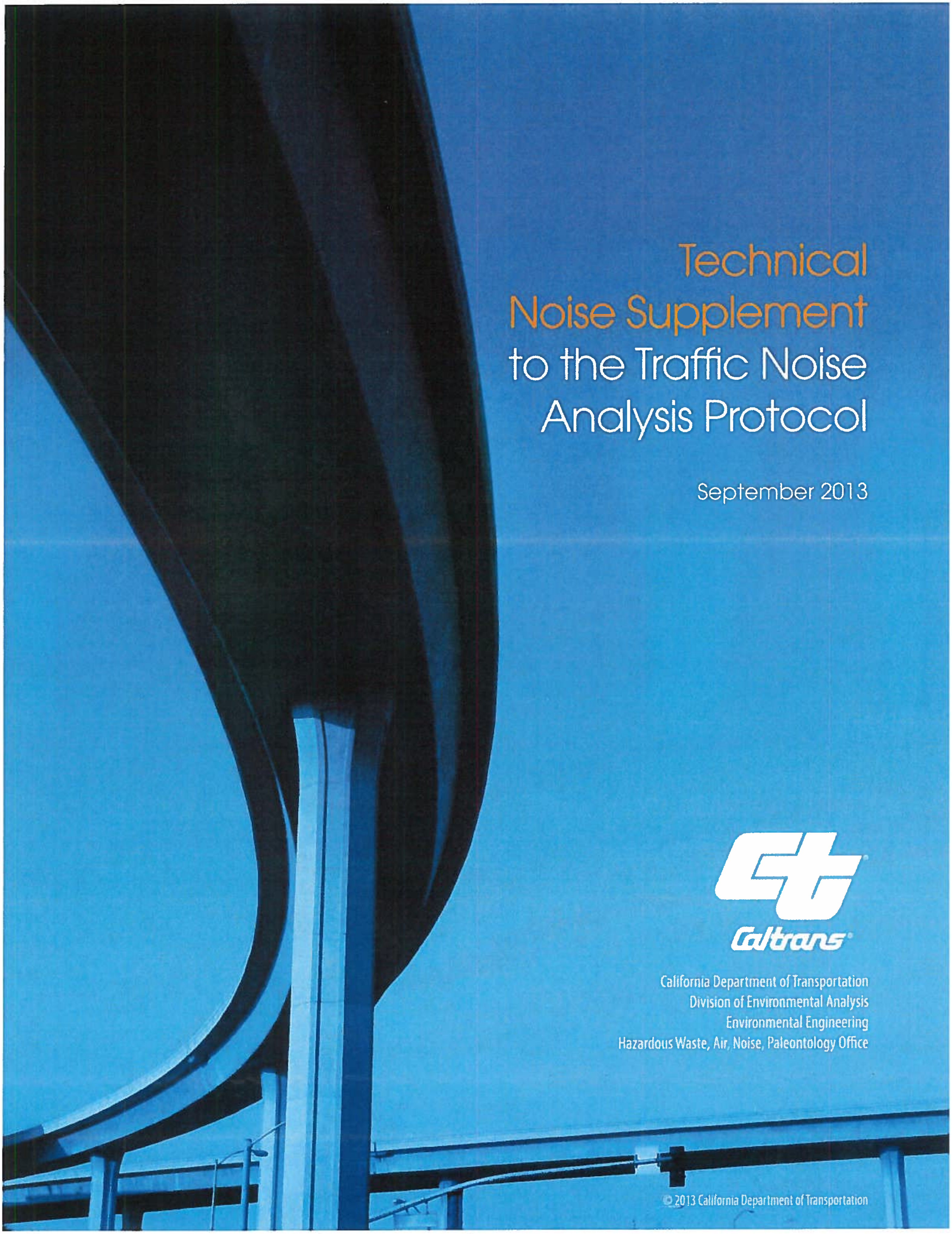

Technical Noise Supplement to the Traffic Noise Analysis Protocol

September 2013

Caltrans

California Department of Transportation
Division of Environmental Analysis
Environmental Engineering
Hazardous Waste, Air, Noise, Paleontology Office

CALTRANS Technical Report Documentation Page

1. Report No.

CT-HWANP-RT-13-069.25.2

2. Type of Report

Reference & Guidance

3. Report Phase and Edition

Final

4. Title and Subtitle
Technical Noise Supplement to the Caltrans Traffic Noise Analysis Protocol
A Guide for the Measuring, Modeling, and Abating Highway Operation and Construction Noise Impacts

