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Rudolf W. Hendricks

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16. ABSTRACT

The California Department of Transportation (Caltrans) is required by standards to predict noise levels for proposed federal aid highway projects. For these predictions Caltrans uses national vehicle noise reference emission levels, which are based on 1975 data collected in North Carolina, Florida, Washington, and Colorado. In 1982, Caltrans initiated a study in response to the need for California data. This report presents criteria, methods and analyses used to develop California vehicle noise emission levels for level roads and heavy truck emission levels on grades.

More than 3000 noise and environmental measurements were made at sixteen level road sites in California. Included were automobiles and medium and heavy trucks traveling at constant speeds between 25 and 65 mph. Microphones were located at distances of 25, 50 and 100 feet, and at heights of 5 and 10 feet. Nearly 1800 measurements were made of heavy truck noise at constant up hill speeds from 10 to 65 mph at six road sites ranging in grade from +3% to +7%.

Analyses of data show that California automobile noise is 0.8 to 1.0 dBA higher than national levels. In contrast, medium and heavy trucks noise is 0.5 to 3 dBA lower than the national levels. The study also indicated that the three vehicle groups adequately represented the California vehicle population and geographical differences may be ignored. Effects of opposite winds of less than 12 mph, and terrain cover introduced errors of no more than 1dBA at the 50-foot reference distance. For +3% to +7% grade, heavy truck noise showed no grade dependency. Speed dependency was best expressed as a second order polynomial.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

CALIFORNIA VEHICLE NOISE EMISSION LEVELS (FINAL REPORT)

Study Supervised by .... Mas M. Hatano, P.E. and Paul Benson, P.E.

Principal Investigator .... Rudy Hendriks

Co-Investigator .... Dick Wood

R. A. FORSYTH, P.E.
Chief, Office of Transportation Laboratory

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

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° Charlie Kay and Gene Lombardi for maintaining a high standard of instrument quality control and for their partnership during the field-measurements.

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° Que Huynh for assisting in data processing.

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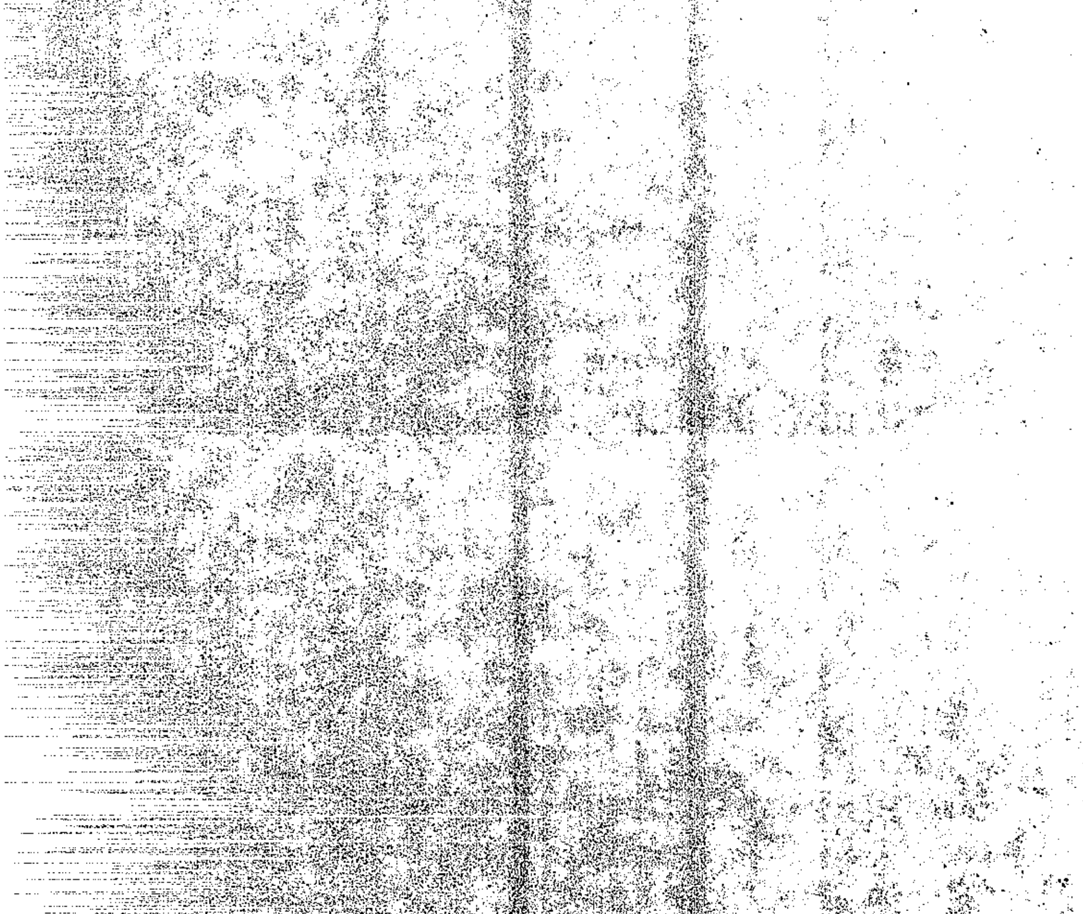


I. INTRODUCTION

This is the final report presenting the results of the California Vehicle Noise (Calveno) Reference Energy Mean Emission Levels study for level roads and heavy trucks on grades. An interim report by the same title and author was published in August 1984(1). It covered the development of speed-dependent vehicle noise emission levels on level roads only.

This final report includes both the interim report and the additional information concerning noise levels of heavy trucks traveling uphill on grades of +3% to +7%.

Background

The noise abatement procedures for Federal or Federal Aid highway projects are governed by the Federal Aid Highway Program Manual (FHPM) 7-7-3(2). This directive requires state highway agencies to determine and analyze expected traffic noise impacts and alternative noise abatement measures to mitigate these impacts.

As part of the traffic noise impact analysis under FHPM 7-7-3, prediction of future traffic noise is required. Any prediction method may be used to satisfy this requirement if it generally meets the following two conditions:

1. The method must be consistent with the FHWA Highway Traffic Noise Prediction Model, Report No. FHWA RD-77-108(3).

2 The prediction method must use either the National Reference Energy Mean Emission Levels as a function of speed(2,3) or reference energy mean emission levels determined by the methodology described in FHWA-DP-45 1R(4).

Since 1978, the California Department of Transportation (Caltrans) has used the National Reference Energy Mean Emission Levels as a function of speed for noise predictions for Federal or Federal Aid highway projects. These noise emission levels were based on FHWA-RD-77-19(5) (autos), and FHWA-RD-78-64(6) which presented statistical analyses on truck data gathered in the 1975 Four-State Noise Inventory(7). California was not among the four states in the study. It was also reasonable to assume that vehicle noise emission levels may have changed since 1975, due to new truck noise emissions regulations and the recent popularity of compact, energy efficient automobiles. For these reasons, Caltrans recognized the need for a California vehicle noise emission study.

A 1981 Caltrans barrier evaluation study(8) comparing before and after barrier measured noise levels with those predicted by FHWA-RD-77-108(3) methods concluded that the latter tended to predict average values of 3 to 4 dBA higher than those measured at eleven barrier sites throughout California. That study recommended further investigation to examine the validity of using the national emission levels in California. The recommendation was followed up, and the results were presented in the interim report(1).

The Calveno curves have since been approved by the FHWA and and are now used in California for noise studies required by FHPM 7-7-3. These levels, however, are valid for level roadways only. They are not suited for grades.

To compensate for this deficiency, the FHWA model allows for an uphill grade correction to be applied to heavy truck emission levels. Two methods for calculating grade corrections were presented(3). The first, "NCHRP Report 117 Method," involves the addition of a grade dependent, speed-independent constant to the noise level based on total truck volume. The second, "NCHRP Report 174 Method," is a grade- and speed-dependent equation which calculates noise adjustments for grades as a function of speed, to be applied to uphill trucks only. FHWA RD-77-108(3) recommends that the corrections of NCHRP 117 be used on the uphill heavy truck noise levels only. The FHWA Level 2 Highway Traffic Noise Prediction Model, computer versions STAMINA1 and STAMINA2, as well as the Caltrans computer versions SOUNDS3and SOUND32 essentially use this recommended procedure.

During the Calveno level road measurements, a limited amount of measurements were made on three different uphill grades. Preliminary analyses of these grade data strongly suggested that the recommended procedures for dealing with grades(3) are not correct. An extension to the research project was requested and approved, to measure and analyze heavy truck noise emission levels on uphill grades. This resulted in a heavy truck speed-dependent energy mean emission level curve for grades of +3% to +7%. This curve, presented in Chapter XI, should be used for uphill heavy truck traffic traveling at sustained speeds only (i.e., far enough up the grade after decelerating from 55 mph to "crawl" speed). Ideally, the curve should be integrated over typical truck speed distributions associated with each percentage increment of grade.

Chapter XI includes observed speed distributions and compares them with previously reported typical speed-distributions on grades in California. It also includes suggested heavy truck noise emission values for each percentage increment of grades from +3% to +7%. These were based on intregration over observed truck speed distributions which proved to be fairly typical. The values may be used as "default" values when detailed truck speed distributions are not readily available.

Objectives

The original objective of this study was to develop California Vehicle Noise Reference Energy Mean Emission Levels for use in California highway noise studies complying with the FHPM 7-7-3 requirements. The methods and criteria used to accomplish the primary objective are consistent with FHWA-DP-451R(4) and FHWA-OEP/HEV-78-1(9). The orignal objective was later expanded to include uphill heavy truck noise emission levels on grades up to +7%.

