HIGHWAY NOISE MEASUREMENT FOR ENGINEERING DECISIONS

by

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CREDITS

Prepared in cooperation with the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration.

ABSTRACT

The problem of providing a practical method for evaluating highway noise using inexpensive equipment and technical personnel already available to a Highway Department has been examined.

A periodic sampling procedure has been developed using a hand-held sound level meter set on the "A" weighted network. Recordings of traffic noise were taken at several sites in Houston, Texas. These recordings were played back in the laboratory and plotted on a strip chart plotter. Using these graphical representations of the highway noise, a periodic sampling procedure has been evaluated. This procedure allowed a hand-held sound level meter to be used to measure highway noise values at 15-second intervals for 5 minutes giving a 95 percent probability of the mean value being within ± 0.5 dBA of the true mean. Using this average value, various percentile values (sound pressure levels exceeded a given percentage of the time) can be estimated.

This procedure permits adequate evaluation of highway noise problems for engineering decisions, but does not replace the more complex equipment and specialized personnel needed for legal cases.

KEY WORDS

Noise measurement, noise evaluation, traffic noise, noise sampling.

SUMMARY

Introduction

This report considers the problem of providing a practical method for evaluating highway noise using technical personnel already available to the Highway Department and inexpensive equipment. A periodic sampling procedure is utilized, which allows the local engineer to make preliminary assessments of highway locations where residents have voiced concern about traffic noise.

The Problem

When complaints of highway noise are received by the Highway Department, the highway engineer must have some tool to assist him in assessing their validity. In the past he could request that recordings be made by acoustical experts using complex and expensive equipment. Even today it is highly unlikely that such personnel and equipment would be in sufficient demand to justify full-time positions in the Highway Department district offices. Consequently, the district would have to request the services of such personnel from the headquarters office. Such requests could result in delays due to the unavailability of the personnel, and upon their arrival in the district they might find the problem nonexistent. If the district has the capability of undertaking preliminary surveys to assess problem locations, such false calls can be minimized.

The Periodic Sampling Procedure

The procedure developed in the project involved the use of a hand-held sound level meter to measure highway noise values at 15-second intervals for a 5-minute period. The average value of these recordings will have 95 percent probability of being within ± 0.5 dBA of the true mean value. Using this

average value, various percentile values (sound pressure levels exceeded a given percentage of the time) can be estimated. These extreme noise levels are important since they represent the objectionable noise sources.

Results*

The field recorded results have been compared with those found using the short periodic sampling procedure and a hand-held meter. Close correlation between each reading existed, thus indicating that the periodic sampling procedure yields relatively accurate results. This procedure permits adequate evaluation of highway noise problems for engineering decisions, but can not replace the more complex equipment and specialized personnel needed for possible legal cases. A typical procedures manual has been included in Appendix A of this report.

RECOMMENDATIONS FOR IMPLEMENTATION

Based on research conducted in this study, it is recommended that the periodic sampling procedure be utilized by engineers, to make preliminary assessments of highway locations where residents have voiced concern about traffic noise.

The periodic sampling procedure allows Highway Department district offices to use inexpensive equipment and existing technical personnel to measure the mean sound level from a highway with a 95 percent probability of being within ±0.5 dBA of the true mean value. It is further recommended that the various percentile graphs (sound pressure level exceeded a given percentage of the time) be used to estimate the peak noise values, since these peaks represent the objectionable noise sources.

RECOMMENDATION FOR FURTHER RESEARCH

The report indicates that further research is necessary in the following areas:

1. Find some way of decreasing truck noises from existing freeways.
2. Proper design of barrier walls to decrease noise from existing and future freeways.
2. Determination of optimum longitudinal profiles and cross-sections and grades for new freeways to reduce the effects of urban noise.

TERMINOLOGY

A) Acoustical Terms (10, 15)

Ambient Noise Level	- The background noise of an area, measured in dBA units.
dBA	- The "A" weighted decibel. A unit of sound level which gives lesser weight to the lower frequencies of sound and is used in traffic noise measurement due to the good correlation with subjective reactions of humans to the noise.
Decibel (dB)	- A logarithmic unit which indicates the ratio between two powers. A ratio of 10 corresponds to a difference in 10 decibels.
Frequency	- Rate of repetition of a sine wave of sound. The unit of frequency is the hertz (Hz) or, until recently, cycles per second (cps).
Hertz (Hz)	- The unit of frequency (cycles per second)
Loudness	- A subjective impression of the strength of a sound. A sound level increase of 10 decibels approximates a doubling of loudness
Noise	- Unwanted sound
Sound Pressure Level	- The root-mean-square sound pressure, p, related in decibels to a reference pressure. The SPL value is read directly from a sound level meter (in dBA)

B) Roadway Terms (15)

At-Grade Roadway	- When the road element is level with the immediate surrounding terrain.
Average Speed	- The weighted average of the design speeds within a roadway section
Barrier	- Infinite or finite walls located near the roadway and parallel to it
Depressed Roadway	- When a roadway element is depressed below the immediate surrounding terrain
Interrupted Flow	- Traffic stopping at an intersection or a junction
Percent Gradient	- Change in roadway elevation per 100 feet of roadway
Roadway Element	- A section of roadway with constant characteristics of geometry and vehicular operating conditions

Finite Roadway Element	- When a roadway element starts and finishes within the 8Dn limits of the roadway, where Dn is the distance from the observer to the nearest lane
Infinite Roadway Element	- When the roadway element length is larger than 8Dn, where Dn is the distance from the observer to the nearest lane
Semi-Infinite Road way Element	- When the roadway element extends across 4Dn in one direction but which terminates within the 8Dn roadway length, where Dn is the distance from the observer to the nearest lane
Single Lane Equivalent	- Of a roadway is a hypothetical single lane which represents the roadway and which is to the observer acoustically similar to the real roadway

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INTRODUCTION

During the last few years the role of the highway engineer has changed. No longer can he design a facility at the least economic cost. He must design facilities at the least economic cost giving increased consideration to social and environmental factors and restraints. To some extent, society blames the engineer for his lack of environmental consideration; however, these critical individuals are frequently the same individuals who only 20 years ago were demanding cost-benefit data to prove economic practicability without regard to other considerations. Perhaps the engineer has not always responded as rapidly as he should to society's demands. If this is the case, such demand very likely relates to giving adequate consideration to highway noise problems.

As society broadens the scope of criteria for evaluation of highways, it becomes increasingly necessary that the highway administrator carefully document his case and present it in terms the layman can understand. When complaints are made to the Highway Department concerning alleged excessive noise from roadways, a relatively simple method of checking these complaints is necessary. While an acoustic engineer could be used for such a service, it is highly unlikely that this level of sophistication would be required for the general public and neither would there be a demand sufficient to justify a full time position.

Therefore, other approaches must be explored to resolve the issues raised above. Many complaints come from people who are supersensitive to noise, and it is often not possible, either physically or economically, to decrease the noise from the offending source. Although suggested maximum individual vehicle noise levels of 77 dBA and 85 dBA for automobiles and trucks respectively during daytime conditions have been suggested in a previous report (1), more positive action will probably be needed. It may be necessary for the local Highway Department districts to send personnel to the field to determine whether these values are being exceeded, and if so, for what percentage of the time.

This report considers the problem of providing a practical method for the evaluation of highway noise using technical personnel already available in the district offices and inexpensive equipment. Every effort has been made to provide a practical means of noise evaluation that can address itself directly to complaints of excessive highway noise, and can be easily adapted to the existing operations of the Texas Highway Department.

THE PERIODIC SAMPLING CONCEPT

The concept of periodic sampling is to record a sufficient number of highway noise measurements so that one is able to say with a high probability that the average of these observations is a reasonable estimate of the mean value of the sound pressure level. Although continuous recording is desirable, it may be neither necessary nor economically feasible. It was recognized that a less complex and less expensive method was needed to evaluate the degree of reported highway noise problems. This project has utilized a technique which uses inexpensive equipment that can be operated by a technician and one which requires relatively short time periods for measurement.

In discussing the validity of the proposed technique, the first factor that must be considered is the required degree of measurement accuracy. Since the periodic sampling technique has been developed as a preliminary scheme to assess the magnitude of the problem it can be assumed that errors of ± 0.5 dBA would be acceptable as this is the approximate limit of the accuracy of the equipment currently available. With this as a basis, the next problem is to determine the frequency of readings to be taken and the total duration of recording which would ensure that the estimated mean would be within ±0.5 decibel with a 95 percent probability of accuracy.

Sampling intervals of 10, 15, 20, and 30 seconds were selected. It was expected that the standard deviation for the 10-second sampling interval would be less than those obtained using a 30-second sampling interval. This is due to the smoothing effect of the larger sample size of the 10-second sampling interval. Preliminary tests indicated that the 15-second sampling interval was sufficient, as it gave the observer time to record the value, observe a watch and read the sound pressure level meter. The confidence interval on the average value for the various sampling intervals tested can be utilized to determine the duration of recording which would provide the desired degree of accuracy.

The peak noise levels are more objectionable to humans and any procedure to evaluate highway noise must consider the problem of determining peak noise levels. For the purposes of this study, it has been assumed that a relationship exists between the mean sound pressure level and the percentage of the time that the sound pressure level exceeds a given value. Identification of these relationships will permit estimation of peak noise levels based on the mean value.

The application of the periodic sampling technique is apparent. A technician can quickly be trained to use the hand-held sound pressure level equipment, and the evaluation of traffic noise complaints can be incorporated into his routine duties.

ENGINEERING MEASUREMENTS OF HIGHWAY NOISE

(1) Recording or Non-Recording Equipment

Why should the District Engineer use a short sampling concept instead of recording the sound levels on a data recorder and analyzing the results?

In brief, the latter method is far too expensive. To implement it, each district must have the necessary equipment and the acoustically-trained personnel. The complex equipment would be unused for a large percentage of the time, and the acoustically-trained personnel would also be relatively unproductive, since it is unlikely that there would be sufficient demand to justify a full time position in acoustics.

It would seem more logical for the Texas Highway Department headquarters office to maintain this type of equipment and acoustically-trained personnel. This approach also has some serious limitations. The demand for these services would fluctuate and might not be readily available to districts, as it is likely that the number of these personnel would need to be kept to a minimum. Consequently, the Highway Department districts would have to request the assistance of the headquarters office and wait until staff personnel were free to come to their districts.

Some combination of effort from both the Austin office and the District offices must be developed. For example each district could be responsible for conducting the preliminary less sophisticated studies to assess whether further detailed measurements are necessary. This would alleviate the need for the acoustically-trained personnel being located at the District level and would also eliminate the possibility of personnel from the Austin office bringing their equipment a considerable distance, only to find that no real problem exists.

Each Highway Department District Office should have available the capability of evaluating highway noise to enable them to estimate the seriousness of any reported highway noise problems in their district. Furthermore, the headquarters office should have the necessary equipment and trained personnel to respond to a district's request for further assessment of highway noise problems that exist in that district, particularly those involving possible legal ramifications.

(2) Utilization of Simplified Highway Noise Measurements

When and where can simplified highway noise measurements be utilized? This question is one that individual administrators must decide. In general, the concept of evaluating highway noise by periodic sampling would be used as a first step in areas where complaints of excessive traffic noise have been made. Basically, this method would allow the District Engineer to have inexpensive equipment on hand which can be operated by his own personnel. Upon receipt of complaints about traffic noise, he could send his technician into the field, and in a matter of hours the average noise level of the traffic, measured at various distances from the highway, would be determined.

It is suggested that measurements taken by a technician using hand-held meter procedure should only be used to determine whether a problem actually exists. There are several reasons for this recommendation. Some people are hypersensitive to almost all noise and, in the case of freeways, there sometimes exists a psychological hostility toward the noise source (2). Furthermore, different socio-economic groups appear to have different thresholds of noise irritation, and the same highway passing through different neighborhoods might be considered objectionable by one group while another group might find it entirely acceptable. Measurements should be taken during both the peak and off-peak periods, since a representative sample of the noise heard by the resident must be reviewed. This includes the testing of problem areas at night. Allowable noise levels must be much lower during the night, as the general ambient noise level of the surroundings has decreased. The engineer must be aware of the problem of low background noise coupled with high traffic noise peaks. For example, a truck recorded at 75 dBA during the daytime when the background noise is 70 dBA is unlikely to cause any complaints; but this same truck will probably be highly objectionable in the early hours of the morning when the ambient level is near 50 dBA. The technician can return from the field to the office with the mean values already computed, and the engineer can then determine the need for further action.

Upon receipt of the average noise values, the engineer can estimate from Figures 13-16 (see Field Recordings) the sound level that is exceeded for a given percentage of the time. Research (3) has shown that knowledge of the mean noise value is, by itself, insufficient. It is also necessary to have knowledge of the peak sound pressure levels since these represent the sources that are so annoying to the adjacent residents. A complete description of the periodic sampling concept is included in a later section dealing with periodic sampling.

(3) Hierarchy of Decision Making

A general overview of the decision making process is necessary to understand the utility of the periodic sampling concept for the evaluation of highway noise problems. There appear to be three distinct levels at which decisions must be made regarding noise problems. These levels are as follows:

1) During the planning and design stages of a new or substantially improved urban roadway;

2) After one or more complaints have been received regarding the noise from an existing roadway; and

3) For the purpose of documenting the sound pressure level for use in lawsuits involving traffic noise or to demonstrate the effectiveness of noise abatement actions which have been taken.

The requirements for information in each instance are considerably different. During the planning and design stages, an estimation procedure must be utilized to determine potential problem areas. This function appears to be fulfilled by the work of Galloway, et al. (3).

The documentation for legal purposes of the sound pressure level adjacent to an existing facility (including octave band analysis) requires rather sophisticated recording equipment and a greater degree of technical competence for the personnel involved. Such cases are rather infrequent, and it does not appear to be economically feasible to purchase (at a minimum cost of approximately $7000) and maintain the equipment necessary to accomplish this level of traffic noise analysis in each highway district.

The intermediate level of decision making (Level 2) is a critical one, especially from the public relations point of view. When a complaint is received regarding the noise from an existing highway facility, the administrator involved, lacking a means of evaluating the noise problem within his own staff, would be reluctant to call for assistance from the headquarters office for a single complaint. It is probable, however, that when one person complains regarding an existing problem there are several others who are concerned about the same situation and simply have not taken the time to file a formal complaint.

Should someone start a citizens' organization to protest the traffic-noise problem, there would be little doubt that he would have the support of these people. On the other hand, the single complaint could come from an individual who is hypersensitive to noise or simply opposed to urban freeways. The administrator needs an objective measure of the degree of the problem in order to decide on the course of action to take regarding the complaint. It is in this area that the periodic sampling technique offers the greatest potential. This technique can be accomplished by personnel with a minimum of training, certainly no more than would be required for recording traffic volumes, and with equipment which costs less than $700.

SOUND PRESSURE LEVEL MEASUREMENT

(1) Equipment Utilized in the Field Studies

The recording of the field data involved the use of several pieces of equipment. In the paragraphs below, these units and their functions in the studies are described.