5. Report Date

September 2013

6. Author(s)

Rudy Hendriks, Bruce Rymer, David Buehler, Jim Andrews

7. Caltrans Project Coordinator
Bruce Rymer, PE
Senior Engineer

8. Performing Organization Names and Addresses
California Department of Transportation
Division of Environmental Analysis
Environmental Engineering
Hazardous Waste, Air, Noise, & Paleontology Office
1120 N Street, Mail Stop 27
Sacramento CA 95814
http://www.dot.ca.gov/hq/env/noise/index.htm

9. Task Order No.
25

10. Contract No. :

43A0269 – ICF International

11. Sponsoring Agency Name and Address

California Department of Transportation
Division of Environmental Analysis
Environmental Engineering
Hazardous Waste, Air, Noise, & Paleontology Office
Sacramento CA 95814

12. Caltrans Functional Reviewers:

Division of Environmental Analysis:
Bruce Rymer & Jim Andrews

13. Supplementary Notes
This document updates and supersedes the Nov 2009 *Technical Noise Supplement.* Refer to the Sept 2013 *Caltrans Highway Traffic Noise Analysis Protocol* for noise-related policy.

14. External Reviewers

15. Abstract

This manual contains Caltrans noise analysis procedures, practices, and other useful technical background information related to the analysis and reporting of highway and construction noise impacts and abatement. It supplements and expands on concepts and procedures referred to in the *Traffic Noise Analysis Protocol*, which in turn is required by federal regulations in 23CFR772. *The contents of this document are not official policy, standard, or regulation*, and are for informational purposes—*unless they are referenced in the Protocol.* Except for some Caltrans-specific methods and procedures, most methods and procedures recommended in this document are in conformance with industry standards and practices. This document can be used as a stand-alone guide for highway noise training purposes or as a reference for technical concepts, methodology, and terminology needed to acquire a basic understanding of highway noise and construction noise-related issues.

16. Key Words
Highway noise, highway noise measurement, noise barrier design, traffic noise impact analysis, noise study reports, construction noise.

17. Distribution Statement

Available to the general public

18. No. of pages

276

Form DEA F 001 (11-07) Reproduction of completed page authorized

Section 7
Non-Routine Considerations and Issues

Sections 2 to 6 address the routine phases of Caltrans highway noise fieldwork and analyses. The subjects in this section are considered non-routine. Because Caltrans is occasionally involved in these special situations, they are included to round out the knowledge base of the Caltrans noise analysts or other interested party. The subjects addressed in this section are listed below.

- 7.1: Noise Barrier Issues
- 7.2: Sound Intensity and Power
- 7.3: Pavement Noise
- 7.4: Insulating Facilities from Highway Noise
- 7.5: Construction Noise Analysis, Monitoring, and Abatement
- 7.6: Earthborne Vibrations
- 7.7: OSHA Noise Standards
- 7.8: Effects of Transportation and Construction Noise on Marine Life and Wildlife (Bioacoustics)

7.1 Noise Barrier Issues

This section discusses some challenging issues and non-routine considerations related to noise barriers. Noise barriers are generally considered beneficial for residents near a freeway. However, there have been claims about perceived noise increases at distances farther than those for which the noise barriers were designed. This issue involves complex relationships between highway and barrier configurations, intervening terrain, receiver location, and atmospheric influences. This section discusses what Caltrans and others have found about this issue and suggests ways to study the effects of noise barriers on distant receivers. Some elements of this discussion involve routine considerations addressed in Section 5.

The effectiveness of vegetation typically used in highway landscaping in reducing noise is also discussed. This issue occasionally surfaces when trimming or removal of shrubs and trees by Caltrans maintenance personnel triggers complaints of perceived noise increases.

7.1.1 Effects of Noise Barriers on Distant Receivers

The public and media in California have on occasion raised concerns that noise barriers increase noise levels at distances of up to 3 miles. The alleged increases were attributed to certain site geometries, noise barrier configurations, intervening terrain, and interacting meteorology. Continuing research by Caltrans and others has provided some answers to these concerns. However, there is a continued need for field research to verify prediction algorithms in prediction models for distances more than 500 feet, alter them if needed, and investigate conditions that lead to any newly identified concerns. This section discusses what Caltrans and others have found.