There were some secondary objectives in this study:

°Verification of the inference from the four-state study that vehicles in California can be categorized in three acoustic source groups to represent the State's entire vehicle population without introducing significant errors in noise predictions.

°Examining the effects of hard and soft site characteristics (as defined by FHWA RD-77-108(3)) on noise emission levels measured at a 50-foot reference distance.

°Studying near and far field (defined in FHWA RD-77-108(3)) single event drop-off rates as a function of distance and vehicle group.

°Examining geographical differences in vehicle emission levels for two regions in California, representing northern and southern California.

°Examining the effects of wind on emission level measurements.

Work Plan

A total of sixteen sites were selected for the original objective, eight in northern California and eight in the southern part of the state. Each vehicle group was about equally represented in the northern and southern portions of the state.

The number of vehicle passby events measured was 3045. Because of stringent contamination control and other rejection criteria, 2734 events were actually used to determine emission levels. Of these, 46.2% were automobiles, 11.6% medium trucks and 42.2% heavy trucks (as defined in FHWA-RD-77-108(3)). Speed-dependent reference energy mean emission levels were developed for each of the three vehicle groups for constant speeds from 25 mph to 65 mph on level roads. These emission curves are presented in Chapter XI of this report.

Six additional sites were selected later for the grade emission levels. These sites were along grades ranging from +3% to +7%. A total of 1907 heavy truck measurements were made of which 1770 were acceptable. These were used to determine the grade emission levels at sustained speeds of 10 mph to 64 mph. The grade emission levels are also presented in Chapter XI.

The secondary objectives were attained by measurements using up to 5 microphones at distances ranging from 25 to 100 feet from the centerline of vehicle travel and at heights of 5 feet and 10 feet.

All noise measurements were made on the A-weighted scale. No frequency spectra were measured, nor was any attempt made to verify vehicle noise centroid heights as reported in FHWA-RD-77-108(<u>3</u>). No measurements were made on the downhill side of the roadway. This was not included in the objectives.

II. CONCLUSIONS

California Emission Levels - Level Roads (Calveno

Automobiles. The California reference energy mean emission levels are from 0.8 dBA at 31 mph to 1.0 dBA at 60 mph higher than the national reference mean energy emission levels.

Medium Trucks. The California levels are from 0.5 dBA at 31 mph to 2.9 dBA at 60 mph lower than FHWA (national) levels.

Heavy Trucks. The California levels are from 0.2 dBA higher at 31 mph to 2.8 dBA lower at 60 mph than FHWA levels.

Because of the importance of heavy truck volumes in noise predictions, the net effect of the above three findings is a lower predicted noise level of about 2 dBA for average traffic mixes.

California Heavy-Truck-On-Grade Emission Levels (Calgrade)

Grade Dependency. For a given speed or speed class, no direct grade dependency could be detected in the measured noise levels for the range of grades studied (+3% to +7%). This paradox can probably best be explained by the following. Sustained uphill truck speed is governed by both grade and load. Trucks traveling at the same maximum sustained speed must carry lighter loads on steeper grades and heavier loads on lesser grades. For a particular speed, the probable increase in noise level due to a steeper grade will be offset by the lighter loads prevalent at that speed. The degree to which load and speed offset each other could not be determined experimentally because the truck weights were not known.

Speed Dependency. Although noise emission levels of heavy trucks lumbering up-grade were apparently not grade dependent, they displayed a definite speed dependency. A second order polynomial curve (noise energy vs. $\log_{10}$ speed) provided the best fit with data collected at each grade site.

Uphill Heavy Truck Speed Distributions. As was expected, a variety of truck speeds was observed at each grade site. Unlike truck speeds on level roads which were largely unaffected by loads at cruise speeds, the uphill heavy trucks were strongly affected by loading, creating wide ranges of observed truck speeds. Average speeds decreased as the percentage of grade increased. The observed speed distributions generally appeared to fit typical distributions of trucks on grades in California(10).

On-Grade Reference Energy Mean Emission Levels. Because of the observed lack of a direct, dependency on grade, one speed dependent heavy truck noise emission curve, valid for +3% to +7% grades, was developed (see Chapter XI). The effects of grade and load are implicit in the estimated truck speed assigned by the user. Using typical average speeds for grades of +3% to +7% in 1% increments, a comparison was made between the California Heavy-Truck-On-Grade Noise (Calgrade) Reference Energy Mean Emission Levels and the NCRHP 117 grade corrections applied to Calveno heavy truck curve. For grades of +3% to +5% Calgrade is higher by 1.6 dBA at +3% to 0.5 dBA at +5%; for grades of +6% and +7% Calgrade is lower by 0.8 dBA at +6% to 2.6 dBA at +7%. Ideally, the Calgrade curve should be integrated over an entire truck speed distribution, rather than using the average speed, since Calgrade is a second-order polynomial with a "sag" at about 25 mph and high values at 10 mph and 65 mph. Using typical speed distributions, predictions based on average speeds will generally be from 0.1 to 0.5 dBA lower than those based on integration of the entire speed distribution. Default values including these integrations are given in Chapter XI.

Acoustic Source Groups

California vehicles can be categorized in three acoustic source groups: autos, medium trucks and heavy trucks, using the same definitions as in FHWA RD-77-108(2).

Hard vs. Soft Sites

The difference in noise levels between hard and soft site characteristics at 50 feet from the centerline of vehicle travel, averaged 2.0 dBA for autos, 1.9 dBA for medium trucks and 1.6 dBA for heavy trucks. Because of the many variations in site characteristics encountered in the sixteen measuring sites, the California emission levels provide a balance between hard and soft site noise levels at 50 feet that guarantees accuracies of well within ±1 dBA for all but the most extreme site conditions.

Near and Far Field Noise Drop-Off Rates

In both near (less than 50 feet) and far (50 feet or greater) fields, site characteristics had an effect on the single event drop-off rates.

On hard sites, the near field drop-off rates were reduced to an average of 5.2 dBA per doubling of distance (DD), probably due to point source degradation close to the vehicles.

In the far field, the average hard site single event drop-off rates were 5.9 dBA/DD for the low microphones (5-foot high) and 5.2 dBA/DD for the high microphones (10-foot high). The latter deviation from the expected 6.0 dBA/DD point source drop-off rate was probably due to greater exposure to reflections from the roadway.

On soft sites, the near field point source degradation effects on drop-off rates was more than offset by excess ground attenuation. The drop off rates averaged 7.0 dBA/DD at a height of 5 feet.

In the far field, the average soft site drop-off rate for single events was 7.9 dBA at 5-foot heights and 6.8 dBA at 10 feet, indicating that soft site characteristics still affect noise levels at 10 feet above the ground.

Geographical Differences

There appeared to be no differences between northern and southern California for autos and medium trucks. Heavy trucks appeared to be louder in Northern California by up to 2 dBA. The California emission curve for heavy trucks, however, provides a balance guaranteeing accuracies within ± 1 dBA in most locations in California.

Wind

For winds of 12 mph or less, direction had no apparent effect on measurements at 50 feet. For opposite cross wind (90° to roadway) directions with speeds between 6-12 mph there appeared to be a statistically significant difference at 100 feet of 3 dBA in noise levels generated by autos. This difference could have been caused by wind direction, site variation, or both. It was not possible to separate individual contributions by each. No differences were detected for medium and heavy trucks at 100 feet.

III. RECOMMENDATIONS

This report makes the following recommendations:

°The California Vehicle Noise (Calveno) Reference Energy Mean Emission Levels should be used in California for highway noise predictions in new studies effective as soon as possible after FHWA approval.

°Computer programs should have an option for either National or California emission levels to allow completion of studies already in progress.

The above recommendations were implemented after FHWA approval of the interim report(1) and have been in use since March 1985 in California.

°The California Heavy-Truck-On-Grade Noise (Calgrade) emission levels should be implemented for use in California as soon as possible after FHWA approval. Calgrade should be used for uphill heavy trucks, on grades ranging from +3% to +7%, at free flowing sustained speeds. For grades less then 3%, straight-line interpolation between level and 3% noise emission values is recommended.

°California vehicle noise emission levels should be updated periodically to account for changes in vehicle fleets. These update efforts do not have to be as extensive as those presented in this report.

°Further research is recommended in line source drop-off rates as a function of distance, height, terrain, wind speed and wind direction. These variables have a significant effect on noise measurements and prediction results.

IV. IMPLEMENTATION

In March 1985, following approval of the interim report(1) by the FHWA, the California Vehicle Noise (Calveno) Reference Energy Mean Emission Levels presented in Chapter XI of this report were programmed into all Caltrans computer versions of the FHWA Highway Traffic Noise Prediction Model (FHWA-RD-77-108). The National Reference Energy Mean Emission Levels will remain available to allow completion of noise studies already in progress.

A memorandum was sent to all Caltrans districts advising concerned environmental and project development personnel of the changes.

Immediately following FHWA approval of this final report and/or the California Heavy-Truck-On-Grade Noise (Calgrade) Reference Energy Mean Emission Levels presented in Chapter XI of this report, Calgrade will be programmed into all Caltrans computer versions of the FHWA Highway Traffic Noise Prediction Model (FHWA-RD-77-108).

A memorandum will be sent to all Caltrans districts advising concerned environmental and project development personnel of the changes.

V. BENEFITS

Calveno

At the outset of this study, benefits could not be estimated in terms of dollar savings. There were three possible outcomes for the California emission level results. First, the levels could have been the same as the national emission levels. In this case, the benefit would have been the reassurance that the levels used for noise prediction and barrier design were accurate.