(a) A General Radio Sound-Level Meter, Type 1565-A (hand-held), using the "A" weighted network on both the fast and slow setting (Figure 1) was used in the sampling studies. The larger, more accurate Type 1551-C meter (Figure 2) was occasionally used as a crosscheck for the accuracy of the 1565-A meter. The 1551-C meter is more accurate, and can be used in many combinations with related instruments. Its higher cost and increased complexity make it less desirable for general use than the less expensive and simpler Type 1565-A. One of the basic objectives of this study was to produce a technique and applicable equipment that could be used by a technician for measurement of traffic noise. The Type 1565-A sound pressure level meter appears

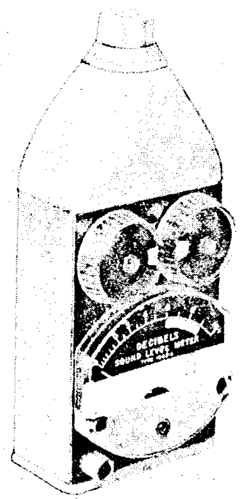


Figure 1

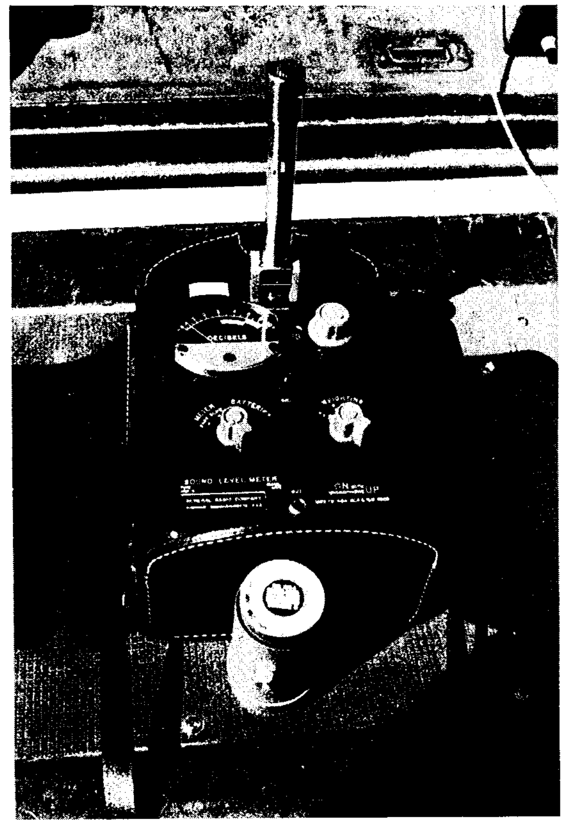


Figure 2

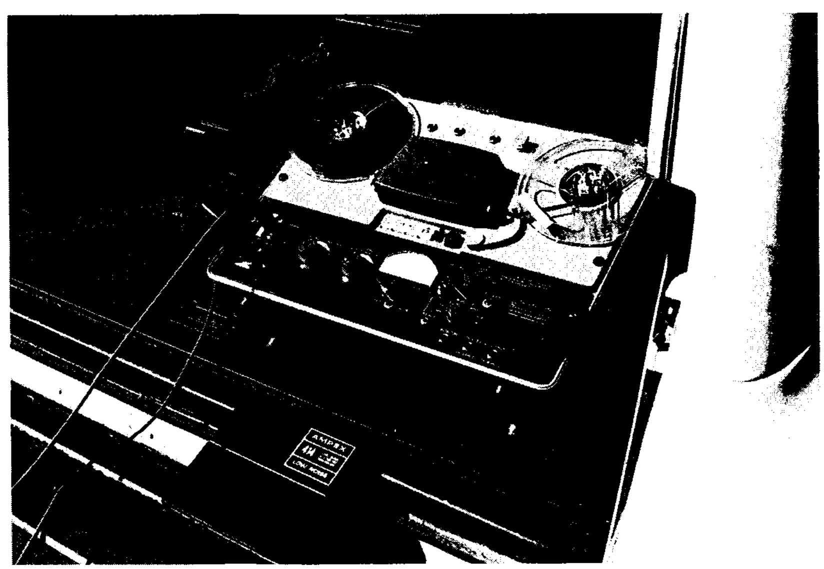


Figure 3

to be well suited for this task.

(b) A General Radio Data Recorder Type 1525-A was used to record the sound pressure level (Figure 3). This instrument is both a sound level meter and an audio tape recorder. These features permitted the researchers to make on-site measurements which assisted in base scale selection, while also recording traffic noise for later laboratory analysis. The 1525-A data recorder has two audio recording channels which permit simultaneous recording of sound pressure level on the main channel and a description of the noise source and other pertinent data by an observer on the secondary channel. Both the main channel and the secondary channel can be played back simultaneously. Ampex 414 "Low Noise" tapes were used for recording. This quality magnetic recording tape is necessary to record accurate data and to insure a minimum of background noise from the recording unit.

(c) A tripod mounted General Radio microphone, Type 1560-P5, was used (Figure 4).

(d) A General Radio Sound-Level Calibrator, Type 1562-A, was used to check calibration of the recording system and the hand-held sound pressure level meter (Figure 5.) The calibration was checked at 114 dB and 1000 hertz. It has previously been determined that the 1000 hertz frequency is typical of most vehicle associated noises (4).

(e) The field power supply was initially from a portable gasoline generator located approximately 200 feet from the microphone,

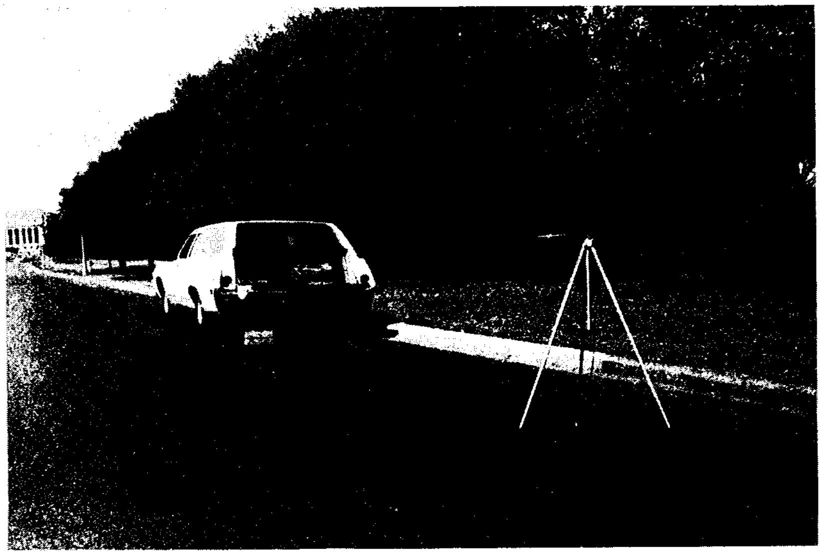


Figure 4

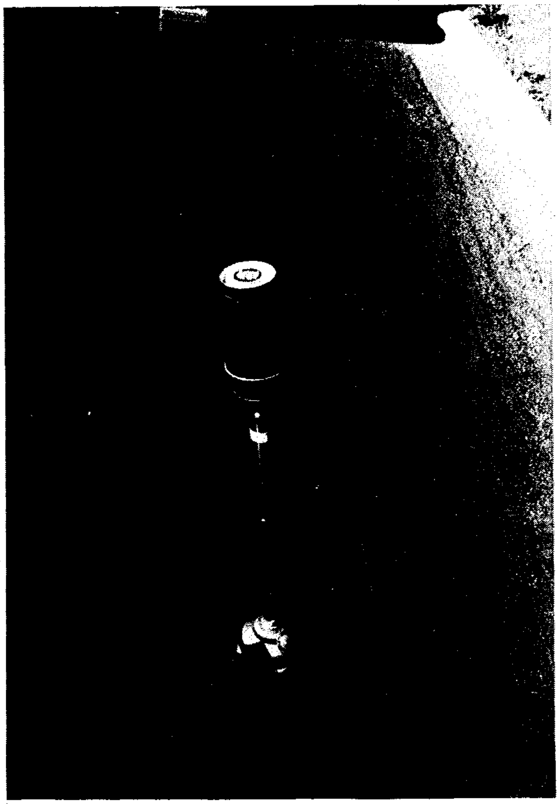


Figure 5

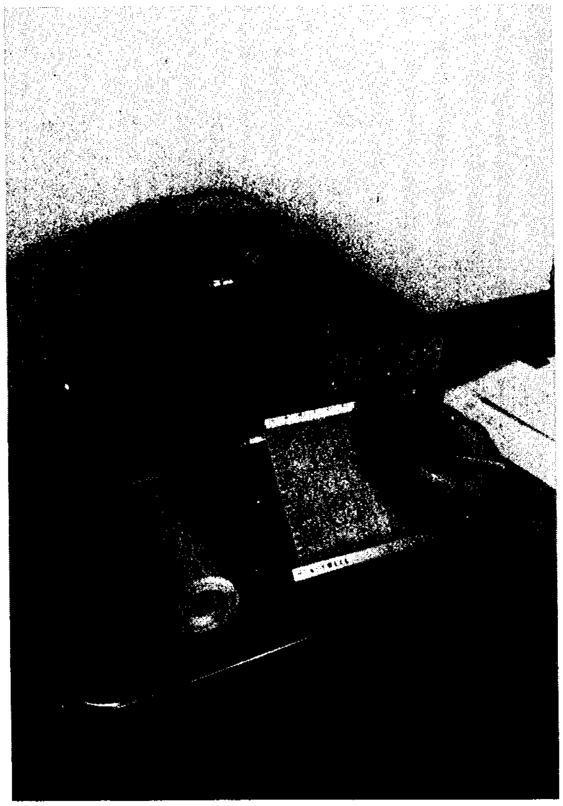


Figure 6

but it was found that the generator-associated noise affected the recordings for locations more than 100 feet from the freeway. The noise from the generator would have also been unacceptable to adjacent residents during night recordings. A Cornell-Dublier Inverter Model 12ESW25 was substituted for the generator and proved ideal during the remaining recordings. This inverter was connected to a vehicle's 12-volt (DC) electrical system. With the vehicle engine idling (to protect the battery from power loss), the 110-Volt (Sine Wave AC) output served as the power source for the data recorder. The inverter had a rated output of 350 watts. The power output was checked before every reading to insure that sufficient power was available at the recorder for efficient operation.

(f) A Honeywell Strip Chart, Model Number Electronik 193 laboratory recorder, was used to plot the recorded sound pressure level from the tapes (See Figure 6).

The logarithmic nature of the decibel means that a unit output from the data recorder represents different changes in the sound pressure level depending upon the magnitude of the sound pressure level. Thus, the analog plot had to be converted to decibels through the use of a conversion curve. This was developed by observing the location of the strip chart plot as the meter on the data recorder indicated a specific sound pressure level. By observation of many combinations the conversion curve presented in Figure 7 was developed.

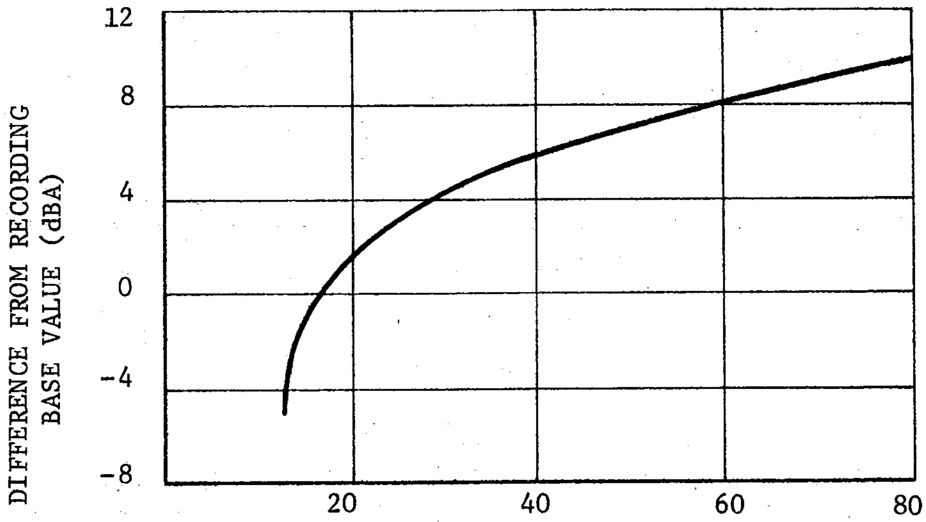


Figure 7

The strip chart was adjusted to plot at a rate of one chart division per second to facilitate data analysis.

(2) <u>Sound Measuring System</u>

Figure 8 shows the diagrammatic layout of the sound recording system used in field studies.

(3) <u>Use of the Hand-Held Meters</u>

The basic procedure for measuring highway noise with a hand-held sound pressure level meter is to point the meter in the general direction of the sound and observe the noise level on a meter. However, research (5) has shown that for sound waves of frequencies below 1000 hertz, a nearby observer can disturb the reading of the sound level meter by 4 decibels or more; the effect of the observer varies with the frequency of the sound. Young (5) noted that at 400 hertz an observer presents serious problems, whereas readings made at 8000 hertz and above are negligibly effected by the presence of an observer.

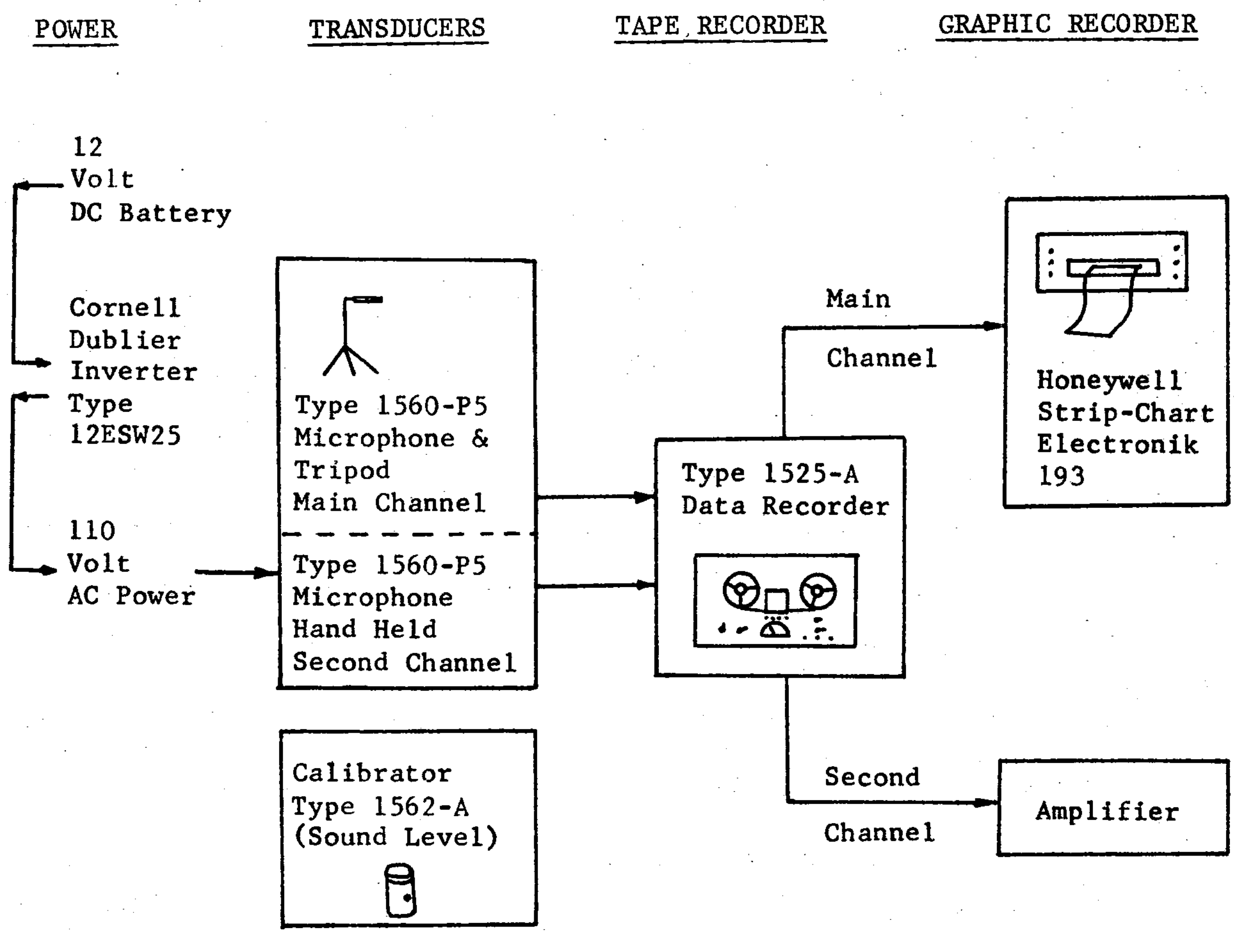

POWER
TRANSDUCERS
TAPE RECORDER
GRAPHIC RECORDER
12 Volt DC Battery
Cornell Dublier Inverter Type 12ESW25
110 Volt AC Power
Type 1560-P5 Microphone & Tripod Main Channel
Type 1560-P5 Microphone Hand Held Second Channel
Calibrator Type 1562-A (Sound Level)
Type 1525-A Data Recorder
Main Channel
Second Channel
Honeywell Strip-Chart Electronik 193
Amplifier

