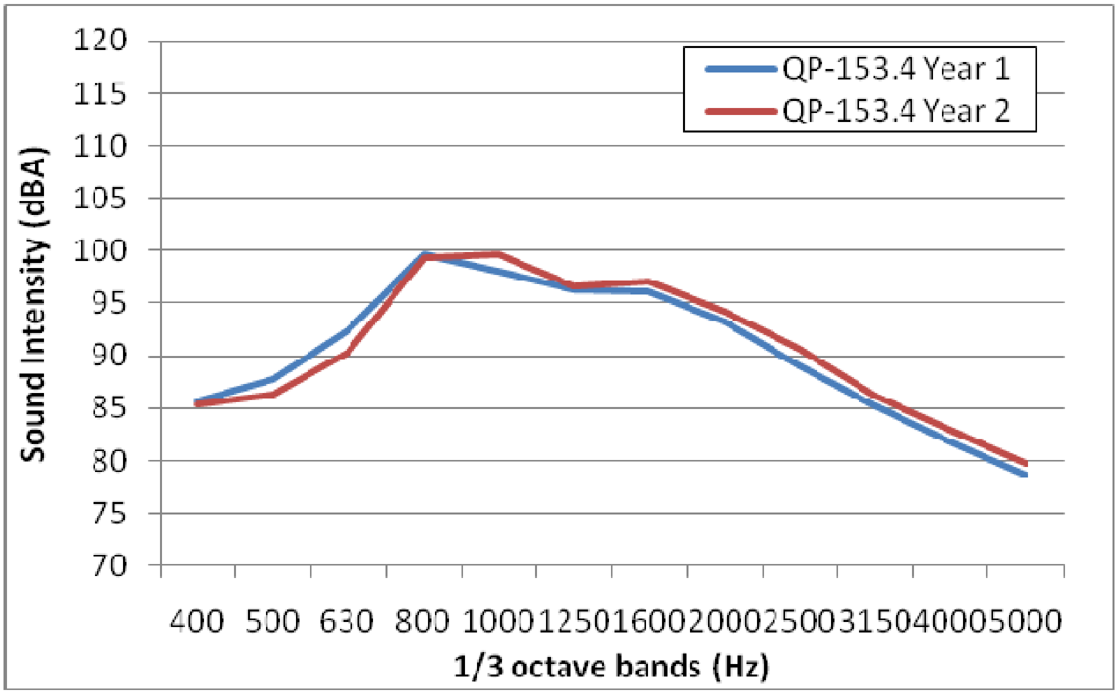


Figure 4.140: OBSI spectra of Section QP-153.4, Year 1 and Year 2.

4.19 Section QP-163.1 on Bridge Number 50 0495R at 06Ker58E111.8

Section QP-163.1, on Bridge Number 50 0495R, is located on the Mojave by-pass on State Route 58 in Kern County. The highway transitions from longitudinally tined concrete pavement to a skewed transversely-tined deck. There was no effect from joints. The longitudinally tined pavement and transversely tined deck had similar noise levels.

Table 4.21: OBSI Results (dB[A]) Section QP-163.1

	Bridge	Bridge without Joints	Pavement
Year 1	103.9	103.9	103.4
Year 2	105.0	105.0	104.7

Figure 4.141: Beginning of Section QP-163.1.

Figure 4.142: Surface and joint on Section QP-163.1.

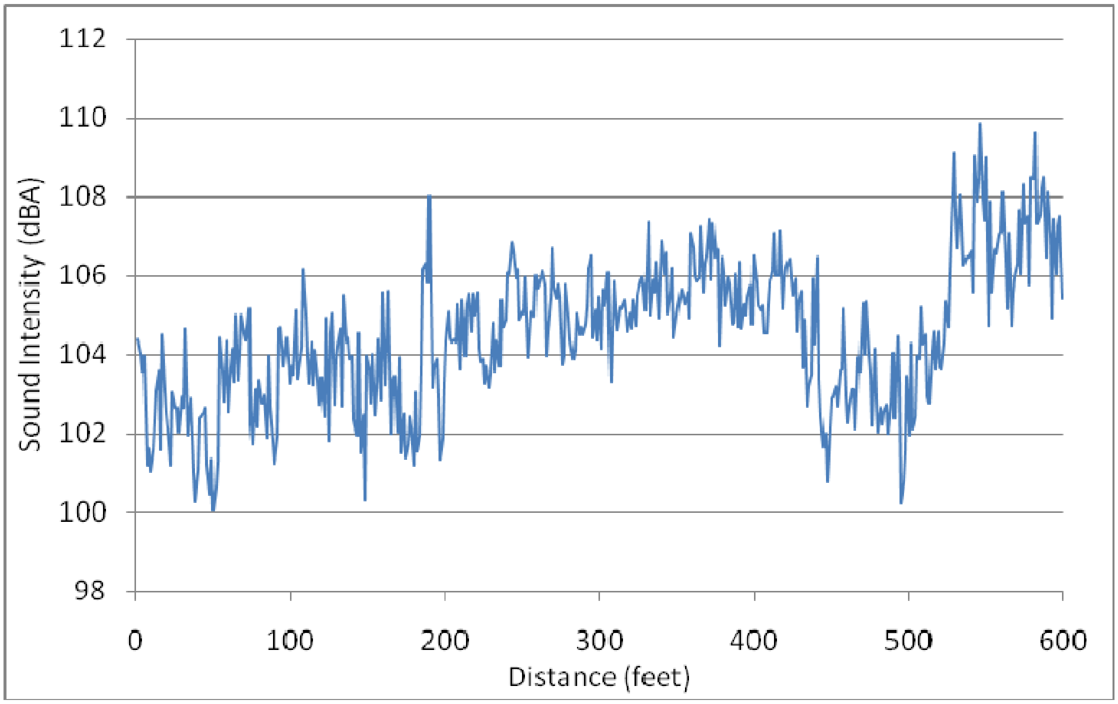


Figure 4.143. OBSI level in 15-msec intervals of Section QP-163.1, obtained in Year 1.