A second outcome could have been that the California emission levels were higher than the national levels. There would not have been any benefit to Caltrans or FHWA in this outcome, at least not directly translatable into dollars. Higher predicted noise levels would result in higher barriers and greater costs. Affected residents, however, would benefit from additional noise reductions.

The third outcome, lower California emission levels, would obviously translate directly into dollar savings for Caltrans and FHWA resulting from reduced mitigation measures:

The benefit common to all three outcomes is the improved accuracy of the model, thereby assuring both increased confidence in the model results, and a higher level of service to the public.

As the conclusions indicate, the third outcome - that of lower California truck emission levels than national levels - occurred.

It is, therefore, not entirely fair to credit the benefit in barrier savings to the design of this study. The benefits, however, may be viewed as incidental to the search for increased accuracy in the model.

For average traffic mixes and speeds of 55 mph predicted noise levels should be approximately 1 to 2 dBA lower using the California emission levels. To translate this into dollar savings, several items need to be considered. Firstly, retrofit barriers for existing freeways will not be affected by the lower emission levels, due to the current Caltrans practice of calibrating the model with existing noise measurements.

Secondly, Caltrans Noise Barrier Design Information Bulletin No. 58(11) requires a barrier line-of-sight (LOS) break between an 11.5-foot truck stack and 5-foot receiver. The actual height of the LOS break depends on the roadway-barrier-receiver geometry. For average, at-grade highway conditions, the break height lies between 8 and 10 feet.

Finally, the acoustical barrier design also depends on traffic mix and geometry.

For future barriers along proposed new highway alignments where model calibration is not possible, barrier cost savings using California emission levels could result in savings of $200,000 per mile for at-grade sections. The estimate is based on typical traffic mixes at 55 mph, at-grade section, barrier to equivalent noise source distance of 50 feet and barrier to receiver distance of 50 feet. A noise wall designed to be 13 feet high with national emission levels could be reduced to approximately 10 feet using California emission levels to achieve the same predicted noise level behind the barrier. In some marginal cases it is possible that a barrier might be entirely eliminated.

Higher predictions of 1 to 2 dBA with national emission levels are consistent with average overpredictions of 3 to 4 dBA reported in a previous Caltrans study(8).

Calgrade

For speed distributions associated with 6% to 7% grade, noise predictions using Calgrade will generally be up to 2.6 dBA lower than those based on Calveno with NCHRP 117 grade corrections. Noise barrier designs based on the Calgrade predictions would be about 1 foot lower if the barrier were located on the uphill-bound side of +6% to+7% grades resulting in a saving of approximately $50,000/mile. On the other hand, Calgrade would result in an increase of approximately the same amount for +3% to +5% grades. It may, therefore, be concluded that no significant cost savings or increases will be realized from implementing the Calgrade curve.

The true benefit in this case is the increased accuracy and greater confidence in predictions, resulting in more reliable noise barrier design procedures.

VI. INSTRUMENTATION

All sound level meters (SLM) used in this study met the requirements of Type I Precision SLM per ANSI S1.4, 1983 (12). The SLM were connected to a datalogger specifically designed for the California Transportation Laboratory.

The datalogger has sixteen channels which may be selectively activated to receive up to sixteen DC output signals from SLM. The signals are then converted by the datalogger's microprocessor into continuous, time-varying noise signals which are digitally displayed and updated at short time intervals depending on the "slow" or "fast" response settings. The datalogger has two mode settings: "standby" and "sampling". In the "sampling" mode the datalogger stores one sample per activated channel per second in the microprocessor. The stored values are used at the end of each sampling period to derive noise descriptors and statistical values. During sampling, an "omit sample" button may be depressed to exclude any noise contamination such as barking dogs, sirens or aircraft noise.

At the end of each noise measurement period, the datalogger prints out the channel number, date, site number, time sampling started, time sampling ended, number of samples lost (due to "editing" during measurement), L_{eq}, L_{10}, L_{50}, a histogram of noise levels vs percent frequency, standard deviations, skewness, and kurtosis for each channel.

The datalogger also has the capability to measure maximum noise levels in either standby or sampling mode while a "peak" button is pressed. Upon release of the button, the maximum noise level received by each channel while the peak button was depressed, is printed with the date, site number, time, and elapsed time of the single event. The datalogger was used in this mode during this study.

A 50-foot reference microphone (mic 2) and SLM were also connected to a graphic level recorder (GLR). The GLR was used as a "valid peak" evaluation tool as will be discussed in the Field Measurements chapter.

Table VI-1 lists the instruments used in this study. Figure VI-1 shows the instrument setup.

Table VI-1

INSTRUMENTS USED IN THIS STUDY

Sound Level Meters

5 Bruel & Kjaer Type 2218 Precision SLM

Microphones

5 Bruel & Kjaer Type 4165 1/2" Microphones

Graphic Level Recorders

1 Bruel & Kjaer Type 2306 Portable GLR

Calibrators

1 Bruel & Kjaer Type 4230 1000 Hz, 94 dB Calibrator

Noise Data Acquisition System

1 ea. Datalogger Microcomputer made to specifications prepared by the Transportation Laboratory; the unit was manufactured by James Cox & Sons, Inc., Colfax, California, and Walt Winter of Engineering Logic, Sacramento, California.

Miscellaneous

1 ea. Range Master 715 (radar gun); Decatur Electronics, Inc. Wind Measuring Instrument; Belfort Instument Company

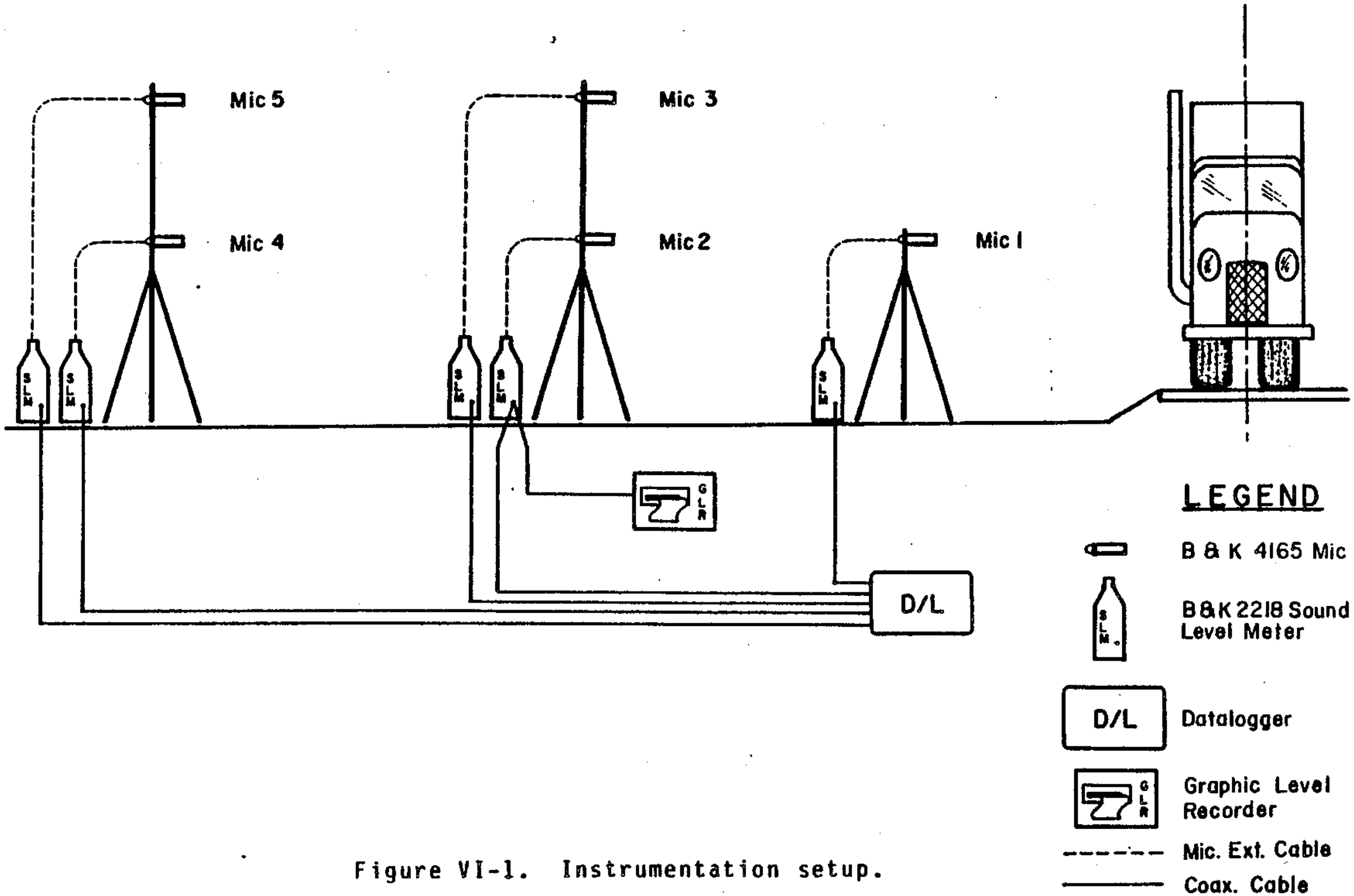


Figure VI-1. Instrumentation setup.

The SLM datalogger system was calibrated before and after each measuring period at each site by a field calibrator. The calibrator was periodically calibrated at the Caltrans Transportation Laboratory (TransLab) in Sacramento. TransLab has the facilities and instruments for performing sound equipment calibrations traceable to the National Bureau of Standards in Washington, D.C., via two Bruel and Kjaer 4160 one-inch laboratory standard microphones. These microphones are sent alternately to NBS every six months to insure the availability of a recently calibrated standard microphone at the TransLab.