Figure 8

Very little research has been undertaken to assess the errors due to the reflection of sound from an observer. There is some disagreement as to which frequencies are most affected by an observer. The International Electro-technical Commission (6) has stated that "the presence of an observer in the sound field in proximity to the microphone may affect the accuracy of the measurements, particularly at higher frequencies." Further research is needed to determine what effect, if any, the observer has on the meter readings. It may not be as critical in approximating the sound pressure level by the method described in this paper, since absolute accuracy is not needed to determine excessive noise conditions. For example, The Handbook of Noise Measurement (7) states that the hand-held "sound-level meter should be held in front of the observer with the sound coming in from the side." It further states that "... if the instrument is held properly, little error in reading of the overall level will occur for most noises." The fact that there is little research regarding observer effects in noise recording may not be too important in roadway noise measurement. There is far more likelihood of erroneous recordings being made due to wind (a wind screen should be used), high temperature, reflection from hard surfaces, or the effect of obstructions between the sound source and the sound pressure meter, than by the presence of the observer (recorder).

(4) Choosing a Weighting Network

The "A" weighted network of the sound level meter was used for all noise measurements in this research. This measure of highway noise has been approved by the International Standards Organization and the Acoustical Society of America (8) and has been found by many researchers to be the most practical measurement of highway noise (1). Both the human ear and the "A" weighted network of the sound level meter are "less sensitive to low-frequency noise components than to those in the mid-frequency range (9)" thus making dBA units ideal for traffic noise measurements.

Sound pressure level meters commonly have two response ranges. The fast range responds on a real-time basis while the slow range dampens the peak levels and thus stabilizes the reading. Both the "FAST" or "SLOW" response range can be used to measure highway noise, but experience indicates that it is somewhat simpler to use the "SLOW" range since the needle fluctuations are dampened, thus facilitating the reading. Since the peak values tend to be diminished when the slow range is used, it may be desirable to use the fast range when recordings of the peak sound pressure levels are to be made.

FIELD RECORDING OF TRAFFIC NOISE

Field studies for this project were undertaken on January 12, 13 and 14, 1971, adjacent to the Katy Freeway (IH-10) and adjacent to U. S. Highway 59, just east of the (IH-610) and U. S. 59 interchange, Houston, Texas. The equipment used in the field and laboratory is described in this section. Also, the problems associated with the use of the hand-held sound pressure level meter and the periodic sampling technique are discussed.

(1) Ambient Weather Conditions

All recordings were taken during periods of very low wind, with light fog conditions being prevalent during the night readings. The fog condition did not wet the pavement to any noticeable degree. The weather was warm (70°F±) during the day recordings and mild in the evenings (60°F±). It was often overcast, and rain prevented one morning peak recording at Site II. Recordings were not taken when the pavement was wet, since this factor could increase the noise level by as much as 10 dBA (10).

(2) Pavement Conditions

The pavements at the test sites were Portland cement concrete, and vehicles crossing the joints made a noticeable noise. Vehicles crossing raised pavement markers also produced a measurable noise.

(3) Recording Sites

Three major study sites were selected in the city of Houston, Texas. These sites represented freeways in a cut, on a fill, and at-grade. Ambient noise recordings were taken a mile from any freeway and yielded estimates of ambient levels in residential areas. Figure 9 shows the location of each site, while Figure 10 illustrates their approximate cross section.

This study was primarily aimed toward traffic noise from the freeway, and noise from vehicles on adjacent local streets has been eliminated from the results of the study. Site III was found to be too close to Newcastle Street, and the local traffic noise was found to be greater than that from the freeway. Consequently, a new site was selected (Site IIIA) a distance of about 200 feet from Newcastle Street. This distance was sufficient to ensure that local traffic noise was of little significance to the overall recorded traffic noise from the freeway.

On-site investigation studies were conducted to find suitable recording locations. This proved somewhat difficult, since it was recognized that buildings would have an effect on the measured sound pressure level, thus sites had to be found where buildings or fixed objects did not actually obstruct the line of sight from the freeway. Sites of fairly level freeway grade were sought for locations I and II, while an overpass was selected for Site III to record noise from climbing vehicles.

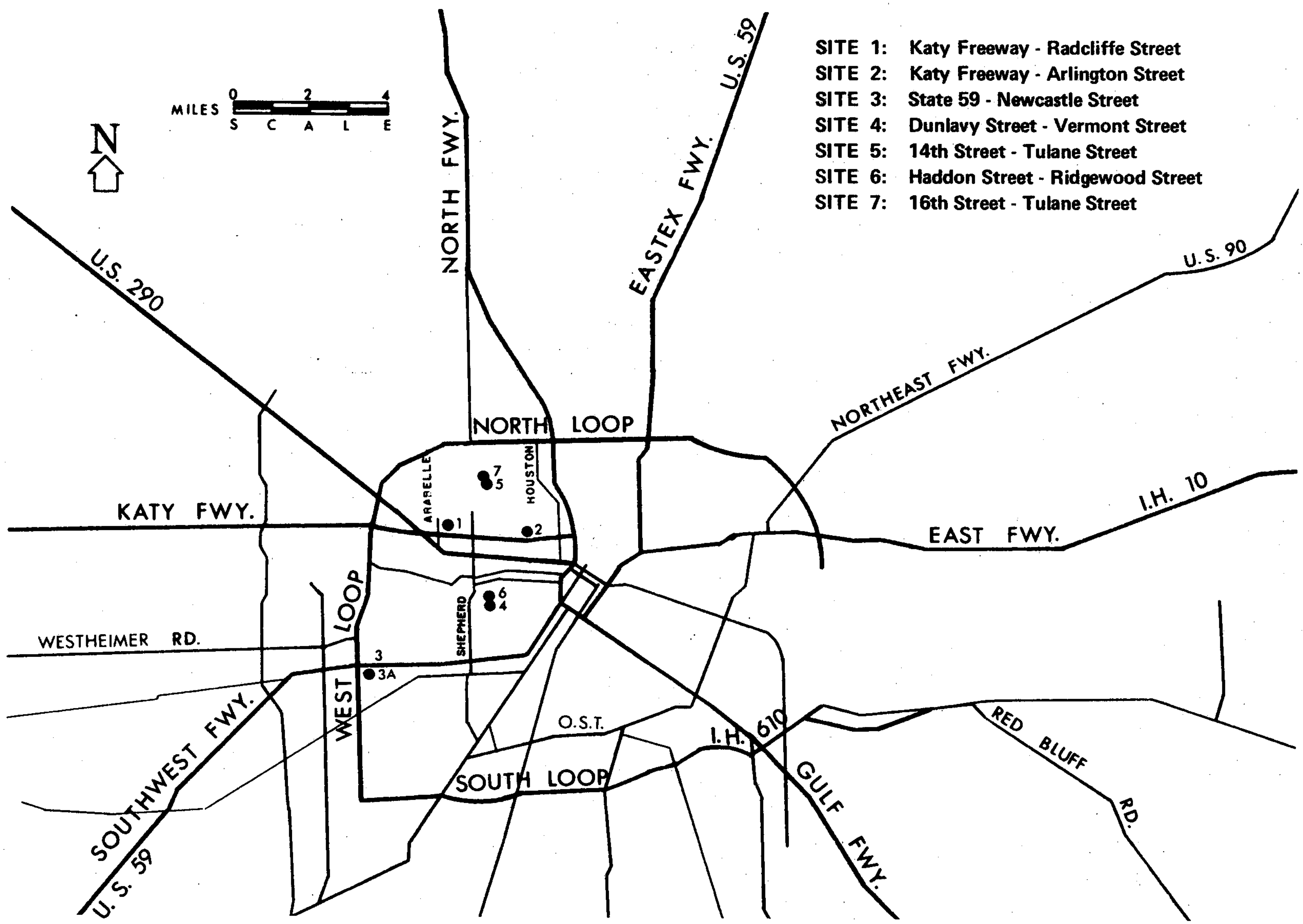
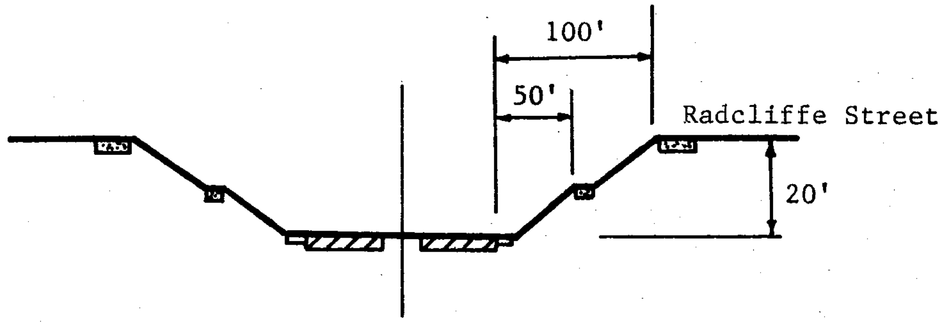
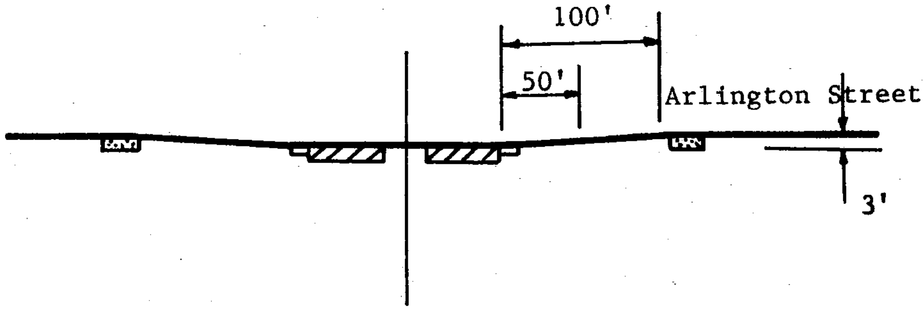


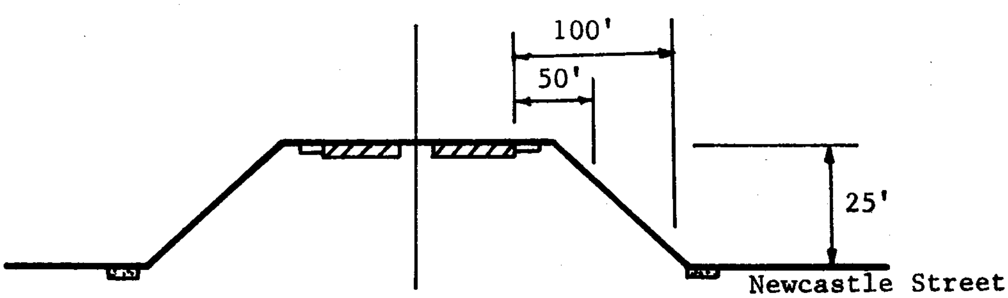
Figure 9. Recording sites in Houston.



SITE 1 IH-10



SITE 2 IH-10



SITE 3 & 3A U. S. 59

(SITES 4, 5, 6, 7 - RESIDENTIAL STREETS)

FIGURE 10

The ambient noise locations were selected at random from a map before going to the field, and upon investigation in the field, proved to be suitable. The primary criterion for selecting these sites was their proximity to a major traffic facility (i.e. no freeway within one mile and no major arterial within 1000 feet).

(4) Location of Data Recording Points

Actual sites on the selected locations were predetermined, and recording distances from the traveled way of 50 feet, 100 feet, 200 feet, and 400 feet were utilized. These distances proved to be ideal when checked in the field, although the 100-foot location often fell adjacent to a service road or ramp.

Care was exercised to note other noise sources, such as aircraft, hammering, wind, voices, and especially traffic noise from local streets. This was accomplished by using the main channel of the acoustical data recorder for traffic noise picked up by the test microphone, whereas the second channel was connected to a hand-held microphone and these outside noise sources were documented by an observer. Background problems were experienced in the initial recordings at Site 1 due to a gasoline engine that was being used to generate power for the data recorder. The engine was initially muffled sufficiently to reduce this effect to an acceptable level, however, with use the noise level increased to an unacceptable level. After recording several positions at this site, this method was abandoned and a power inverter was used. This equipment was attached to an automobile electrical system, and no further interference of this nature was experienced.

(5) Recording Times

Recordings were made during the AM peak period, the PM peak period and the off-peak period. Ambient readings were made during early morning hours (12 a.m. - 1 a.m.) and morning (8 a.m. - 9 a.m.) hours. These recordings varied in length from about 4 minutes to 10 minutes, the time span being reduced when field conditions indicated that a representative sample had been recorded. At most sites, an average recording time of 6 minutes was used.

Recordings using the hand-held noise level meter were taken at selected sites, the time increments varying between 10 seconds and 30 seconds for different samples. This concept has been reviewed in a previous section.

(6) Measurement Procedure

At each position the microphone was set on a tripod, parallel to the ground with the recording head pointed in the direction, and perpendicular to, the traffic flow. The test microphone could be fitted with a windshield, but conditions were such that this was generally found to be unnecessary.

The test microphone was set on the tripod, 5 feet from the ground at the desired distance from the edge of the traveled way. The microphone was then attached to a Type 1525-A General Radio Data Recorder, which was set on the "A" weighting scale.

Before each sample was taken, an acoustical calibration was performed. A sound pressure level calibrator of 114 decibels with an ensured accuracy of better than ± 0.5 dB was used. Rarely were field adjustments necessary for the equipment.

