

**Technical Advisory
TAN-98-01-R9701**

*California Department of Transportation
Environmental Program
1120 N Street, Sacramento, CA 95814*

**GENERAL GUIDELINES FOR STUDYING THE EFFECTS OF NOISE
BARRIERS ON DISTANT RECEIVERS**

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NOTICE:

This technical advisory is a revision of an earlier technical advisory (TAN-9701-R9301) with the same title, prepared by the same author, dated October 6, 1997. This revision does not alter the basic information of the earlier version; some wording was changed for clarity and easier reading, and some references have been added. Although this document is not an official policy, standard, specification or regulation, the guidelines herein have been successfully used on previous studies. They may be referred to as an acceptable method for studying the effects of freeway noise barriers on distant receivers, generally understood to be between from 0.15 to 3 km from freeways. Any views expressed in this advisory reflect those of the author, who is also responsible for the accuracy of facts and data presented herein.

INTRODUCTION

This is an updated version of general guidelines for performing before-and-after noise barrier noise studies at distant receivers. The original guidelines, dated June 3, 1992, were titled: "General Guidelines For Statewide On-Going Noise Barrier Reflection Studies At Distant Receivers". Later revisions in 1993 and 1997 essentially contained the same information as the 1992 document, with a few minor corrections and changes to make this document more versatile for studying the long-range effects of noise barriers in all configurations, rather than just the ones involving reflective noise. This 1998 revision adds the numbers and titles of two new documents for reference and cites the latest revision to an ANSI standard (see Guidelines and Criteria).

The guidelines and criteria in this document were written to cover complex, non-routine noise barrier noise studies for receivers generally located 0.15 to 3 km from highways. These studies have been performed on a limited basis in the San Francisco Bay Area because of some public concern that noise barriers increase noise levels at distances beyond 400 m from freeways. Many of the guidelines given should be considered experimental. They are not meant to be all-inclusive, nor are they meant to be rigid. Additional guidelines may be necessary to cover specific site conditions, and some of the guidelines may have to be changed if experience and future studies show a need for it. This document will be updated as the need arises.

The author has conferred with many experts across the nation about performing studies involving distant receivers. The general consensus is that it is not practical to do these studies on a routine basis because of their high cost, both in terms of money and necessary resources.

OBJECTIVE OF THE STUDIES

The primary objective of the before and after noise barrier studies covered by these guidelines is to determine through measurements if noise barriers inadvertently increase noise levels at distant receivers. Residents at various locations in the San Francisco Bay Area have perceived increases in noise at 0.4 km to 3 km from freeways after noise barriers were constructed. Previous research studies have shown no objective evidence of the alleged noise increases.

The objective of these before and after studies is not to determine the performance of noise barriers at receivers for which they were designed. Instead, the before and after studies referred to in this document pertain to distant receivers, generally 0.15 km or more from the highway. These receivers are usually not considered to be significantly impacted by highway traffic noise, or influenced by the noise barriers.

These guidelines are considered valid for studying the effects of the following three noise barrier configurations:

1. Barrier between the highway and receivers
2. Barrier on the opposite side of the highway from the receiver (highway between barrier and receivers)
3. Two parallel reflective barriers, on each side of the highway

BACKGROUND AND SCOPE OF STUDIES

Noise studies involving distant receivers cannot at this time be considered routine. There simply are too many variables in site topography and atmospheric conditions, to allow

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"quick and dirty" before and after measurements. Caltrans experience has been that atmospheric conditions can fluctuate noise levels by more than 10 dBA (with or without noise barriers) at distances of 1.5 to 2.5 km from a highway.

Refraction is the main atmospheric process responsible for these noise fluctuations. A vertical gradient of either temperature or wind velocity produces a vertical gradient of sound velocity, which causes sound waves to refract (bend) either upwards or downwards. Upward refraction occurs during sound propagation in upwind direction, or in temperature lapse conditions (temperature decreasing with height). Upward refraction tends to reduce noise levels measured both before and after noise barrier construction. Downward refraction occurs during sound propagation in downwind direction, or in temperature inversions (temperature increasing with height). Downward refraction tends to increase measured noise levels, also in all barrier situations. The effects of refraction can be substantial over long distances.