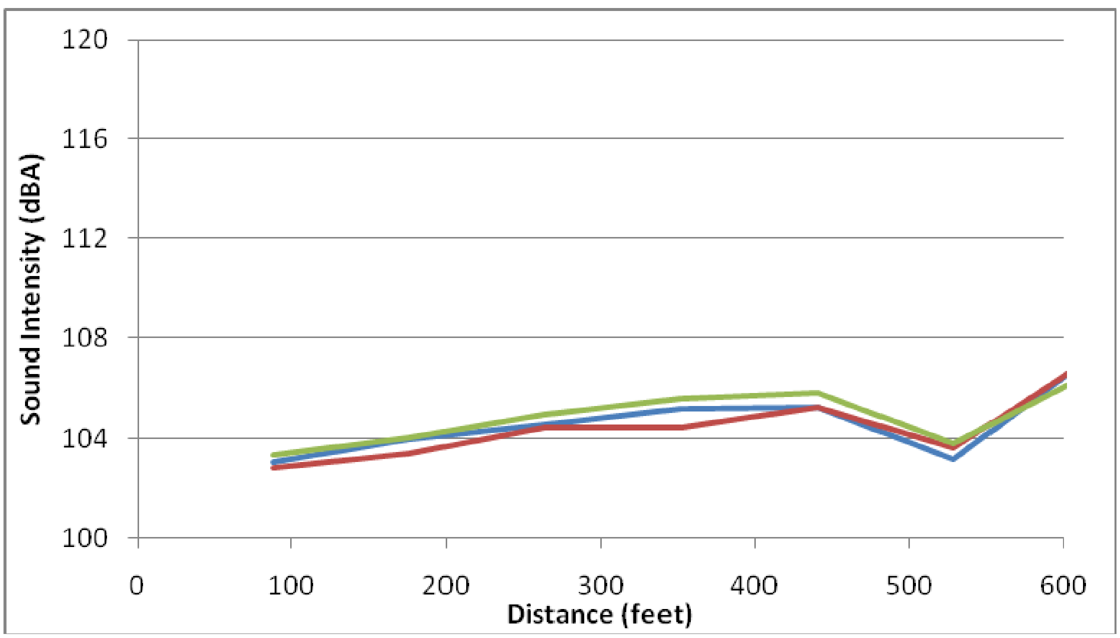


Figure 4.144. OBSI level in 1-sec intervals of Section QP-163.1, Year 1, three passes.

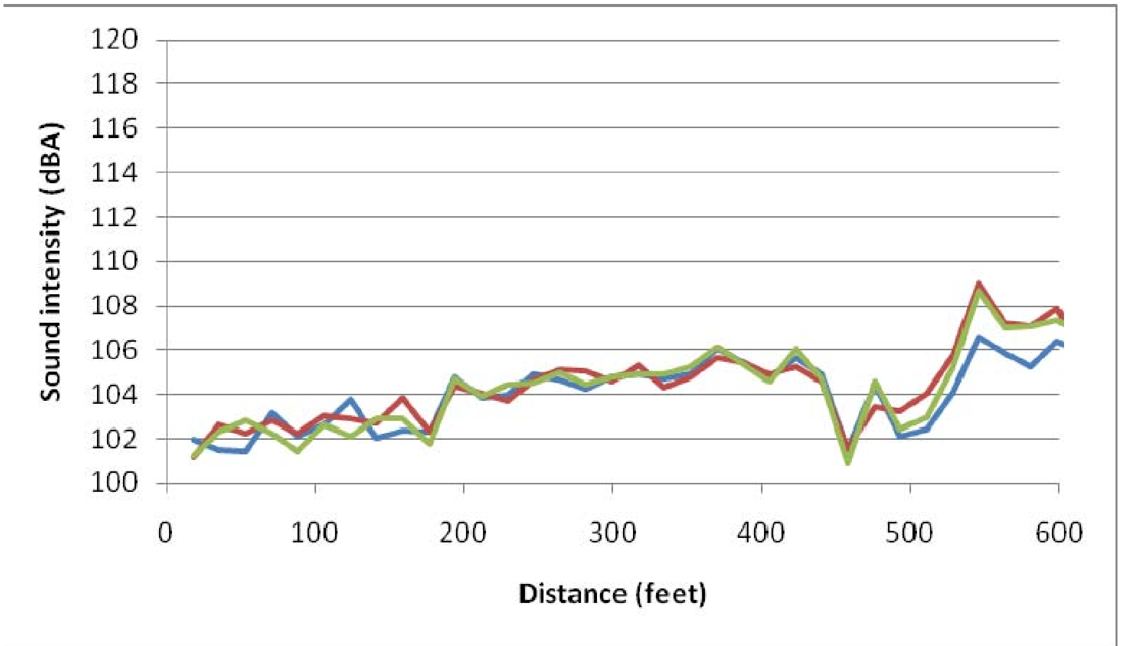


Figure 4.145: OBSI level in 0.2-sec intervals of Section QP-163.1, Year 2, three passes.

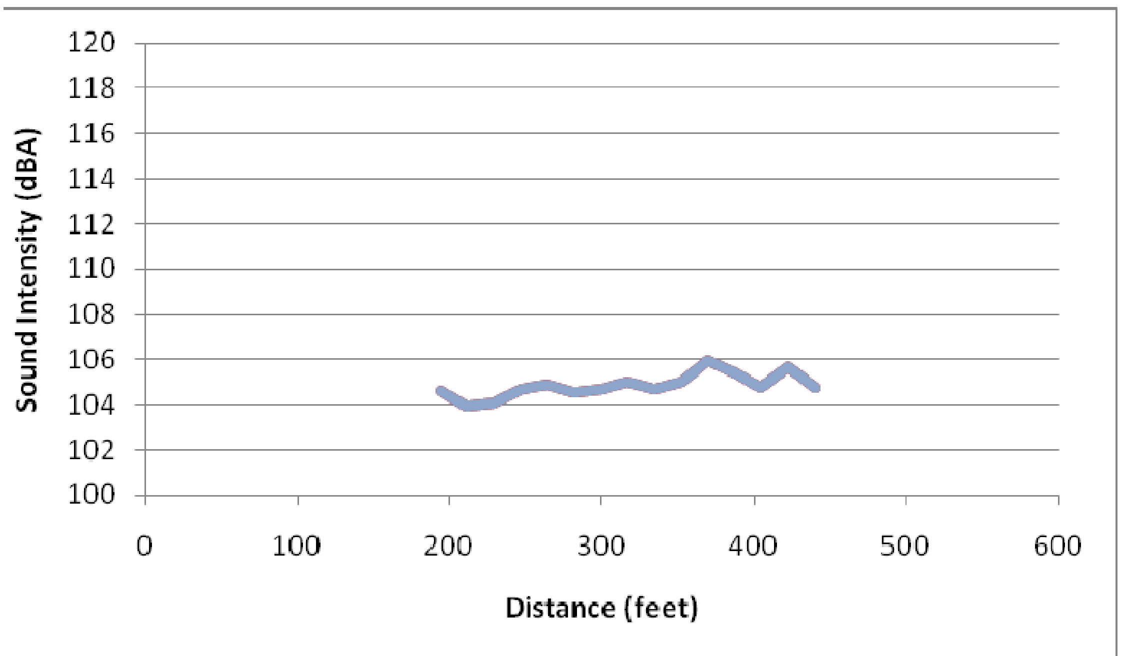


Figure 4.146: OBSI level in 0.2-sec intervals of Section QP-163.1, the bridge only, Year 2, average of three passes.