For each sample taken, the base scale set on the data recorder was noted. This base scale was selected in the field and was rapidly found by trial and error, although it was often possible to select the proper base scale on the basis of previous experience. The base scale selected should be sensitive to the traffic noise, but not such that the noise level frequently goes outside the recording range. An example of this is the selection of a 70 dBA base for noise levels ranging from about 68 dBA to about 78 dBA. If it is found that peaks caused by trucks consistently exceed the maximum reading on the recorder, then the base should be raised to 80 dBA; however, this tends to make the lower values less sensitive.

Traffic volumes and types of traffic were counted during the noise recordings for both directions of travel. Speeds were calculated using the "speed trap" technique of timing vehicles over a known length. Since the recording apparatus was moved a considerable distance from the traveled way, the recording team communicated with the personnel counting vehicles by the use of two-way citizens band radios.

(7) Length of Recordings

The problem of the duration of the field studies was investigated in the study. Consequently, sufficient recordings had to be made to insure a representative sample. A review of previous studies on acoustical measurements suggested that 15 minutes was the usual measurement time taken by other researchers to obtain representative samples (11, 12, 13, 14). It was decided based on the initial series of recordings that durations of 5-10 minutes should give acceptable results. After several recordings of 10 minutes duration each, an average time of about 6 minutes was selected for recording freeway noise and only a few minutes for ambient level recordings.

DATA REDUCTION

Each individual run was plotted using a strip chart recorder (see Figure 11) from the tapes recorded in the field. The speed of the strip

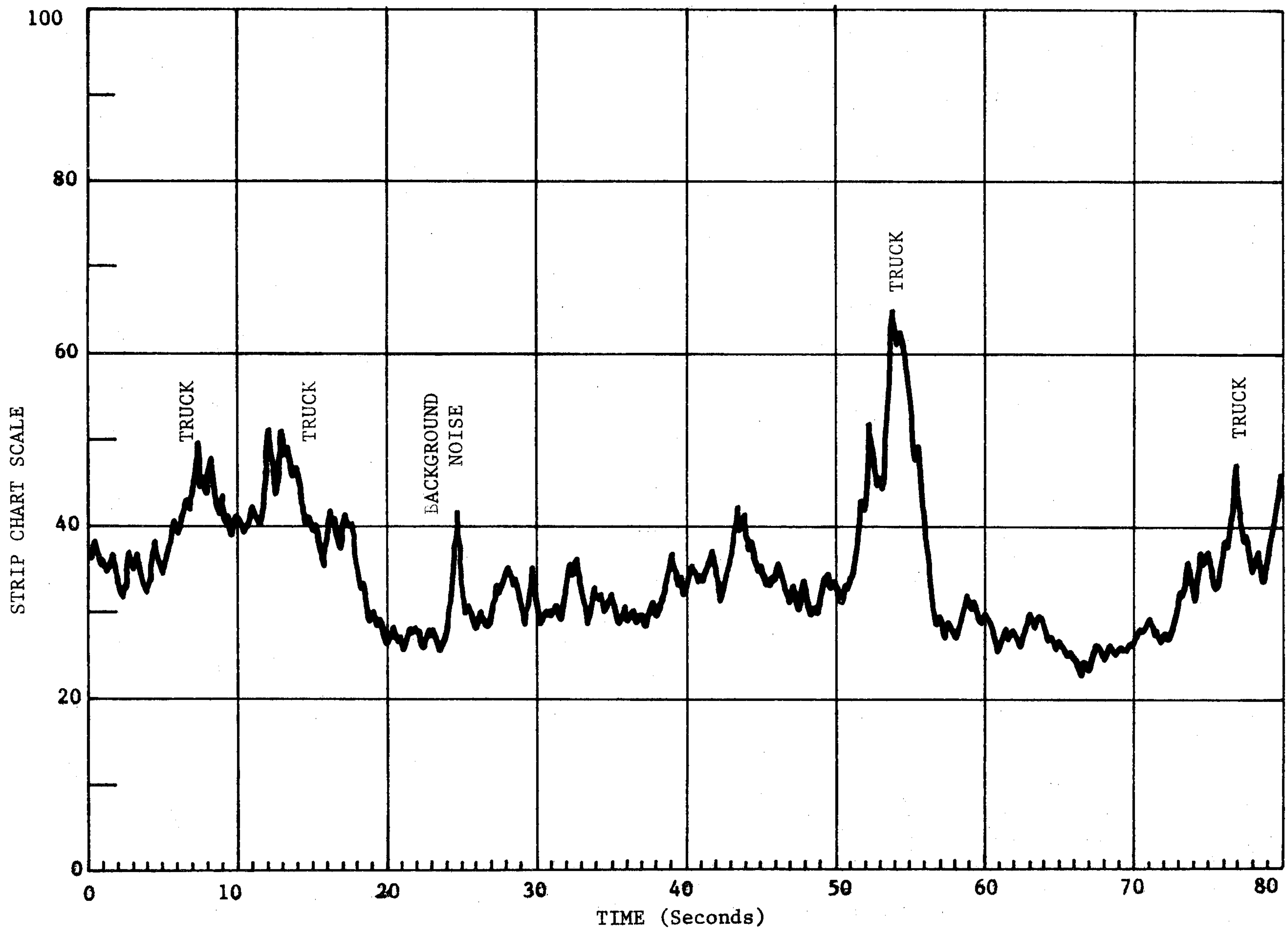


FIGURE 11. TYPICAL STRIP CHART SOUND LEVEL PLOT

chart was set at one division per second to facilitate data analysis. The base scale set on the data recorder was noted on the resulting plot, and conversion factors were applied to obtain the sound pressure level in dBA for each second of plot.

Local noises (sources other than freeway traffic) were noted on the strip chart analog plot, and these peaks were ignored in the data analysis.

Occasionally, a truck noise would exceed the strip chart limits, and approximations of the maximum values were made in these cases. For each run, the sound pressure level for each second of recording was determined and, using a computer program (see Appendix E) the following were calculated:

1. The mean sound pressure level for the run;
2. The frequency distribution of sound pressure levels of the run; and
3. The mean sound pressure level at 10-second, 15-second, 20-second, and 30-second intervals for each run.

Spot checks were made manually to insure that the computer output was accurate.

A computer program was used to reduce tedious hand computations. The one-second graph values were selected from the strip chart plot and converted to dBA values using the conversion graph (see Figure 7). The final sound pressure level values consisted of simply adding the converted graph value to the base sound pressure level used for that recording. In all cases the base sound pressure level was in increments of 10 dBA and ranged from 40 dBA to 80 dBA. The starting points for the computer computations were randomly selected. The four sampling intervals (10, 15, 20, and 30 seconds) were determined as the range of sampling times that would be most likely to be applicable in the field. Field tests revealed that the

15-or 20-second interval allowed easy recording of the data. The 10-second intervals were too short to record with ease, and at 30 seconds the observer had a tendency to be distracted during the pause between readings. These four sampling times were used to calculate values for sampling duration times ranging from 1 minute to 8 minutes.

Graphs showing the mean sound pressure level for the various total sampling duration times were initially plotted for each run and for all four sampling intervals (10, 15, 20, and 30 seconds). For each of these sampling duration times the standard deviation of the sound pressure level was determined. The 95th percentile confidence interval was computed and graphs prepared for each sampling duration time (1 to 8 minutes). The graphs were exponential in nature, tapering toward the sample mean valve as the sampling interval increased. Inspection of the graphs revealed that a more meaningful presentation could be made by summarizing all of the data into four graphs (one each for 10-, 20-, and 30-second sampling intervals) showing the mean and 95th percentile confidence interval of the mean for each sample interval (see Figure 12).

SUMMARY OF 95 PERCENTILE CONFIDENCE INTERVALS

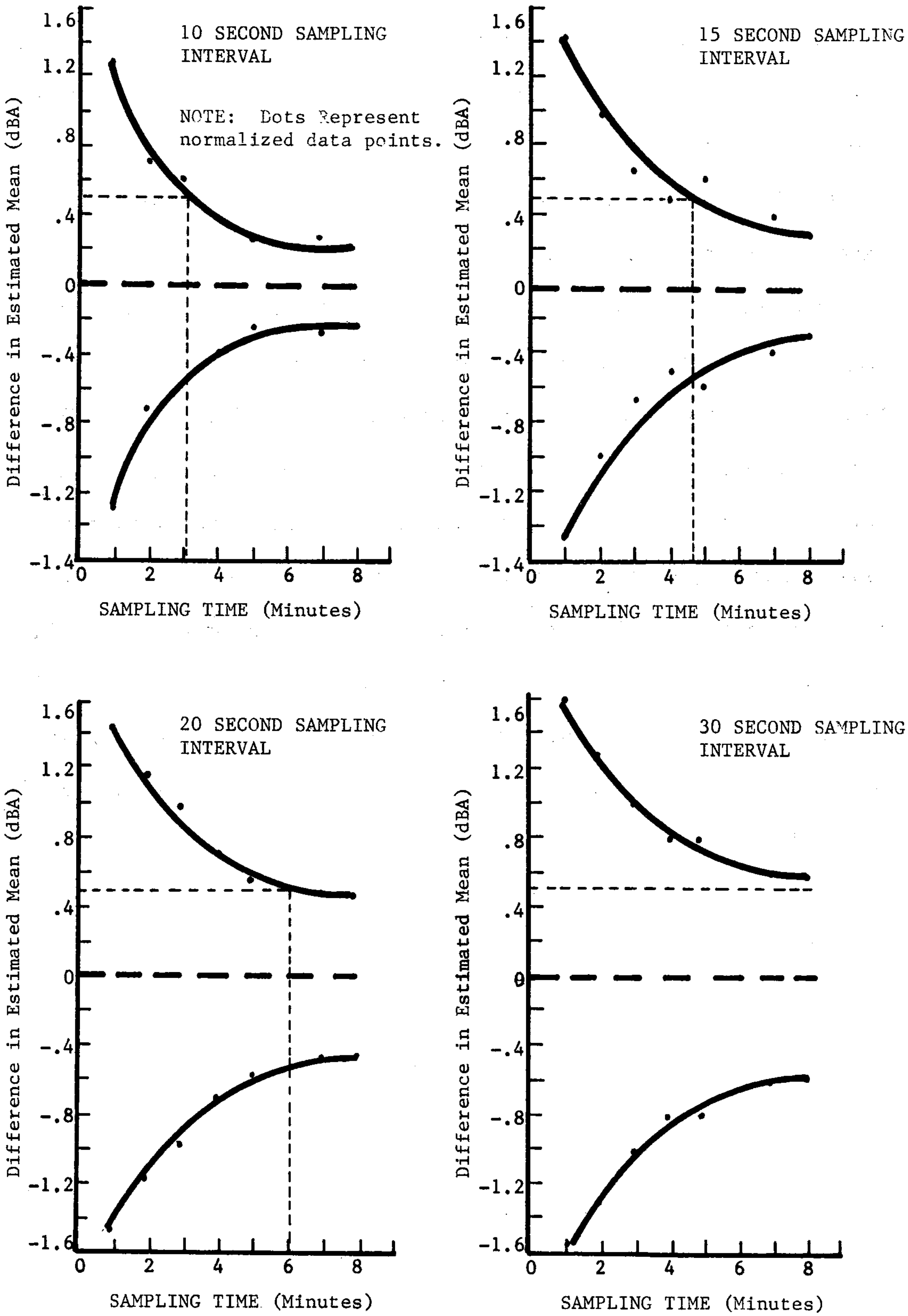


FIGURE 12

ANALYSIS OF RESULTS

(1) Freeway

Figure 12 shows that the relative error associated with increased sampling duration time is exponential in nature as anticipated. These graphs represent the 95th confidence intervals for the expected average difference from the actual value for a particular known sampling interval and for a duration of recording. Thus, for an acceptable error of ±0.5 dBA, the duration of recording time varies from about 3 minutes for a 10-second sampling interval to more than 8 minutes for a 30-second sampling interval. Inspection of these graphs indicates that for a 5-minute duration of recording at a 15-second sampling interval, a 95 percent probability of ±0.5 dBA accuracy in the estimated mean value is ensured.

It can be seen in all the graphs that the range of the 95 percent probability curve decreases very rapidly in the first 4 minutes of recordings, but then decreases very slowly. There is little advantage in increasing the recording duration to 8 or 10 minutes, since only a slight decrease in the relative error in estimating the mean value can be expected.

The use of a 15-second sampling rate for 5 minutes would permit a technician to complete his recording at any location in one hour, assuming a 10-minute setup time, plus 5 minutes recording at each location and further assuming that selected distances of 50 feet, 100 feet, 200 feet, and 400 feet are readily accessible at each site. Field tests revealed that a recording time of 15 minutes per location was ample. This includes time for acoustical calibration of the sound level meter at the beginning of the recording at each site, measurement of the distance from the traveled way, and recording of the reference data for the site.

(2) Relationship of Mean to Various Percentile Values

The mean value at each location was obtained and plotted on the respective strip chart plot. With the mean plotted, the total time (in seconds) was determined for which the sound pressure level exceeded the mean value. Similarly, for increments of 2 dBA above the mean, the time that the sound pressure level exceeded the specified value was accumulated. These time values were then converted to a percentage of the total sampling time. Typical values and graphs are shown in the Appendix D. An accumulative curve was then plotted for each data set (run), with the percentage of the time that the sound pressure level was exceeded versus that particular sound pressure level (dBA). Using these graphs, the 80th, 85th, 90th, and 95th percentile values were determined and plotted against the mean sound pressure level in dBA (Figures 13-16). Inspection of these points indicated a linear relationship. Linear regression analyses were performed for each percentile level, and the resulting relationships had correlation coefficients (r^2) ranging from 0.95 to 0.98. These plots are, in fact, point estimates of the percentile values. This means that by using the 90th percentile graph and knowing the mean sound pressure level (dBA) of a run, the 90th percentile value can be estimated quite simply (see Figure 15). For example, if the mean sound pressure level is estimated as 72 dBA, the 90th percentile would be estimated as 74 dBA.