Another important atmospheric process is molecular absorption of noise through the air. This also has a large effect on noise levels over long distances, and has a complex relationship between temperature and humidity.

Measurements of before and after noise levels must therefore be matched by pertinent meteorological conditions, measured simultaneously with noise. Some of these conditions, such as temperature gradients with height (lapse rates) are difficult to measure. To represent the entire noise path from source to receiver requires extensive meteorological instrumentation.

Finally, detailed traffic volumes, mixes, and speeds must be measured at the source. This process is very labor intensive.

Each before and after study therefore becomes a costly research project, requiring sophisticated instrumentation, substantial amounts of data, meticulous documentation, and statistical analyses. A simple before-and-after measurement without comparing matched conditions is completely meaningless.

GUIDELINES AND CRITERIA

Pertinent criteria of the American National Standards Institute (ANSI) S12.8-1998 standard, titled: "Methods for Determination of Insertion Loss of Outdoor Noise Barriers", or the latest revision thereof will be the default criteria for items not covered in these guidelines. The ANSI standard was not designed for distant receivers, however, it is the only standard that deals with most of the meteorological parameters covered in these guidelines. Other measurement criteria not covered by these guidelines are assumed to comply or be consistent with pertinent sections of FHWA-PD-96-046, DOT-VNTSC-FHWA-96-5 titled: "Measurement of Highway-Related Noise" and latest revision (if or when issued) of Caltrans "Technical Noise Supplement" (TeNS), October 1998 – a technical supplement to the "Traffic Noise Analysis Protocol".

It is hoped that with these guidelines noise level increases of 3 dBA or more due to noise barriers can be detected at receivers up to 3 km from the highway.

A. Noise Measurement Sites

For the purpose of the guidelines in this document, three study site categories will be recognized:

1. Barrier between the highway and receivers

2. Barrier on the opposite side of the highway from the receiver (highway between barrier and receivers)
3. Two parallel reflective barriers, on each side of the highway

Except for a few instances, which will be pointed out at appropriate times, the guidelines for single and parallel barrier noise measurement sites will be the same.

Sites selected for before-and-after noise barrier studies should remain unchanged during the study. With the obvious exception of the presence of the noise barrier(s), the "after" site conditions should be acoustically equivalent to the "before" site conditions, in terms of noise source, noise path, and receiver(s).

Acoustical equivalency of a site is determined by source characteristics (vehicle types, traffic mix, traffic speeds, pavement types and condition), topography (natural as well as man-made features) between the source and receiver(s), and receiver locations (3-dimensional). Although "before" and "after" site conditions should be the same, it is understood that traffic volumes change during the day, week, season, and longer periods. As long as factors influencing the frequency spectrum of the source (traffic mix, speeds, and pavement) do not change drastically, the fluctuations in traffic volumes can be accounted for by the reference Mic(s).

Ideally, the selected sites should be on a tangent section of highway with no nearby on/off ramps or connectors, and with free-flowing traffic.

1. After barrier noise measurements must be taken at the same three-dimensional locations as the before barrier measurements.
2. There must be at least one reference Microphone (Mic) site, located along the highway, and a minimum of two sites at locations of interest, called receiver Mic sites.
3. The reference Mic site must be selected near the highway according to the following location criteria:
 - a) For sites with a single barrier between the highway and the receiver(s), the reference Mic must be located on the receiver side of the highway, **and**:
 - 1) at a location not influenced by the noise barrier: at least 30 m off one end of the barrier (on the barrier line produced), **or** at least 1.5 m above the barrier (note that the before barrier position of the reference Mic(s) should be at the same height above the ground, i.e. proposed barrier height plus at least 1.5 m).
 - 2) at least 1.5 m above the ground
 - 3) a minimum height of 1.5 m above the highway pavement
 - 4) at a distance of no less than 7.5 m and no greater than 15 m from the centerline of the nearest traffic lane
 - b) For single barriers on the opposite side of the highway, the reference Mic must be placed on the receiver side of the highway, **and**:
 - 1) at a location not significantly influenced by reflections from the noise barrier on the opposite side, at least 90 m beyond a point opposite to one end of the barrier, and
 - 2) the same as 3. a) 2), 3. a) 3), and 3. a) 4)

NOTE: For single barriers with receivers on both sides of the highway, two reference Mics should be used as outlined in 3.a) and b), one to be used with the receiver(s) behind the barrier, and one to be used for receiver(s) on the opposite (reflective side) of the barrier.

- c) For parallel barriers on both sides of a highway, the reference Mic(s) must be placed on either one (receiver of interest side) or both sides of the highway (to cover receivers on both sides), **and:**
 - 1) at a location not influenced by shielding or multiple reflection from either barrier, at least 90 m from the end(s) of the barriers, and
 - 2) the same as 3. a) 2), 3. a) 3), and 3. a) 4)
- d) In either case the reference Mic must not be obstructed from the highway traffic by natural or man-made features.
- e) The reference Mic site should not be located near on or off ramps.
5. Beginning at a location of no less than 0.2 km and no more than 0.6 km from the highway, subsequent receiver Mic sites must be selected according to the following guidelines:
 - a) At the same or increasing distances, spaced perpendicularly to the highway no more than 0.8 km between receiver sites.
 - b) Maximum distance from highway is 3 km. This distance may be increased to include special sensitive receivers that are slightly farther away from the highway.
 - c) Mics must be positioned 1.5 m above the ground. Additional heights are encouraged, but not required. For instance, in addition to the 1.5 m Mic it may be desirable to have a Mic positioned at a second story height.
6. Each receiver Mic must subtend a left and right barrier angle of no less than 30 degrees measured from a perpendicular line to the highway and a line to the left and right end of the barrier.
7. Background noise (from other-than-highway noise sources) must be at least 10 dBA lower than the noise from the highway at all noise measurement sites.
8. All receiver sites must be free of major natural terrain features breaking the line of sight to the highway, over a sector of at least 45 degrees left and right of a perpendicular from receiver to highway.
9. Major artificial obstacles (such as houses, apartment buildings, etc.) between receiver and the highway should not be higher than 10 degrees measured from the ground to the top of the obstacle (or a slope of 6:1).
10. There must be no major reflecting surfaces within 3 m from the reference or receiver Mics.

B. Meteorological Measurement Sites

Meteorological sites should be representative of the atmospheric conditions along the general noise path between highway and receivers. The same sites must be used for before and after measurements.

1. Each noise barrier study site should have a minimum of two meteorological sites, one located near the highway and one located at or near the farthest noise receiver site. A third site between these two locations is strongly recommended.
2. The sites should be open, without any major local obstacles to alter prevailing wind speed or direction of the project area, and should be representative of air temperature structure and humidity of the noise path, and not be influenced by highway traffic (turbulence).

C. Traffic Count Sites

Traffic count sites must be as close to the reference noise measurement site as possible, in order to allow accurate counts of volumes, mix, and speeds of traffic passing the reference Mic. Typical locations of these sites are pedestrian or street over crossings from which traffic can readily be observed. Traffic must be representative of the traffic passing the reference Mic(s).

D. Measurements and Instrumentation

Before and after noise measurements should only be compared when atmospheric conditions are equivalent. Limits of atmospheric equivalence appear in the Atmospheric Equivalence section of these guidelines.

1. Sufficient amount of noise measurements must be taken to determine the mean of the differences between reference Mic and each receiver Mic with a 95% confidence interval of +/- 1.5 dBA, for each category of atmospheric equivalence, for before as well as after measurements.
2. Noise measurements at the reference Mic and all receiver Mics must be performed simultaneously.
3. Sufficient amount of noise measurements must be taken under different categories of atmospheric equivalence to insure before and after atmospheric equivalence in three categories. Attempts must be made to include as one of these categories, a "worst case" condition. (See Atmospheric Equivalence).
4. All noise measurements must be made with ANSI S1.4 (1983) Type 1 sound level meters (SLM), or better.
5. Noise measurements must be time- averaged for a minimum of 15 minutes, using the L_{eq} descriptor; sound pressure levels must be A-weighted.
6. Additional octave band measurement and analysis are encouraged, but not absolutely necessary. The added information will provide a better understanding of the effects of certain atmospheric processes on noise frequencies, and may explain various human perceptions.
7. Meteorological measurements must be taken simultaneously at each of the sites discussed in section B. The following meteorological measurements or observations must be made simultaneously with each set of noise measurements:
 - a) Wind speed and direction shall be measured at a minimum height of 6 m and a maximum height of 10 m. Once a height is selected, it must be used at all sites during the entire study.
 - b) Before and after air temperature measurements should be taken at the same location and height, shielded from sun, at a minimum height of 1.5 m above the ground.
 - c) Temperature lapse rate (difference in air temperature per unit height, or Delta-T), at a minimum between two heights: one at 10 m, and one at 0.6 m. A third point between these two heights is recommended. The Delta-T probes must be factory-matched.
 - d) Relative humidity, at a minimum height of 1.5 m above the ground.
 - e) Sky condition shall be estimated by the observer.
 - f) All instruments used shall be accurate enough to measure guidelines set forth in the Atmospheric Equivalence section.

E. Traffic Counts

Traffic counts must be made during each noise measurement. The counts must be grouped by direction (such as east- and westbound, or north- and southbound). The volume in each direction must be further segregated by vehicle type defined in FHWA-RD-77-108 report, i.e. heavy trucks, medium trucks, and automobiles.

Average directional traffic speeds must be measured by radar, or any other reliable method. The average speeds must be representative of corresponding time periods of noise measurement and traffic counts. Speeds may need to be stratified by vehicle type if there is a significant difference between truck and auto speeds.

F. Atmospheric Equivalence

All comparisons between before and after noise levels must be done for the same atmospheric conditions. Atmospheric conditions before and after barrier construction are considered equal if:

1. The wind class defined in Table 1 remains unchanged and the crosswind vector components of the average wind velocity from the source to the receiver do not differ by more than 1 m/s. In any case, no noise measurements shall be made when the average wind velocity exceeds 5 m/s regardless of direction. Strong winds with a small crosswind vector component in the direction of propagation (calm class) should also be avoided, because of large errors due to wind fluctuation.

Table 1. Classes of wind conditions.

Wind Class	Crosswind Vector
Upwind	-1 to -5 m/s
Calm	-1 to +1 m/s
Downwind	+1 to +5 m/s

2. Air temperature remains within 10^o C.
3. The temperature lapse rate class defined in Table 2 remains unchanged.

Table 2. Classes of temperature lapse rates

Lapse Rate Class	Lapse Rate
Strong Lapse	< -0.02 °C/m
Near Isothermal	-0.02 ° to +0.02 °C/m
Strong Inversion	> +0.02 °C/m

4. The relative humidity is not greater than 90%, or less than 30%. The before and after relative humidity remains within 20%.
5. The before and after noise measurements are made for the same class of cloud cover class as shown in Table 3:

Table 3. Cloud cover classes

Class	Description
1	Heavily overcast
2	Lightly overcast (either with continuous sun or the sun obscured intermittently by clouds 20% to 80% of the time)
3	Sunny (sun essentially unobscured by clouds at least 80% of the time).
4	Clear Night (Less than 50% cloud cover)
5	Overcast Night (50% or more cloud cover)

The above criteria are consistent with ANSI S.12.8-1998.

G. Analysis

1. For each of a minimum of three atmospheric equivalent conditions described above, the average measured before and after barrier differences between each reference Mic/receiver Mic pair must be calculated and compared. The before barrier difference minus the after barrier difference is the noise increase, or decrease due to the barrier(s). A positive result indicates a noise increase, a negative result a decrease. A change of 3 dBA or less will be considered no change.
2. Measured noise levels at the reference Mic shall be verified by using the traffic counts expanded to hourly volumes, and speeds in the latest version(s) of the noise prediction computer program(s) routinely used by Caltrans. The measurement will be rejected if the difference between measured and calculated noise levels is greater than 3 dBA, unless there is a good explanation for the difference. The calculated result will not be used in the before and after comparisons.