VII. SITES

Site Selection and General Requirements

All selected sites for this study were in conformance with emission level site criteria set forth by FHWA-OEP/HEV-78-1 (9) and FHWA-DP-45-1R(4). In addition to these physical criteria, the following general requirements were strived for during the selection process:

1. Adequate representation of hard and soft sites as defined by FHWA-RD-77-108(3).

2. Adequate geographical representation of vehicles.

3. Adequate speed representation.

With the exception of requirements 1 and 2, the six grade sites followed the same criteria and requirements described above. All grade sites consisted of compacted, uniformly graded dirt. They were judged to have site characteristics of some what less reflectivity than hard sites. They were typically large emergency turnouts. All grade sites were located along major interstate or state freeways. Traffic moved at free flowing speeds averaging 55 to 60 mph on the level approaches to the grades. The sites were located far enough uphill to allow truck speeds to decelerate to a sustained "crawl" speed determined mainly by load and grade. Distances from the bottom of the grade to the site ranged from 1 mile for the 7% grade to 2 miles for the 3% grade. There were no other constraints on truck speeds such as lane merging, restrictive speed limits, or roadway construction.

These site criteria and requirements will be discussed in greater detail.

Physical Criteria. The following physical criteria were imposed on the sites:

1. The site shall be open without obstacles or large reflecting surfaces within 100 feet of either the vehicle path or microphone positions.

2. The ground surface at the microphones shall be no more than 2 feet above or below the roadway elevation or the plane of pavement (if the cross slope, crown or superelevation is significant).

3. The ground surface elevations along a line perpendicular to the roadway and passing through all microphones shall not vary more than 2 feet parallel to the plane of pavement.

4. The ground within the measurement area may be hard or soft as defined in FHWA-RD-77-108(3).

5. The roadway pavement shall be either concrete or asphalt concrete, dry, and in good condition.

6. The site shall not be near other significant noise sources such as heavily travelled frontage roads, ramps, construction, aircraft, etc.

7. The site shall not be near intersections, lane mergings or any other features that would cause traffic to slow down or speed up. Traffic has to pass at constant speed.

8. Other criteria are discussed in Chapter VIII, Field Measurement Methodology, under Typical Instrument Set Ups.

Hard and Soft Site Representation. Of the sixteen level sites selected, five were considered hard sites (sites 2, 9, 11, 12, 14), and eleven soft (sites 1, 3, 5, 6, 7, 10, 15, 16, 17, 18, 19). The effects of hard vs. soft sites on noise levels measured at 50-foot reference distance will be discussed in Chapter X, Data Analysis and Results.

Geographical Representation. California is a large and diverse state with many different types of traffic. Truck traffic, for example, consists of various types: interstate, urban industrial, rural agricultural, etc. In order to get representative samples of the state's traffic, a few samples were taken at many sites rather than the opposite.

In California, the FHWA Highway Traffic Noise Prediction Model is used mainly with higher speed traffic in urban and suburban regions. Geographical representation was therefore concentrated on these regions. Adequate high speed representation of automobiles and heavy trucks was obtained by sampling in the following areas:

1. Sacramento and vicinity.
2. San Francisco Bay area.
3. Los Angeles/Ventura area.
4. San Diego and vicinity.
5. San Bernardino/Riverside area.

Site selection was limited to the outskirts of the above urban regions to avoid congested traffic conditions.

Low speed traffic and all medium trucks were not necessarily represented geographically because of the relative difficulty in obtaining enough samples. Low constant speed traffic was generally difficult to find. Medium trucks were also relatively scarce.

Site Locations and Descriptions

Selected noise sites were numbered sequentially, in the order of measurement. A total of nineteen level sites were originally selected. However, three sites - sites 4, 8 and 13 - were not used. Site 4 was a Caltrans test site at the California Highway Patrol Academy. Some limited passby noise measurements were made for another research project at this site, using a medium truck and auto at various speeds. It was decided not to include the data in this study because the single medium truck and auto were not representative of the California vehicle population.

The sequential number at site 8 was assigned just before measurement. Because of adverse weather conditions, no measurements were made at site 8. Subsequent measurement attempts were also foiled by inclement weather.

Measurements were made at site 13 in the Mojave Desert. Later it was discovered that the roadway is on a 3% grade. This fact went unnoticed at first because the entire desert floor in the area is along an average 3% incline. Profile elevations taken after the noise measurements exposed the gradient.

Although sites 4, 8 and 13 were eliminated, the remaining sites were not renumbered to avoid confusion and maintain correlation with the original data. In addition to the sequential numbers, the sites were also given names.

The six grade sites were numbered 20, 21, 22, 23, 23A and 23B. The respective grade percentages were: 6.0%, 7.0%, 3.0%, 4.5%, 5.6%, and 4.2%.

General site locations are shown in Figure VII-1, followed by detailed location descriptions in Table VII-1. Cross sections, layouts and area maps are shown in Appendix A.

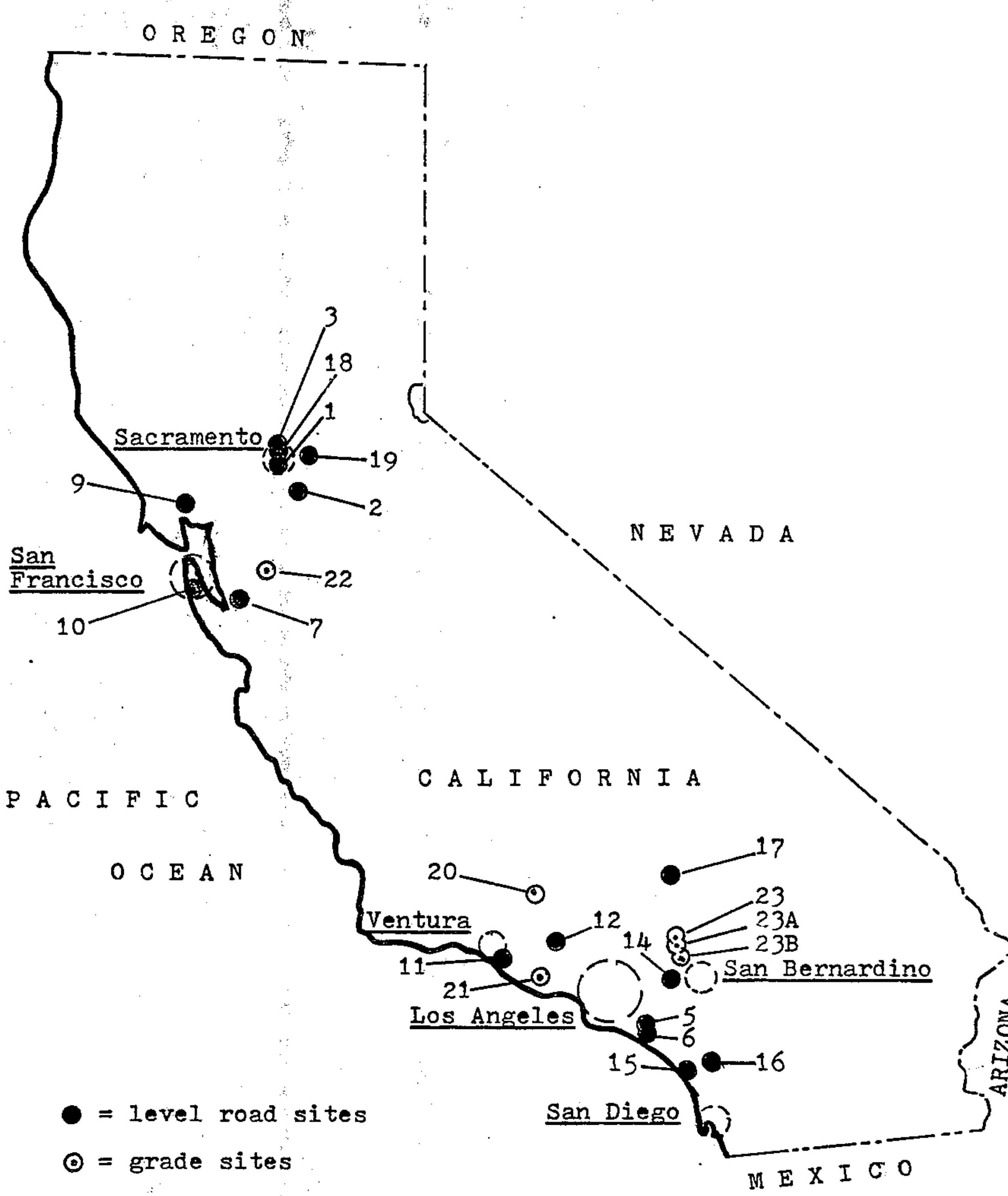


Figure VII-- I. Locations Of Noise Measurement Sites.