(3) Urban Ambient Noise Levels

Recordings in quiet residential areas, taken late at night, gave ambient noise levels of about 45 - 50 dBA. In similar areas, but in morning hours (8:00 - 8:30 a.m.), this ambient increased by about 10

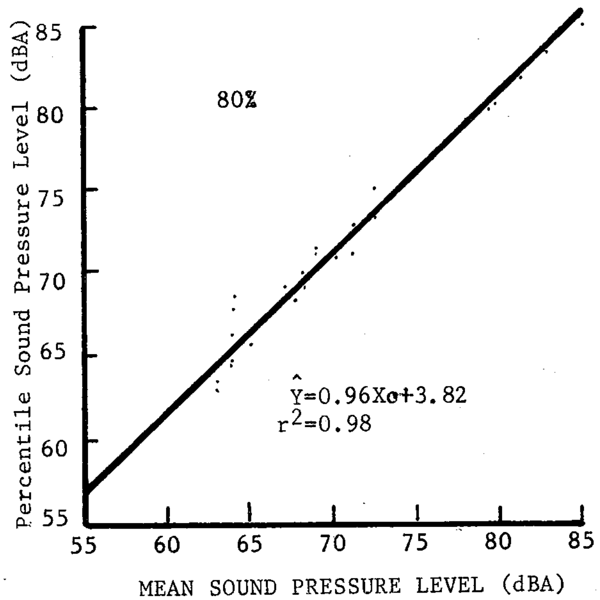


FIGURE 13

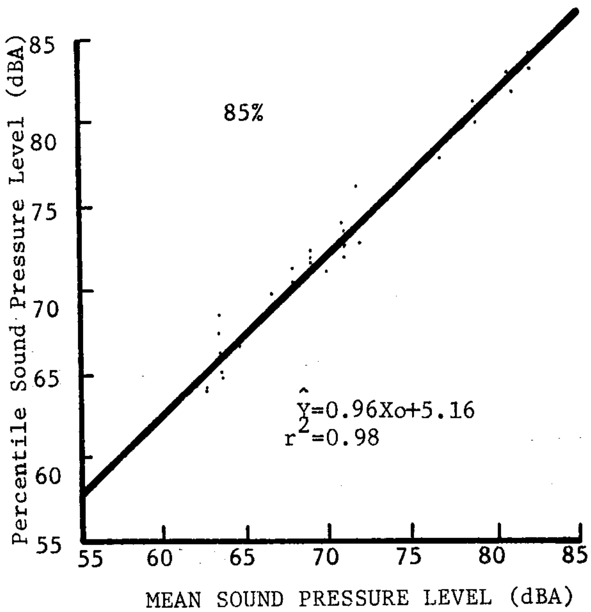


FIGURE 14

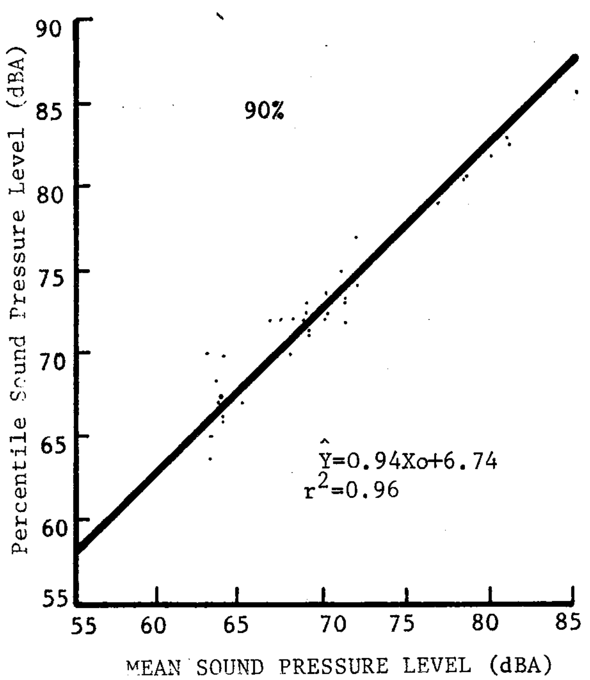


FIGURE 15

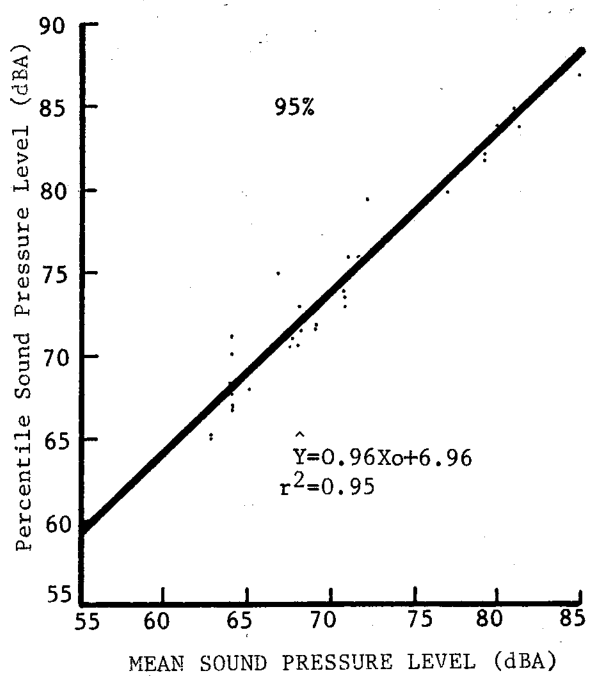


FIGURE 16

LEAST SQUARES LINEAR REGRESSION LINES FOR VARIOUS PERENTILE LEVELS AND THE MEAN SOUND PRESSURE LEVEL decibels; i.e. the noise heard by the human ear approximately doubled. These ambient levels compare favorably with the values found by Thiessen (16) in his research on factors influencing background noise levels. He found night ambient levels of just over 50 dBA and daytime levels just over 60 dBA.

The ambient noise levels recorded in residential areas and those recorded 400 feet from a freeway are presented in Table 1. Inspection of Table 1 indicates that in the areas sampled there generally occurs a doubling (i.e., a 10 dBA increase) in noise level between ambient levels in residential areas late at night, as compared to those recorded during the early morning hours. Between morning noise levels in residential areas and those measured 400 feet from a freeway during the day, there is about an 8 dBA difference. However, it is interesting to note that the morning noise level in residential areas is as high as that measured 400 feet from the freeway during night hours. While this level does not appear to be excessive (±56 dBA), it could be significant to adjacent residents during sleeping hours. More important, however, are the 90th percentile values. These are the sound pressure levels which occur for 10 percent of the time and are usually associated with truck exhausts, motor bikes, sports cars, or automobiles in hard acceleration. Using the 90th percentile graph previously mentioned (Figure 15), a mean value of 56 dBA would give a 90th percentile value of 59 dBA. This means that noise levels above 59 dBA occur for 10 percent of the time, which during night hours is likely to be considered even more objectionable than the mean value.

Table 1

MEAN AMBIENT NOISE LEVELS IN HOUSTON, TEXAS

Locations	Time of Recording	Approximate Mean dBA
Dunlavy-Vermont	11:43 p.m.	49
14th - Tulane	1:12 a.m.	45
Haddon-Woodwick	8:00 a.m.	57
16th - Tulane	8:30 a.m.	56
400' Arlington*	12:46 a.m.	53
400' Arlington	5:50 p.m.	64
400' Newcastle	11:15 p.m.	58
400' Newcastle	2:45 p.m.	64
400' Radcliffe	3:30 p.m.	63

*Indicates 400 feet from the freeway on Arlington Street.

(4) Comparison With Noise Design Guide (15)

Comparisons of sound pressure levels for the various conditions observed in the field studies have been made using the hand-held meter, the values obtained using the data recorder, and the highway noise design guide (15). The design guide procedure includes both a long method and short method; the long method utilizes various geometric configurations, and the short method considers one type of geometric element (at-grade, depressed or elevated) and is considerably simpler to use.

In most cases the sites selected could be calculated as a single, infinite, straight element. Since the Newcastle site readings were more complex, they had to be separated into two elements: at-grade and elevated. These roadway elements must have lanes that can be grouped together as a single equivalent traffic lane, and over the length of the element the cross section, alignment, and traffic volumes must not change.

Comparison of values taken by the hand-held sound pressure level meter and those calculated using the design guide are within one or two dBA's. By recording with the hand-held meters for 5 minutes, rather than 2½ to 3 minutes actually used in testing the feasibility of the use of the hand-held meters, higher correlation would probably have resulted. The hand-held meters were used only to test the feasibility of using the equipment in the field at various sampling intervals, and no attempt was made to record for an extended period of time. The values obtained in the field and the values found using the design guide are presented in Table 2. Typical computation sheets and input data used to find mean and 90 percentile values using the design guide method (15) are included in Appendix B.

Table 2

COMPARISON OF RECORDED NOISE LEVELS WITH VALUES OBTAINED USING THE DESIGN GUIDE (15)

Location			dBA Value Using Hand-Held Meter		dBA Value Calculated Using The Design Guide (15)	
Site #	Time	Recording Interval Seconds	50th Percentile	90th Percentile from (Figure 15)	50th Percentile	90th Percentile
1	3:20 p.m.	15	61	63	59	63
1	2:25 p.m.	10	76 73	78 75	74	79
1	3:00 p.m.	15	67(Base Set 70 dBA) 65(Base Set 60 dBA)	70	64	69
2	4:45	15	76(Fast Setting) 75(Slow Setting)	78 77	76	78
2	5:45	15	63	66	63	66

SUMMARY OF FINDINGS AND RECOMMENDATIONS

(1) Summary of Findings

a) Recordings taken during this project show that sample intervals of 10, 15, and 20 seconds for a time interval of 5 minutes results in accuracies of ±0.3 dBA to ±0.6 dBA (for 95 percent probability), with the recommended 15-second sampling time giving an accuracy of ±0.5 dBA.

b) Tests using a hand-held sound pressure level meter show close correlation with values obtained using the data recorder. These values were usually within 1 or 2 dBA and may have been closer if the 2 to 3 minute recording duration had been extended to 5 minutes as recommended in this study.

c) Care should be taken not to include values of outside (background) noises, such as airplanes, people, or local vehicles. This problem often occurs as the recording site is moved farther from the freeway, when the background noise approaches that heard from the traffic stream. Sites immediately adjacent to local streets should be avoided wherever possible.

d) Using the curves presented in Figures 13-16, the mean value can be used to obtain a point estimate of the sound pressure level which will be exceeded a selected percentage of the time with a high degree of confidence (i.e. 95 to 98 percent).

(2) Recommended Equipment

The following equipment, or equivalent, is recommended. The use of a particular brand of equipment does not necessarily mean that this product is being endorsed, but means that this equipment was successfully used during the project.

a) A General Radio Sound-Level Meter, Type 1565-A, with carrying case and replacement battery

b) A General Radio Sound-Level Calibrator, Type 1562-A

This equipment is available on the market today, and periodic checks should be made before any purchase to insure that new or improved models have not been released.

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16. Thiessen, G. J. "Community Noise Levels." Transportation Noises: A Symposium on Acceptability Criteria, Edited by J. D. Chalupnik, University of Washington Press, Seattle, 1970, pp. 23-32.

APPENDIX A

Typical Procedure Manual

A PROCEDURE FOR CONDUCTING PERIODIC SAMPLING MEASUREMENTS FOR THE EVALUATION OF HIGHWAY NOISE PROBLEMS

Pre-Field Phase (Supervising Engineer)

1. Select site or sites at which a measurement is to be made. For example, if a complaint has been received, measurements should be made at a point opposite the property line nearest the objectionable source (highway), opposite the property line farthest from the source and at selected points between the property and the source. Distances of 50, 100, 200, and 400 feet are recommended as common recording points.

2. Select the sampling interval and duration of recording to be used. A 15-second sampling interval for 5 minutes duration is recommended.

3. Determine whether peak noise levels are to be recorded in the field, since these may be of interest in the evaluation of the total problem. However, these data can be estimated with acceptable accuracy using the techniques outlined in the evaluation section of this procedure.

4. Select the level of peak noises to be estimated (90th percent, 95th percent, etc.).

5. Advise the technician to use the "FAST" response on the sound pressure level meter if the peak noises are to be recorded. In other cases use the "SLOW" response setting.

6. Remind field personnel to use the "A" weighting network.

7. Ensure that the sound pressure meter is checked for both electrical and acoustical calibration before leaving the office.

8. Remind field personnel to take the acoustical calibrator into the field with them.

9. Advise field personnel as to procedure to be used when dealing with the public. For example, in a routine investigation of a complaint, getting in touch with the individual involved and simply advising him that the Department is concerned and is attempting to evaluate his complaint, can have a very positive public relations result. Stress the importance of being a good listener and being courteous at all times.

10. Necessary supplementary information will include the volume and speed of automobiles and trucks. If these data are not available, measurement should be made in the field concurrent with the sound pressure level measurements.

FIELD PROCEDURE FOR CONDUCTING PERIODIC
SAMPLING MEASUREMENTS OF HIGHWAY NOISE

Field Phase (Field Personnel)

a) Review site to insure that study locations planned in the office are feasible.
b) Mark distances of 50, 100, 200, and 400 feet from the near edge of the traveled way, as well as other points as identified by the supervising engineer.
c) Set the selector switch on the "A" weighting network.
d) Check electrical calibration of sound pressure level meter.
e) Check acoustical calibration of sound pressure level meter. A frequency of 1000 hertz (cps) is recommended for acoustical calibration.
f) Fill out site reference information on the data sheet including location sketch in the back of the data form.
g) Select and record the base level (use a base value which will keep the needle on the scale for a majority of the time).
h) Set response switch to either "FAST" (F) or 'SLOW" (S) as instructed by the supervising engineer.
i) Record time at the beginning of the data recording.
j) Begin sound pressure level recordings using the "A" weighting scale at the sampling interval and for the duration given by the supervising engineer.
k) Record time at the end of the data collection.
l) Recheck both electrical and accoustical calibration to insure that no appreciable change has occurred.
m) Check data sheet to be certain that all information has been recorded.

Post Field Phase (Field Personnel)

1. Review data sheet for completeness. Note any omissions or difficulty in reading recorded data.

2. Compute the number of observations (A) and the sum of the observations (B) and enter them at the appropriate points (A or B) on the form.

3. Compute the mean sound pressure level and enter it in the space (C) provided on the form.

4. Using the percentile level previously selected by the supervising engineer, estimate the sound pressure level for the appropriate percentile from Figure A-1 and record it in the space provided on the form (D).

5. Return completed data form to the supervisor.

SOUND PRESSURE LEVEL ESTIMATION

Location: ____
(Route Number or Street Address)

Site Description: Roadway Elevated______Feet; Roadway Depressed_____Feet;
Roadway At-grade

Distance From Near Edge of Traveled Way: ____________________________Feet

Is Line of Sight to Traffic Stream Blocked: Yes________No________

If "Yes" by what?____

Date: __/__/__ Recorder: _________________Meter:_________________

Scale: Fast ______; Slow _____ Weighting Network: "A"

Sampling Interval: ______seconds, Sampling Duration: ______________minutes

(1) Observation Number	(2) Time of Day Hr	Min	Sec	(3) Base Level (dBA)	(4) Meter Reading (dBA)	(5) Instantaneous Sound Pressure Level (dBA) (Base Value + Meter Reading)	(6) Maximum Observed Noise in Interval (dBA)	(7) Comments
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								

No. of OBS = (A) = ______________ Sum of Col. 5 = (B) = ____________________dBA

Mean Sound Pressure Level = $\frac{\text{Sum of Col. 5}}{\text{No. of OBS}}$ = (B)/(A) = ____= C = ____dBA(No Fractions)

Estimated ____ percentile sound pressure level = (D) = ____________________dBA

Was Contact made with complaintant? Yes ____________No ____________________

If "Yes" give name or address of person contacted: ____________________

Remarks: ____

Reference Sketches

1. Show North arrow
2. Show roadway from which noise occurs
3. Show measurement points
4. Locate buildings and trees
5. Draw cross section along line of measurement

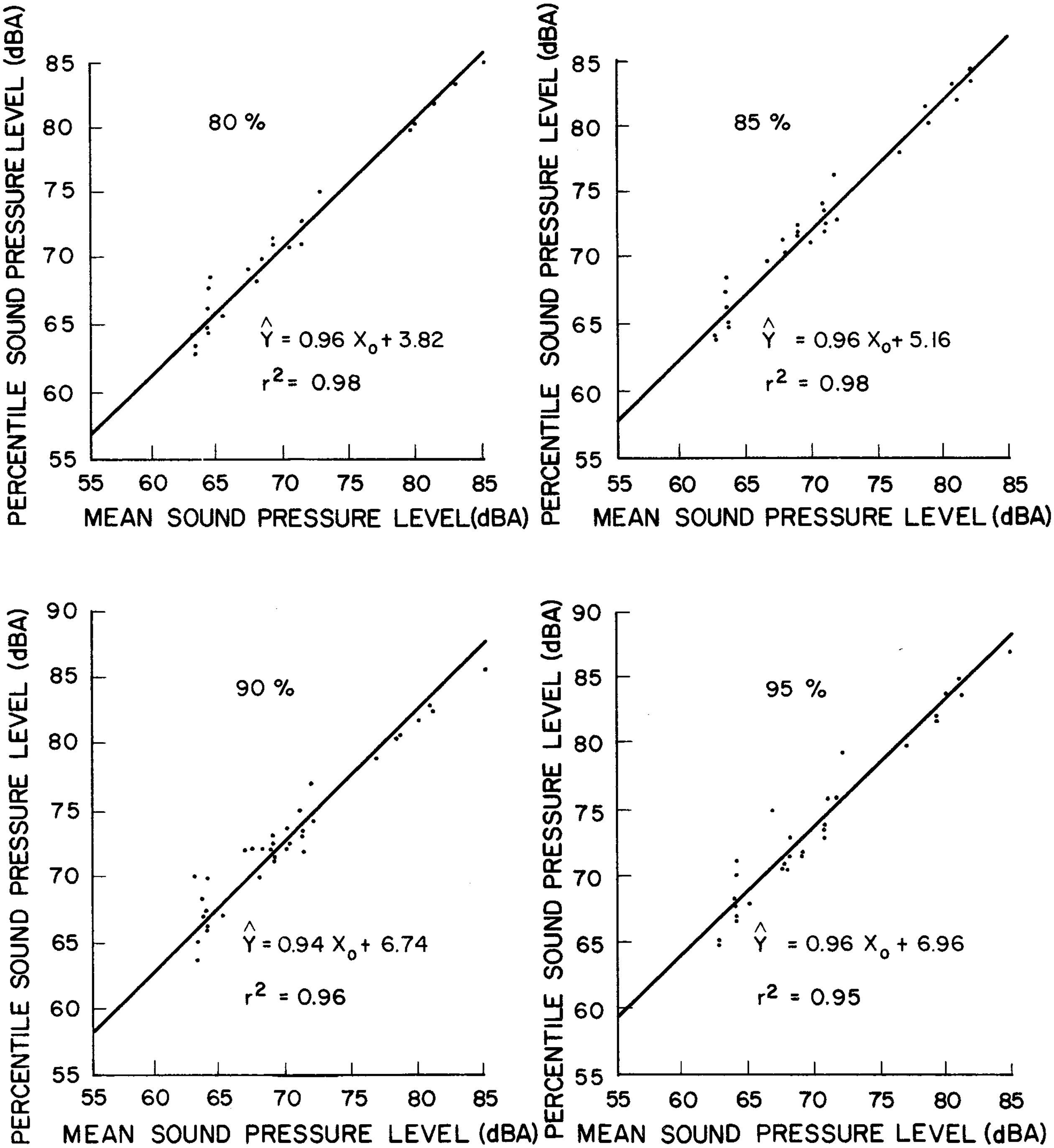


FIGURE A-1. LEAST SQUARES LINEAR REGRESSION LINES FOR VARIOUS PERCENTILE LEVELS AND THE MEAN SOUND PRESSURE LEVEL.

APPENDIX B

Typical Design Guide Solution

Taken from Galloway (15)

ROAD ELEMENT IDENTIFICATION

Lane Grouping | change in

Group	DESCRIPTION	Alinement	Section	Gradient	Flow
		–	–	–	–

Lane Group / Element No.	Type *	DESCRIPTION	Position Parameter D	L	O	Pavement P	N
1	1	At Grade 50' Radcliffe St.	50'	400'	154	116'	8
2							
3							
4							
5							
6							
7							
8							

* Element Type Classification: Type I Infinite Element
II Semi-Infinite
III Finite

TABLE B-I WORK SHEET NO. I ROAD ELEMENT IDENTIFICATION

WORK SHEET NO. 2

TRAFFIC FLOW PARAMETERS

Line	Symbol	Ref.	ROAD ELEMENT / TIME INTERVAL	Number: #4 Type: 1 10 min			
1			Estimated AADT, Vehicles per Day				
2		Fig C 1	Vehicle Volume, % AADT				
3	V		Vehicle Volume, vph				
4		Fig C 2	Truck/Vehicle Mix, %				
5	V_T		Truck Volume, vph	390			
6	V_A		Auto Volume, vph	3282			
7	S_T	Fig C 3	Average Truck Speed, mph	50			
8	S_A	Fig C 3	Average Auto Speed, mph	65			

TABLE B-2. WORK SHEET NO. 2 - TRAFFIC FLOW PARAMETERS

PARAMETER WORK SHEET

	Line	Symbol	Ref.						
				ROAD ELEMENT	Number	#4			
					Type	1			
				TIME INTERVAL		10 min.			
TRAFFIC PARAMETERS	1	V_A	W.S. 2	VEHICLE VOLUME (vph)	(a) Automobiles	3282			
		V_T			(b) Trucks	390			
	2	S_A	W.S. 2	AVERAGE SPEED (mph)	(a) Automobiles	65			
		S_T			(b) Trucks	50			
ROADWAY CHARACTERISTICS	3			FLOW CHARACTERISTIC	(a) Uninterrupted *	√			
					(b) Interrupted *				
	4		W.S. 1	PAVEMENT	(a) Width (P)	116			
					(b) No. of Lanes(N)	8			
	5			PERCENTAGE GRADIENT (if greater than 2%) *		-			
	6			VERTICAL CONFIGURATION	(a) Elevated *				
					(b) Depressed *				
					(c) At Grade *	√			
	7	/		ROAD SURFACE	(a) Smooth *				
					(b) Normal *				
					(c) Rough *	√			
OBSERVER CHARACTERISTICS	8		W.S. 1	POSITION PARAMETERS	(a) D (ft.)	50			
					(b) D_E (ft.)	95			
					(c) L (ft.)	400			
					(d) θ (deg.)	154			
	9			SHIELDING EFFECTS	(a) Barriers *				
					(b) Buildings *				
					(c) Others *				
					(d) None *	√			
	10			TERRAIN EFFECTS					

* Check Where Applicable

TABLE B-3. PARAMETER WORK SHEET

NOISE PREDICTION WORK SHEET

ACOUSTIC CHARACTERISTICS

Line	Symbol	Ref.	ROAD ELEMENT								
			Number	#4							
			Type	1							
			TIME INTERVAL	10 min.							
			VEHICLE TYPE	Auto	Truck	Auto	Truck	Auto	Truck	Auto	Truck
1			Reference L_{50} at 100 ft.	71	73						
2	Δ_1		ADJUSTMENTS: Distance	+1	+1						
3	Δ_2		ADJUSTMENTS: Element	–	–						
4	Δ_3		ADJUSTMENTS: Gradient	–	–						
5	Δ_4		ADJUSTMENTS: Vertical	–	–						
6	Δ_5		ADJUSTMENTS: Surface	+4	+4						
7	Δ_6		ADJUSTMENTS: Shielding (a) Barriers	–	–						
7	Δ_7		ADJUSTMENTS: Shielding (b) Structures & Plant.	–	–						
8			TOTAL ADJUSTMENT (add rows 2 through 7)	+5	+5						
9			L_{50} AT OBSERVER (add row 1 to row 8)	76	78						
10		W.S.5	$L_{10} - L_{50}$ ADJUSTMENT	4	7						
11			INTERRUPTED ADJUSTMENT								
12			L_{10} AT OBSERVER (add row 10 & 11 to row 9)	80	85						
13		W.S.6	ELEMENT TOTAL L_{50}	80							
13		W.S.6	ELEMENT TOTAL L_{10}	86							
14		W.S.6	GRAND TOTAL	L_{50} = 80 dBA				L_{10} = 86 dBA			
15				$L_{10} - L_{50}$ = 6 dBA							

TABLE B-4. NOISE PREDICTION WORK SHEET

WORK SHEET NO. 5

L_{10} ADJUSTMENT

Line	Symbol	Ref.	ROAD ELEMENT								
			Number	#4							
			Type	1							
			TIME INTERVAL	10 min.							
			VEHICLE TYPE	Auto	Truck	Auto	Truck	Auto	Truck	Auto	Truck
1	V	P.W.S.	Vehicle Volume, vph	3282	390						
2	S	P.W.S.	Average Speed, mph	65	50						
3	D_E	P.W.S	Observer – Equiv. Lane Distance, ft.	95	95						
4	A		Parameter $A = VD_E/S$, Vehicles ft/m	4800	740						
		Fig. B 10	L_{10} Adjustment, dB	4	7						

TABLE B–5 WORK SHEET NO. 5 – L_{10} ADJUSTMENT

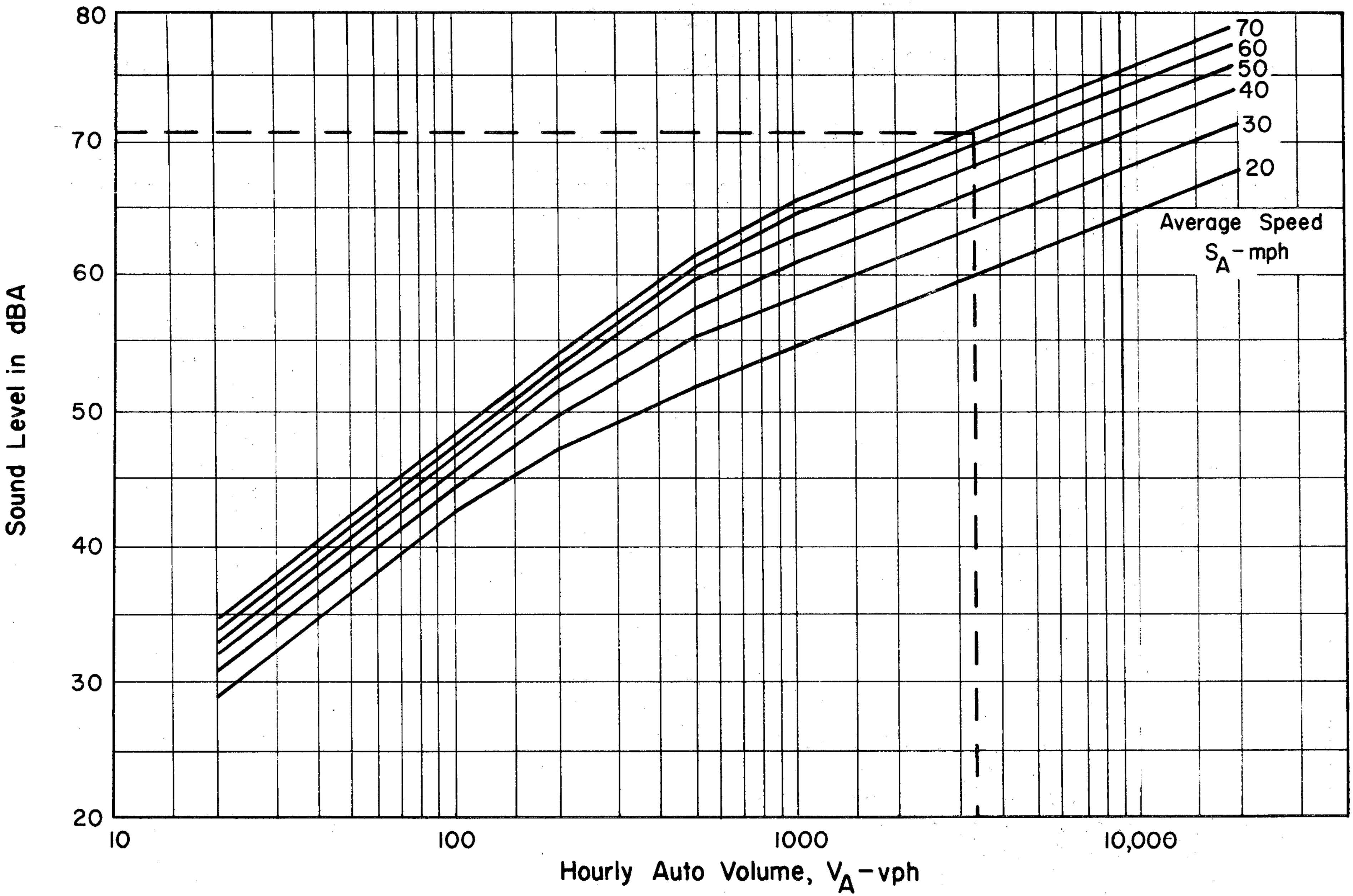


FIGURE B-1. PLOT OF L_{50} FOR AUTOMOBILES AS FUNCTION OF VOLUME FLOW AND AVERAGE SPEED

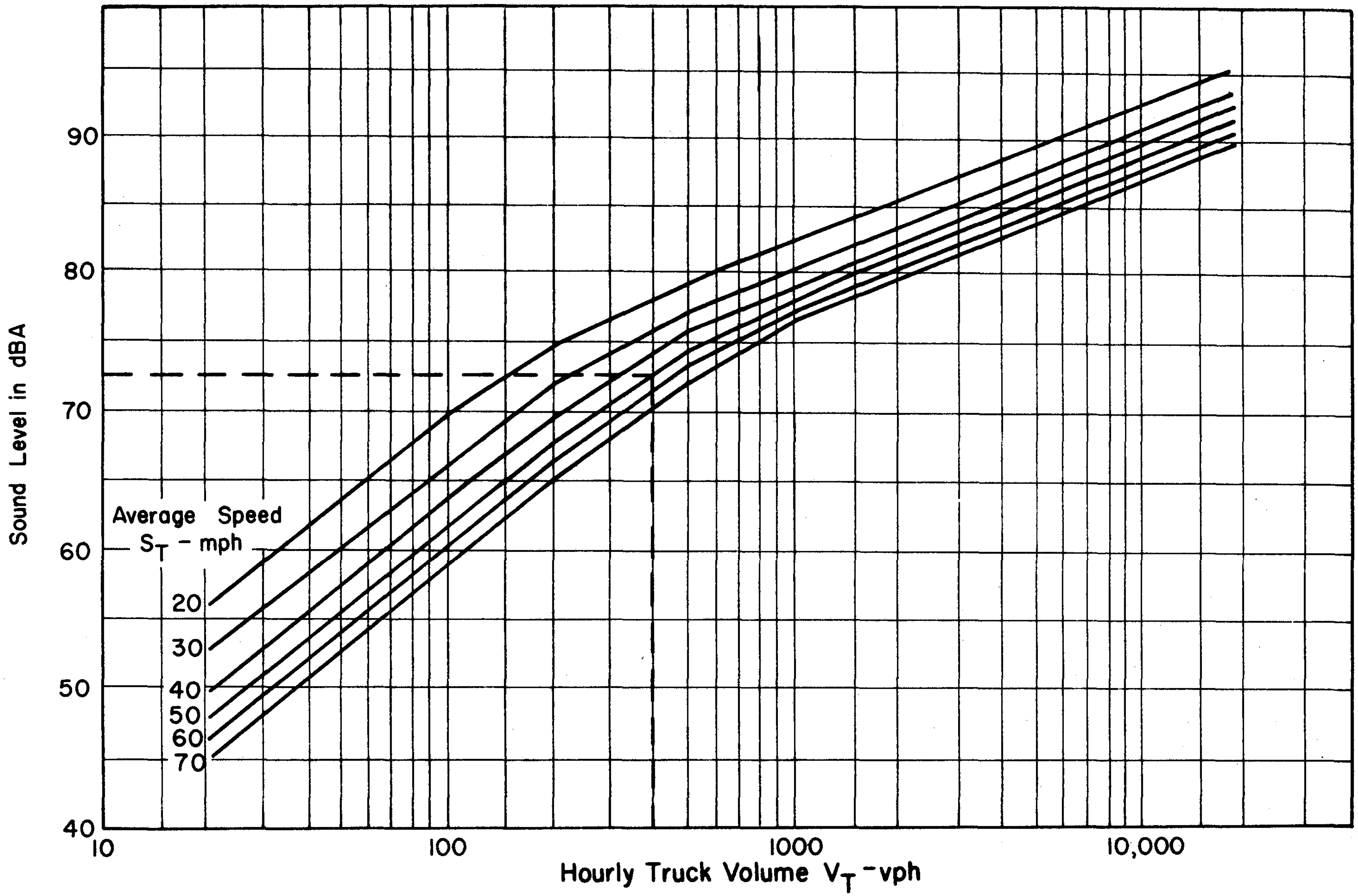


FIGURE B-2. PLOT OF L_{50} FOR TRUCKS AS FUNCTION OF VOLUME FLOW AND AVERAGE SPEED

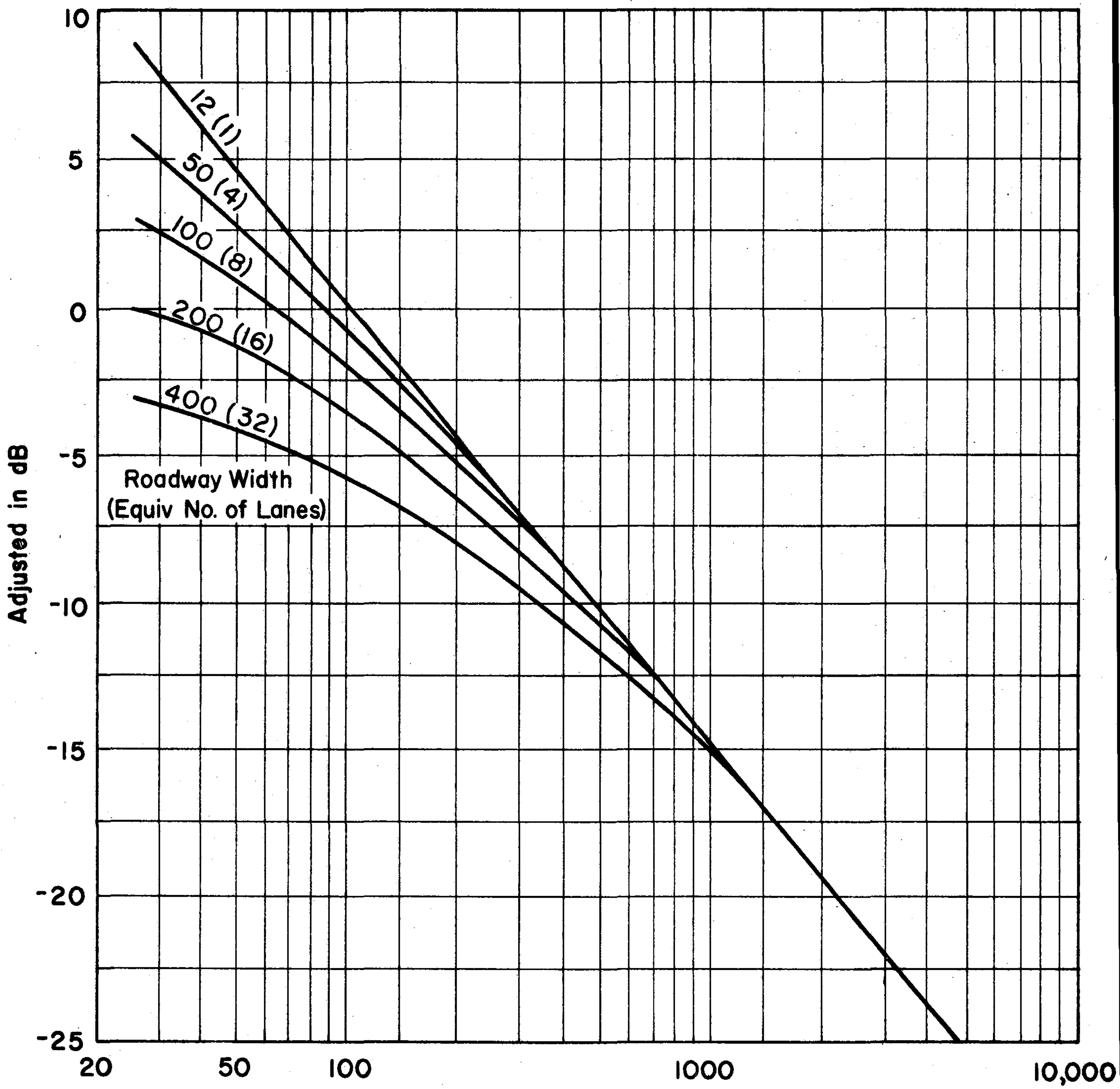


FIGURE B-3. DISTANCE ADJUSTMENT TO ACCOUNT FOR OBSERVER NEAR LANE DISTANCE AND WIDTH OF ROADWAY

WORK SHEET NO. 6

DECIBEL ADDITION

Source or Element No.	Sound Level-dB	Antilog Colums-Left Digit of Sound Level								Antilog Table	
		9	8	7	6	5	4	3	2	Right Digit of Sound Level	Antilog
Run No. #4	76			3	9	8	7			0	1000
	78			6	3	1	1			1	1259
										2	1585
										3	1995
										4	2512
										5	3162
										6	3981
										7	5013
										8	6311
Total L_{50}	80		1	0	2	9	2			9	7944

List sound levels by source or Roadway Elements.

Enter antilog table with right digit of sound level to obtain antilog value.

Enter antilog on work sheet under antilog Columns. Position by entering left digit of antilog under the column numbered the same as the left digit of the sound level.

Add the antilog values of the individual sources to obtain the antilog of the total sound level.

Enter antilog table with antilog of total sound level. Obtain right digit of total sound level by selecting digit from table whose antilog is closest numerically to the antilog obtained in Step 4.

Indentify column number containing left most digit of the antilog derived from Step 4. This is the numerical value of the left digit of the total sound level.

TABLE B-6. WORK SHEET NO. 6 - DECIBEL ADDITION

WORK SHEET NO. 6

DECIBEL ADDITION

Source or Element No.	Sound Level—dB	Antilog Columns—Left Digit of Sound Level								Antilog Table	
		9	8	7	6	5	4	3	2	Right Digit of Sound Level	Antilog
Run No. #4	80		1	0	0	0				0	1000
	85		3	1	6	2				1	1259
										2	1585
										3	1995
										4	2512
										5	3162
										6	3981
										7	5013
										8	6311
Total L_{10}	86		4	1	6	2				9	7944

List sound levels by source or Roadway Elements.

Enter antilog table with right digit of sound level to obtain antilog value.

Enter antilog on work sheet under antilog Columns. Position by entering left digit of antilog under the column numbered the same as the left digit of the sound level.

Add the antilog values of the individual sources to obtain the antilog of the total sound level.

Enter antilog table with antilog of total sound level. Obtain right digit of total sound level by selecting digit from table whose antilog is closest numerically to the antilog obtained in Step 4.

Identify column number containing left most digit of the antilog derived from Step 4. This is the numerical value of the left digit of the total sound level.

TABLE B-7 WORK SHEET NO. 6 – DECIBEL ADDITION

APPENDIX C

Vehicle Counts

PROJECT 2166

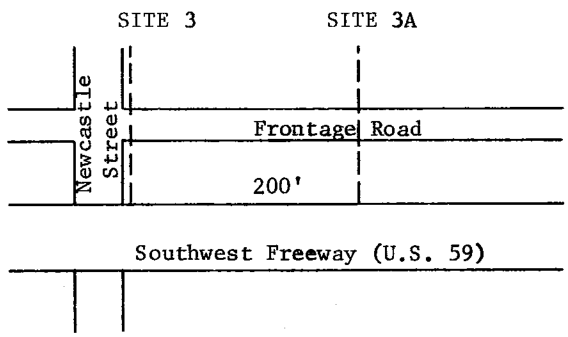
SUMMARY OF NOISE RECORDINGS
HOUSTON, TEXAS JANUARY 12-15, 1971

TIME	RECORDING	SITE	DISTANCE	LOCATION
7:30 ± a.m.	1	1	50'	Radcliffe St.
	2	1	100'	"
	3	1	150'	"
2:00 ± p.m.	4	1	50'	"
	5	1	100'	"
	6	1	200'	"
	7	1	400'	"
5:00 ± p.m.	8	2	50'	Arlington St.
	9	2	100'	"
	9A	2	200'	"
	10	2	400'	"
7:00 ± a.m.	11	2	50'	"
2:00 ± p.m.	12	3	50'	Newcastle St.
	13	3	100'	"
	14	3	200'	"
	15	3	400'	"
5:00 ± p.m.	16	3A	50'	Near Newcastle St.
	17	3A	100'	"
	18	3A	200'	"
	19	3A	400'	"
11:00 ± p.m.	20	3A	50'	"
	21	3A	100'	"
	22	3A	200'	"
	23	3A	400'	"
11:43 p.m. Ambient	24	4	Ambient	Dunlavy-Vermont St.
12:15 a.m.	25	2	50'	Arlington St.
12:20 a.m.	26	2	100'	"
12:35 a.m.	27	2	200'	"
12:46 a.m.	28	2	400'	"
1:12 a.m.	29	5	Ambient	14th St.-Tulane St.
7:12 a.m.	30	3A	50'	Near Newcastle St.
7:19 a.m.	31	3A	100'	
7:24 a.m.	32	3A	200'	
7:38 a.m.	33	3A	400'	
8:08 a.m. Ambient	34	6	Ambient	Haddon-Ridgewood St.
8:30 a.m. "	35	7(near 5)	Ambient	16th St.-Tulane St.

NOISE STUDY - HOUSTON - JANUARY 1971

VOLUME SUMMARY

SITE 1 - INTERSTATE 10 & RADCLIFFE
SITE 2 - INTERSTATE 10 & ARLINGTON
SITE 3 - SOUTHWEST FRWY. & NEWCASTLE
SITE 3A - SOUTHWEST FRWY. & NEWCASTLE



VOLUME DATA

DATE	TIME	SITE	DISTANCE FROM ROADWAY	#VEHICLES EASTBOUND	#VEHICLES WESTBOUND	#TRUCKS BOTH WAYS	TOTAL # VEHICLES	TOTAL TRUCKS & VEHICLES
1/12/71	A.M. 7:25- 7:35	1	50'	1040	320	34	1360	1394
1/12/71	A.M. 7:38- 7:48	1	100'	1112	439	41	1551	1592
1/12/71	A.M. 7:59- 8:08	1	150'	900	352	40	1252	1291
1/12/71	P.M. 2:05- 2:10	1	50'	129	113	28	242	270
1/12/71	P.M. 2:11- 2:16	1	50'	148	157	37	305	342
1/12/71	P.M. 2:21- 2:26	1	100'	136	152	38	288	326
1/12/71	P.M. 2:36- 2:41	1	100'	111	126	27	237	264
1/12/71	P.M. 2:56- 3:06	1	200'	280	355	67	635	702
1/12/71	P.M. 3:21- 3:31	1	400'	313	395	66	708	774
1/12/71	P.M. 4:40- 4:44	2	50'	148	244	13	392	405

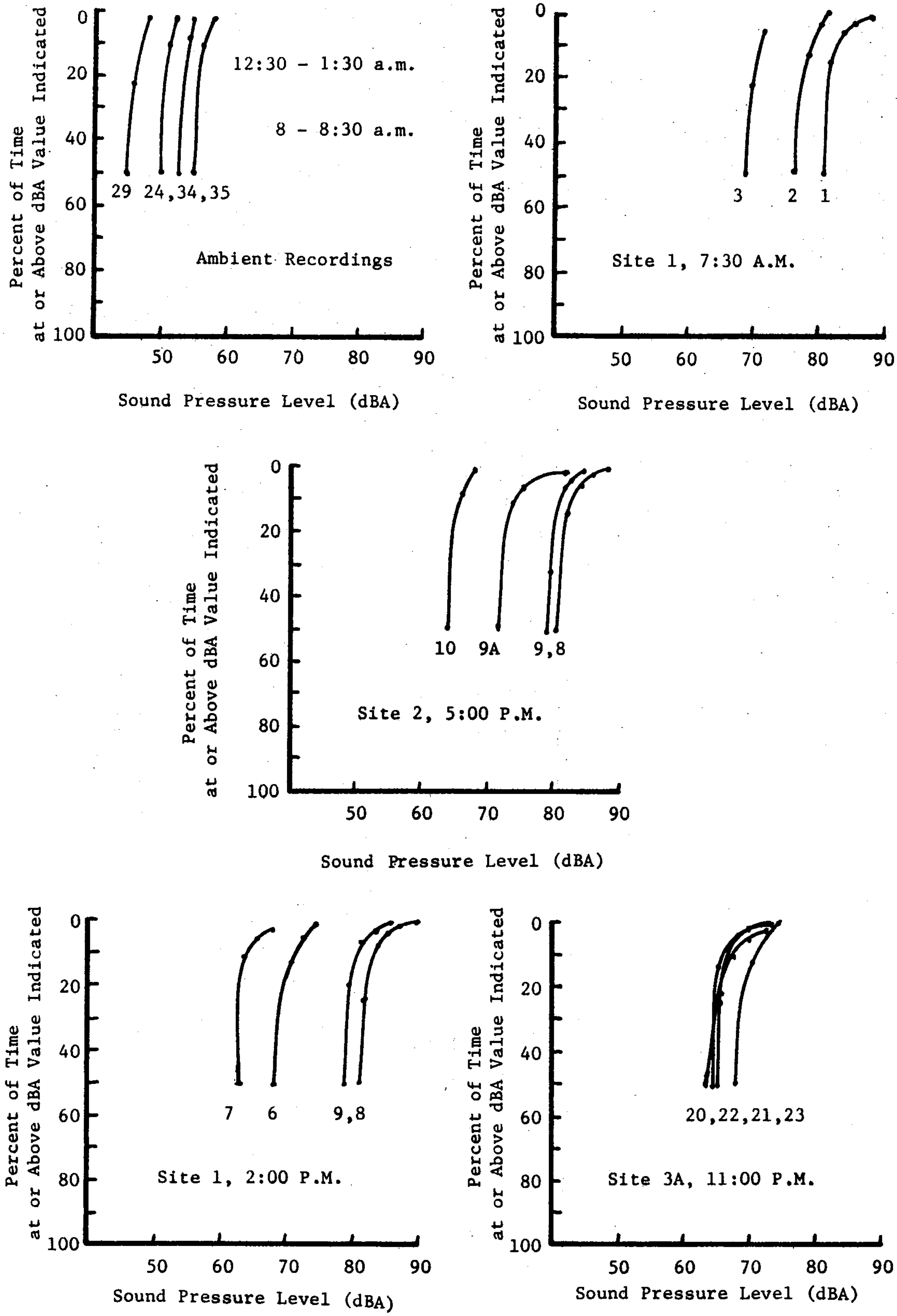
DATE	TIME	SITE	DISTANCE FROM ROADWAY	#VEHICLES EASTBOUND	#VEHICLES WESTBOUND	#TRUCKS BOTH WAYS	TOTAL # VEHICLES	TOTAL TRUCKS & VEHICLES
1/12/71	P.M. 4:46- 4:54	2	50'	340 (assumed)	570	37	910	947
1/12/71	P.M. 5:00- 5:10	2	100'	340	1086*	38	1426	1464
1/12/71	P.M. 5:20- 5:30	2	200'	308	1134*	36	1442	1478
1/12/71	P.M. 5:45- 5:55	2	400'	328	1003*	30	1311	1361
1/13/71	A.M. 7:18- 7:28	2	50'	1000	282	31	1282	1313
1/13/71	A.M. 7:41- 7:43	2	100'	115	64*	9	179	188
1/13/71	P.M. 2:02- 2:08	3	50'	302	340	34	642	676
1/13/71	P.M. 2:19- 2:24	3	100'	446	320	30	766	796
1/13/71	P.M. 2:31- 2:36	3	200'	274	335	27	609	636
1/13/71	P.M. 2:43- 2:48	3	400'	302	404	31	706	737
1/13/71	P.M. 4:34- 4:39	3A	50'	346	592	11	938	949
1/13/71	P.M. 4:42- 4:47	3A	100'	435	648	23	1083	1106
1/13/71	P.M. 4:55- 5:01	3A	200'	407	690	24	1097	1121
1/13/71	P.M. 5:10- 5:15	3A	400'	413	461	11	874	885
1/13/71	P.M. 10:45-10:50	3A	50'	79	112	4	191	195
1/13/71	P.M. 10:53-10:58	3A	100'	90	97	3	187	190
1/13/71	P.M. 11:02-11:07	3A	200'	67	108	7	175	182
1/13/71	P.M. 11:12-11:17	3A	400'	62	133	2	195	197
1/14/71	A.M. 12:15-12:20	2	50'	83	40	3	123	126
1/14/71	A.M. 12:22-12:27	2	100'	35	48*	1	83	84
1/14/71	A.M. 12:35-12:40	2	200'	38	33*	8	71	79
1/14/71	A.M. 12:46-12:51	2	400'	33	29*	3	62	65