7.1.1.1 Background

Normally, noise barriers are designed for residences and noise-sensitive receptors located adjacent to a highway, and their effects are generally limited to receivers within about 500 feet of the highway. With few exceptions, there is little disagreement that properly designed noise barriers reduce highway noise within this distance, except for the limited conditions described in Section 5.1.7. Noise prediction models have not been adequately validated for distances beyond 500 feet. Caltrans' *Distance Limits for Traffic Noise Prediction Models* (2002) discusses the reasons for the distance limits. However, if there is a reasonable expectation that noise impacts would extend beyond 500 feet those impacts must be evaluated. This may require engineering judgment and supplemental noise measurements to determine impacts.

With the proliferation of noise barriers in California, public concern has emerged that under certain conditions of topography and meteorology noise barriers can increase noise levels at receivers located from 0.25 to 2 miles from freeways. To date, the concerns have been based on subjective perception only. No objective evidence based on noise measurements has been advanced that noise barriers increase noise levels at any distance or under any conditions other than under the limited conditions described in Section 5.1.7. As indicated, present noise prediction models are not reliable to accommodate distances more than

500 feet. In addition, noise prediction models are unable to predict meteorological effects, which play an increasingly important role in observed noise levels with distance, independent of the nature and strength of their source.

The concerns raised by the public, primarily in the San Francisco Bay Area and Los Angeles area, include all three possible categories of source, barrier, and receiver configurations.

- Reflective noise barriers on the sides of highways opposite from those of the receivers (i.e., highways between barriers and receivers).
- Parallel reflective noise barriers on each side of highways.
- Noise barriers between highways and receivers.

The first two issues involve reflective noise of single and parallel barriers, discussed in Section 5.1.7. The third, however, deals with diffracted noise. All three issues of concern involve long noise propagation distances, which are difficult to study because of the numerous variables in topography and meteorology. Caltrans' experience has been that atmospheric conditions can cause measured noise levels at those distances to fluctuate by more than 10 dBA, with or without noise barriers.

Atmospheric refraction is the principal atmospheric process responsible for these fluctuations. A vertical gradient of either temperature or wind velocity produces a corresponding vertical gradient of sound velocity. This causes sound waves to refract (bend) upward or downward. Upward refraction occurs during sound propagation in an upwind direction or temperature lapse conditions (air temperatures decreasing with height). This tends to send noise skyward, leaving a noise shadow near the ground and thereby reducing noise levels. Downward refraction occurs during sound propagation in a downwind direction or in temperature inversions (temperature increasing with height above the ground). Downward refraction tends to send skyward noise down, concentrating noise near the ground, thereby increasing noise levels. Both upward and downward refraction occurs with and without noise barriers. Atmospheric refraction of sound waves is discussed in Section 2.1.4.3.

7.1.1.2 Results of Completed Studies

Caltrans and its consultants and others have performed elaborate research-level studies concerning noise from highways at adjacent and distant receivers, with and without noise barriers for the three barrier configurations mentioned in Section 7.1.1.1 above. It is not the intent of this section to discuss these studies in detail, only to mention their combined results. The studies were performed along the following routes: Interstate (I-) 405 in Los Angeles, various locations on I-680 and I-80 in the Bay Area, and one along State Route (SR) 99 in Sacramento. These studies followed the general guidelines and criteria outlined in Caltrans' *General Guidelines for Studying the Effects of Noise Barriers on Distant Receivers* (1998). The John A. Volpe National Transportation Systems Center (VNTSC) in Cambridge, Massachusetts, performed two similar studies at Dulles International Airport near Washington, DC, and along I-495 near Baltimore for parallel noise barriers. In addition to the research studies, Caltrans has gathered numerous anecdotal data during routine project studies.

In each research study, before– and after–noise barrier measurements were carefully matched by wind speed, wind direction, temperature, relative humidity, and temperature gradients with height above the ground. All measurements were also normalized for traffic variations. Brief summaries of results of the studies are provided below.

Study Results for Single Barrier on the Opposite Side

The results of studies involving noise level increases for single barriers on the opposite side of a highway in simple terrain, as discussed in Section 5.1.7.2, agreed remarkably with the theoretical calculations shown in the same section, particularly in Figure 5-26. For distances of 50 to 100 feet, the increases were generally 0 to 1 dBA. At 400 feet, the measured results were a 2.4-dBA increase as calculated. For longer distances, the increases were difficult to discern with accuracy but never more than 3 dBA, even in complex terrain as discussed in Section 5.1.7.2.