TABLE VII-1 SITE LOCATIONS

SITE I.D.		SITE LOCATION						
No.	Name	Dist.	County	Route, Street	P.M.	Description	Date(s) Measured	Hard or Soft
1	Freeport	3	Sac	5	14.7	Southbound I-5, 1.5 mi. south of Meadowview/Pocket Rd. S. Sacramento.	8-17-82	Soft
2	Mingo	3	Sac	99	5±	Northbound Rte 99, 0.5 mi. north of Mingo Rd., at frontage road cul-de-sac; approx. 4 mi. north of the town of Galt.	8-18-82	Hard (Dirt & Pavement)
3	Elkhorn	3	Sac	Elkhorn Bl.	-	Eastbound Elkhorn Bl, south side, 0.5 mi. east of Rte 99, 200 ft east of a dirt road; approx. 10 mi. northwest of Sacramento.	9-21-82 9-22-82 9-23-82	Soft
4*								
5	Barranca	7	Ora	Barranca Rd.	-	South-eastbound Barranca Rd, south-west side, 0.3 mi. northwest of Culver Dr.; approx. 1 mi. north of I-405; City of Irvine.	10-27-82	Soft
6	Michelson	7	Ora	Michelson Dr.	-	Eastbound Michelson Dr., south side, 100 ft east of Seton Rd., 100 ft west of Elmtree Ln; approx. 0.6 mi. east of Culver Dr., 0.3 mi. south of I-405, Irvine.	10-28-82	Soft
7	Mission	4	Ala	680	1.3	Southbound I-680, 1.1 mi. south of Mission Rd. (south), 1.1 mi. north of Scott Rd., approx 3 mi. north of Milpitas.	1-10-83	Soft

* = Not Used (see text for reasons)

TABLE VII-1 SITE LOCATIONS (Con't.)

SITE I.D.		SITE LOCATION						
No.	Name	Dist.	County	Route, Street	P.M.	Description	Date(s) Measured	Hard or Soft
8*								
9	Weigh-Station	4	Son	37	2.51	Eastbound Rte 37, south side, 0.5 mi. east of Lakeville Rd., at old weigh-station, approx. 6 mi. east of Rte 101 and Novato.	1-11-83	Hard (Pavement)
10	Hills-borough	4	SM	280	15.1	Southbound I-280, 1 mi. north of Black Mountain and Hayne Rd. in Hillsborough	1-12-83	Soft
11	Kimball	7	Ven	126	2.8	Eastbound Rte 126, 200 ft± east of Kimball Rd. overcrossing, City of Ventura.	2-8-83	Hard (Pavement)
12	Indian Dunes	7	LA	126	3.7	Eastbound Rte 126, south side, 2.1 mi. west of I-5, 0.4 mi. west of bridge No. 53-93 (Castaic Creek), 3.7 mi. east of Ventura Co. Line.	2-9-83	Hard (Dirt)
13*								
14	San Sevaine	8	SBd	15	7.68	Southbound I-15, 5.3 mi. north of I-10, at bridge No. 54-9641-San Sevaine Wash, 0.4 mi. south of Rte 30, in Etiwanda.	2-11-83	Hard (Pavement)
15	Oceanside	11	SD	5	59.4	Northbound I-5, at rest area, large space between I-5 and rest area, 6 mi. north of Rte 76 and Oceanside.	2-15-83	Soft

* = Not Used (see text for reason)

TABLE VII-1 SITE LOCATIONS (Con't.)

SITE I.D.			SITE LOCATION					
No.	Name	Dist.	County	Route, Street	P.M.	Description	Date(s) Measured	Hard or Soft
16	Half Fifteen	11	SD	15	R48.0	Southbound I-15, 1.5 mi. north of Rte 76 overcrossing, approx. 16 mi. north of Escondido.	2-16-83	Soft
17	Kramer Junction	8	SBd	58	6.8	Eastbound Rte 58, south side 1.4 mi. of Rte 395, at entrance of dirt road; at old wood post: "State Hwy 466".	2-17-83	Soft
18	Richards	3	Sac	Richards Bl.	-	Westbound Richards Bl, north side, 0.05 mi. west of N. 3rd St. and 0.2 mi. east of I-5, in North Sacramento.	8-30-83 1-19-84	Soft
19	Sunrise	3	Sac	Sunrise Bl.	-	Northbound Sunrise Bl., 0.3 mi. north of White Rock Bl. east side, 1.0 mi. south of Rte 50, near Rancho Cordova.	2-1-84	Soft
20	Grapevine(+6%)	6	Ker	5	6.8	Southbound I-5, west side, 3.8 mi. south of S/B Grapevine exit, north of Fort Tejon.	8-14-84 8-15-84	Soft/Hard
21	Conejo (+7%)	7	Ven	101	10±	Southbound Rte 101, 3/4 mi.± southeasterly of Camarillo Springs.	12-11-84 12-13-84	Soft/Hard
22	Altamont(+3%)	4	Ala	580	6.5±	Eastbound I-580, south side,0.4 mi. west of N. Flynn Rd.	1-8-85 1-10-85	Soft/Hard
23	Cajon (+4.5%)	8	SBd	15	R25.2	Northbound I-15, east side, 11.4 mi. northerly of jct. I-15 & I-215	1-15-85	Soft/Hard
23A	CajonA(+5.6%)	8	SBd	15	R24.2	Northbound I-15, southeast side, 10.4 mi. northerly of jct. I-15& I-215.	1-29-85	Soft/Hard
23B	CajonB(+4.2%)	8	SBd	15	R14.91	Northbound I-15,northeast side,1.1 mi. northerly of jct. I-15&I-215.	1-30-85	Soft/Hard

VIII. FIELD MEASUREMENTS

General Approach

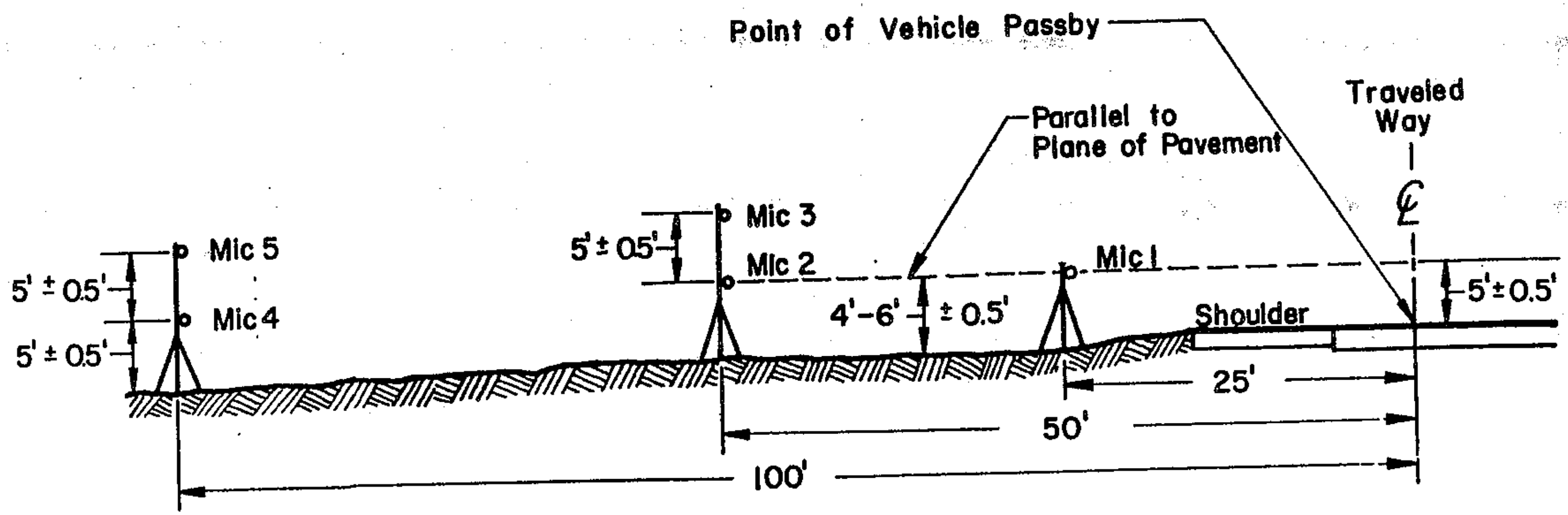
In the interest of safety, at least 2 persons were required to perform field measurements near the highways. Appendix B covers the general safety rules followed during measurements.

The field measurements consisted of three operations: 1) vehicle identification and speed measurements, 2) A-weighted noise measurements, and 3) meteorological measurements. The first operation was performed by a vehicle observer, the last two operations by an instrument operator. All measurement procedures and criteria reported in this chapter were consistent with FHWA-OEP/HEV-78-1(9) and FHWA-DP-45-1R(4).

The following sections discuss the instrument setups, measurement procedures and criteria used in this study.

Typical Instrument Setups

Where space and other conditions permitted the use of five mic's and SLM's, the typical microphone setup shown in Figure VIII-1, was used to measure highest noise levels of individual vehicles. These were assumed to occur when vehicles crossed the point closest to the mic's, called the "Point of (Vehicle) Passby". Figure VIII-1 also shows typical site cross section and setup criteria, including a mic numbering convention used throughout the study, distances from the centerline of vehicle travel and mic height criteria. Mic height criteria were obviously linked to cross section criteria discussed in the preceding chapter. Nine level sites (Nos. 1, 2, 5, 7, 11, 12, 15, 16, 17) had



*Three mic setup is identical, except for elimination of mic 's 4 and 5

Figure VIII-1. Typical setup, five microphones*.

the typical setup shown in Figure VIII-1. Of these, there was one exception, site 5. At this site, mics 4 and 5 were located 75 feet from the centerline of traveled way, instead of the typical 100 feet.

At each of the seven remaining level sites, the terrain did not allow a setup of five mic's. At these locations a setup of three mic's was used. Except for the elimination of mic's 4 and 5, the mic location criteria and numbering convention for three mic setups were identical to those shown in Figure VIII-1. Sites 3, 6, 9, 10, 14, 18 and 19 had a three mic configuration.

Of the six grade sites, four (Nos. 20 thru 23) had the three mic setup. Two of the sites (Nos. 23A and 23B) used only the reference mic at 50 feet. The latter two sites were selected for confirmation of data when preliminary analyses revealed the lack of grade dependency at sites 20 through 23.