*Including westbound service road

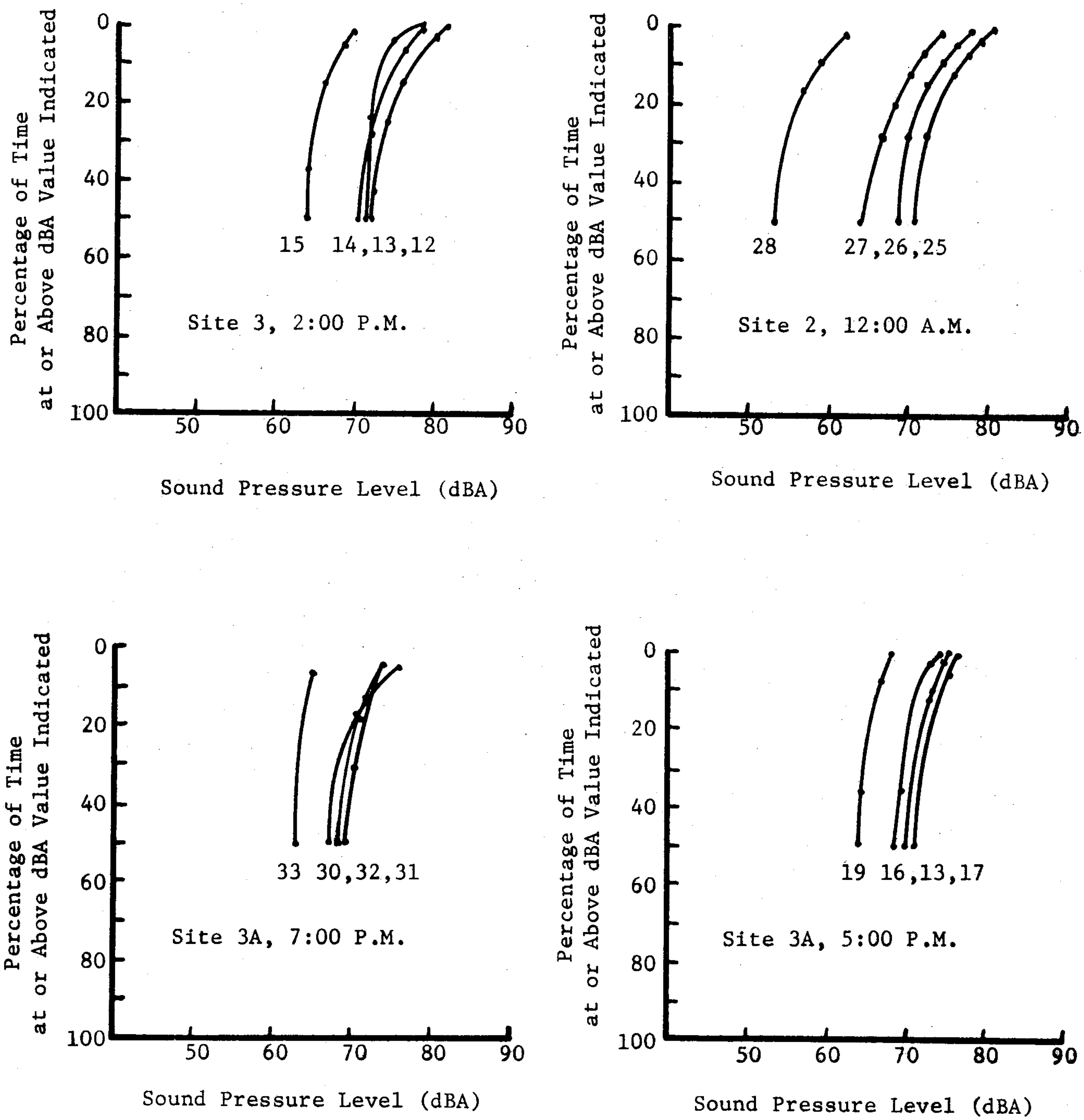
DATE	TIME	SITE	DISTANCE FROM ROADWAY	#VEHICLES EASTBOUND	#VEHICLES WESTBOUND	#TRUCKS BOTH WAYS	TOTAL # VEHICLES	TOTAL TRUCKS & VEHICLES
1/14/71	A.M. 7:12- 7:17	3A	50'	460	200	9	660	669
1/14/71	A.M. 7:19- 7:24	3A	100'	458	203	2	661	663
1/14/71	A.M. 7:29- 7:34	3A	200'	468	302	5	770	775
1/14/71	A.M. 7:38- 7:43	3A	400'	418	280	8	698	706

APPENDIX D

Cumulative Frequency Curves



CUMULATIVE FREQUENCY CURVES FOR THE
SOUND PRESSURE LEVEL AT EACH STUDY SITE



CUMULATIVE FREQUENCY CURVES FOR THE
SOUND PRESSURE LEVEL AT EACH STUDY SITE

APPENDIX E

Program To Find Mean Values

```
//$WATFIVR JOB (326T7,1-J   ,*20,005,01),' STOCKTON, WR NERP-1          '      9-
C NERP-1   NOISE EVALUATION AND REDUCTION PROGRAM
C THIS PROGRAM COMPUTES THE MEAN NOISE LEVEL BASED ON DATA AT ONE SECOND
C INTERVALS.  THESE DATA CAN THEN BE SAMPLED AT ANY DESIRED INTERVAL AND
C SAMPLING FREQUENCY. WRITTEN BY D. L. WOODS JANUARY 1971
C BASIC INPUT VARIABLES
C    TYPE 1 CARD -SITE  -COLS 1 THRU 8  EXAMPLE  2166-3A
C                 PLACE -COLS 9 THRU 40 EXAMPLE  ALLENDALE RD AT SWFWY
C                        HOUSTON
C                 DATE  -COLS 41 THRU 48 EXAMPLE  1/13/71
C                 NEEDIT-COLS 49 THRU 53 INDEX OF DESIRE TO PERFORM
C                        SAMPLING RUNS
C                     1-SAMPLING DESIRED
C                     0 OR BLANK - NO SAMPLING EXPECTED
C                    RUNNUM -COLS 54 THRU 57  EXAMPLE  12
C                    TIMDAY-COLS 58 THRU 69 EXAMPLE 12 56 AM
C    TYPE 2 CARDS- IEND -COLS1 THRU 3 --INDEX OF LAST DATA CARD
C                     1 IN COLUMN 3 INDICATES LAST DATA CARD -- CARD CAN
C                       BE FULL, PARTIALLY FULL OR BLANK
C                   NOISE- COLS 4 THRU 72 IN UNITS OF 3
C                        THIS IS THE BASIC NOISE DATA
C    TYPE 3 CARDS-ISTART COLS 1 THRU 6 -- INDICATES BEGINNING OF SAMPLING
C                        RUNS
C                     ITIME  COLS 7 THRU 11 --INDICATES SAMPLING INTERVAL
C                        (SECS)
C                     ISTOP  COLS 12 THRU 16 --INDICATES PT TO END  SAMPLE
C                     IAGAIN  COLS 17 THRU 20 - INDICATES ANOTHER SAMP
C                              LING RUN
      DIMENSION DATA(650), NOISE(23),FREQ(650),CMFREQ(16),SITE(2),PLACE
     *(8), DATE(2), TIMDAY(3)
CREAD  IN IDENTIFICATION DATA
    1 READ(5,10,END=99)SITE,PLACE, DATE, NEEDIT, RUNNUM, TIMDAY
   10 FORMAT(2A4,8A4,2A4,I5,F4.0,3A4)
C READ IN NOISE DATA
      M=1
 1001 READ(5,100)IEND, NOISE
  100 FORMAT(I3,23I3)
      KK=1
      K=M+22
      DO 1005 I=M,K
      INUM=I-1
      IF ( NOISE(KK).EQ.0  ) GO TO 2000
      DATA(I)= NOISE(KK)
      IF(KK.EQ.23) GO TO 1006
      KK=KK+1
 1005 CONTINUE
 1006 M=K+1
      IF(IEND.EQ.1) GO TO 2000
      GO TO 1001
C COMPUTE THE AVERAGE NOISE LEVEL
 2000 SUM=0.0
      DO 2005 J=1,INUM
 2005 SUM=SUM+DATA(J)
      ANUM=INUM
      AVNOYS=SUM/ANUM
C COMPUTE FREQUENCY DISTRIBUTION OF NOISE LEVELS
C INITIALIZE FREQUENCY MATRIX TO ZERO
 3000 DO 3005 J=1,650
 3005 FREQ(J)=0.0
 3006 DO 3010 J=1,INUM
      INDEX=DATA(J)+0.01
```

```
 3010 FREQ(INDEX)=FREQ(INDEX)+1.0
C REGROUP FREQUENCY DISTRIBUTION INTO 5DBA RANGES-40 OR LESS,40-45 ETC
C INITIALIZE THE GROUPED MATRIX TO ZERO
      DO 4005 I=1,16
 4005 CMFREQ(I)=0.0
C SETUP ACCUMULATED GROUP MATRIX (CMFREQ)
      DO 4010 I=1,40
 4010 CMFREQ(1)=CMFREQ(1)+FREQ(I)
      DO 4020 J=2,15
      DO 4020 K=1,5
 4020 CMFREQ(J)=CMFREQ(J)+FREQ(30+5*J+K)
      DO 4025 I=1,10
 4025 CMFREQ(16)=CMFREQ(16)+FREQ(I+110)
C WRITE SUMMARY OF DATA
 5000 WRITE(6,200)SITE,PLACE,DATE,AVNOYS
  200 FORMAT(1H1,' PROJECT 2166 NOISE REDUCTION ANALYSIS'/'  DATA FROM S
     *ITE NUMBER'1X,2A4, 8A4,/'  DATE OF DATA COLLECTION'2A4,//'  AVERAG
     *E NOISE LEVEL ='F6.2)
C WRITE OUT THE FREQUENCY DISTRIBUTION
 5010 WRITE(6,205) (CMFREQ(I),I=1,16)
  205 FORMAT(1H0,' GROUPED FREQUENCY SUMMARY'/1H0,'40 DBA ORLESS ='F6.2/
     *' 41 TO 45 DBA ='F8.2/' 46 TO 50 DBA ='F8.2/' 51 TO 55 DBA ='F8.2/
     *' 56 TO 60 DBA='F8.2/' 61 TO 65 DBA ='F8.2/' 66 TO 70 DBA ='F8.2/
     *' 71 TO 75 DBA ='F8.2/' 76 TO 80 DBA ='F8.2/' 81 TO 85 DBA ='F8.2/
     *' 86 TO 90 DBA ='F8.2/' 91 TO 95 DBA='F8.2/' 96 TO 100 DBA ='F7.2/
     *' 101 TO 105 DBA ='F6.2/' 106 TO 110 DBA ='F6.2/' 111 DBA OR MORE
     *='F6.2)
C CHECK TO SEE IF SAMPLING OF DATA IS DESIRED
      IF(NEEDIT.EQ.0)GO TO 1
C SAMPLE NOISE LEVELS AT VARIOUS INTERVALS
 6000 READ(5,300)ISTART,ITIME,ISTOP,IAGAIN
      TOTAL=0.0
      SUM=0.0
      DO 6010 I=ISTART,ISTOP,ITIME
      STOP = I - ITIME
      IF(I.GT.INUM)GO TO 7000
      SUM=SUM+DATA(I)
 6010 TOTAL=TOTAL+1.0
  300 FORMAT(I2,2I6,I3)
C COMPUTE AVERAGE NOISE LEVEL FOR SAMPLE
      STOP = I
 7000 SAMAVE = SUM/TOTAL
C WRITE OUT RESULTS OF SAMPLING NOISE DATA
      START=ISTART
      RUN=(STOP-START)/60.0
      WRITE(6,400)SITE, PLACE, DATE,RUNNUM, TIMDAY,START,ITIME,RUN, SAMA
     *VE
  400 FORMAT(1H0,' SUMMARY OF AVERAGE NOISE LEVEL USING SAMPLING PROCEDU
     *RE'/' DATA FROM SITE NUMBERSITE NUMBER'2A4,8A4/' DATE OF DATA COLL
     *ECTION'2A4/' RUN NUMBER -'F4.0/' TIME OF DAY - ' 3A4/' STARTING
     * TIME OF SAMPLING = 'F6.4'SECONDS'/
     *            ' SAMPLING INTERVAL ='I5' SECONDS'/' TOTAL SAMPLING
     *TIME ='F6.2 ' MINUTES'/' AVERAGE NOISE LEVEL OF SAMPLE ='F6.2 ' DB
     *A')
 8000 IF(IAGAIN.EQ. 1)GO TO 6000
C SEND CONTROL BACK TO BEGINNING OF PROGRAM
      WRITE(6,401)
  401 FORMAT(1H1)
      GO TO 1
   99 STOP
      END
```