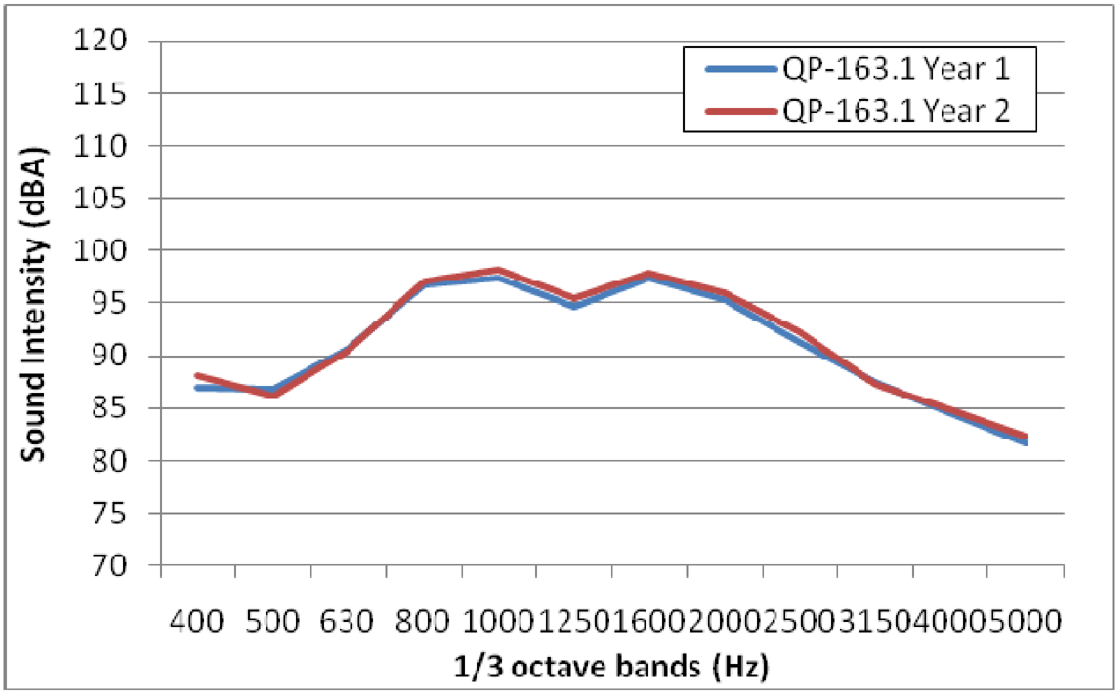


Figure 4.147: OBSI spectra of Section QP-163.1, Year 1 and Year 2.

4.20 Sections QP-164.1 and QP-164.2 on Bridge Numbers 50 0497L and 50 0494L at 06Ker58W108.7 and 06Ker58W108.5

Sections QP-164.1 and QP-164.2, on Bridge Numbers 50 0497L and 50 0494L respectively, are on State Route 58 in Kern County near Mojave, and are approximately 400 feet (122 m) apart. The surfaces on the decks are different, the first being a diamond-ground surface and the second a transverse-transversely tined surface. The pavements before the first bridge, in between, and after the second bridge are longitudinally tined concrete. The first bridge (QP-164.1) was quieter than the pavement while the second bridge (QP-164.2) was louder.

The second bridge is the quietest of the transversely tined textures found in this study. Although the photo is not a close-up view, it can be seen in Figure 4.146 that the transversely tined texture is not aggressive and the concrete has a good finish. The finish and noise levels on this bridge can be compared with the poor finish and high noise measurements of Section QP-119.1 shown in Figure 4.12.

Table 4.22: OBSI Results (dB[A]) Section QP-164.1

	Bridge	Bridge without Joints	Pavement
Year 1	100.2	100.2	101.6
Year 2	101.1	98.3	103.9

Table 4.23: OBSI Results (dB[A]) Section QP-164.2

	Bridge	Bridge without Joints	Pavement
Year 1	103.9	103.9	101.6
Year 2	104.9	104.9	103.4

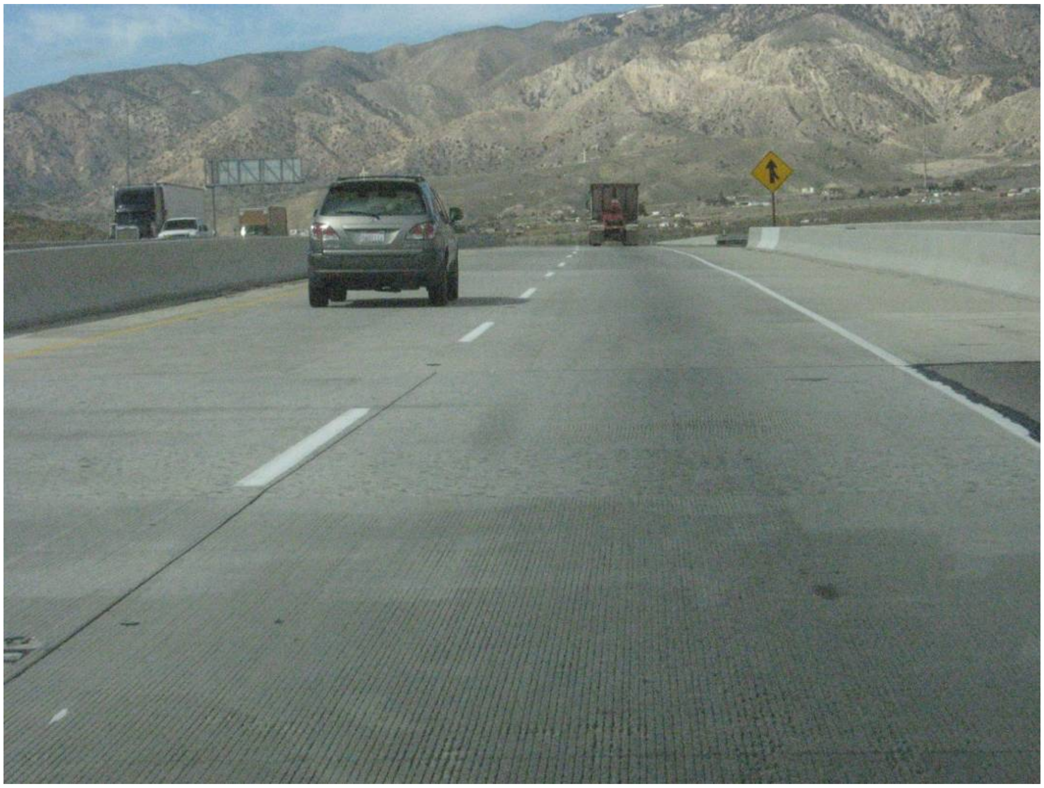


Figure 4.148: Transition from pavement to Section QP-164.1.

Figure 4.149: Surface texture on Section QP-164.1.

Figure 4.150: Surface texture on Section QP-164.2.

The following figures show continuous measurements that include the two bridges, one of which is located between 140 and 390 feet and the other between 850 and 1,120 feet.