Figure VIII-2 shows a typical site layout with mic clearances for 3 and 5 mic setups. Actual mic heights, distances, site cross sections , and layouts at each site are illustrated in Appendix B.

The typical setup of five mic's was designed to:

°Include site and setup criteria set forth by FHWA-OEP/HEV-78-1(9).

°Include the 50-foot reference distance for energy mean emission level determination(3,9).

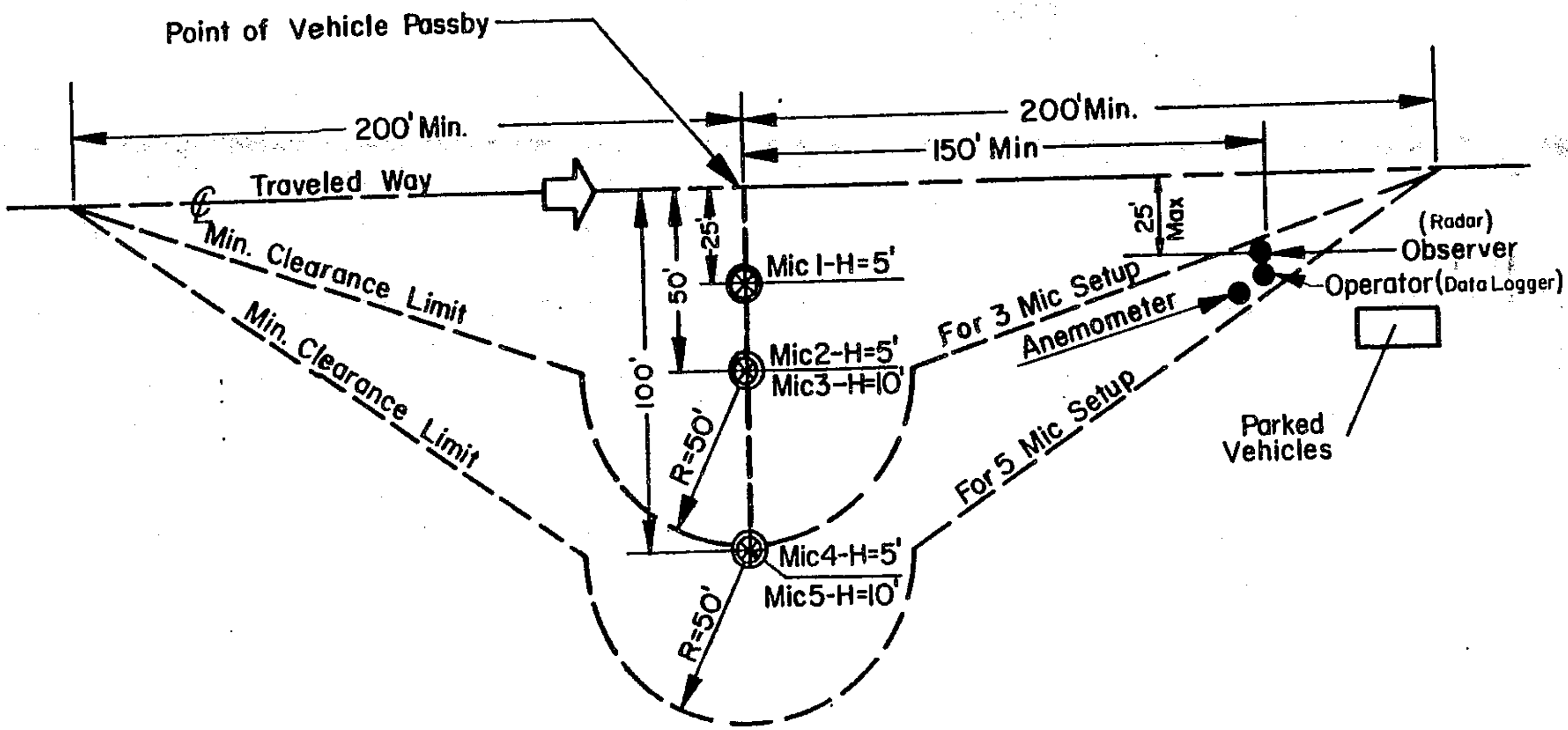


Figure VIII-2. Typical site layout and microphone locations.

°Include a 100-foot distance to measure noise drop-off rate as a function of site type (hard site vs soft site), and wind direction.

°Include average mic heights of 5 and 10 feet at both the 50- and 100-foot distances, to investigate ground attenuation.

The three mic setups at four grade sites were designed to ensure that the grade sites all had the same ground characteristics. This was checked by comparing noise level differences between mic 1 and 2, and mic 1 and 3.

Except for the elimination of the 100-foot distance (mic 4 and 5), the above items also apply to the three mic setups.

Event Quality and Contamination Control

In this report, an event is defined as the set of vehicle, noise, and environmental measurements of a vehicle passby. One of the most challenging problems in measuring vehicle noise emission levels was to insure that measurements were not significantly contaminated by background noise. For the purposes of this report, background noise is defined as the combined noise level of all on and off highway noise sources received by a microphone during a vehicle passby (event), excluding the vehicle passing by and in some instances, such as vehicle separation criteria (discussed in the next section), another designated vehicle. Contamination was especially difficult to avoid for autos because of their relatively high volumes and low noise emission levels compared to trucks.

The quality of the single passby events was maintained by using three noise contamination control strategies: 1) selecting vehicles that were adequately separated from other vehicles, 2) analyzing the GLR trace for compliance with "valid peak" criteria, and 3) audio-visual observation by the radar observer and instrument operator. Strategies number 1 and 3 were enforced in the field at the time of the measurements. Determination of "valid peaks" was done later in the office. The three strategies will be discussed in detail in the following three sections.

Vehicle Separation Criteria. Figures VIII-3 through VIII-6 show a progressive development of the minimum vehicle separation criteria used during field measurements.

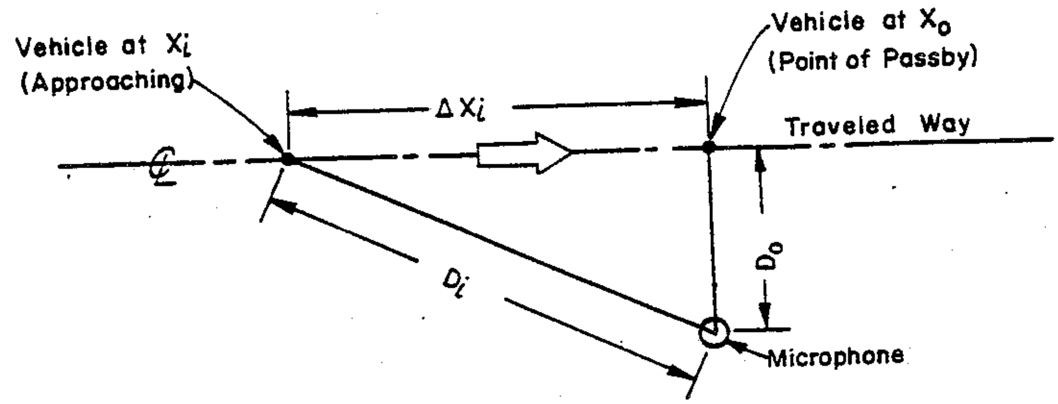
When a vehicle approaches the point of passby at a constant speed, the observed noise level at a microphone is related to the vehicle position as follows:

$$L_i = L_o - 20 \log \frac{\sqrt{\Delta X_i^2 + D_o^2}}{D_o}. \qquad \text{Figure VIII-3)}$$

where: L_i is the noise level at vehicle position X_i.
L_o is the highest observed noise level at vehicle position X_o, the point of passby.
ΔX_i is the distance between position X_i and X_o.
D_o is the distance from microphone to X_o.

This relationship is based on two assumptions: 1) the vehicle is a point source, and 2) there is no ground attenuation of the noise.

Figure VIII-4 is a plot of relative noise levels (L_o=20 dBA) vs ΔX_i for the case of D_o=50 feet. Note that this plot is representative of a point source traveling at a constant



When Vehicle is at X_o:

Highest observed noise level = L_o = Noise Emission Level

When Vehicle is at X_i:

Observed noise level, $L_i = L_o - 20 \text{ Log } \frac{D_i}{D_o} =$

$$L_i = L_o - 20 \text{ Log } \frac{\sqrt{\Delta X_i^{\,2} + D_o^{\,2}}}{D_o}$$

(Assuming point source)

Figure VIII-3. Vehicle noise level as a function of vehicle position.