Study Results for Parallel Barriers

The results of studies involving parallel noise barriers (i.e., one on each side of the highway), as discussed in Section 5.1.7.4, showed degradations in performance of each barrier because of multiple reflections between two reflective barriers. The degradations appeared to increase with distance from and height above the highway/barrier configuration. Degradations also appeared to be a function of the W/H ratio, discussed in Section 5.1.7.4 and depicted in Figure 5-33. The VNTSC study at Dulles International Airport concluded that the maximum degradation at a 6:1 W/H ratio was 6 dBA at distances for which noise barriers are typically designed. At another location near Baltimore, a maximum degradation of 2.8 dBA was measured by VNTSC for a 9:1 W/H ratio. Caltrans measured a maximum degradation of 1.4 dBA for a W/H ratio of 15:1 along SR 99.

Almost all parallel barrier configurations in California have a W/H ratio of at least 10:1, and most are about 15:1. Based on the studies by VNTSC and Caltrans, Caltrans Highway Design Manual Chapter 1100 advises a minimum W/H ratio of 10:1 or more to avoid degradations of 3 dBA or more. Please note that degradation in barrier performance does not indicate an increase in noise level above that without a noise barrier. Instead, it reduces the effectiveness of each barrier on each side of the highway.

Studies along I-680 and I-80 in the Bay Area also showed no measurable noise increase at receivers 0.25 to 2 miles from the highway and barriers.

Study Results for Receiver behind Single Barrier

For receivers behind a single barrier, field studies indicate that barriers are effective within about 330 feet of a highway. Caltrans has collected an abundance of data in research and routine studies over the years to substantiate this claim.

Caltrans has also experienced, in the course of many measurements, that beyond 330 feet or so from a highway, traffic noise levels often approach background levels (the noise levels associated with normal day-to-day activities in the community). Although soundwalls cannot attenuate noise below these levels, Caltrans has never experienced noise increases (above no-barrier noise levels) at any distance behind noise barriers. However, some people continue to believe that noise barriers will increase noise levels at distant receivers behind a barrier.

Explanations have sometimes centered on noise waves "going over the wall and coming back to the ground." This is called diffraction and is actually responsible for noise attenuation, rather than an increase in noise, when compared to the direct noise received without a noise barrier, as explained in Sections 2, 4, and 5.

Another popular "explanation" for perceived noise increase from soundwalls is that the soundwall "lifts" the noise over tiers of homes that normally would shield the receiver. A soundwall will elevate the noise source over tiers of homes no more than the intervening homes do. Soundwalls in California are generally limited in height to 16 feet, approximately equal to the average height of residential development.

There generally is a loss of "ground effect" behind a noise barrier. Without a noise barrier, the direct path of the traffic noise to the receiver travels closer to the ground than after a noise barrier is built. Noise waves close to the ground are subject to excess attenuation because of absorption by the ground. Therefore, when a noise barrier is built, there is a trade-off between barrier attenuation (a decrease in noise) and a loss of excess attenuation.

The net reduction of noise from barrier attenuation and loss of excess attenuation is called barrier insertion loss (see Section 5.1.5). Close to a barrier, the barrier attenuation benefit far outweighs the loss of excess attenuation. At farther distances, however, barrier attenuation diminishes while the cumulative effects of the loss of excess attenuation increase. Caltrans acoustical design procedures for noise barriers take these factors into consideration by applying different noise dropoff rates to with– and without–noise barrier cases. If these drop-off rates were kept constant and applied to long distances, there would be a distance at which the loss in ground effect would eventually exceed the barrier attenuation.

Extensive amounts of field data gathered during a Caltrans noise propagation research project show that differences between excess attenuation rates of elevated sources (e.g., truck stacks, noise diffracted over a noise barrier) and those close to the ground (e.g., tire noise) diminish after few hundred feet or so. The findings can be applied to noise barriers, which in essence "elevate" the source. The cumulative effect of decreasing differences in elevated and near-ground excess attenuation rates with distance appear to be at a maximum at about 200 to 300 feet behind the barrier, where the effect of the differences is the greatest. At greater distances, the differences in elevated and near-ground noise levels appear to become smaller until they disappear at some distance beyond about 400 feet.

Questions have also been raised at times about whether noise "redirected" by noise barriers "bounces off" temperature inversion layers. Redirections on the scale being discussed involve a maximum of 16-foot-high noise barriers and a distance of 0.25 mile or more, are less than 1 degree, and therefore are negligible. Studies under these conditions have confirmed that the difference between barrier and no barrier was not measurable although the noise levels were considerably higher.

After years of research and field measurements under controlled conditions, Caltrans has found no objective evidence that noise levels increase perceptibly because of noise barriers. It is widely accepted by acousticians that normal human ears can barely perceive 3-dBA changes in traffic noise levels when the frequency content of the noise has not changed. Such an increase in noise levels from noise barriers has never been measured.

7.1.1.3 Studying the Effects of Noise Barriers on Distant Receivers

Allegations of noise barriers increasing noise levels at distant receivers based on perception only are unreliable at best. With possible noise fluctuations of more than 10 dBA from meteorological factors alone, people making such claims must not only remember the noise levels before the barrier, but also have knowledge of the meteorological conditions associated with those noise levels. To confirm whether noise barriers do increase noise levels in some instances, a complex before- and after-barrier field study must be undertaken.

Before– and after–noise barrier noise measurements do not adequately address the previous issues unless the measurements are carefully matched by before- and after-barrier conditions of meteorology, traffic, and topography. These types of studies are not routine. Technical Advisory, Noise, TAN-98-01-R9701 *General Guidelines for the Effects of Noise Barriers on Distant Receivers*, November 30, 1998, provides guidelines and criteria for conducting such studies. The advisory is available on the website of Caltrans Division of Environmental Analysis, Noise and Vibration Studies (http://www.dot.ca.gov/hq/env/noise/index.htm).

Procedures for measuring the performance of noise barriers including parallel barriers are provided in the 2009 version of TeNS.

7.1.2 Shielding Provided by Vegetation

No discussion on noise barriers is complete without mentioning the shielding effectiveness of trees, shrubs, and other vegetation typically used for landscaping along highways. Caltrans research on the shielding effectiveness of such vegetation at three different sites in late 1980s and early 1990s concluded that the mean noise reduction was less than 1 dBA, and ranged from 0 dBA to less than 3 dBA (California Department of Transportation 1995). The research further concluded that such vegetative barriers were not an effective measure to reduce highway traffic noise on a routine basis.

However, Caltrans receives complaints of noise increases when Caltrans maintenance personnel trim shrubs and bushes along highways. The most likely explanation for the increase in noise complaints is more related to visual aspects than noise. When shrubs shield traffic from the view of residences, the awareness of the traffic is reduced (i.e., “out of sight, out of mind”). When the vegetation is trimmed or eliminated, the adjacent residents will be able to see the traffic and will be reminded of the noise.

In some cases, residents complaining about ineffective noise barriers have been satisfied when noise barriers have been combined with trees, shrubs, or ivy. Although noise did not noticeably decrease in those cases, the aesthetics of the barriers were improved. Early community acceptance studies have indicated a correlation between barrier acceptance and perceived effectiveness in reducing noise. Therefore, the use of vegetation with noise barriers can be beneficial by improving community acceptance and perceived effectiveness.

As discussed above wind can cause sound waves to refract (bend) upward or downward. When wind is blowing from a source to a receiver downward refraction can increase the sound energy received at the receiver. When a barrier is located between the source and the receiver downward wind refraction can reduce the affective noise reduction provided by the barrier. Research conducted by University Ghent in Belgium (Renterghem and Botteldooren 2008) studied how a tree canopy between the barrier and the receiver affects the degredation of barrier performance from downwind refraction. The study concluded that the presences of a row of trees between a barrier and receiver can provide an important improvement in downwind noise barrier performance up to a distance of 30 times the noise barrier height. Coniferous trees were found to the most effective in this regard. Other references indicate that 100 horizontal feet of tall grass and thick shrubbery can provide up to 5 dB of additional attenuation and 100 feet of dense woods can provide up to 2 dB of additional attenuation (Hoover & Keith 2000).

7.2 Sound Intensity and Power

This document has consistently described the amplitude of sound at a specific location in terms of sound pressure level or noise level. This is also the case for all noise standards, criteria, and descriptors mentioned in this document. In fact, SPL is used in virtually all environmental noise studies for two primary reasons: 1) it is easiest to measure, and 2) it best describes the impact at the receiver.

However, it is important for the noise analyst to know that there are other ways to express sound amplitude. Although considerably more difficult to measure, sound intensity and sound power often provide more useful information about noise sources than sound pressure level. Caltrans has begun using sound intensity in pavement noise studies, and future plans call for other uses to locate and map specific locations of vehicle noise subsources. This section briefly discusses sound power and intensity to broaden the knowledge of noise analysts who may in the future be involved with sound intensity or sound power studies.