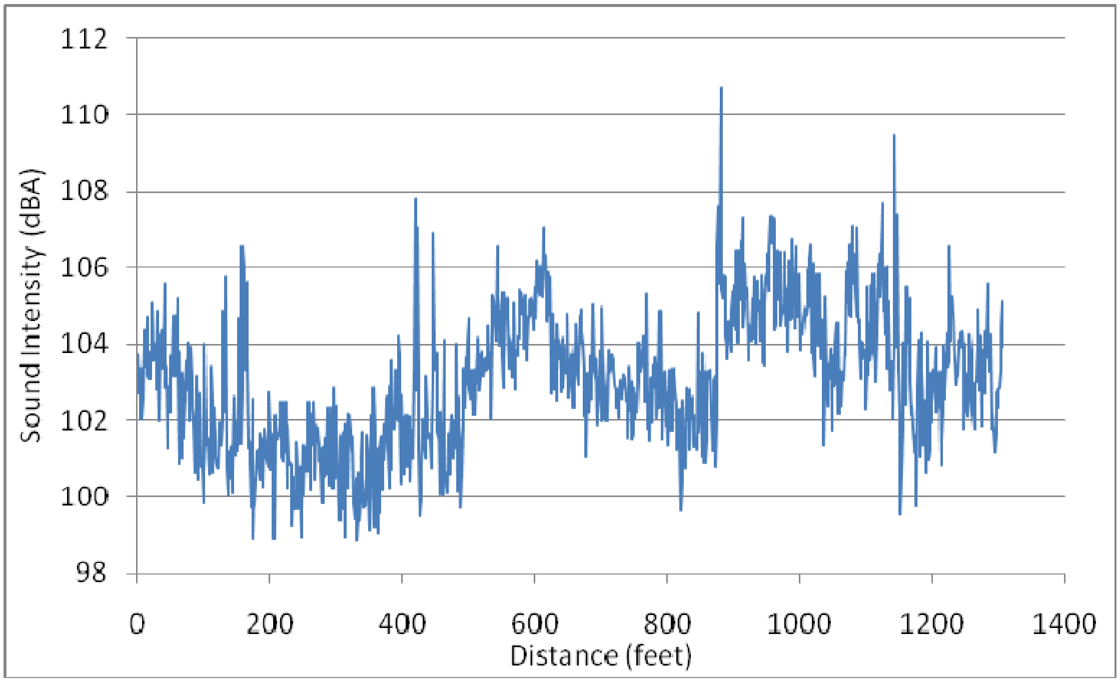


Figure 4.151: OBSI level in 15-msec intervals of Sections QP-164.1 and QP-164.2, obtained in Year 1.

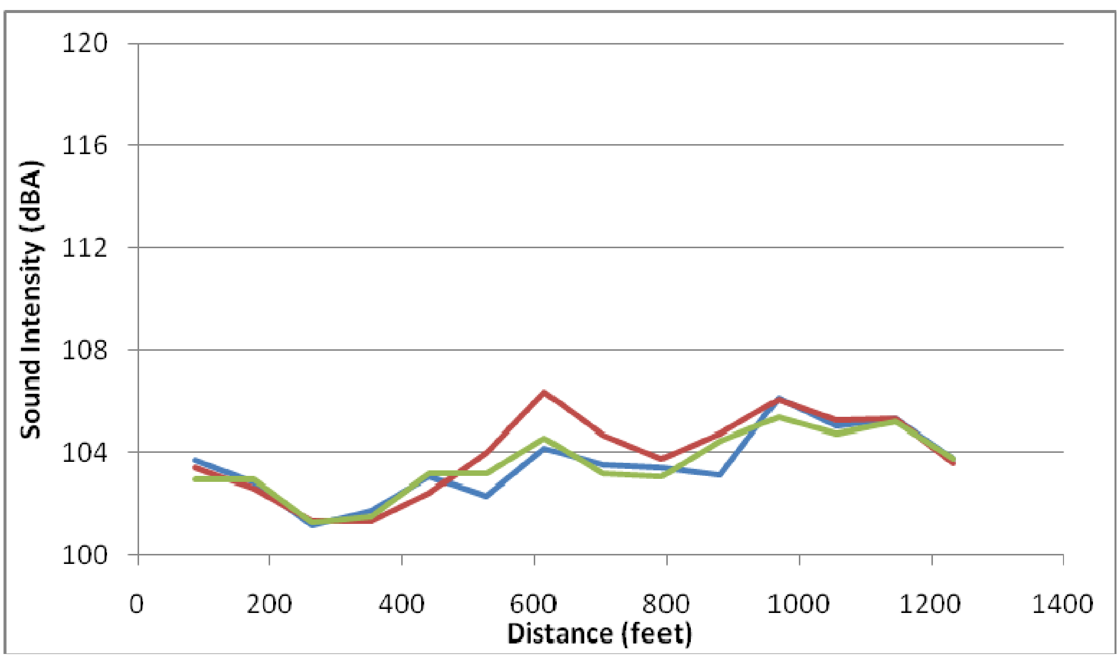


Figure 4.152. OBSI level in 1-sec intervals of Sections QP-164.1 and QP-164.2, Year 1, three passes.

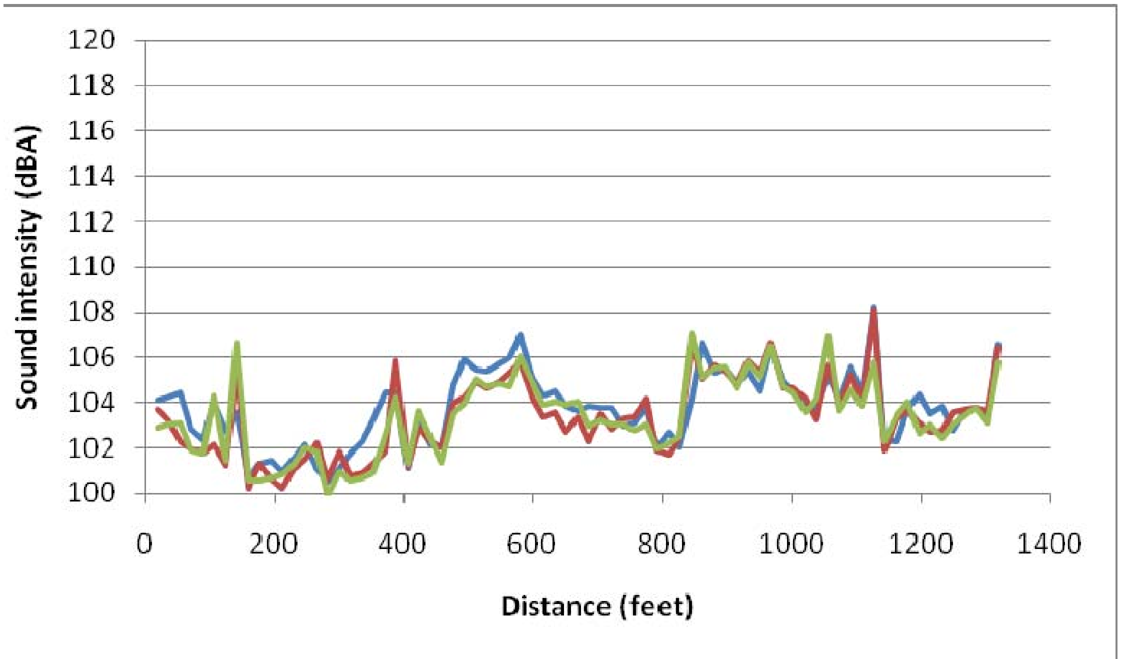


Figure 4.153: OBSI level in 0.2-sec intervals of Sections QP-164.1 and QP-164.2, Year 2, three passes.

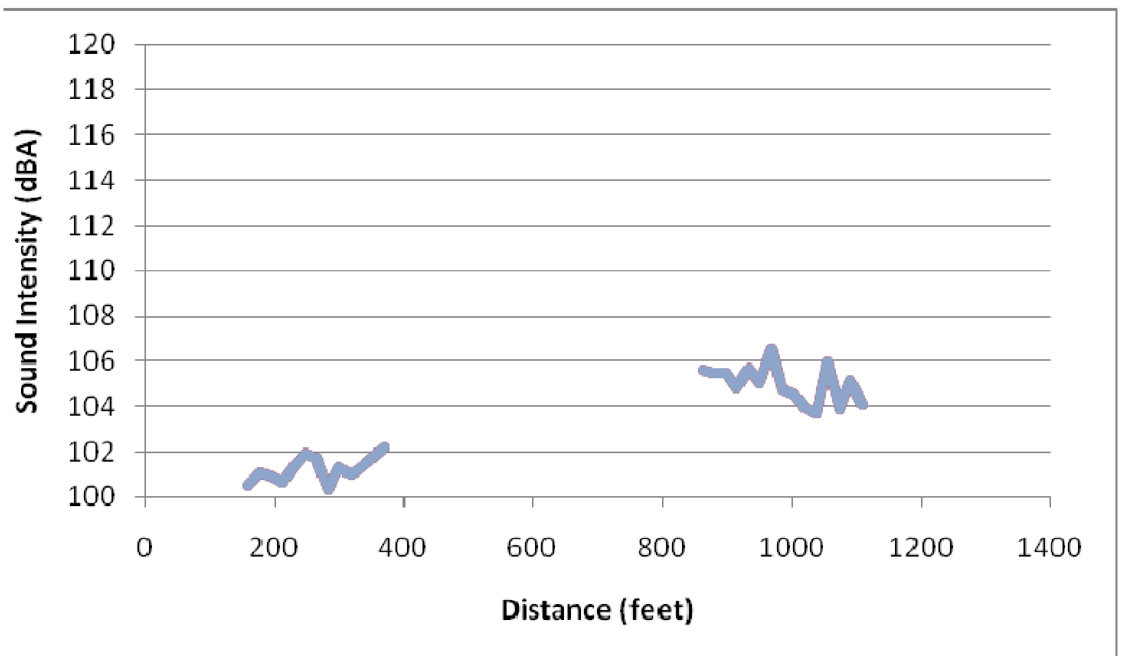


Figure 4.154: OBSI level in 0.2-sec intervals of Sections QP-164.1 and QP-164.2, the bridges only, Year 2, average of three passes.

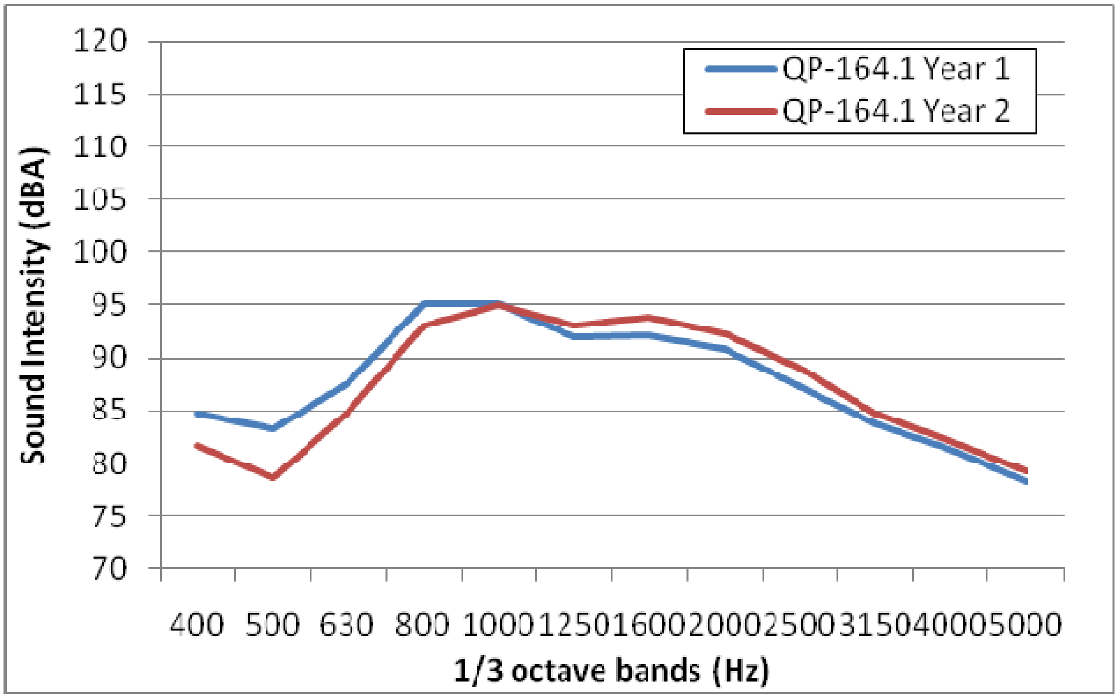


Figure 4.155: OBSI spectra of Sections QP-164.1, Year 1 and Year 2.

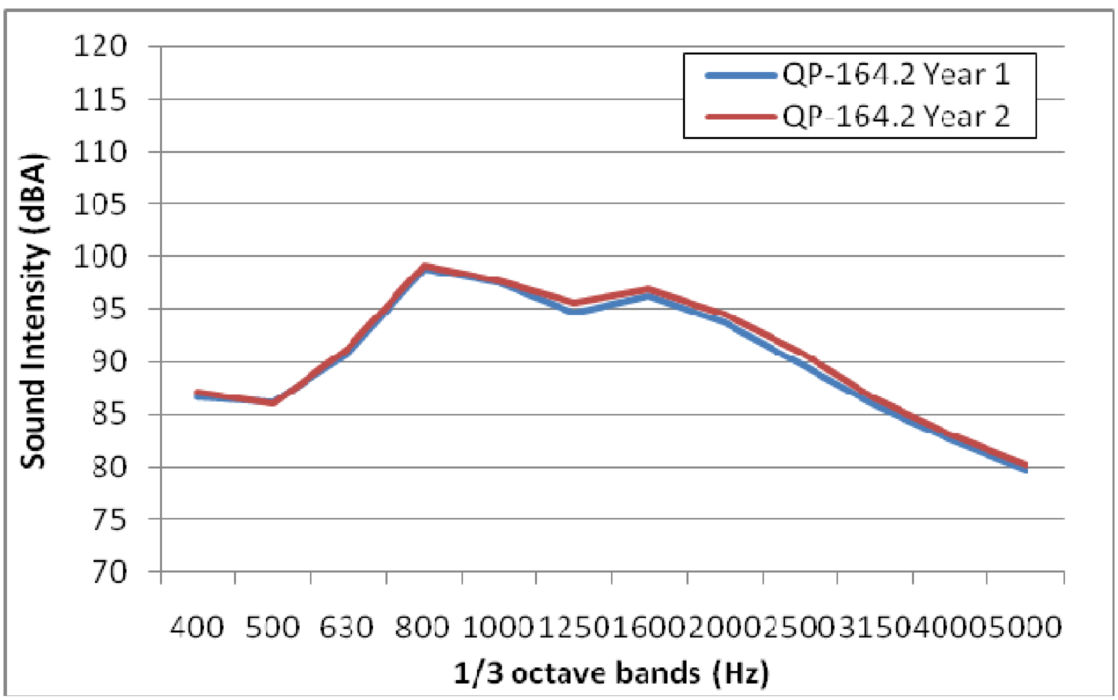


Figure 4.156: OBSI spectra of Sections QP-164.2, Year 1 and Year 2.

4.21 Section QP-165.1 on Bridge Number E50 0496 at 06Ker58R108.90

Section QP-165.1, on Bridge Number E50 0496, is located on Business Route 58, east of the junction with State Route 58, near Mojave in Kern County. It is a diamond-ground deck that is quieter than the asphalt concrete pavement around it. The deck originally had a transversely broomed texture, which was later subjected to diamond grinding over 80 percent of its surface.

Table 4.24: OBSI Results (dB[A]) Section QP-165.1

	Bridge	Bridge without Joints	Pavement
Year 1	99.2	99.2	100.9
Year 2	99.7	99.7	102.3

Figure 4.157: Transition from pavement to Section QP-165.1.

Figure 4.158: Detailed view of texture on Section QP-165.1.

Figure 4.159: Overall view of texture on Section QP-165.1.

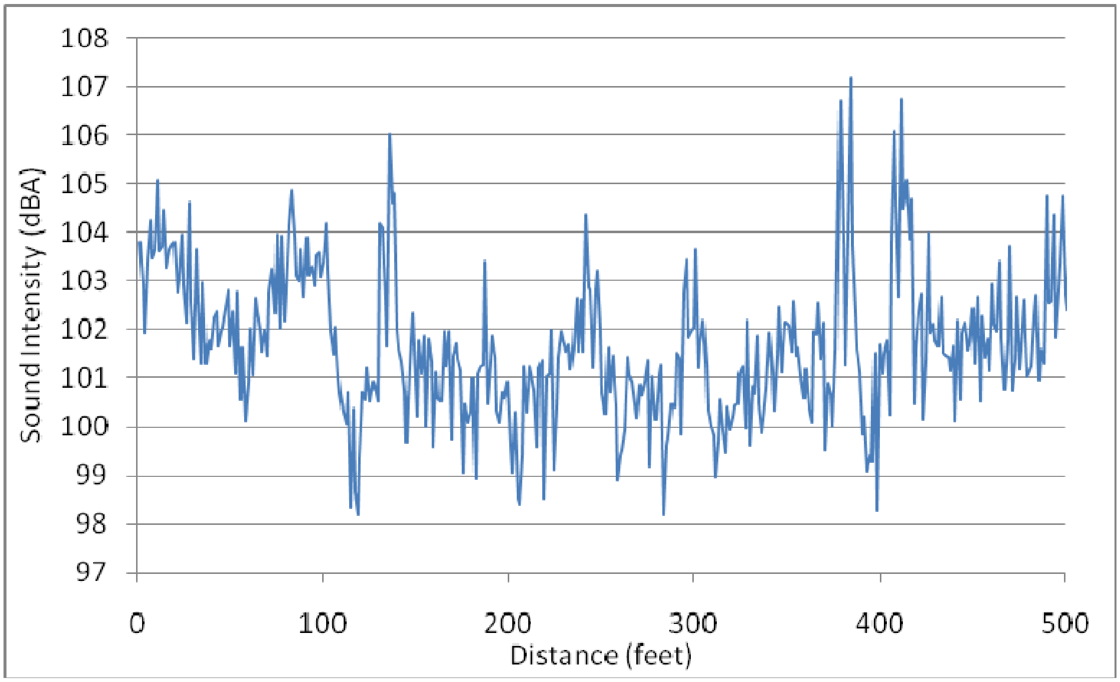


Figure 4.160: OBSI level in 15-msec intervals of Section QP-165.1, obtained in Year 1.

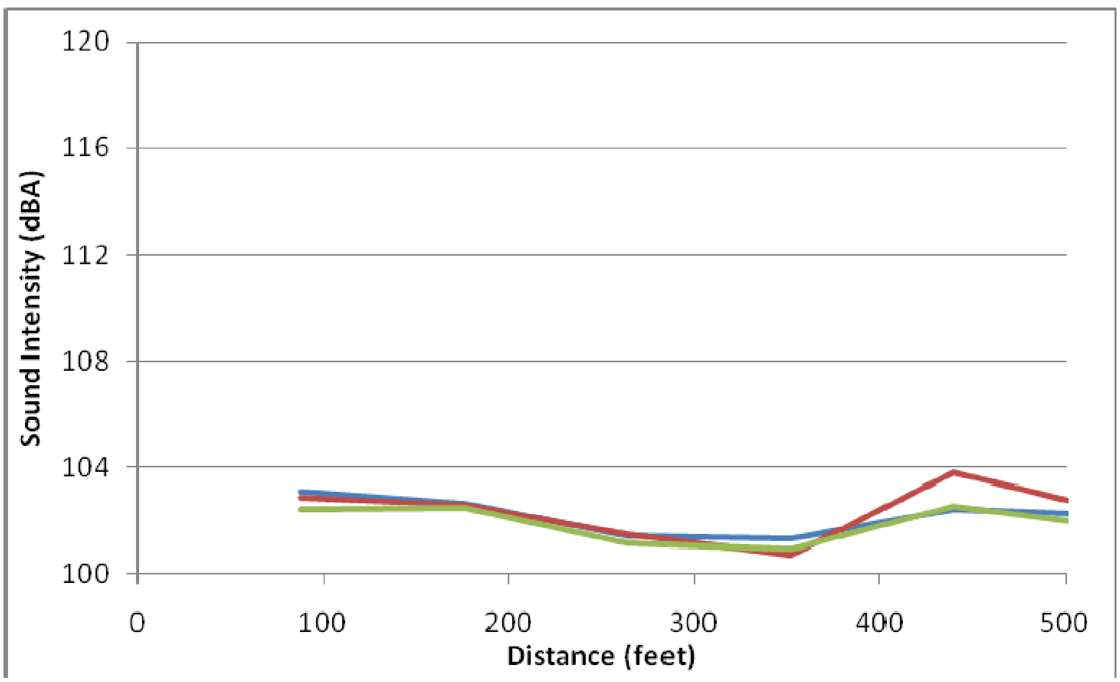


Figure 4.161: OBSI level in 1-sec intervals of Section QP-165.1, Year 1, three passes.

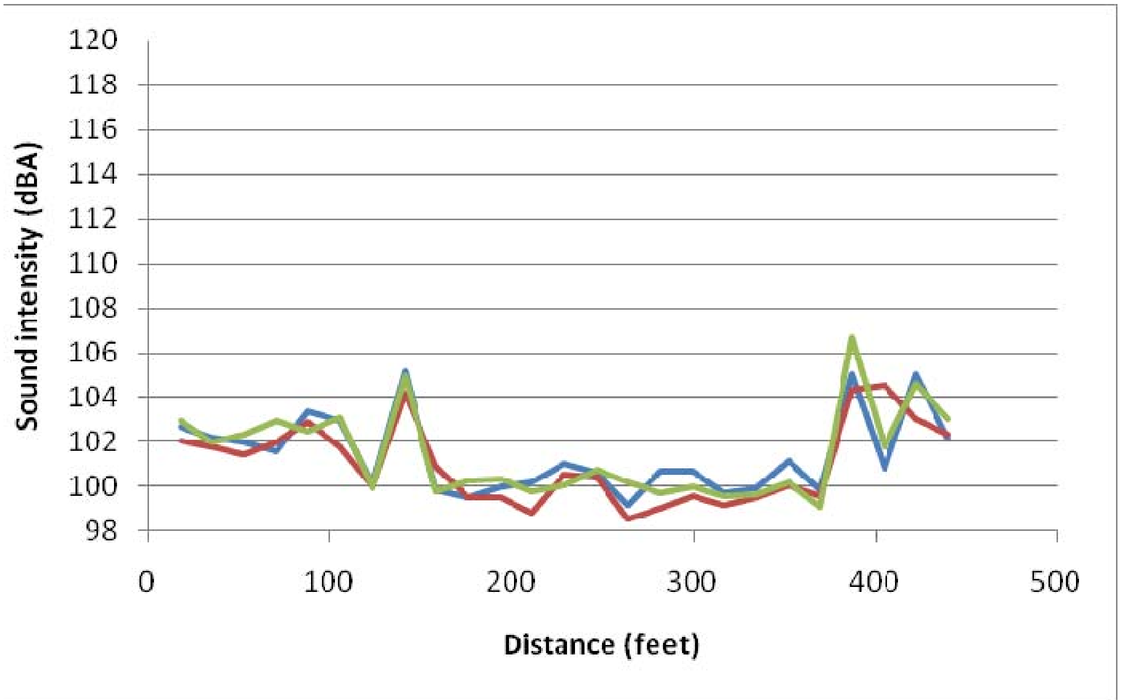


Figure 4.162: OBSI level in 0.2-sec intervals of Section QP-165.1, Year 2, three passes.

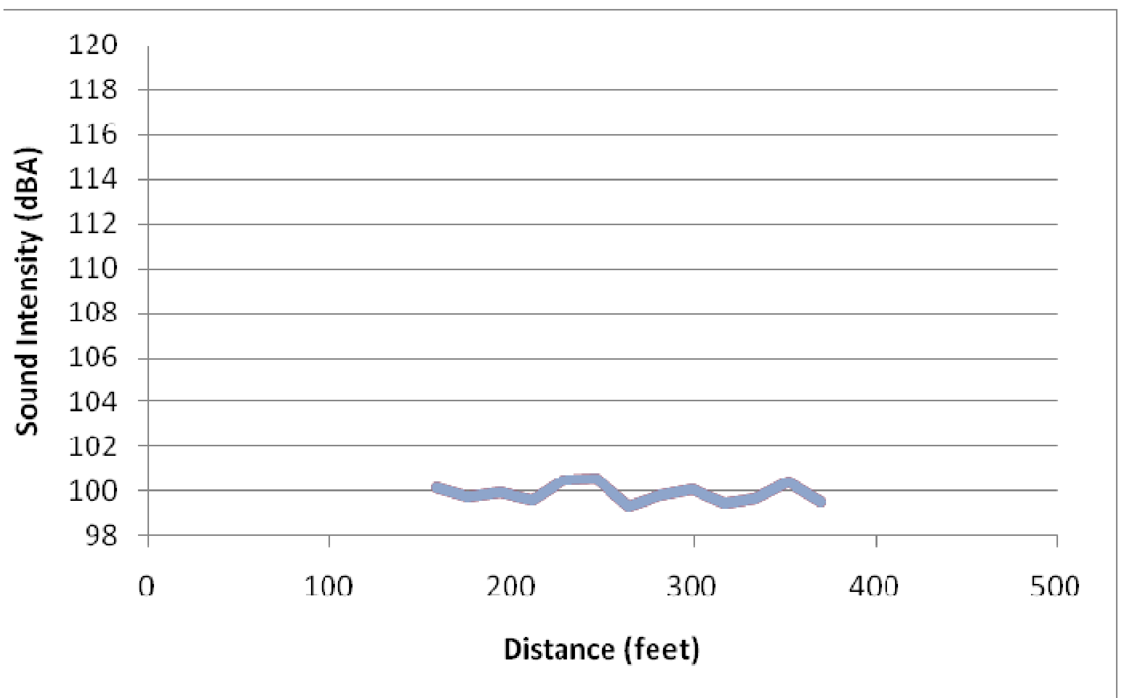


Figure 4.163: OBSI level in 0.2-sec intervals of Section QP-165.1, bridge only, Year 2, average of three passes.

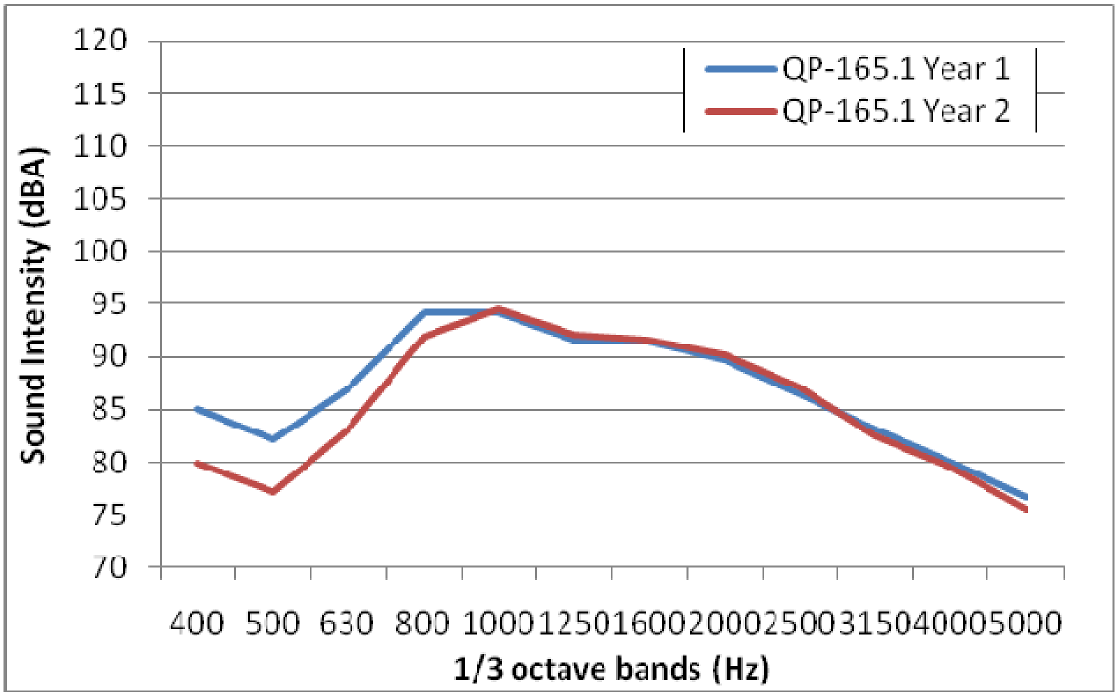


Figure 4.164: OBSI spectra of Section QP-165.1, Year 2.

5 CONCLUSIONS AND RECOMMENDATIONS

These conclusions have been drawn from noise measurements on the 24 bridge decks included in this study. It must be remembered that the purpose of this study was to provide an initial investigation of tire/pavement noise on bridge decks, and that the experiment design is not a complete factorial with respect to surface type and age. In addition, there is no established practice method for use of the OBSI method for bridge decks, and part of this investigation included experimentation with regard to test method. Hence, the conclusions and recommendations made here must be considered as preliminary.

The following conclusions have been drawn with respect to the identification of relationships between the design variables, in this case the bridge deck surface type and the presence of joints:

- The general order, from noisiest to quietest, of On-board Sound Intensity (OBSI) for the bridge deck surfaces with more than one section in the study was: transversely tined, transversely broomed, polyester overlay, and diamond ground. On-board Sound Intensity (OBSI) levels in the range of 99.2 to 104.2 dB(A) were measured on the four diamond-ground bridges evaluated, with an average of 101.9 dB(A). The polyester overlays were also quieter than the other surface types, with OBSI generally lower than 105.0 dB(A). Transversely tined and transversely broomed textures had the greatest OBSI levels, generally between 105.0 and 109.0 dB(A). Human hearing can generally detect changes in sound intensity greater than 2 to 3 dB(A), which suggests that there is a perceivable difference in noise between bridge decks with transversely tined or transversely broomed surfaces, and the quieter bridges with diamond-ground or polyester overlay surfaces. The results from measurement of one bridge indicate that hot-mix asphalt surfaces can also be quieter than transversely tined or transversely broomed surfaces, although the longevity of the noise benefit from the asphalt surface on the bridge deck was not identified in this study. Hot-mix asphalt is generally not allowed on bridge decks because of the potential for delamination and pot holes and because asphalt overlays make it difficult for bridge maintenance inspectors to see the condition of the underlying deck. The results from one other bridge show that the noise level on the burlap drag surface was near the mean of the transversely broomed sections.
- OBSI one-third octave band spectra had similar distributions, with quieter surfaces generally quieter across all frequencies and noisier surfaces generally noisier across all frequencies. Peak frequencies (dB[A]) were typically 800 Hz, with a few at 1,000 Hz. Many of the transversely tined and transversely broomed surfaces had a second peak frequency at 1,600 Hz.
- The differences in noise levels between the bridge decks and the pavement before and after the bridge decks varied, with the pavements noisier than the bridge decks in some cases and the opposite in other cases. The transversely tined and transversely broomed decks were all louder than the adjacent

pavement. The other bridge deck surfaces (polyester overlay, diamond ground, burlap drag, and asphalt concrete) were all quieter than the adjacent pavement, except for one case.

- Although the effect of joints causes a very high short-duration noise on the order of 112 dB(A), in all cases but one the effect on noise when traveling across the entire bridge deck was found to be less than 0.4 dB(A) in terms of average OBSI. The exception to the 0.4 dB(A) effect noted occurred on the quietest polyester overlay deck (QP-145.1), where a joint effect of 0.5 dB(A) was measured. The joint effect was captured with data collection at 15-msec and 0.2-sec intervals, but currently there is no standard method for assessing joint slap. Additionally, although there is no significant increase in noise from joint slap as measured using the OBSI method, the effect on humans is difficult to judge because there is no methodology for assessing the impact on humans of short, intense noise events like these.

With respect to establishing trends in noise level versus age for different bridge deck surface types, the number of replicate sections was not large enough and the monitoring period was not long enough to establish strong conclusions. The following preliminary statements can be made based on the data that could be collected:

- In general, OBSI levels changed very little over the two years of data collection.
- Because the data points are from bridge decks of different ages rather than a time series of the same bridge decks, it is difficult to estimate a per year increase in noise on transversely tined surfaces. Results from nine such bridges indicated OBSI levels in the range of 103 to 106 dB(A) from sections whose surface had been in service less than five years, while the approximately 15-year old sections evaluated were above 108 dB(A). One transversely tined bridge, QP-119.1, showed a reduction in noise between the first- and second-year measurements.
- Transversely broomed surfaces about 10 years old had OBSI levels of about 106 dB(A).
- The polyester-overlaid decks were tested on sections six months to six years old, with results of 102 to 106 dB(A). Using the 10 data points that result from combining the Year 1 and Year 2 results, a preliminary estimate could be made that noise increases at a rate of 0.4 dB(A) per year.
- Diamond-ground sections at 10 years of age showed OBSI levels of about 104 dB(A). Younger sections had OBSI levels between 99 and 102 dB(A).
- A section of burlap drag that had been in service for 44 years presented an OBSI level of 106 dB(A), well within the midrange of results found for much younger transversely broomed sections.

Although this study does not include a sufficient number of bridge decks to make recommendations regarding all bridge deck surface types currently used in the state, and does not include sufficient observations to draw strong conclusions regarding the longevity of noise levels, the results indicate that diamond-ground surfaces will provide initial noise reductions that are perceptible to human hearing compared with transversely tined and transversely broomed surfaces, both initially and over at least a 15-year period.

Polyester overlays provide some noise reduction, although not when they are applied as a thin overlay on transversely tined and transversely broomed surfaces where the overlay does not eliminate the underlying texture. However, the limited results from this study indicate that differences in noise levels compared with the transverse textures may not be perceptible to human hearing after approximately 10 years of service. Polyester overlays are typically longitudinally tined or diamond-ground, which may be the primary reason they are quieter than the transversely tined surfaces they are placed on. Both the polyester overlays and the diamond-ground decks were generally quieter than the approach and leave sections pavement before and after the bridges.

It is therefore recommended that diamond-ground surfaces or, as a second option, polyester overlays be used when the minimization of tire/pavement noise on bridge decks is a desirable design feature.

It should be remembered that the frictional properties of diamond-ground versus transversely tined and transversely broomed surfaces were not considered in this study, and should be considered in any decision.

It is recommended that some additional bridge deck surfaces be measured, particularly any older diamond-ground and polyester overlay surfaces that might exist in the state, and that the bridge decks included in this study be monitored for several more years to provide a better estimate of changes in tire/pavement noise over time. Additionally, it would be interesting to investigate whether the lower noise level on polyester overlay decks is the result of the polyester material, or if it is just due to the longitudinally tined finish applied on the overlay.

Although current methods for reducing the effect of joint slap have little effect on the overall OBSI during travel across a bridge deck, it is still recommended that they be used where possible and that the human perception of joint slap be further investigated.

It is recommended that the literature be continually reviewed for updates on standardization of measurement methods for OBSI on bridge decks as additional years of measurements are added to this study. In particular, development of standardized methods for measuring OBSI on bridges and for isolating the noise from joint slap would be useful for monitoring of bridges, for setting performance requirements, and for use in bridge management.

REFERENCES

1. ASTM Work Item WK26025, 2010, "New Practice for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method," ASTM International, West Conshocken, PA, 2010. *astm.org/ DATABASE.CART/WORKITEMS/WK26025.htm.* (Accessed June 30, 2010.)
2. NCHRP 630 (2009). "Measuring Tire-Pavement Noise at the Source." Transportation Research Board, National Cooperative Highway Research Program. Project 1-44, ISSN 0077-5614, ISBN: 978-0-309-11768-5, Library of Congress Control Number 2009900077, 2009.
3. Donavan, P. (2005). "Quieting of Portland Cement Concrete Highway Surfaces with Texture Modifications." Proceedings of the Conference of the Institute of Noise Control Engineering NOISE-CON 2005, Minneapolis, Minnesota, October 17–19, 2005.