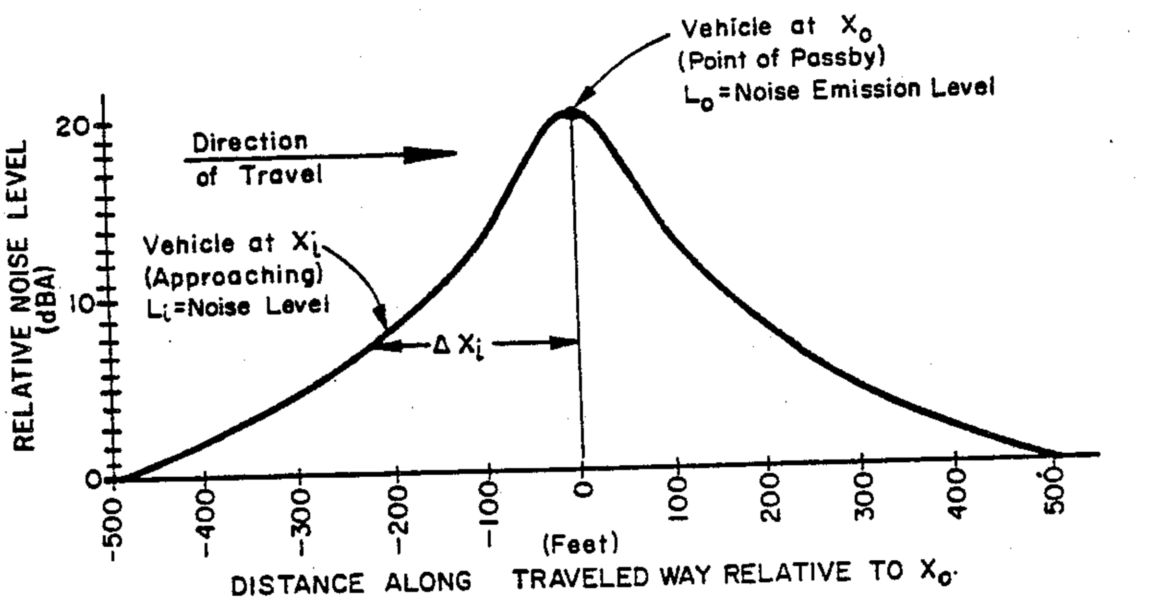


Figure VIII-4. Relative noise level vs. vehicle position (Microphone distance from ℄ travel, D_o = 50 feet).

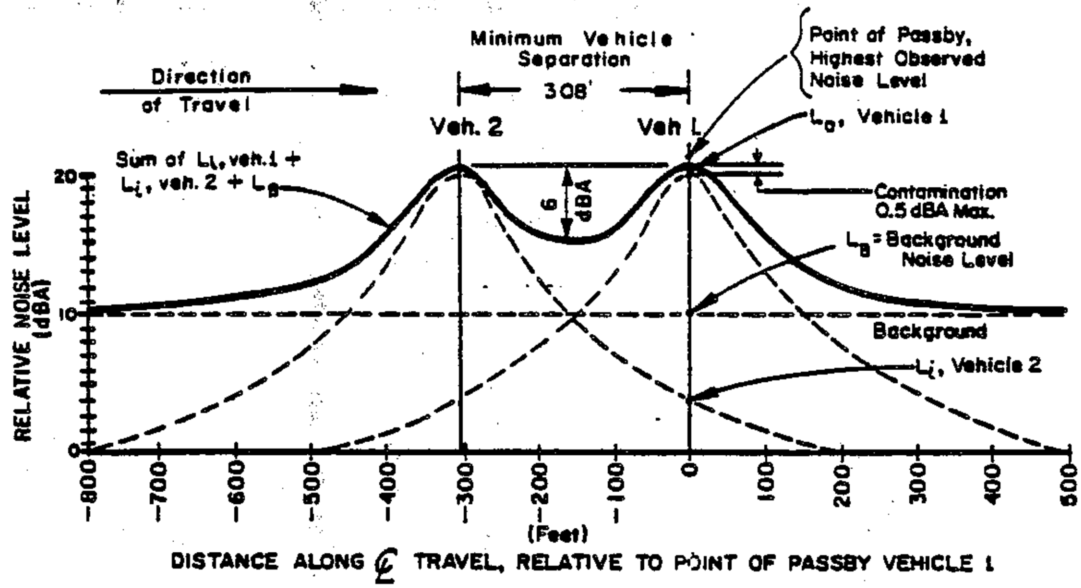


Figure VIII-5. Minimum separation between two vehicles, equal noise sources (L_O = 20 dBA Rel. Noise Level), background noise level (L_B) = 10 dBA R.N.L. (D_O = 50').

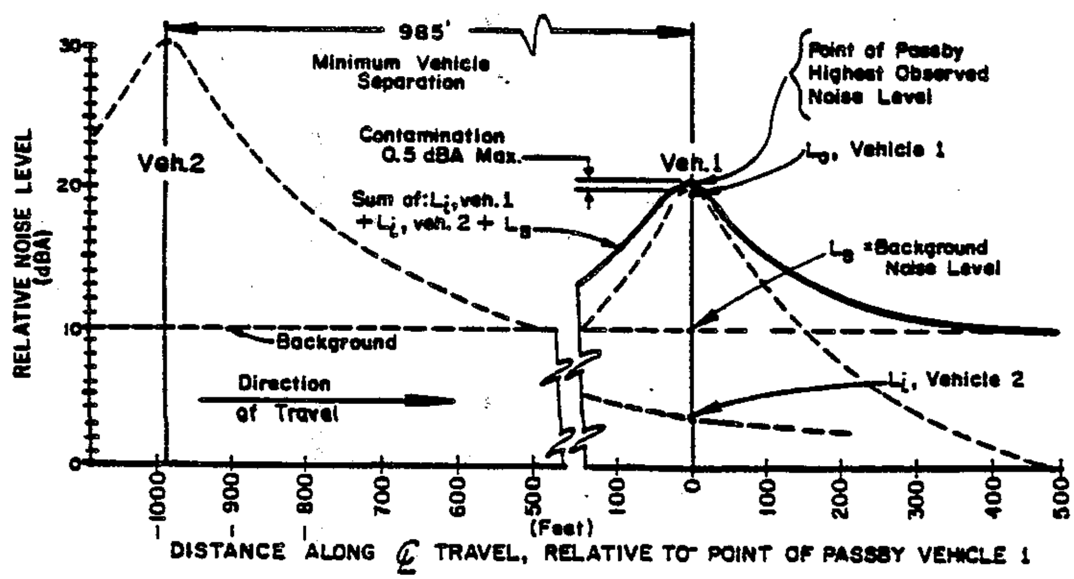


Figure VIII-6. Minimum separation between two vehicles, unequal sources (L_O veh. 1 = 20 dBA; L_O, veh. 2 = 30 dBA, background noise level (L_B) = 10 dBA Relative Noise Level (D_O = 50').

speed, with the microphone positioned 50 feet from the centerline of travel. This distance coincides with the reference distance of 15 meters for the National Reference Energy Mean Emission Levels per FHWA-RD-77-108(3).

The noise level vs vehicle position plot in Figure VIII-4 was used in determining the minimum separation distances between two vehicles in two scenarios approximating conditions (Figures VIII-5 and VIII-6). The first scenario (Figure VIII-5), illustrates two vehicles with equal noise source strengths, and a "background" noise level (L_B) of L_o-10 dBA. The two vehicles are separated by a minimum distance so that the highest observed noise level includes no more than 0.5 dBA contamination when vehicle 1 crosses the point of passby. Because of the symmetrical relationship between the two noise sources, the same contamination is present when vehicle 2 crosses the point of passby. A GLR documenting the events would produce a trace similar to the solid line in Figure VIII-5 depicting the sum of L_i vehicle 1 + L_i vehicle 2 + L_B. This scenario approximates the passing of two autos without the presence of trucks, and may also be applied conservatively to the passing of two trucks. The minimum distance of 308 feet between the vehicles provides a criterion of separation when two vehicles of equal noise source are involved.

Because of uncertainties in actual background levels, and the fact that usually more than two vehicles were in the vicinity, the minimum distance criterion between the measured vehicle and any other vehicle of approximately equal source was set at 400 feet. A traffic cone placed 400' ahead of the point of passby aided the observer in estimating the minimum distance criterion in the field.

The second scenario, shown in Figure VIII-6 involves two vehicles of unequal source strength. In this scenario, the noise source of one vehicle is 10 dBA higher than that of the other vehicle. The background noise is assumed to be 10 dBA below the lower noise source. This scenario approximates that of measuring the noise emission level of an auto while a truck is approaching. In this case, the minimum vehicle separaton should be 985 feet, or approximately 1000 feet, to avoid contamination of more than 0.5 dBA.

The observer in the field had to estimate the 1000-foot distance when the second scenario applied. Usually this did not present a problem. Most auto measurements were taken when there were no trucks in sight. In the cases where trucks were present, the observer and instrument operators made independent judgements as to the measurement quality. Because of the probable presence of considerable ground attentuation and some atmospheric attenuation over a 1000-foot distance (not included in the criterion calculation), this criterion was probably conservative.

Finally, a short discussion about the reverse of scenario 2 (Figure VIII-6) should be included. In this scenario the louder vehicle is measured and the quieter vehicle is in the vicinity. If the difference between the sources is 10 dBA or greater, no separation should be necessary when two vehicles are involved. However, when the louder source is surrounded by several quieter sources, contamination may still occur. No criteria were set to cover this situation, but in general, trucks were not measured with more than two or three autos in the immediate vicinity. In most cases, trucks selected for measurement were adequately separated from autos so that few judgments were necessary.

The vehicle separation criteria used for the field measurements were all for the 50-foot microphone positions. Examination of Figures VIII-3 through VIII-6 indicate that these criteria will always satisfy the 25-foot, but not the 100-foot mic positions. However, mics 4 and 5 were not used for emission level measurements. The purpose of the 100- foot noise measurements was to determine the effects of terrain and wind. Other criteria were used to evaluate the quality of those measurements at the 100-foot distance as shall be discussed in the next section.

Valid Peak Criteria. Due to uncertainties in background noise levels (defined in the previous section) at the time of measurement, vehicle separation criteria by themselves were not sufficient insurance against contamination. Valid peak criteria were developed to help determine whether background noise contributed to the highest observed noise level of each event (vehicle passby). These criteria were based on a GLR trace of the event, recorded at 50 feet from the centerline of vehicle travel at a mic height of 5 feet (Ref mic 2 location).

In order to limit contamination to less than 0.5 dBA, the background noise levels should be at least 10 dBA lower than the highest observed value. This would have been a convenient criterion to use. A study by the New Jersey Department of Transportation(13), however, suggests that accepting only peaks of 10 dBA or greater would introduce a bias toward noisier vehicles. This is especially true when background noise is relatively high. The New Jersey study used a rise and fall criterion of 6 dBA to prevent this bias, at the risk of slightly contaminating the measurement.

Figure VIII-7 shows GLR traces of four passby scenarios and their associated valid peak criteria. Scenario "a" illustrates a single vehicle passby at 54.5 mph (80 feet/sec), with a background noise level of 30 dBA or more below its noise emission level, L_o, of 84 dBA. This trace is unaltered by any background noise. Scenario "b" depicts the same single event with a steady background noise level of L_o - 10 dBA. Note that the highest observed noise level, L_{max}, is 84.4 dBA and the measurement is contaminated by $L_{max} - L_o = 0.4$ dBA.

Scenarios "a" and "b" comprise "event quality 2". Quality 2 events represent the least contaminated events. They were used for all analyses, including those made for the 100 ft mic's. The criterion for quality 2 events is a peak that rises 10 dBA or more above the background noise level, measured by a SLM and GLR at a 50 ft distance and 5 ft mic height.

Scenario "c" shows contamination caused by a relatively steady background noise of L_o - 5 dBA. The contamination is 1.2 dBA above the background. Scenario "d" illustrates the trace of two vehicles of equal source strength, at the minmum separation distance discussed in the previous section. A steady background noise level of L_o - 10 dBA is assumed. As shown in Figure VIII-5, the peaks are separated by a 6 dBA valley, and contamination is 0.5 dBA. Scenarios "c" and "d" were grouped into "quality 1" events. These events were used only for emission levels analyses up to and including the 50-foot microphones. Quality 1 events were not used to analyze the noise levels measured at the 100-foot distance. The criterion for quality 1 events is a peak that rises 6-9 dBA above the background. Note that minimum vehicle separation criteria are under no circumstances in conflict with the quality 1 criterion.

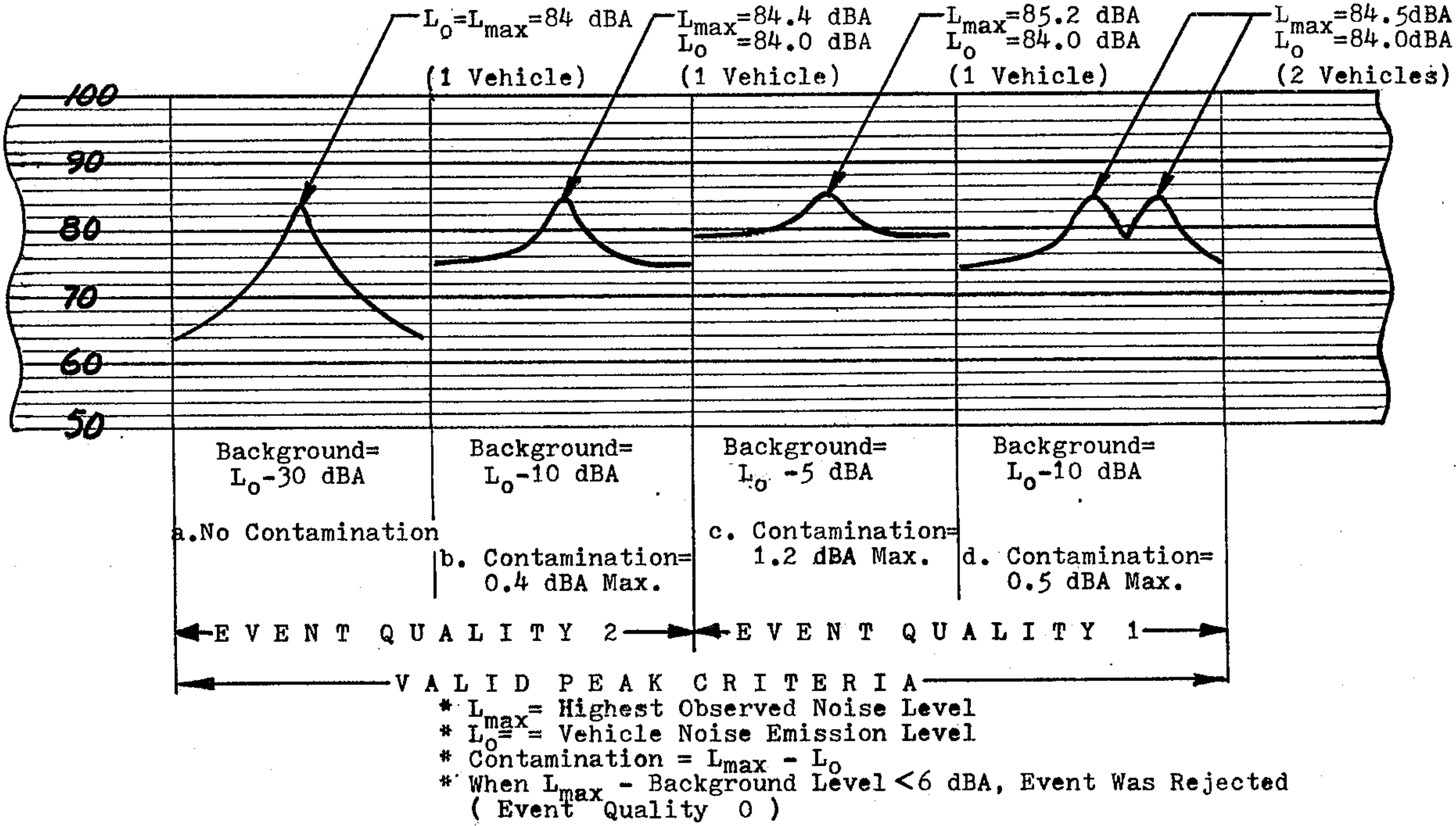


Figure VIII - 7. Valid Peak And Event Quality Criteria

Peaks that rose less than 6 dBA above background were coded event "quality 0" and later ignored in computer analyses.

Audio-Visual Observation. The preceding two methods of controlling noise measurement contamination - the vehicle separation and valid peak criteria - were objective criteria that required a minimum amount of judgment. Rigid compliance with the criteria appeared to be sufficient insurance against contamination in most cases. In some instances, however, it was necessary to apply subjective, on-the-spot judgment to determine the quality of an event. In these instances, judgments were made through audio-visual observations, i.e., using ears and eyes. Common examples included: sudden rises in background noise during measurements, due to aircraft, nearby construction, sporadic traffic on nearby frontage roads or ramps. When these rapid background noise increases coincided with vehicle passby measurements, they sometimes blended in with GLR traces, and showed valid peaks. Contamination would have gone undetected except for the alertness of the observers during measurements.

Other Event Criteria. In addition to the three contamination control strategies described in the previous sections, there were other factors governing rejection or acceptance of events. These included, but were not necessarily limited to: change of speed during passby, sudden change in environmental conditions (e.g., wind gusts), unusual vehicles, and measurement errors. Criteria for some of these factors will be discussed in the vehicle criteria, environmental criteria, and measurement procedure sections.

Number of Events Accepted and Rejected. When an approaching vehicle was judged to be a likely event, measurement began and a sequential number was assigned to the event. After the vehicle had passed, an evaluation was made using all previously described criteria. The data were recorded, whether the event was rejected or not. If rejected, the reason for rejection was coded on either the GLR trace, vehicle observation sheet, data logger printout or environmental data sheet. A rejection on one or more of these four data sources was treated as an event quality "0" and the event was ignored in later computer analyses. If the event was accepted it was given a quality 1, except in the valid peak evaluation, where it was assigned either a quality 1 or 2 as previously discussed. For convenience, combinations of qualities 0,1 and 2 and 0, 1 will be called event quality 0, (e.g., 2011 = 0), the combination 2111 will be referred to as quality 2, and the remaining combination 1111 will be called quality 1.

Of the total of 3045 vehicles measured at mic 2 (50 ft reference mic), on level roadways, the following statistics were derived by quality:

Quality 2 events - 2426 or 79.7% (Accepted)
Quality 1 events - 308 or 10.1% (Accepted)
Quality "0" events - 311 or 10.2% (Rejected)

Of the above 2734 accepted events, 88.7% were quality 2 and 11.3% quality 1.

Of the total of 1905 heavy trucks measured at mic 2 (50 ft reference mic), on grades, the following statistics were derived by quality:

Quality 2 events - 1474 or 77.4% (Accepted)
Quality 1 events - 295 or 15.5% (Accepted)
Quality 0 events - 136 or 7.1% (Rejected)

Of the above 1769 accepted events, 83.3% were quality 2 and 16.7% quality 1.

Sample Size

For the purposes of determining the sample sizes required for each major vehicle group considered for emission level curves, the following criteria were set:

1. Total speed range from 25 mph to 65 mph.

2. Subdivision of the 40 mph range into equal sized intervals (speed classes) small enough to insure that any noise value along the curve inside the speed class is within ±1 dBA from the mean noise value in that speed class.

3. 95% confidence interval for the mean of each speed class of 1 dBA.

The National Reference Energy Mean Emission Level curves (Figure VIII-8) per FHWA-RD-77-108(3) were examined to estimate the speed class size necessary to satisfy above criterion No. 2. Due to its steep slope, the lower end of the automobile curve was selected to represent the greatest change in noise levels with speed. From 50 km/hr to 56.5 km/hr, the FHWA auto emission levels increase 2.0 dBA, or ±1 dBA from the mean level at the 53.25 km/hr center point. A 6.5 km/hr (4 mph) interval would therefore satisfy criterion 2.

The following speed classes were designed to cover the entire range of desired speeds for level roads: