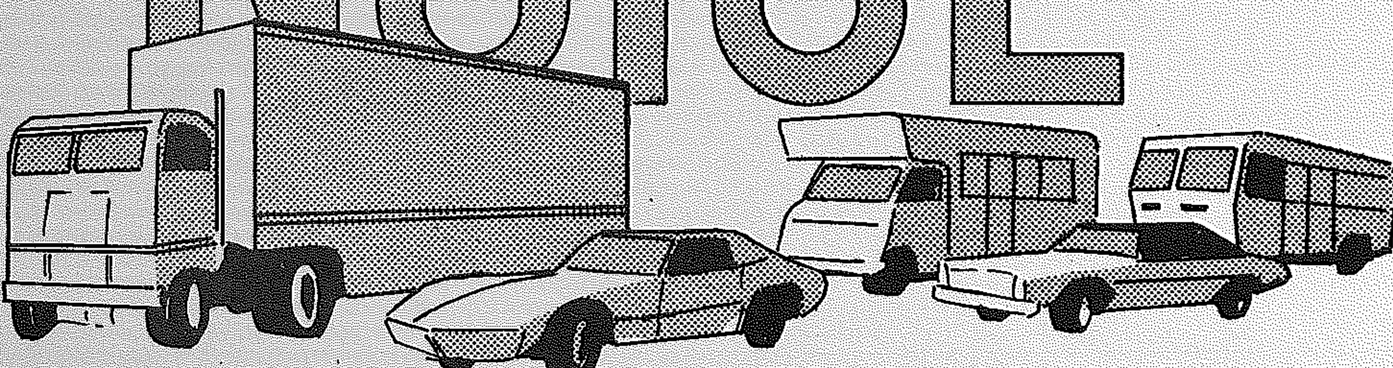
POLLUTION OF MICHIGAN URBAN ATMOSPHERES BY HIGHWAY GENERATED NOISE



MICHIGAN DEPARTMENT OF STATE HIGHWAYS
SEPTEMBER 1972

POLLUTION OF MICHIGAN URBAN ATMOSPHERES BY HIGHWAY-GENERATED NOISE

A Highway Planning and
Research Investigation Conducted by the
Michigan Department of State Highways in
Cooperation with the US Department of Transportation
Federal Highway Administration

Research Laboratory Section
Testing and Research Division
Research Project 68 G-162
Research Report No. R-828

Lansing, February 1973

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the assistance and advice so freely given, both directly and indirectly, by Dr. William J. Galloway and B. Andrew Kugler of Bolt Beranek and Newman, Inc. The frequent reference to, and reliance on, the work of BBN throughout this report testifies to the high esteem held for the work of these individuals and their company.

No authors have been listed for this report because of the cooperative nature of its preparation, and the significant quantity of material drawn from the literature and other sources. The principal Michigan contributors to the report, however, were L. E. DeFrain, Paul Milliman, G. H. Grove and P. G. Gray.

Others whose contributions must be acknowledged include Professor T. M. Allen, Michigan State University, engineer-psycologist consultant to the project; L. F. Holbrook and C. D. Church, research statisticians of the Research Laboratory's Statistics and Data Processing Unit; and certainly to the members of the Instrumentation and Data Systems Group for their study and efforts over and above normal work demands, to achieve competence in a new and unfamiliar work area--highway noise.

CONTENTS

Page

SECTION I

INTRODUCTION

INTRODUCTION

This report describes the first year's progress and experience on a programmed three-year Highway Planning and Research Investigation conducted by the Michigan Department of State Highways in cooperation with the US Department of Transportation - Federal Highway Administration.

The Michigan study described is titled, "Pollution of Michigan Urban Atmospheres by Highway-Generated Noise." The specific objectives of that study, quoted from the Project Proposal, are as follows:

> "The broad objectives of this study are to secure information on the Highway-Generated noise problem as it now exists in Michigan, and to determine methods which will facilitate the control and abatement of this noise in the future.
>
> Specific objectives are as follows:
>
> 1. To assemble a comprehensive bibliography, with abstracts of all studies pertinent to the highway noise problem.
>
> 2. Determine and characterize the sound spectra of the various types of vehicles in the traffic stream.
>
> 3. Determine and characterize the composite sound spectra radiating from different highway sites carrying various mixtures of private and commercial vehicles.
>
> 4. Develop a computer program of verified accuracy which will predict the noise spectrum that will radiate from a highway under any given set of known conditions.
>
> 5. To conduct experiments aimed at validating the reputed correlation between the Zwicker Method (1) and human subjective response (perception only). If it is verified that the Zwicker Method does reflect subjective perception of highway noise with good fidelity then it will be possible to estimate the perceptual effects of various noise situations without the need for difficult and complicated human response studies. Simultaneously with the response - Zwicker studies, A-scale weighted decibel readings (dbA) will be taken to determine their correlation with subjective response as at least one report (2) has indicated a good dbA - response relationship.

6. To determine, through experimentation, a practical and economical combination of available materials and configuration for barring or absorbing the noise radiating from any highway site thereby preventing it from entering the areas adjacent to the highway."

The reader will find that this report not only describes the progress to date but in addition reflects the conceptual and attitudinal changes which have evolved in the researcher's visualization of the highway noise problem. Certainly Michigan's highway noise study team has learned much since first considering an attack on the problem in 1967. As a logical result of extensive and continuing experience with highway noise problems, study of the work of other noise researchers, and work on the subject project, the Michigan team is now much more noise-sophisticated and, thereby, better equipped to reevaluate and reconsider their original study plan.

Later sections of this report will make it evident to the reader that the authors and their fellow scientists and engineers see the problem in a different light than when the original study proposal was prepared and submitted.

At that time an inventory of highway noise information needs was taken to facilitate preparation of a study proposal directing efforts towards high priority areas. Scrutiny of the publically available information disclosed only a meager quantity of completed studies pertinent to the highway noise problem. Having no practical avenues to determine that the inventory results were not valid it was assumed that there was an apparent dearth of information and the study proposal was prepared accordingly.

It has evolved, however, since receiving proposal approval and initiating work on the study, that a veritable flood of highway related noise studies have surfaced. These include studies that were in progress or completed; in university, industry or governmental files; in acoustical consultant files; in periodical files; and in various organizations in foreign countries. Such works literally seemed to appear from every direction once the need for them was established.

This occurrence is important here because many of the reports from those studies contain answers which the Michigan study had set out to determine; thereby eliminating the need for much of the proposed Michigan work. This, then, raised questions as to the proper future course of the Michigan study.

The alternatives available include: 1) continue with the study as proposed despite the probable redundancy of much of the work; 2) recommend cancellation of the project; or 3) proceed with the study after revising the goals and specific objectives.

In logical development the report sections which follow describe the progress to date on the HPR study, the many other non-project Michigan activities related to the highway noise problem, and a rationale for deleting the original project objectives, and cancelling further work on the project.

One of the primary purposes of this report is to provide other states with information concerning noise abatement research programs. As Michigan's researchers got further into the problem of highway-generated noise, it became evident that many aspects--originally viewed as side issues--became of primary importance. Our staff became more involved in the problems of the Planning Division, Environmental Liaison group, and the Design Division, answering requests for evaluative studies at certain sites for both proposed and existing roadways. Since it is inevitable that all the other states will become involved in such issues, it is our feeling that perhaps the publication of the results of our own experience will expose others to the sorts of problem areas that might arise in the near future.

SECTION II

REVIEW OF PROJECT PROGRESS

REVIEW OF PROJECT PROGRESS

Michigan, as most other states, is experiencing a great increase in both public and private concern with environmental noise, and particularly so with respect to highway noise. Development of the tools, techniques and knowledge needed to deal with this new problem and the resulting expanded work load is taxing the facilities and personnel of highway testing and research organizations throughout the nation, and particularly so in Michigan.

This expansion of this work in Michigan coupled with the developmental problems characteristic of new disciplines, and further compounded by the imminent or already accomplished redundance of earlier planned project objectives, has resulted in a failure to achieve some of the project's scheduled goals. Other non-scheduled accomplishments, however, are believed to offset any deficiencies in the original schedule programmed in the project proposal.

In the following review of project accomplishments the reader will recognize that some parts of the original objectives have been achieved and that, in addition, a number of non-scheduled accomplishments have also been achieved.

DEVELOPMENT OF INSTRUMENTATION AND MEASUREMENT TECHNIQUES

Instrumentation for noise analysis is necessarily a function of the equipment and desired output information. An equipment complement for noise measurement can be elaborate or simple depending upon the planned degree of involvement.

If one is only interested in measuring noise levels, a sound level meter, properly calibrated, is sufficient. Meters having A, B, C, and D weighting networks will allow the user to obtain a measure of the frequency content of the sound in addition to the sound pressure level (unweighted C scale). The noise sources must be stationary in order to allow time to record measurements on each of the scales. A cursory determination of "L" levels[1] can also be obtained by manually recording levels at a predetermined sample rate. For example, a reading can be taken every five seconds for a ten-minute interval or until ten events are noted for a given db level. This

(1) That level exceeded a specific percentage of the time, e.g., L_{10} equals that level exceeded 10 percent of the time.

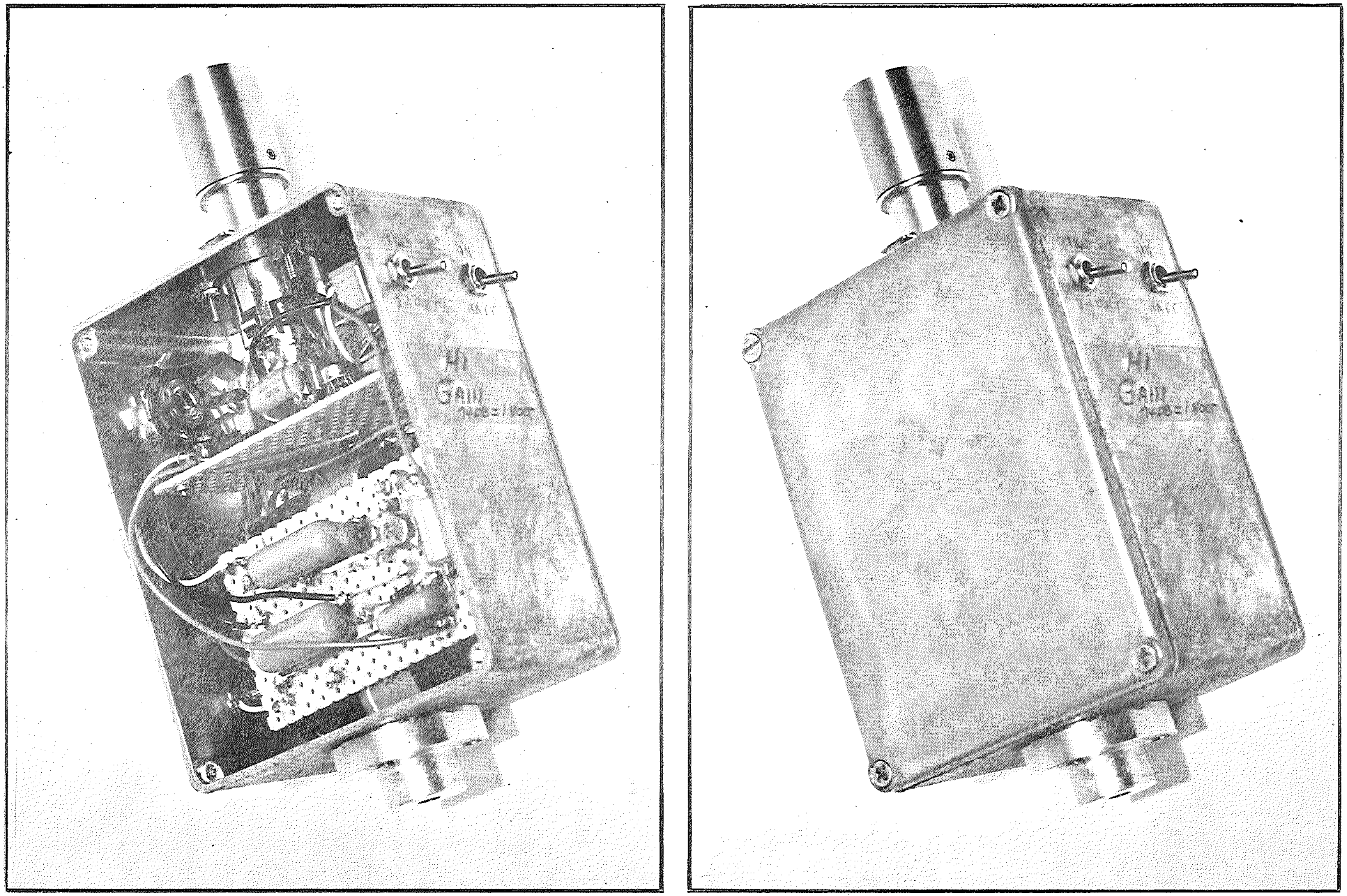


Figure 1. Interior and exterior views of a typical MDSH preamplifier with microphone attached.

procedure can be repeated several times to determine if the noise is non-stationary or to obtain a more valid measure of the nature of the sound.

If noise levels are to be monitored at more than one study site location simultaneously, or if a more complete analysis is desired, it will be necessary to record the data.

Magnetic tape instruments for recording highway noise should have a uniform frequency response characteristic within 2 db between 100 and 12,000 Hz, a V-U meter for each channel, and a revolution counter for ease of data location. A four to seven-channel unit should fulfill most requirements. It is recommended that instruments having more than four data channels use 1/2-in. tape. This will allow for adequate channel separation to eliminate cross-channel noise.

Some acousticians have found that several single-channel units are more satisfactory. These have the advantage of being battery powered and easily transported. They do, however, require some means of syncronizing for subsequent analysis.

Multi-channel recorders for field use are usually powered by d-c to a-c inverters. Careful selection of these inverters is necessary to insure that high level transients, inherent in most square-wave inverters, do not distort the recorded data.

The authors have used two recorders for their noise studies. An Ampex Model SP300 seven-channel, FM or direct recorder for multi-channel applications; and for studies utilizing one or two inputs, an Ampex Model 2100 two-channel, four-track deck using 1/4-in. tape. This latter unit is easily transported and incorporates preamplifiers for ease of recording and tape editing.

Since microphones are usually placed at some distance from the recorder, preamplifiers are required to drive the signals over the 100 to 300-ft cables. The gain of each amplifier must be adjusted to prevent distortion at maximum anticipated signal level.

Preamplifiers were designed and constructed to meet the requirements of each recorder and the dynamic range of the anticipated noise. Signal levels from ceramic microphones located near the source require considerably less amplification than distant positions.

Figure 1 shows an exterior and interior view of a typical Michigan built preamplifier. Figures 2 and 3 give the schematic diagrams for amplifiers

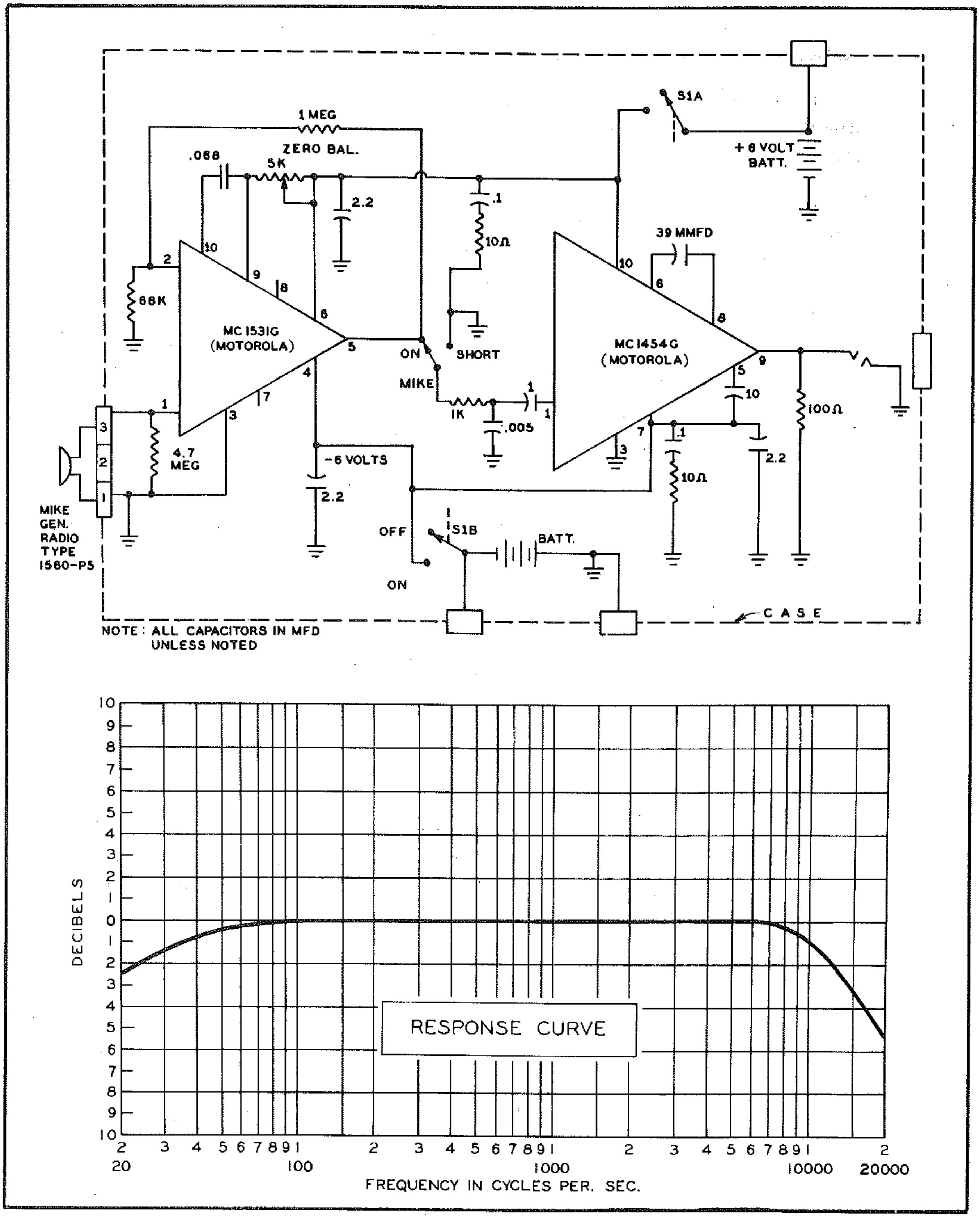


Figure 2. MDSH microphone preamplifier (41 db gain) schematic and response curve.

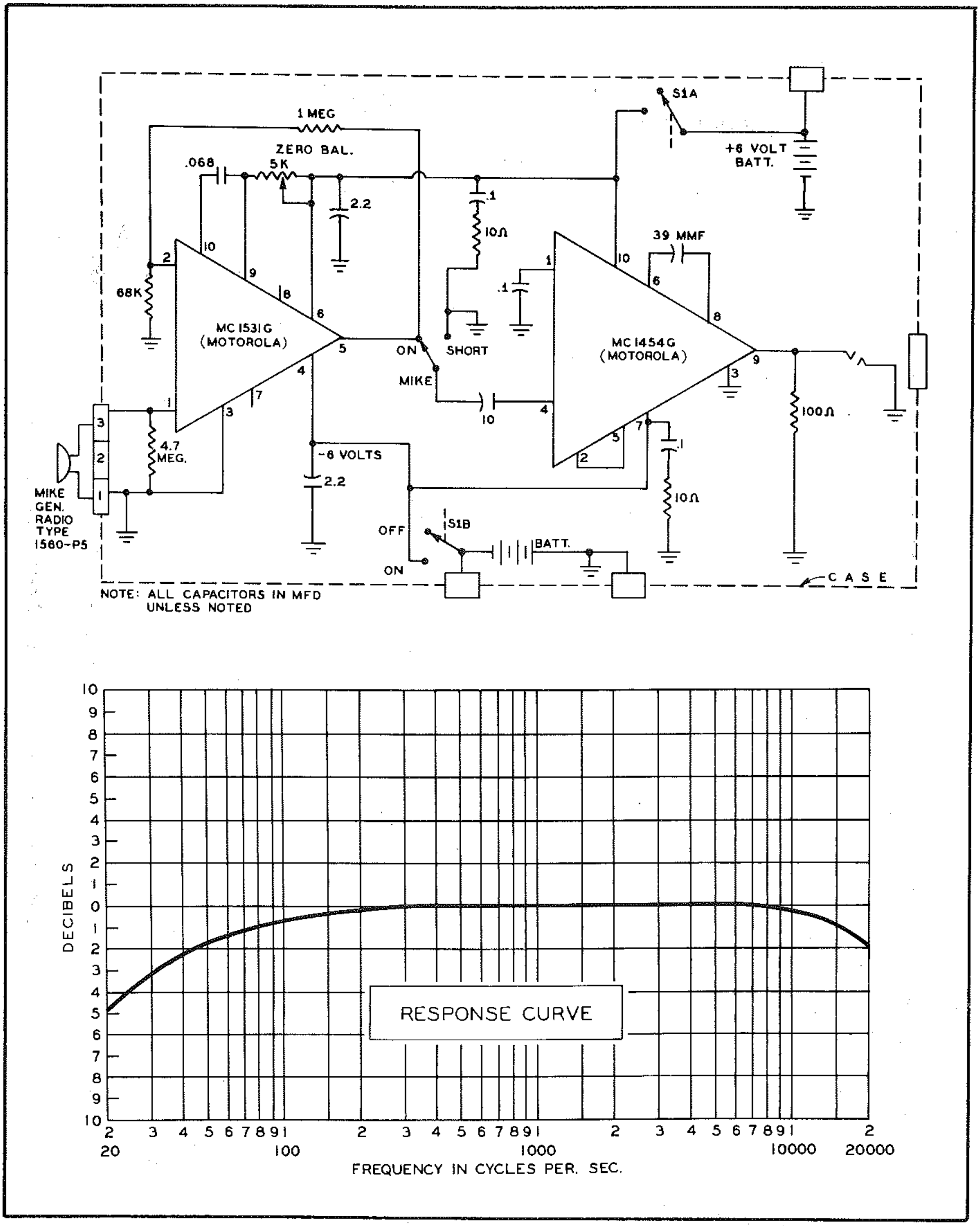


Figure 3. MDSH microphone preamplifier (54 db gain) schematic and response curve.

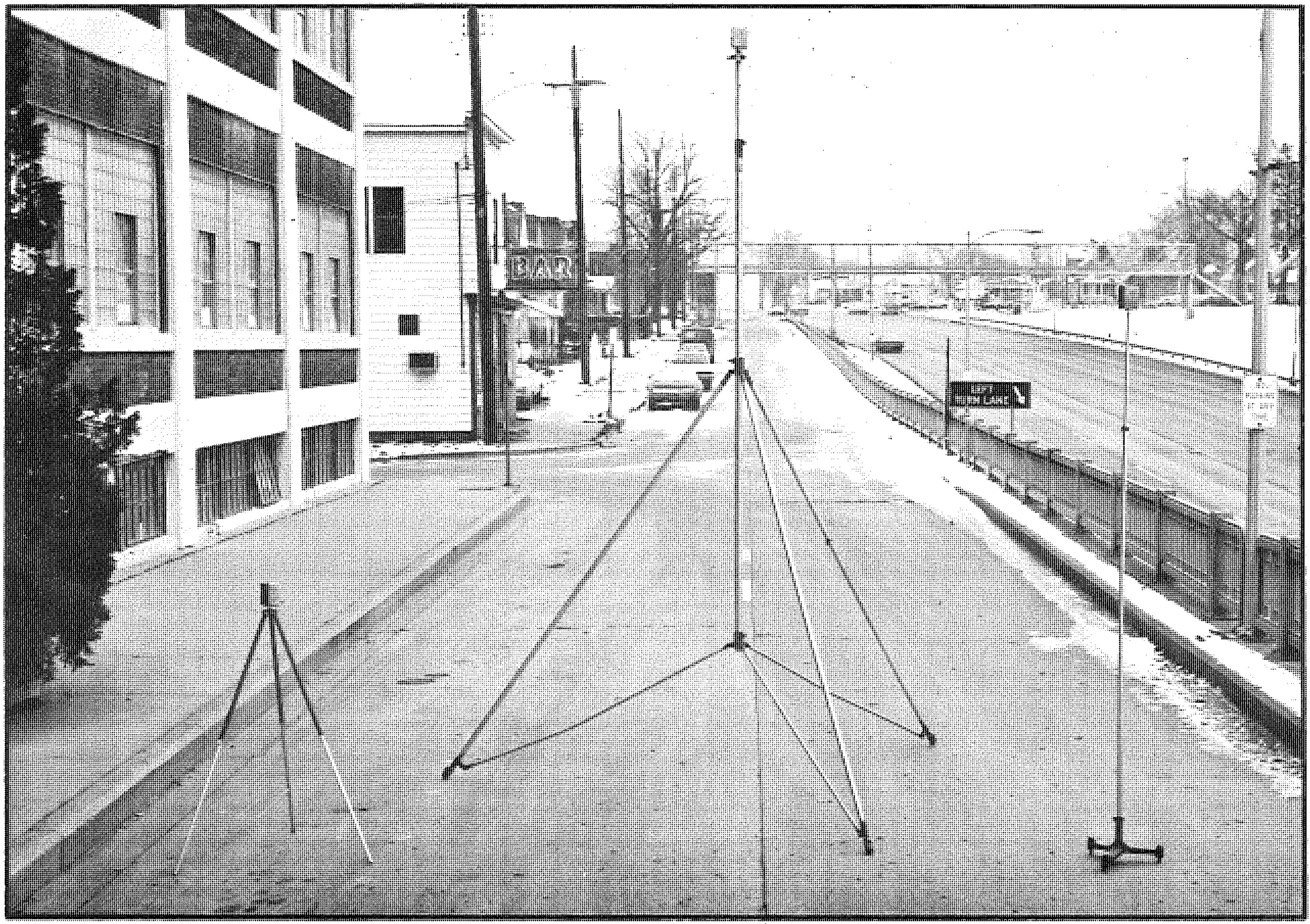


Figure 4. Variable height (to 25 ft) microphone stands.

having gains of 41 and 54 db respectively. These units use eight, 1-1/2 volt, penlight batteries.

The dynamic range of noise near a highway sometimes varies as much as from 50 to 105 db or a range of 55 db. Since most recorders have only a 20 or 30 db range, the researcher must determine what portion of the total sound is of interest. Specifically, 50 to 80 db or 75 to 105 db. The authors have recorded the total dynamic range on some occasions by using two microphones at the same observer distance, each having a different signal gain. Analysis is performed by appropriate real-time computer techniques.

The 1-in. ceramic microphones were mounted on three different types of stands depending upon the desired microphone height and site characteristics. The three types are shown in Figure 4. The two larger stands are capable of supporting the microphones at heights up to 25 ft.

The recording procedure used at each site was necessarily a function of the site geometrics, the length of the recording, and the type of analysis to be performed. During some test series, recordings were made over a 12-hr period. The recorder was controlled by a timer to record for a two-minute interval every 10 minutes, or 20 percent of the time. Control signals for subsequent computer control were recorded simultaneously on other channels. At other sites, four microphones were used. They were placed at distances of 50, 100, 200, and 400 ft from the center of the nearest lane of travel. This technique was used to obtain noise levels for verification of computer simulation models. While recordings were being made, traffic counts were obtained for each lane of travel and vehicle types were classified according to passenger car or truck.

Signal levels from each microphone preamplifier were adjusted to provide maximum gain at the highest experimentally determined noise level present at each location. A sound level calibrator was modified in order that variable calibration levels, at 1,000 Hz, could be recorded for each microphone position. Wind screens were mounted over the microphones after calibration.

A calibration device such as a piston phone should be used to check the operation of sound level meters and recording systems, and to provide a calibrated signal level for recordings. These calibrators are supplied with a fixed output level of 94, 114, or 124 db depending upon manufacturer and model. Some of the devices provide the output level at one frequency only, while others have several selectable frequencies.

The authors have found these calibrators to be somewhat unsatisfactory since most recorders have no provision for fixed attenuation levels and only have a dynamic range of approximately 25 db. If a microphone is placed some distance from the roadway the levels may not exceed 90 db and the calibrator cannot be used. Therefore, it was found necessary to modify the calibrator to provide a range of output levels. The calibration procedure used is as follows:

1) Adjust calibrator to fixed or normal output (114 db at 1,000 Hz).

2) Mount calibrator on sound level meter microphone to check operation of both instruments.

3) Switch calibrator to variable output position and adjust signal output potentiometer until sound level meter indicates desired level.

4) Place pre-adjusted calibrator on observer microphone for recording of known signal level.

Some sound level meters are provided with a low impedance output for direct connection to a recorder without a preamplifier. This option significantly reduces the complexity of instrumentation and calibration. However, one sound level meter is required for each microphone position. It should also be noted that the range of the output signal is independent of the selectable scale setting. A 50 db level on the 50 db scale would produce the same output signal level as a 70 db level at the 70 db scale. Thus, one must note the scale setting for each recording and each time it is changed. The range of this output level is limited to the dial setting + 10 db, to -6 db for a dynamic range of 16 db. On other instruments the range is +10 db to $-\infty$. The latter instrument is more desirable for direct connection to a recorder.

In the laboratory, a more complete analysis of sound recordings can be made. Frequency analysis can be performed using octave or 1/3-octave filters. Noise levels at each observation point can be plotted. These analog traces may then be digitized and L_1 through L_{99} values computed. The sampling rate is usually determined by available reduction equipment and time interval of data. Computers having analog-to-digital conversion capabilities and priority interrupts or sense lines can be used for on-line processing of the L levels. A procedure for performing this operation is given in a later section describing EDP techniques for data reduction.

Another instrument, a so-called "Loudness Analyzer" has been used to obtain a measure of human subjective response to noise, and also a spectral decomposition of impulsive sounds and continuous noise. The instrument incorporates the method developed by Zwicker to weight rms values of noise (band loudness density) according to subjective band width (barks) and intensity (phons). The effects of masking due to adjacent frequencies is also incorporated.

It has been found necessary to generate loud noises for evaluation of noise barriers and related structures. This requirement was attempted by procuring an audio signal generator, two 100-watt audio amplifiers and two 100-watt speakers. Unfortunately, this equipment has been found to produce inadequate noise levels for areas close to highways. The generated levels are barely discernable above the roadway noise levels.

A random noise generator was also purchased for use in field and laboratory work. Random noise generated by the speaker system has been recorded and subsequently analyzed to determine the effectiveness of barriers as a function of frequency. The generator is also used to insure correct instrumentation and system response of laboratory data reduction techniques.

Noise Measurement Using Modified Loudness Analyzer (Zwicker)

It was intended to conduct experiments aimed at validating the reputed correlation between the Zwicker Method (ISO Recommendation 532) and human subjective response (Objective 5). After reviewing the research conducted by Mills and Robinson (2) it was decided that this objective had been sufficiently attained. However, equipment capable of determining a real-time measure of loudness using Zwicker's method had already been purchased. This loudness analyzer (Fig. 5) has many unique features for sound analysis. It provides data which correspond closely to the subjective sensation of loudness, makes a continuous analysis of sound inputs from microphone or tape recorder, displays the resulting Zwicker diagram on a cathode ray tube and a meter indicates the continuous sone loudness values. A new plot is made every 25 milliseconds so that transient sounds can be analyzed.

The instrument consists of 20 filters--2 octave bands, 1-2/3 octave and 17-1/3 octave bandwidth filters encompassing the center frequency bands from 43 to 12,500 Hz.

To expand the capability of the loudness analyzer, it has been modified so that in addition to the above capabilities it also provides real-time spectral decomposition of noise recordings. This modification was achieved in the following manner:

1) The pulse that controls the display time of each filter was diode-coupled to an output connector and used to control the sample rate of an analog-to-digital converter.

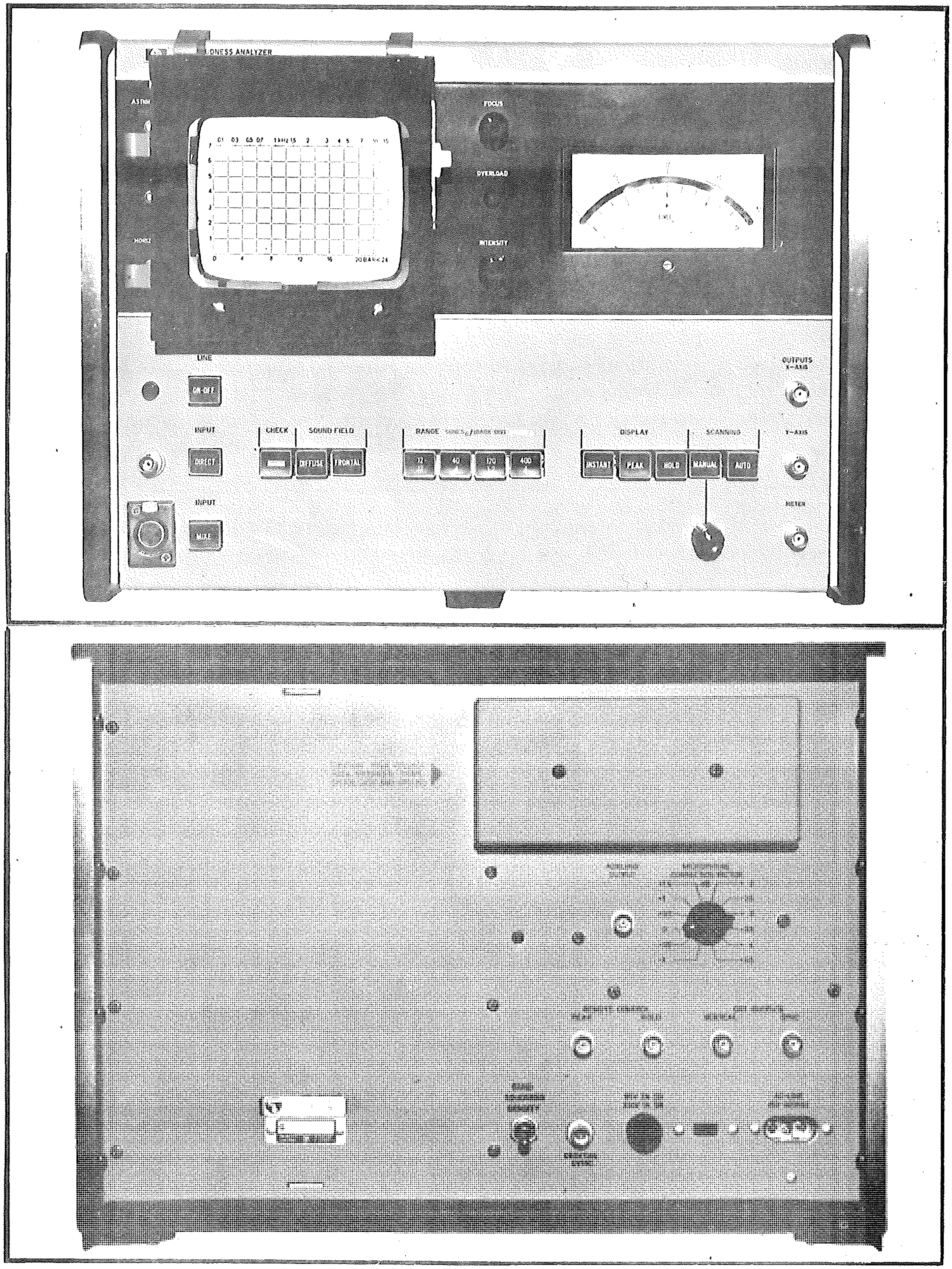


Figure 5. Front and rear panel views of the Hewlett-Packard Model 8051A Loudness Analyzer (Zwicker Method).

2) The masking circuitry of the instrument was disabled to eliminate the masking effect of low level, high frequency energy by high level, low frequency energy. The circuitry can be optionally enabled or disabled by a switch on the instrument's rear panel. The effects of this on the output spectra can be seen in Figure 6.

3) The front bezel of the instrument was modified in order that an oscilloscope camera could be used to record the displayed spectra.

This modified instrument, in conjunction with a small computer and digital tape recorder, allows continuous analysis of noise. The system is shown pictorially and schematically in Figure 7 and 8, respectively.

The recorder output is in-put through an A-weighted filter (optional) to the Loudness Analyzer. Control signals indicating the position of the vehicle are located on another tape channel and are in-put to computer sense lines. Control pulses from the Analyzer inform the computer when to sample the CRT analog input. The appropriate control signals assure that each of the twenty filter output levels are sampled every 25 milliseconds or 800 spectral points per second. This information is stored in computer memory and periodically transferred to digital magnetic tape. Subsequent to this operation, the digital tape is processed on a Burroughs B5500 computer, which functions as follows:

The amplitude of the horizontal portion of each filter output amplifier (band loudness density) is weighted to approximate the response of the human ear (ISO Recommendation 226). This subjective weighting function, however, is removed in the computer program to obtain an objective measure of the spectral content at the noise source. The mean, standard deviation and amplitude histogram, for each frequency and for each event, results from this process.

This technique can be used to characterize impulsive as well as continuous events. The Doppler effects associated with the pass-by of a single vehicle can be studied. This information can also be used for a more precise representation of vehicles in noise prediction models using statistical techniques.

Development of EDP Techniques for Data Reduction

Highway noise recordings in Michigan are usually analyzed in the laboratory. Spectral content and amplitude distributions are determined for each microphone position used during a field study.

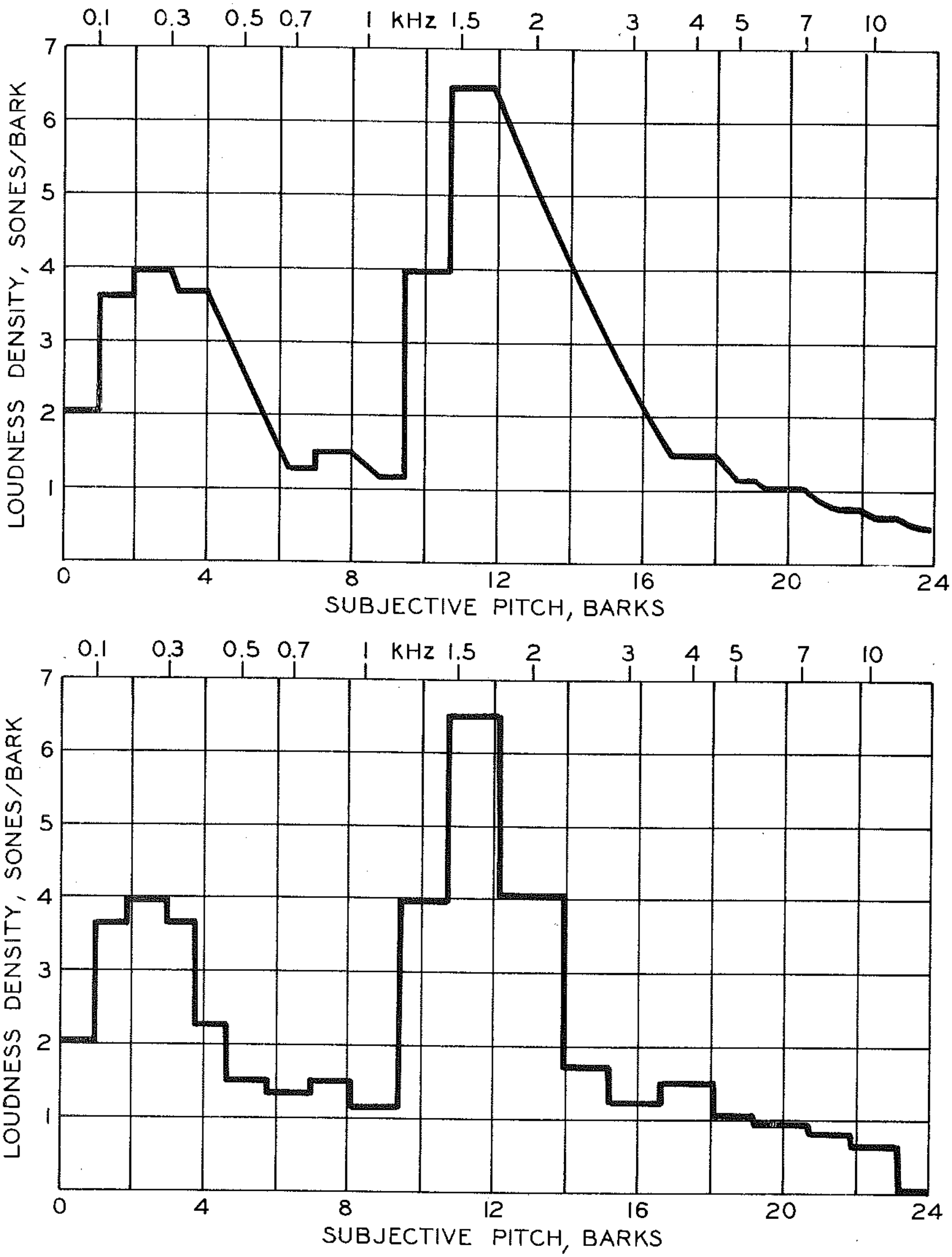


Figure 6. Example of loudness analyzer output spectra with masking (above) and without masking (below).

Figure 7. View of MDSH data reduction facilities. From right to left: 7-channel AM-FM recorder; analog computer; analog-digital interface and controller; XDS-92 computer; ASR-35 teletype; digital tape deck.

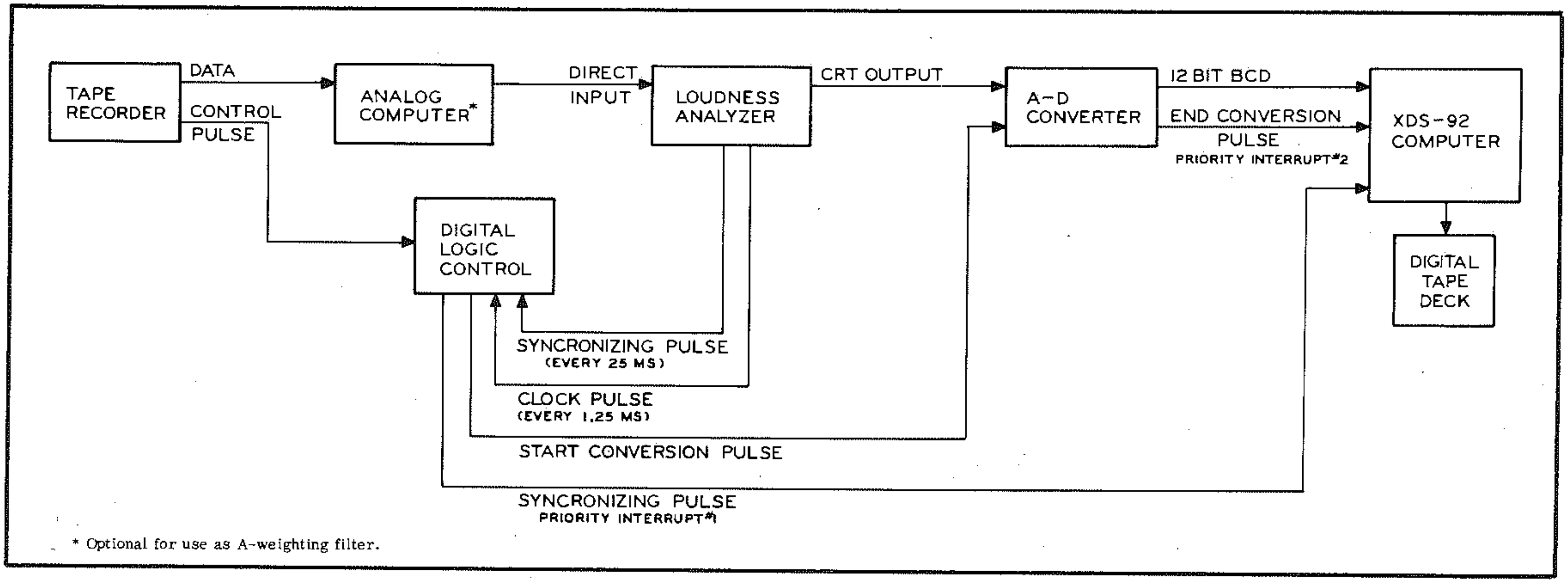


Figure 8. Block diagram of processing method for obtaining the spectral composition of highway noise data.

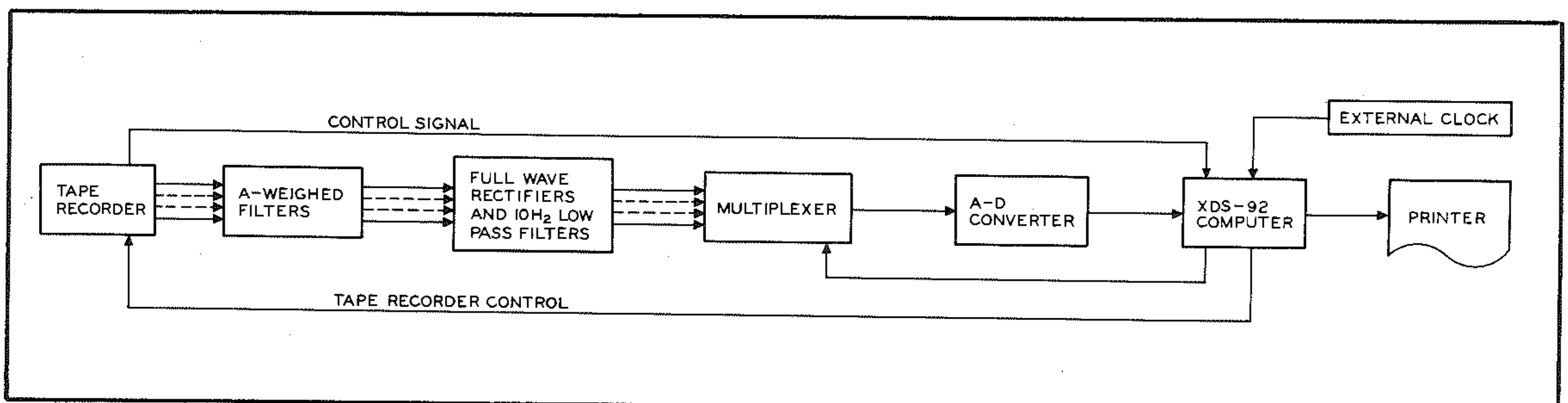


Figure 9. Block diagram of processing method for obtaining A-weighted (dbA) L noise levels.

Spectral content is obtained through the loudness analyzer as described earlier and since recordings are made using a flat response (no weighting) they can be in-put directly to the analyzer.

Reduction of noise data to obtain L levels requires some weighting of the recorded signals. The procedure used to obtain this statistic is shown in Figure 9.

The recorded noise signal is first filtered by three cascaded first-order filters to obtain an approximated A weighting. These filters consist of two high-pass, and one low-pass, having break points at 114 Hz, 700 Hz, and 6.8 KHz. The frequency response of this transfer function was implemented on a TR10 analog computer and the resulting frequency response characteristic was well within the tolerances of ANSI S1.4-1961. The output of each of these active filters, one for each channel of data, is rectified in a full-wave bridge and smoothed with a 10 Hz low-pass filter.

The circuit diagram and response function are given in Figure 10.

The design transfer function is:

$$T(S) = \left(\frac{T_1 S}{1 + T_1 S}\right) \times \left(\frac{T_2 S}{1 + T_2 S}\right) \times \left(\frac{K}{1 + T_3 S}\right)$$

The potentiometer settings were determined as follows:

$A = 1/T_1 = 2\pi(114) \approx \cdot 716(10^3)$
$B = 1/T_2 = 2\pi(700) \approx \cdot 440(10^4)$
$C = 1/T_3 = 2\pi(6800) \approx \cdot 396(10^5)$
$D = K/T_3 \approx \cdot 613(10^5)$

An assembly language program was written for the XDS-92 computer to obtain these L levels. This program controls the operation of the tape recorder, multiplexer, and analog-to-digital (A-D) converter. The sampling time is controlled by an external clocking pulse, at a rate of three times per second for each channel. Control signals located on another tape channel determine the data to be processed. These signals can be recorded in the field, but usually are added subsequently in the laboratory.

The program is designed to count the number of times the input voltage (calibrated in decibels) attains any given level. These voltages and corresponding event counts are printed for each channel at the termination of a sample period. These data are then processed on the B5500 computer.

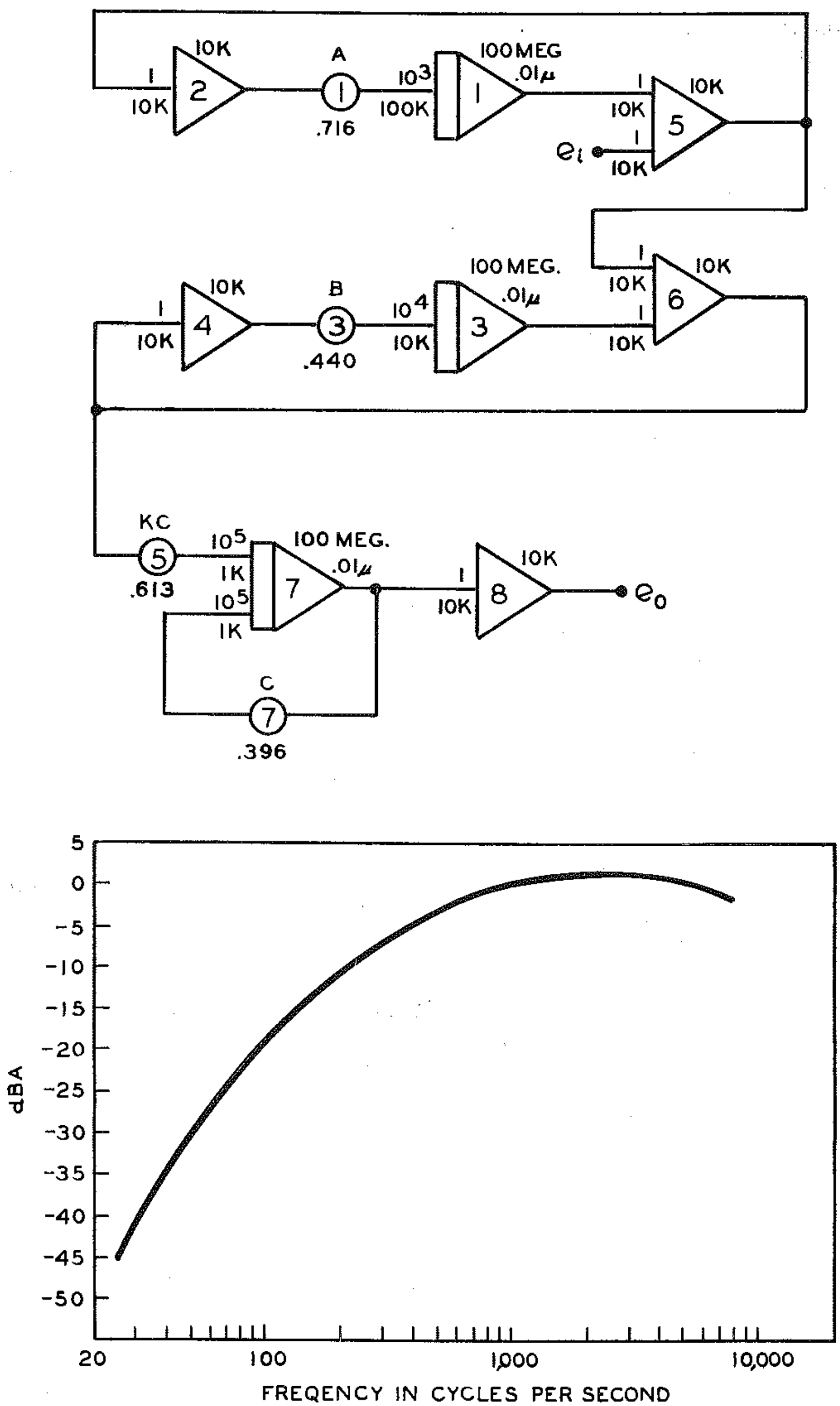


Figure 10. Circuit diagram and frequency response curve of A-weighted filter implemented on a PACE, Inc. TR-10 analog computer.

This procedure has been improved to obtain the L levels directly. A PDP 8/e mini-computer with floating point software is now being used to implement this procedure.,

COMPUTER IMPLEMENTATION OF THE NOISE PREDICTION METHOD OF NCHRP REPORT NO. 117

The Michigan Department of State Highways has updated its computer program of the so-called "Complete Method" of Bolt Beranek and Newman's NCHRP Report No. 117, (5) titled: "Highway Noise - A Design Guide for Highway Engineers."

The program was written with a view towards ease of use on a time-share computer terminal. It allows the user to rapidly determine L_{50} and L_{10} noise levels at any specified distances from the highway for any combinations of the design options available--pavement elevation variables, barrier variables, surface types, grades, etc.

The changes to the original program are the results of: 1) Bolt Beranek and Newman's Report 2209 (Final Draft; March, 1972) titled: "Highway Noise - A Field Evaluation of Traffic Noise Reduction Measures," and 2) refinements by the authors and comments from the various users in the State Highway Departments and consulting firms across the United States.

The program (complete listing in Appendix B) represents the entire "Complete Method" with one exception - it will handle 1 to 8 lanes per lane group. Other choices of "Number of lanes" can be achieved by program modification, if desired.

Potential users are strongly urged to carefully study Reports No. 117 and 2209 prior to using the program and, more importantly, before making judgements from the resulting decibel values.

After printing out the predicted L_{50} and L_{10} values for a given configuration the computer will offer the user four options:

1. Continue at the same site for different observer distances, different barrier heights or locations, or different barrier included angles

2. Iterate on observer distance to achieve a selected L_{10} dbA level (only for single roadway element and one or two lane group geometries, at present)

3. Set up for a new site location

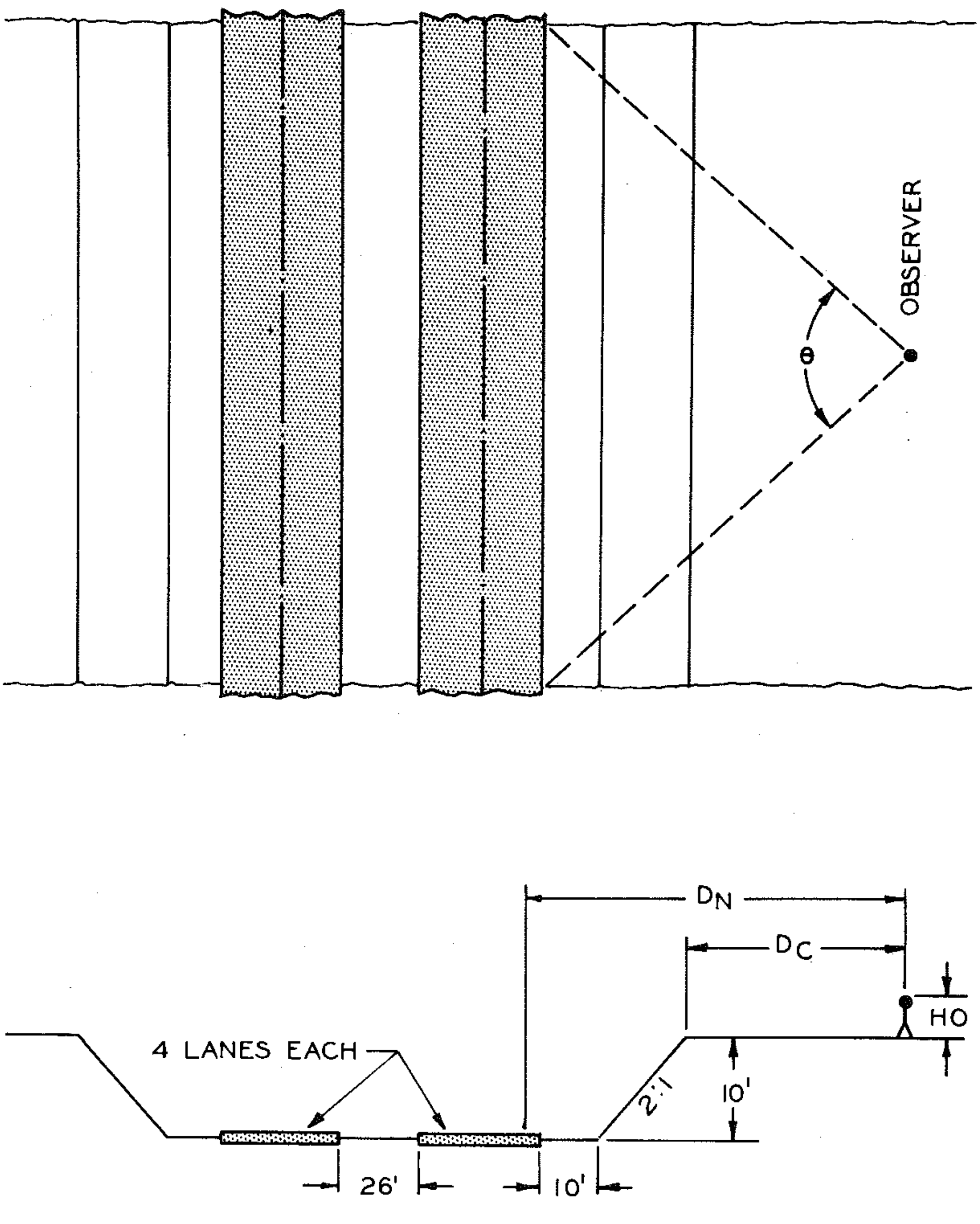


Figure 11. Roadway geometry for example problem.

4. Terminate the program.

Option 2 (Iterate Mode) is an addition to the original program. After an L_{50} and L_{10} have been calculated for a given configuration, "Iterate" can be specified whereby the operator will be asked to input the desired L_{10} dbA level in which he is interested (such as 70 dbA for land use Category B for residences in PPM 90-2) and the program will determine the distance DN for that dbA level. Additional dbA levels for that site geometry can be found by re-specifying "Iterate" and the desired L_{10} level.

Presently the "Iterate Mode" can be used only for single roadway element (NRE = 1) and one or two lane group (N = 1 or 2) geometries. Further expansion of this capability will be completed as time permits.

Example of Program Use

The physical configuration of the roadway selected for this example is such that it is best approximated by a single finite length element with two lane groups each (Fig. 11).

Each lane group consists of four lanes, separated by a 26-ft median, depressed 10 ft with less than 2 percent grade and a rough surface.

Traffic data consist of a two-way, evenly divided ADT of 100,000 veh/day, 8.33 percent ADT, 10 percent truck mix, 55 mph truck and 65 mph car speeds freely flowing.

There is a 100-ft observer distance, 5-ft observer height, 64-ft cut distance and roadway element angle of 50 degrees.

The objective is to find the L_{10} noise level at the observer point for the given geometry and traffic data. If this L_{10} exceeds 70 dbA, then determine the observer distances for the 70 dbA and 60 dbA limits.

This problem would be set up as shown on the data sheet (Fig. 12) and solved as shown on the facsimile of the computer printout (Fig. 13).

The answer was found to be:

L_{10} (dbA)	Observer distance, ft
78.2	100.0
70.0	178.1
60.0	403.1

DATA SHEET

Parameter Description	Symbol	Roadway Element #1		Roadway Element #2		Roadway Element #3	
		Lane Group #1	Lane Group #2	Lane Group #1	Lane Group #2	Lane Group #1	Lane Group #2
Number of roadway elements	NRE	1					
Number of lane groups per roadway element	N	2					
Avg. annual daily traffic per lane group (veh/day)	ADT	50000					
Percent ADT during time interval	PCADT	8.33					
Percent truck mix	TMIX	10					
Truck speed (mph)	ST	55					
Auto speed (mph)	SA	65					
Roadway elevation type (1 = depressed, 0 = at grade, -1 = elevated)	HD	1					
Observer to center of near lane (feet)	DN	100					
Roadway length type (1 = ∞ , 2 = semi-∞ , 3 = finite)	RL	3					
Barrier length (0 = no barrier, 1 = ∞ , 2 = finite)	BL	0					
Traffic flow (0 = interrupted, 1 = free flow)	FLO	1					
Number of lanes per lane group	P	4					
Grade correction (0,2,3,5 for ≤ 2,3-4,5-6, ≥ 7% resp.)	DEL3	0					
Roadway surface correction (-5, 0, +5 for smooth, normal, rough)	DEL5	+5					
Structure shield correction (-4.5/1st row houses, -1.5/others, -10 max.)	DEL7	0					
Median width for divided highways (feet)	MED	26					
Observer height rel. to ref. plane (feet); +above, - below	HO	5					
Roadway element angle (degrees); only for RL ≠ 1	THETA	50					
Elevated height (feet) } only for HD = -1	H1						
Observer to shoulder (feet) } only for HD = -1	DS						
Depressed height (feet) } only for HD = 1	H2	10					
Observer to cut (feet) } only for HD = 1	DC	64					
Barrier height (feet) } only for BL ≠ 0	H						
Observer to barrier } only for BL ≠ 0	DB						
Barrier included angle (degrees); only for BL = 2	ALPHA						
Barrier end-normal angle (degrees); only for RL = 2 and BL = 2	BETA						

Figure 12. Data sheet for example problem

```
*****  *****  *****  *****  *****  *****  *****
* CAUTIØN, METHØD NØT VALIDATED. READ REPØRT  *
* NCHRP 117. PRØGRAM VERSIØN NØ. 2, 8/1/72.   *
*****  *****  *****  *****  *****  *****  *****

INSERT NRE= # ØF RØADWAY ELEMENTS
?1←
INSERT N= # ØF LANE GRØUPS FØR RØAD ELEMENT # 1
?2←

INSERT ADT,PCADT,TMIX,ST,SA,HD,DN,RL,BL,FLØ,P,
DEL3,DEL5,DEL7 FØR LANE GRØUP  1
?50000,3.33,10,55,65,1,100,3,0,1,4,0,5,0←
INSERT MED
?26←
INSERT THETA
?50←
INSERT HØ
?5←
INSERT H2,DC
?10,64←

*******************
L50= 72.6  L10= 78.2  DN1=  100.0
*******************

INSERT 2,1,0,-1 FØR CØNTINUE,ITERATE,NEW,STØP
?1←
INSERT DESIRED L10
?70←

*******************
L50= 65.3  L10= 70.1  DN1=  178.1
*******************

INSERT 2,1,0,-1 FØR CØNTINUE,ITERATE,NEW,STØP
?1←
INSERT DESIRED L10
?60←

*******************
L50= 56.5  L10= 59.9  DN1=  403.1
*******************

INSERT 2,1,0,-1 FØR CØNTINUE,ITERATE,NEW,STØP
?-1←
```

Figure 13. Facisimile of computer printout for example problem.

COMPUTERIZED STATISTICAL METHOD OF NOISE SIMULATION

Bolt Beranek and Newman In NCHRP Report 78 (3) have developed a computer simulation model that allows the engineer, designer, or researcher to predict--under fixed conditions of vehicle speeds, truck mix, vehicular volume, and distance from the highway--the vehicle noise levels for any existing or planned highway situation with freely flowing traffic. This program utilizes random number generators, probability functions, and statistical techniques to determine the dbA level and frequency distributions of noise levels radiating from the roadway. The three-dimensional center line roadway coordinates and vehicle spectral information can be specified.

After modifying and de-bugging this simulation model on the B5500, the next degree of sophistication was accomplished by adding the attenuation calculations due to an earth mound or wall-type barrier.

Appendix C of NCHRP Report No. 78 provides a detailed description of the simulation program except for the subroutines which compose the barrier calculations. The interface flow chart of Figure 14 shows the interconnection of subroutines required in the barrier attenuation equations.

Only the two most dominant effects, namely diffraction and ground reflection are considered in the barrier attenuation calculations. This is based on Maekawa's method (4).

All required input data describing the barrier position and its characteristics appear on one computer card under the (I1, 6A1, 2X, 10F7.1) format, as used for all other input data. The following is the required barrier data card setup:

14	BARLOC	b̸b̸	HB	HR	HD	B1	BL	H2	H3

where: HB - Barrier heights, ft

HR - Receiver height, ft

HD - Road level to receiver level elevation, ft

B1 - Barrier to receiver distance, ft

BL - Barrier length (1. = ∞ , 2. = semi ∞ , 3. = finite)

H2 - Barrier length to left of receiver, ft

H3 - Barrier length to right of receiver, ft

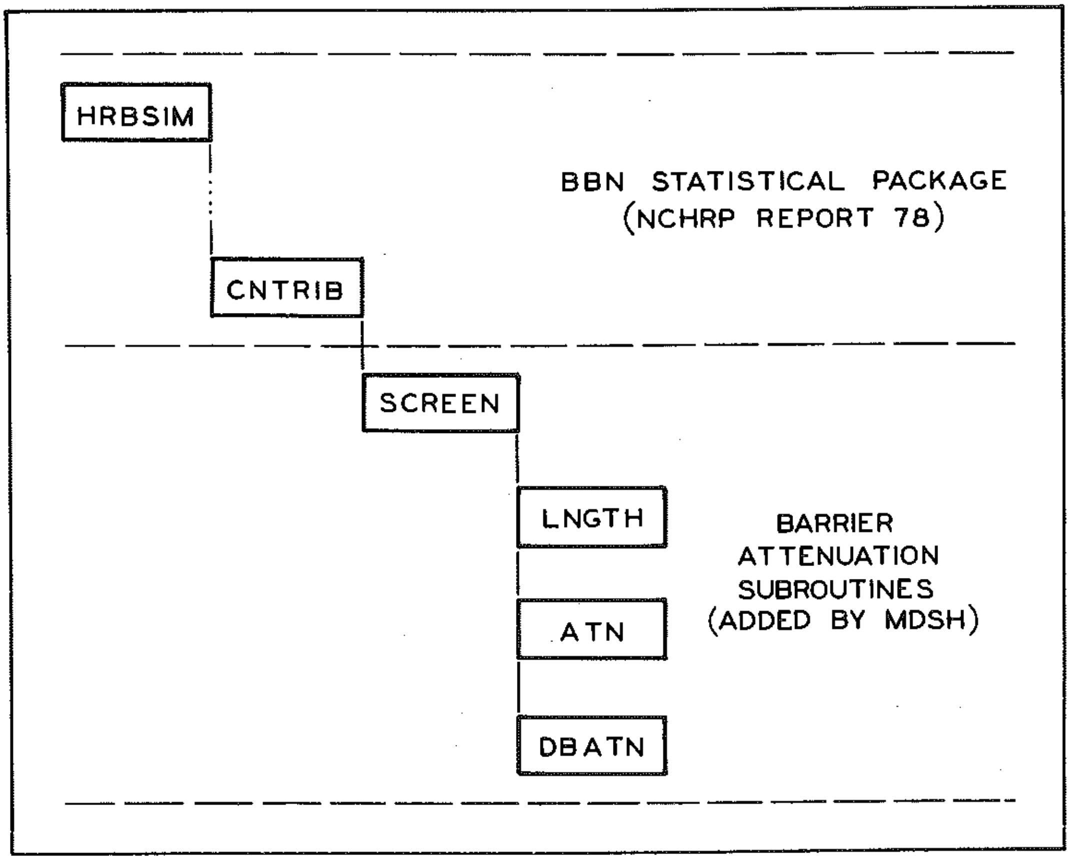


Figure 14. Interface flow chart showing interconnection of subroutines for barrier attenuation calculations.

A simulation run provides as results, a set of 8 octave band noise spectra (for two cases, with and without a barrier) corresponding to momentary samples (snapshots), in time, of noise from the total contributing traffic. Summary measures (dbA and dbC) are also provided for each snapshot noise spectrum, including minimum, maximum, mean, and standard deviation.

An input data card format, typical output listing and complete FORTRAN IV program listing (for Burroughs B5500 computer) are given in Appendix C.

HIGHWAY NOISE BARRIERS

It is the intent of the authors to provide the reader with a brief summary of the characteristics and effectiveness of barriers used to reduce the penetration of highway noise into adjacent land areas. The material presented is based on research performed by many acousticians. It is hoped that the highway engineer will find this information beneficial in considering and selecting proposed barrier types.

Sound in a homogeneous space propagates outward from the source uniformly. The sound pressure produced by a point source decreases by 6 db for every doubling of the distance. Noise radiating from a highway, however, approximates a line source and decreases at only 3 db per doubling of distance. This noise is a non-homogeneous time-varying function. The bandwidth of interest is considered to be from 60 Hz to 8,000 Hz, but with principal concern for the lower frequencies.

If one ignores the effects of temperature gradient, wind turbulence, reflections and refractions, then it can be said that sound travels in a straight line emanating from the source. In our everday world, however, this condition never exists, and the transmission of sound is affected by the cited factors.

In Figure 15 the relationship between A-weighted L_{10} sound pressure levels and observer distance are given for three discrete traffic densities. The values given were obtained from methods developed by BBN in NCHRP Report No. 117 (5). Effects of wind, temperature gradient, reflection and refraction on the observer have not been included.

The wind has several effects upon sound transmission. Some researchers have found that the mean level of the sound is little affected; but that the deviation of the levels about the mean will increase by 10 to 20 dbA. It is also known that the wind tends to bend the sound waves down in the downwind direction and up in the upwind direction.

Temperature also affects sound transmission. Temperature gradients where the air is cool near the ground tend to bend sound waves downward while temperature inversions cause an upward bending of the sound waves. The bending of low frequency sound waves (diffraction) is more pronounced, thus low frequency sound is essentially non-directional in nature.

The significance of these factors also change as a function of observer distance. High frequency noise energy is absorbed by air molecules leaving only frequencies below 500 Hz at distances beyond 1,000 ft (6). Temperature gradients, relative humidity, and wind become more significant as the observer distance is increased. Reflective and refractive properties of highway noise are significant at locations near to the roadway where levels are higher and where the noise contains directional high frequency energy.

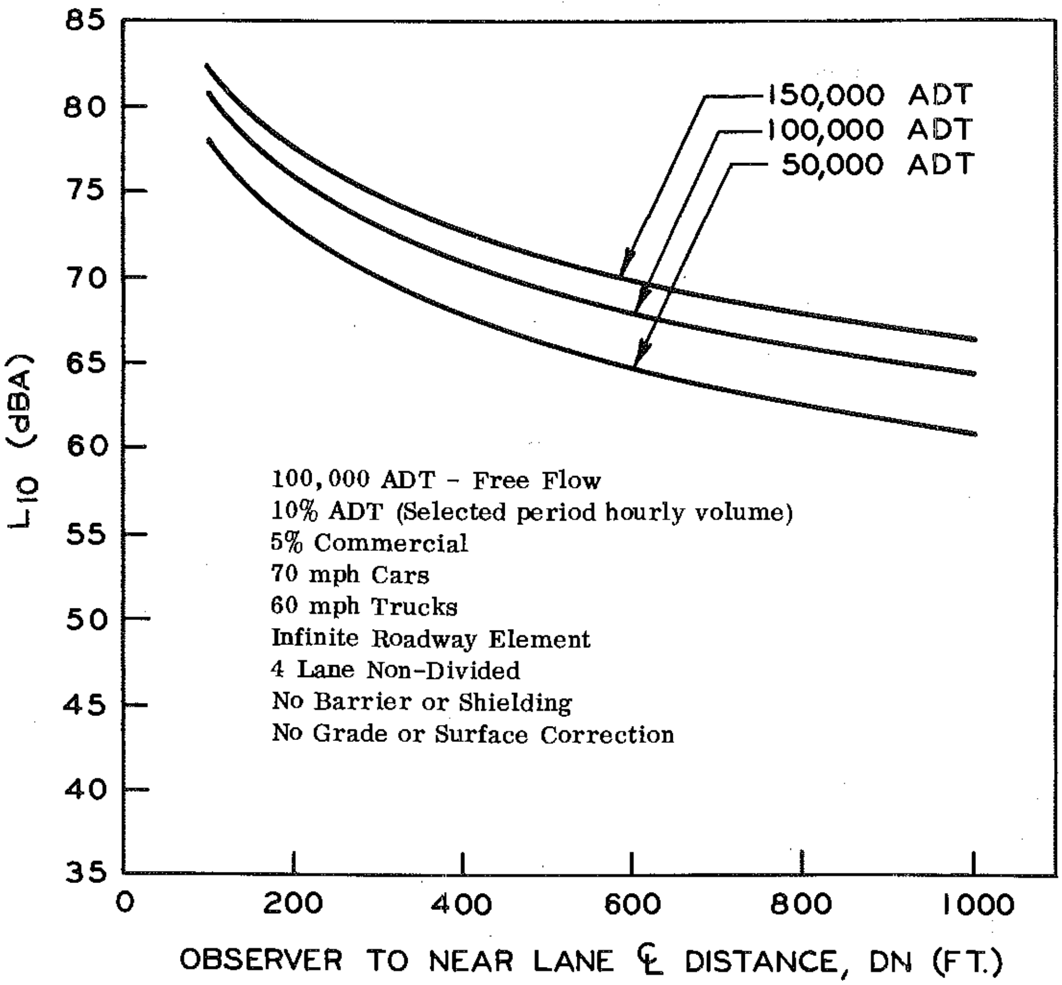


Figure 15. L_{10} noise levels versus distance for three traffic volumes.

At the present time there are a limited number of methods available to the highway engineer for the reduction of noise radiating from the highway.

1) Reduce the noise generated by individual vehicles. This goal can be achieved through legislative action and enforcement. The establishment of practical effective limits of noise emission for vehicles using the roadway will provide the best solution.

2) Depress or elevate the roadway. This alternative places a shadow zone between the source and the receiver. Thus, those who are in this zone receive less sound energy. Figure 16 shows the effects of depressing or elevating the roadway.

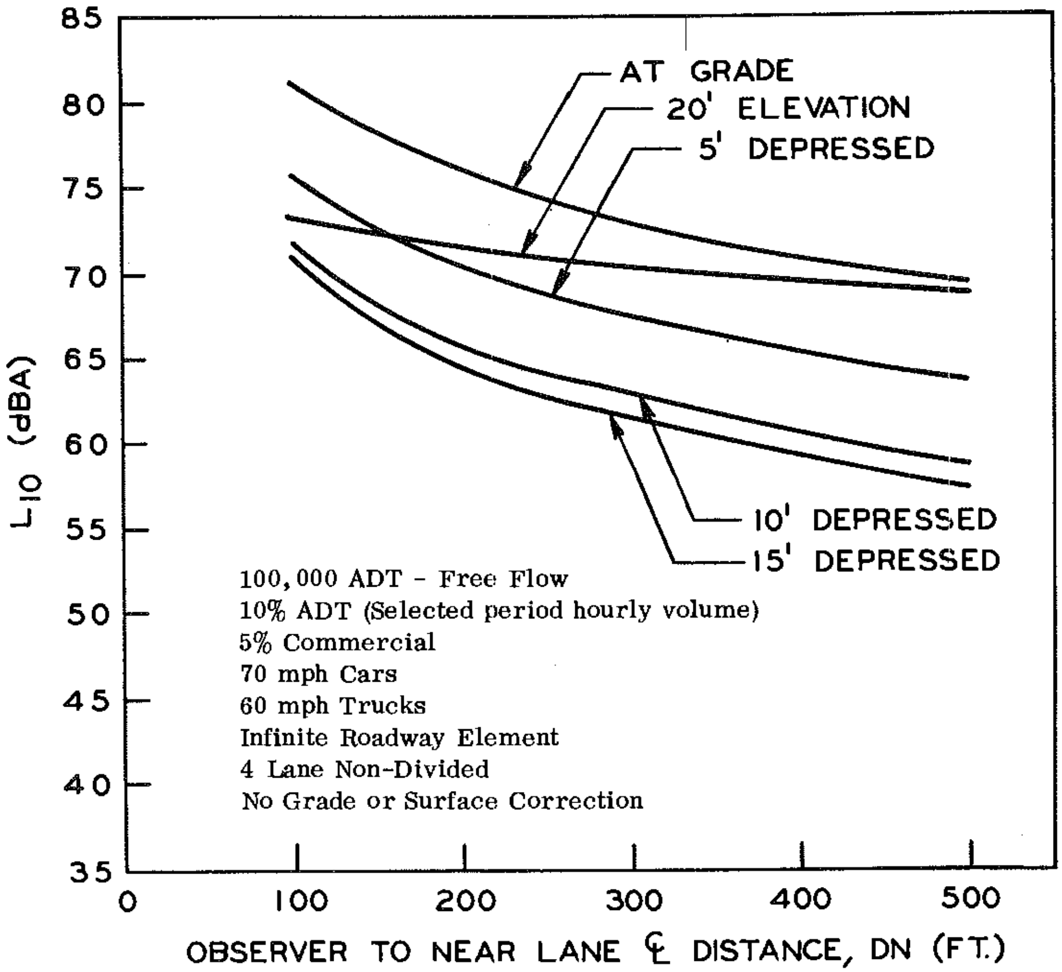


Figure 16. L_{10} noise levels versus distance for elevated or depressed roadways.

3) Place a barrier between the source and observer. This method will reflect a portion of the sound back at the source. At the same time, some of the energy will be absorbed by the barrier. The amount reflected or absorbed is dependent on the barrier length and heights, its location relative to the noise source, the material and configuration of construction and the porosity or texture of the wall surface. Some of the radiated noise will be transmitted over and around the wall, reducing its effectiveness.

4) Pavement surface textures. Noise levels emitted from a highway may be reduced by use of smooth wear surfaces. Highway noise levels for such surfaces will be 5 to 10 dbA lower than for rough textured surfaces.

5) Other attenuations. Further noise reduction may be achieved by eliminating intersections, ramps, and grade changes.

Use of Walls for Noise Barriers

There are many conditions that may preclude the depression of a roadway. Subsurface geologic, hydrologic, or soil conditions may be unfavorable, or urban area utilities may present serious problems. Often, however, the critical determining factor will be the extremely high costs associated with depressing and to a certain degree with elevating. In weighing the alternatives it will most frequently be concluded that the only feasible solution is to construct a barrier between the highway and the noise sensitive area. Also, cost and right-of-way limitations must be considered in barrier design because maximum effectiveness of barrier walls is achieved when the wall is close to either the source or observer.

Materials suitable for fabricating into noise barrier walls, and capable of withstanding the highway environment are very limited. One requirement for an effective barrier material is that the sound transmission loss at all frequencies in the vehicle noise spectrum be sufficiently high that sound transmitted through the barrier can be neglected in comparison to that diffracted over and around the barrier edges. For this reason, there should be no air paths through or under the barrier and the weight per square foot of surface should be at least $10 Kg/m^2$ (2.0 lbs/sq ft) depending upon its heights and length. Figure 17 gives the attenuation theoretically realizable as a function of wall density, in those cases where no sound paths over or around the wall exist.

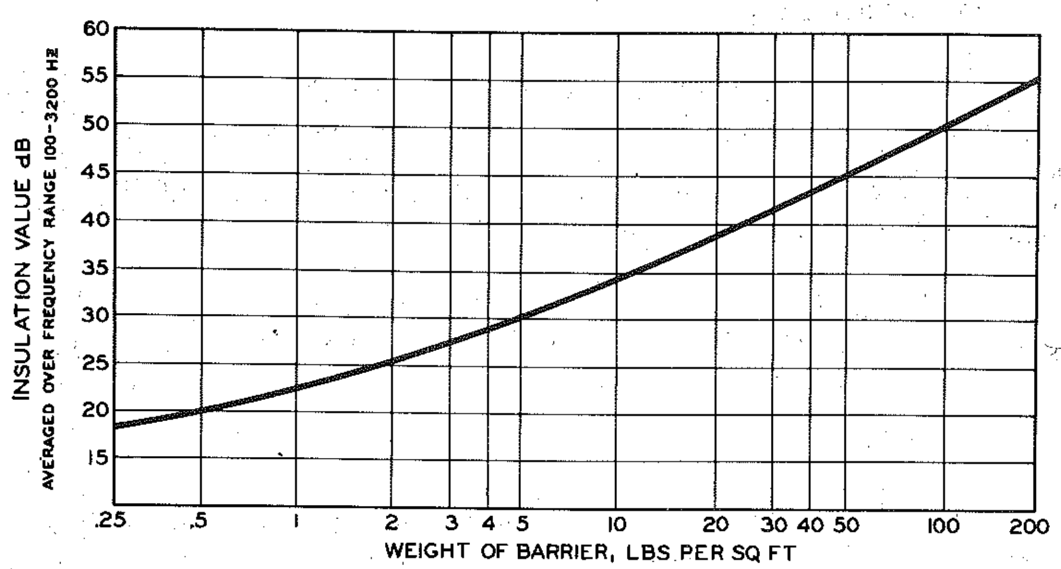


Figure 17. Insulation value versus barrier weight per sq ft ("Mass Law" of Sound Insulation).

Barrier materials must withstand the summer heat, winter salts, wind forces, and ultraviolet radiation which tends to deteriorate organic materials. Provisions should be made for snow removal and drainage. Barrier walls constructed in West Germany were provided with emergency escape doors for vehicle occupants in distress.

Barrier efficiency is also effected by wind conditions. Wind velocities above 4 to 7 mph, blowing towards the observer, will reduce barrier effectiveness by 2 to 3 dbA. Winds traveling towards the source can increase the barrier effectiveness by an even greater margin. Winds, however, are turbulent by nature and thus, the mean level of barrier attenuation is rarely affected over one or two hour time periods. However, the deviation of the sound pressure level at distances beyond 100 ft is increased by 4 to 20 dbA.

Barrier design should consider the safety of the driver. Sharp, dark, shadows resulting from walls may obscure vision. Sun glare off the barrier surface or edges must be considered. Long walls located close to the roadway may produce a hypnotic effect. A retaining or guard rail should be placed in front of the wall to protect both the wall and nearby pedestrians from impinging vehicles.

In densely populated areas, the reflective characteristics of the wall may merely redirect the noise to adjacent areas and also back at the drivers. Using a material with a surface which absorbs sound will reduce these effects. A surface having a 100 percent absorption factor can theoretically increase the barrier effectiveness by 3 db.

The physical parameters of barrier height and length and their psychological effect upon residents should also be considered. A barrier which is not esthetically pleasing may be equally as annoying as the noise.

Earth Walls

One of the most attractive possibilities for barriers is the earthen wall because of its low construction cost. Such earth mounds can be made pleasing in appearance by covering with grass and shrubs, and the root systems of these plantings will retard erosion. The main disadvantage is the right-of-way required. Wall slopes of 1 on 3 to 1 on 1-1/2 are feasible, depending on soils available and other factors. This could mean that a 10 ft high barrier would need a minimum width of 60 ft. Additional barrier height could be obtained by constructing a wall on top of the earth mound.

The Maryland State Road Commission (7) reported a noise abatement project in which an earth mound was constructed. Results were stated to be so successful that the high frequency noise from highway traffic was reduced to the point that it was masked by normal conversation.

In Figure 18 the effectiveness of an earth wall is given as a function of height. The length of the wall as with all noise barriers should be such that the distance between the noise sensitive area and the end of wall is three to five times the perpendicular distance to the barrier.

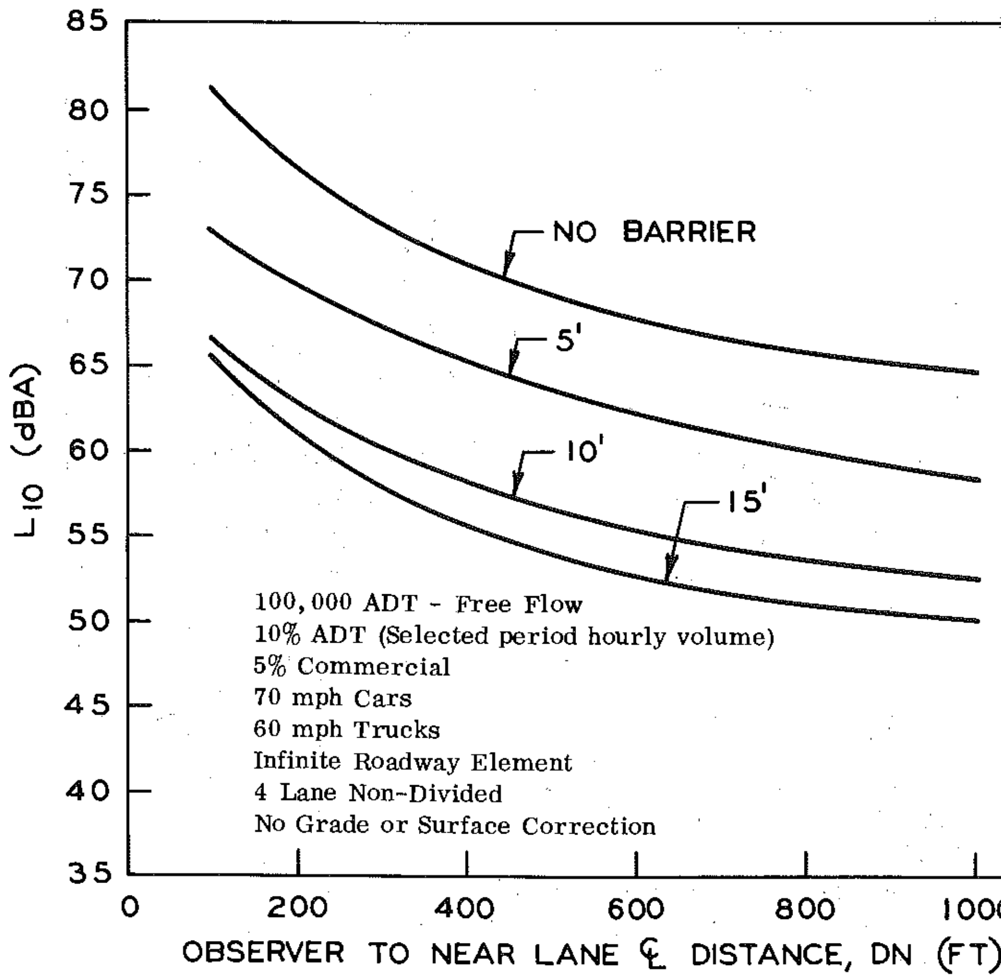


Figure 18. L_{10} noise levels versus distance for various height earth mound barriers.

Concrete Block Walls

Concrete walls have the advantage of requiring little land space and minimal maintenance. Among their disadvantages are appearance, construction costs, and creation of sharp shadows as with other wall type barriers. The wall, depending on its placement, may need to be protected by a retaining or guard rail. Noise attenuation for a concrete wall closely approximates that of a earth mound. The ordinary concrete block wall, however, has low noise absorption, and therefore occasions may arise where the reflected energy will cause disturbance in regions other than that protected by the barrier. A commercial product called "Soundblox" (8) has a patented cavity-slot construction which will absorb part of the striking sound energy. This product should be evaluated for its performance and durability in the highway environment. Figure 19 illustrates both standard and "Soundblox" construction and the average transmission loss characteristic of each. Other "Soundblox" cavity-slot configurations are available.

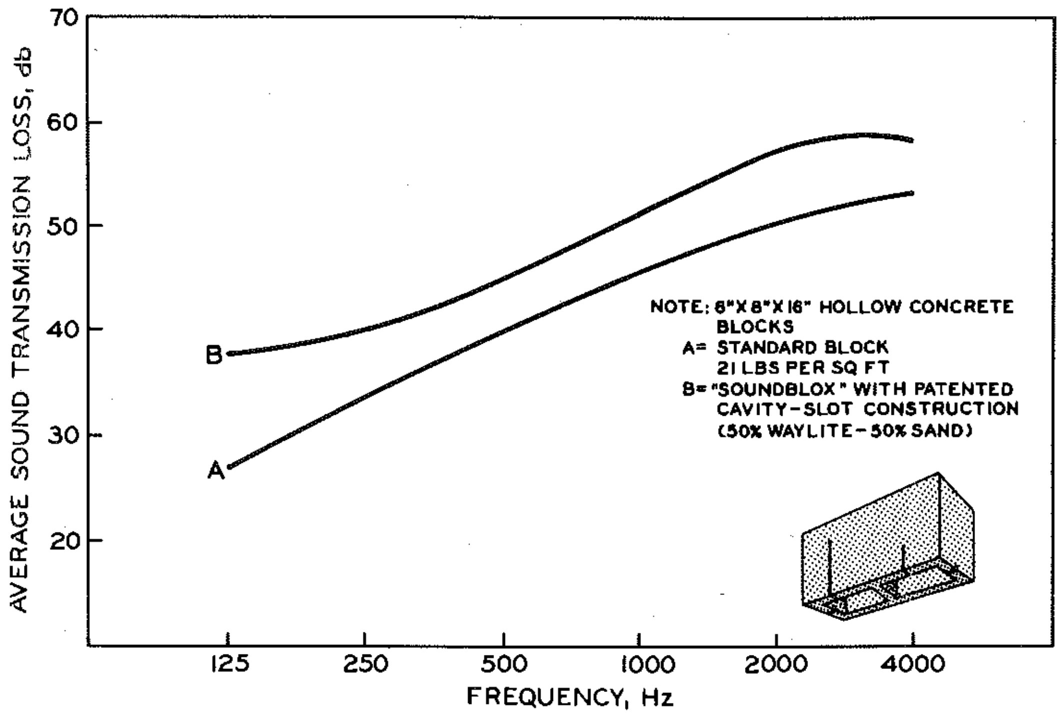
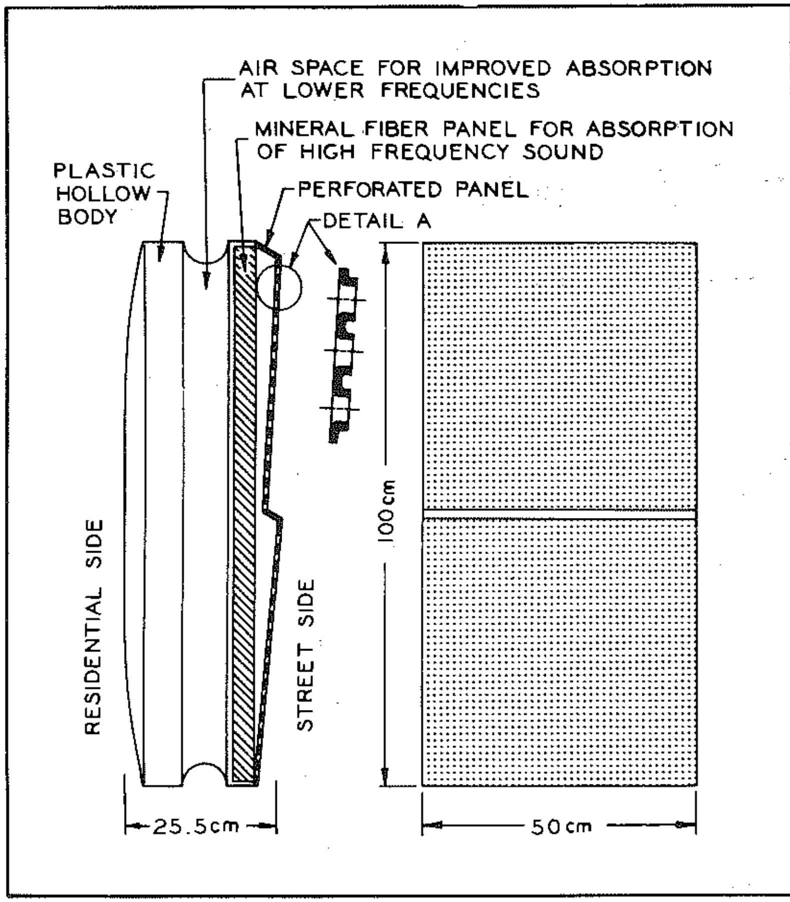


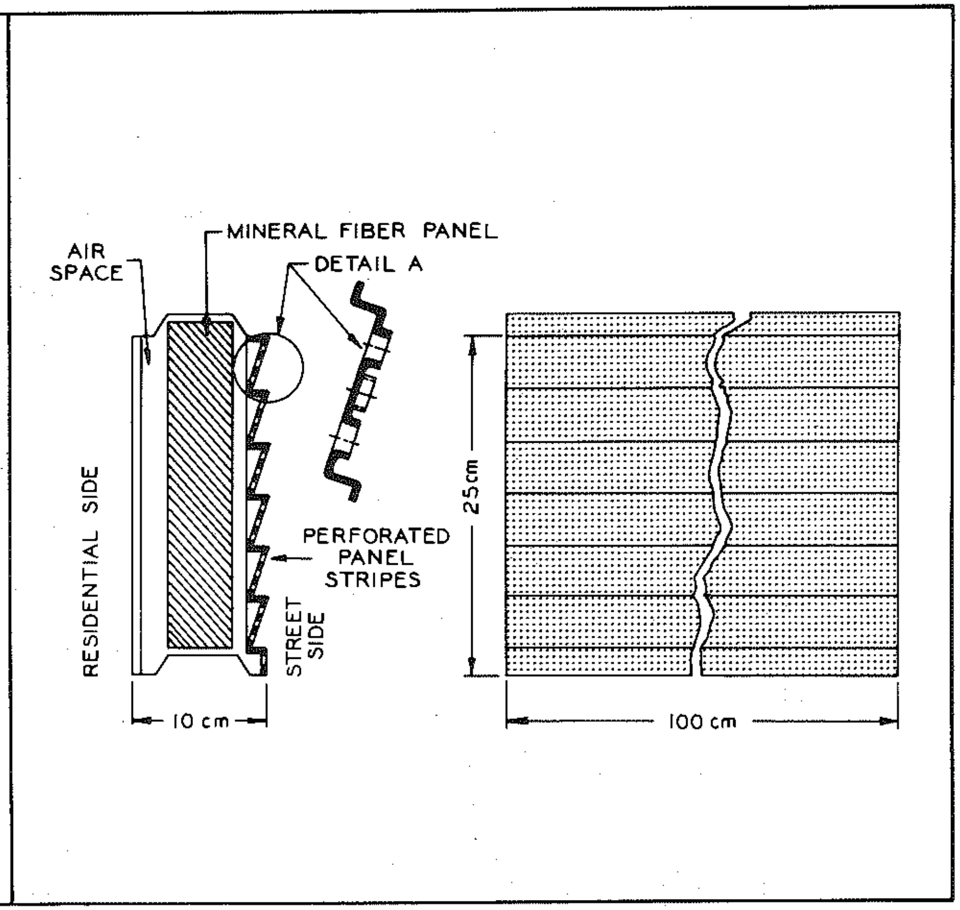
Figure 19. Sound transmission loss for walls of standard concrete blocks and for blocks of cavity-slot construction--Soundblox (8). (Losses measured when no paths exist around wall.)

Modular Type Walls

Reinhold and Burger (9) of West Germany have constructed a number of noise barriers having different types of absorptive claddings. Figure 20 shows the surface appearance of two of these units. In each case the barrier is fabricated of steel-framed modular sections for erection at various heights and lengths. The barrier cross-section consists of perforated plastic exterior facings, enclosing an air space and a film covered mineral fiber panel. The air space improves absorption at lower frequencies while the



Unit is supported on galvanized steel tubes embedded in concrete pillars 6 meters apart. Elements are subsequently calked.



Unit fastened using self sealing strips. Supported on metal up-rights embedded in concrete.

Figure 20. Surface appearance and cross-sections of two barrier elements having modular construction installed along Autobahn in Cologne, Germany.

TABLE 1
BARRIER TYPES AND CHARACTERISTICS
(All barriers are 10-ft high)

Barrier Description	Cost per linear foot	Maintenance	Construction Time and Features	Remarks
1. Earth mound 3:1 side slopes	\$2 - 4	Grass cutting, Planting	Immediate construction; trucking traffic conflict.	Application dependent on r-o-w availability.
2. Concrete block	\$20	Minimal	Lengthy construction time; minimum of equipment.	Poor appearance.
3. Timber or plywood	\$20	Painting	Lengthy erection time.	Not anticipated to be sound opaque.
4. Lead laminate	\$20 - 30	Minimal	Fast erection after quick shop fabrication.	Price range to cover thickness of lead required, to be determined by experimentation.
5. Brick wall	\$30	Minimal	Lengthy construction time; minimum of equipment.	Pleasing appearance.
6. New Jersey barrier	\$30	Normal	Minimal if pre-cast.	Only type applicable to fills over 5 to 10 ft high.
7. Armco bin wall	\$40	Minimal	Fast erection with "in stock" materials.	Corrugated panelling infilled with earth.
8. Pre-cast concrete	\$40	Minimal	Fast erection.	Price based on 6-in. thick, 25-ft long panels.
9. In-situ concrete wall	\$50	Minimal	Slow construction requiring heavy equipment.	Normal forming 9-in. thick.

mineral fiber panel attenuates higher frequencies. Typical traffic noise attenuation achieved with such units is given in Figure 21.

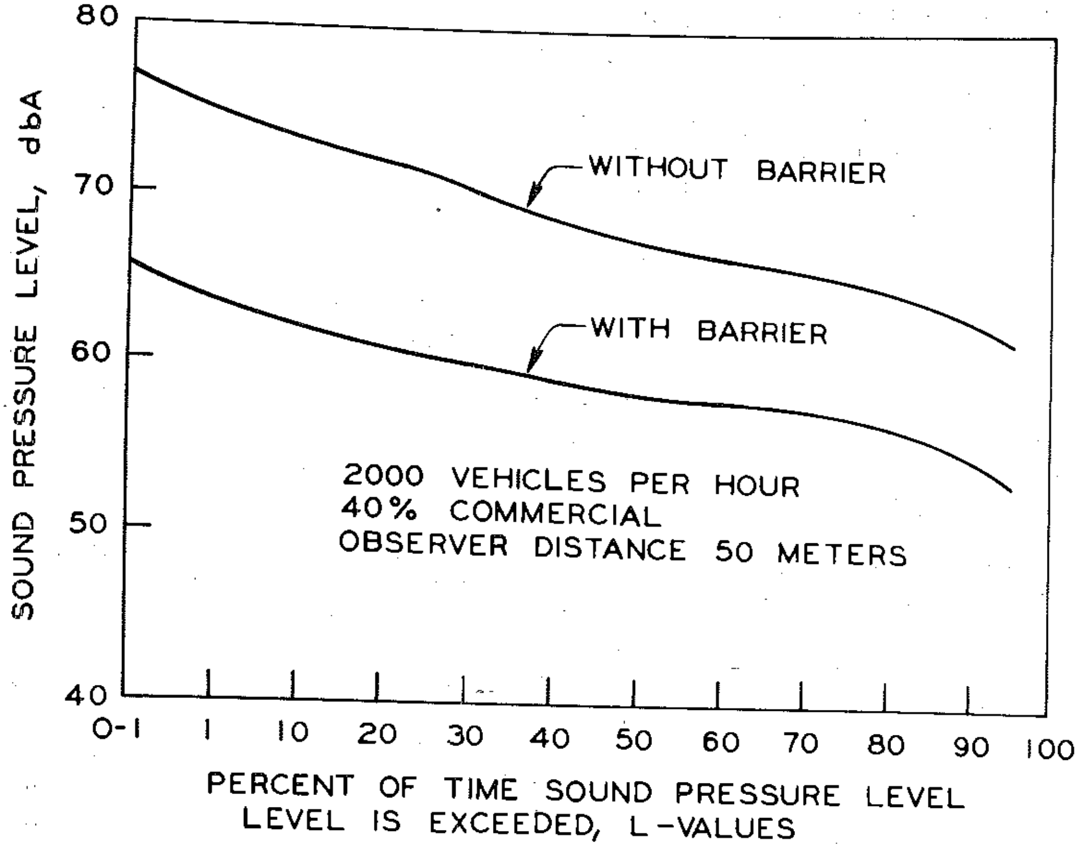


Figure 21. L-levels with and without 4 meter high barrier using absorptive claddings. (9)

Rucker and Gluck (10) also reported on the use of absorbing elements on concrete surfaces for reducing sound reflection. They tabulated the acoustical and physical properties of four different sound absorbing wall cladding elements. Their conclusion was that a noticeable decrease of sound level, particularly at the higher frequencies, could be obtained at the street level and in the neighborhood by the application of sound absorbing elements to concrete wall surfaces.

Other Types

The Ontario Department of Highways (11) has listed other possible types of barriers; their findings are given in Table 1.

The differences in transmission loss of each barrier material appear to be insignificant. The designer, however, should be aware of the maximim attenuation possible for a given weight per sq ft. Beranek, Rettinger, Moore, and Maekawa cite 25 db as a maximum attenuation for any practical barrier. Bolt Beranek and Newman (5) suggest a maximum of only 15 db because of diffraction of sound energy over the top of the barrier. In general, most barrier types provide attenuation over the entire band of frequencies inherent in vehicle noise. There are however some materials which have "acoustical holes" (little or no attenuation) at some frequencies. Thin plastic or metal panels have this characteristic.

Rucker and Gluck tested structures with jalousies (louvers) that redirect the sound energy. Although these might have merit in special situations, they do not appear to be generally applicable to highway noise.

Trees and Shrubs

The use of trees and shrubs as noise barriers is often mentioned, and in some instances may have application to a highway. Cook and VanHaverbeke (12) reported obtaining attenuation levels of 5 to 10 dbA, from a site having 10 to 45-ft high trees, 10 ft apart and 100 ft deep. Deciduous varieties would only be effective when in full leaf. Practically, the time to maturity, and land area required for this type of barrier considerably limits its use.

Beaton and Bourget (13) are particularly critical of the use of plantings indicating that their real merit is to improve appearance and to provide some "psychological shielding."

Summary of Barrier Types and Materials

At this time it is difficult to get anything into print on highway noise barriers that is not "dated" before it can be circulated. The impending (July, 1972) highway noise "standards" resulting from Section 136(b) of the Federal-Aid Highway Act of 1970, have caused great noise awareness in the State and Federal agencies responsible for implementation of highways. To obtain Federal-Aid for their new highway projects, states must show inclusion of noise consideration in all phases; planning, location, and design.

These considerations must be such as to insure that any proposed highway will not radiate noise levels exceeding those permitted by the standard. Achieving this, in many instances, will be possible only by placing noise barriers between the highway and the area being protected. And it is because of this that many acousticians, engineers, planners, designers, etc., have become barrier conscious, and have initiated studies on all of the many aspects of highway noise barriers.

In support of this increasing awareness and activity a brief listing of the current highway noise barrier methods may be of value. Therefore, the following summary tabulation is presented. It includes barrier methods and materials now in use, under consideration, or feasible for use.

1. Depression of highway.
2. Elevation of highway.
3. Earth mound walls.
4. Concrete block walls; including both standard blocks, lightweight blocks, and those with cavity-slot construction for noise absorption.
5. Concrete walls; including poured-in-place and precast, both standard or lightweight concrete.
6. Concrete or concrete block walls atop earth walls.
7. Concrete or steel retaining walls. These walls are essentially one-half an earth mound faced with a vertical wall, they are more economical of land area and also lend themselves better to esthetic treatment.
8. Modular panel walls. This is the type of wall showing most promise for future development. They can be pre-constructed for various heights and made of steel, aluminum, plastic, or wood; single membrane or laminates with perforated, shaped, louvered, or flat surfaces and containing layered air spaces, mineral fibers, lead sheet, expanded plastics, etc.
9. Brick walls. This component can be used singly or as a facing for concrete or block walls. Considerably more expensive than most other types but lends itself well to improved esthetics.
10. Wood walls: can be used as timbers, planks, or sheets; single layer, laminates, louvers, honeycombs or other. Ease of fabrication and installation is at least partially offset by maintenance requirements and lower strength of wall structure.
11. Louvered walls: can be fabricated of metal, wood, or plastic and has the potential for improved esthetics. Limited experiments have shown reasonable noise attenuations despite the presence of directional air paths.
12. Trees, shrubs and ground cover. Such barriers are only effective when present in depths of 250 to 300 ft and to heights of 45 ft. Not practical to install because of time to maturity, but worthy of consideration in route location where such stands are in fully developed existence.
13. Claddings. This is a subject area in itself for application to proposed walls or to existing walls (retaining walls in depressions); used to absorb sound energy and prevent back and forth reflections across roadway or into adjacent areas.

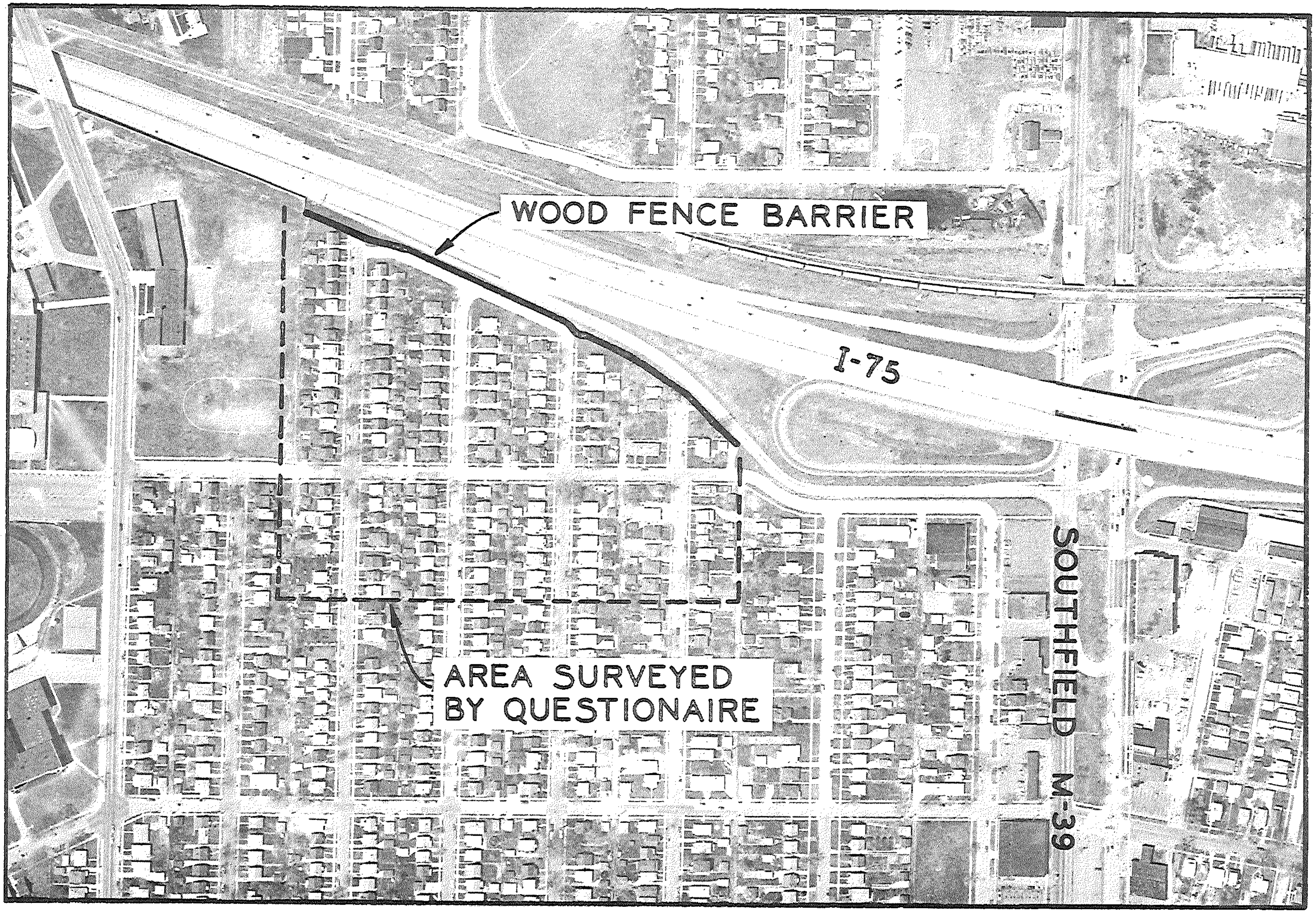


Figure 22. Aerial photograph showing location of wooden noise barrier and residential area surveyed for subjective response to barrier.

Conclusion

In the literature, the thesis continually appears that the noise problem can be considered in three parts: 1) source, 2) transmission path, and 3) receiver. The barrier is concerned with the transmission path as an impediment to the transmitting of the noise energy from source to receiver. Therefore any discussion of barriers should include a consideration of possible reduction in noise source emission and sound insulation for the receiver, or possible removal or prevention of undesirable types of receivers such as residential areas, hosptials, or schools. Zoning and route location are thereby important. In priority, barrier would appear to be lowest, and used only as a last resort.

Esthetic and driver behavior effects must be considered despite having been given minimal attention in the literature. Reinhold and Burger have reported some measurements to determine driver reaction to a barrier, but more investigation appears to be needed.

SURVEY OF RESPONSE TO A MINIMAL NOISE BARRIER

In past years, the Michigan Department of State Highways rarely received complaints of excessive noise from highway vehicles. This, however, changed drastically in 1968. As a result of feature newspaper and magazine articles on noise, people became sensitized to the problem and complaints suddenly increased. Currently, the Department receives a new noise-related problem at least every month. One of the resulting investigations was particularly interesting and is elaborated upon here in the hope that it may be of benefit to other highway engineers.

In July, 1968 a petition signed by property owners living in single family dwellings at a Detroit location adjacent to Interstate 75, was received. An aerial photograph of the site is shown in Figure 22. Traffic counts for the six lane divided pavement were:

ADT:	45,800
DHV:	7,350
Percent Commercial:	30

Sound level measurements taken at the site showed that the residents were being subjected to average noise levels between 70 and 80 dbA, with peaks frequently exceeding 90 dbA.

While at the site, laboratory personnel were approached by a group of housewives from the neighborhood. In conversations which ensued, they

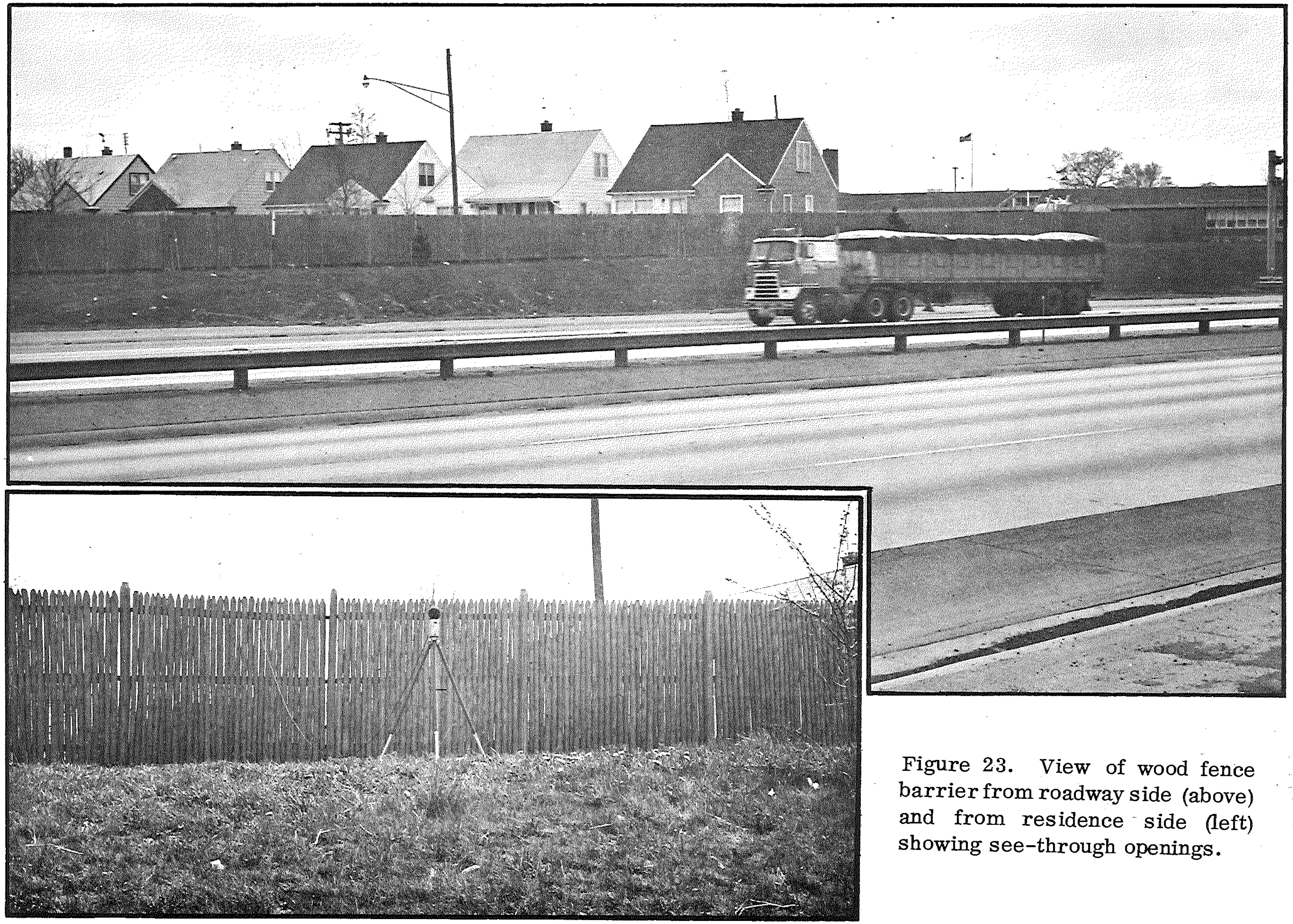


Figure 23. View of wood fence barrier from roadway side (above) and from residence side (left) showing see-through openings.

made it clear that they were very unhappy about the highway noise, claiming it prevented them from using their yards, being able to sleep, and forced them to keep their windows and doors closed while using their radio or television receivers.

In response to these problems, a cedar post fence 1,100 ft in length, varying in height from 6 to 8 ft was installed by the Department in March of 1969. Although an earth or solid concrete block wall was warranted, it was not installed due to excessive materials and construction costs. Also, such a barrier could establish a precedent for other problem areas.

Subsequent to the fence installation, additional measurements were made. A controlled sound source consisting of a signal generator, a random noise generator, two 100-watt amplifiers and speakers were used to produce the appropriate signals. Spectral level measurements were made using a fixed microphone placed on the traffic side of the fence and a second located at various distances and heights behind the fence. As expected, no significant attenuation could be attributed to the cedar fence. Considerable difficulty was experienced in taking the measurements since the traffic noise almost obliterated the levels produced by the speaker system. Figure 23 shows the completed fence and the see-through openings which almost completely reduced its effectiveness.

Although no measureable difference in the noise levels could be detected, the researchers were interested in determining the subjective response of the neighborhood to the fence and in general to the highway. Therefore, in May 1970, questionnaires were distributed to each home in the first block from the highway and to selected households located in the second block. Of the 100 questionnaires delivered, 48 were returned or 48 percent response. Virtually all respondents owned their own home, and had lived there 14 years on the average. The highway, however, had been there for only the last seven years.

Figure 24 is a sample questionnaire. It includes the overall percentage responses to each alternative indicated. The number of responses is enclosed by parentheses. Each percentage is based on the number of responses to a particular question or alternative per the total (48) responses and not per the total responses to that specific question. This manner of summarizing was chosen since it was felt that otherwise some percentages might be misleadingly high. In this way one is forced to consider the statistics in the context of total responses including those that were not bothered by highway noise in the first place. Relative comparisons as between yes and no can be made in any event.

Questionaire No. 239
Date

NOISE BARRIER STUDY QUESTIONAIRE

1. Persons living in home:

	MALE	FEMALE	TOTAL	
	25	23	48	48% response

(one response both male and female)

	Number	Ages
Male adults	35	46
Female adults	23	44
Male children	35	--
Female children	15	--

2. Circle the entry above which represents the person filling out this questionaire.

3. Is home rented 2% or owned 98% ?

4. Length of time at this address. 14 years.

5. Did you move to this home before 81% (39) or after 19% (9) the I 75 expressway was opened to traffic?

6. Does the nearby I 75 expressway bother you in any way? Yes 81% (39) No 19% (9)

7. If your answer to Question 6 in yes, are you bothered by noise 77% (37), smoke 19% (9), odors 27% (13), light 8% (4), vibration 52% (25), other dirt 19% (9); salt 10% (5); fumes 8% (4); dust 4% (2); spray 4% (2).

If your answer to Question 6 was yes, please answer the remaining questions. If your answer was no, only answer additional Questions 12 thru 16.

8. Do you feel that the wooden noise barrier fence:

	Yes	No	Not Responding
(a) reduced the expressway noise?	27% (13)	56% (27)	17% (8)
(b) improved the view?	29% (14)	42% (20)	29% (14)
(c) reduced headlight glare?	52% (25)	12% (6)	35% (17)
(d) made porch and yard more usable?	27% (13)	50% (24)	23% (11)

9. Would you recommend using such a fence as a standard highway noise control method? 23% (11) 54% (26) 23% (11)

- 2 -

10. Do you feel that any of your following activities have been affected by local highway noise?

	Before Fence Installation Yes	Before Fence Installation No	After Fence Installation Yes	After Fence Installation No
(a) sleep	34%(16)	11%(5)	30%(14)	15%(7)
(b) relaxation	32%(15)	6%(3)	32%(15)	6%(3)
(c) conversation	27%(13)	9%(4)	23%(11)	13%(6)
(d) yard or porch use	32%(15)	11%(5)	30%(14)	13%(6)
(e) TV or radio	32%(15)	13%(6)	30%(14)	15%(7)
(f) General health	19%(9)	11%(5)	21%(10)	5%(4)

11. If you are bothered by highway noise can you identify the nature of the disturbing noise?

(a) Truck rumble (35) 73%
(b) Engine and muffler (26) 54%
(c) Tires (21) 44%
(d) Other (please state) (5) brakes, sirens, drag racing

12. Do you feel that highway noise is an unavoidable result of our highway transportation system: Yes 65% (31) No 21% (10)
(7) 14% unanswered

13. Should primary responsibility for reducing and controlling highway noise rest with:

(check one)

		ad	(1)	2%
		abd	(2)	4%
(a) Federal government	12%(6)	bd	(3)	6%
(b) State government	4%(2)	cd	(2)	4%
(c) City government	0%(0)	abcd	(4)	8%
(d) Michigan Department of State Highways	50%(24)	bc	(1)	2%

14. Have you ever protested about highway noise to anyone? Yes 42% (20) No 58% (28)

15. If answer to Question 14 is Yes, to whom did you protest.

16. What were the results, if any, of your protest?

17. Any additional remarks or comments you have in regard to highway noise.

Figure 24. Subjective response questionnaire with survey results entered.

It is quite evident from the responses that the residents are bothered by highway noise. Suprisingly, vibration is the next most annoying aspect. It should be noted at this point that experience has shown that if a questionnaire is sponsored by a government agency, responses may be exaggerated hoping to influence regulations. More honest and open responses are elicited if sponsorship is identified as a university or non-profit group.

About the only benefit which the majority gained from the wooden noise barrier fence was a reduction in headlight glare.

Question 10 shows a large differentation between the various activities affected by the intrusion of highway noise. Supposedly, reaction to interference from sleep, rest, etc. is different quantitatively from conversation, use of TV, etc. No such differences are apparent in the responses to this question; however, all activities were equally affected according to one third of the respondents.

The comments that accompanied many of the questionnaires indicate a feeling of hoplessness on the part of the respondents.

MICHIGAN PARTICIPATION IN THE 1970 SAE TRUCK TIRE NOISE STUDY

In late August 1970, the Department assisted the SAE Subcommittee on Truck Tire Noise in a study aimed at determining the relationship between subjective and objective evaluations of truck tire noise. The study's goal was to develop an objective test method having a known relationship to human subjective response. Once developed, the method would aid manufacturers to evaluate their efforts at producing quieter tires--a very worthwhile objective.

The Department provided a site on an in-service, Interstate highway; and handled the traffic control associated with test vehicle entry, exit, and test performance (Fig. 25). The Department also furnished four jurors (including two research statisticians who later analyzed the data for Department information) for the 24 member subjective evaluation panel, plus an engineer-psychologist consultant to observe the experiment.

Department instrumentation, in parallel with that used by the subcommittee, made recordings of the noise signals from each test run; and at the completion of the experiment copies of the subjective responses of the evaluation panel were turned over to the Department for its own study. Naturally, this information is the property of the SAE and its release to this Department was on the basis of its remaining confidential. That provision

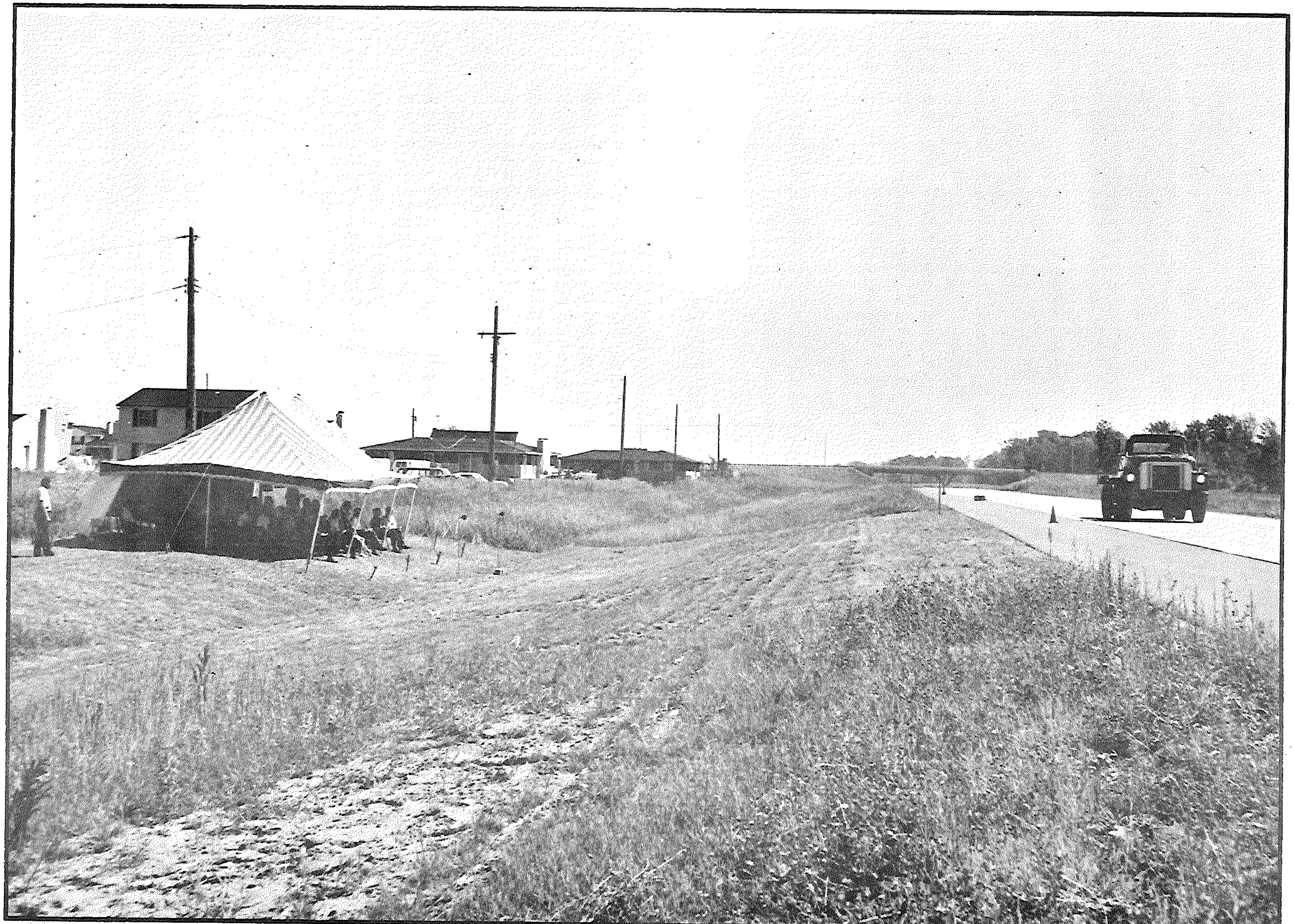


Figure 25. View of I 496 SAE test site showing observer station (tent at left) and noise source (passing truck at right).

has been respected and none of the data or results are presented here, or elsewhere, by the Department.

Although this entire test program was planned, controlled and performed by the SAE, the Department's participation and subsequent study of the results has proven to be a valuable learning experience. Subjective response studies are difficult at best, and in the area of response to highway vehicle noise there is the added difficulty that few earlier studies exist to be drawn upon for guidance. Department analysis of the test procedures and data brought out the fact that determining subjective response to noise is equally as difficult as other types of human response studies. The selection of panel members, the charge given to them, the site location and characteristics, the type and order of noise stimulus presentation--all these are very important factors which must be carefully planned and controlled if valid results are to be obtained.

In summary, this test program was very interesting and informative and the Department's participation was a worthwhile experience.

PARTICIPATION IN THE MICHIGAN PHASE OF NCHRP PROJECT 3-7

In September 1971, Michigan researchers assisted personnel of Bolt Beranek and Newman, Inc., in the Michigan phase of their continuation of NCHRP Project 3-7. This continuation of a project which has already produced the two excellent highway noise studies reported in NCHRP Reports Nos. 78 and 117, is aimed at further validation of the Highway Noise Prediction Method of Report No. 117. Particular attention is being given in this work to validating the noise attenuation of various types of highway noise barriers, a subject of critical importance to highway departments throughout the country.

In mid-1971, in response to a request from BBN, several highway sites having barrier-like characteristics were suggested for possible inclusion in the study. Ultimately, one of the sites, on Michigan's I 94, was selected for study. The site (Fig. 26) selected is typical of many areas adjacent to urban interstate roadways--a residential neighborhood immediately adjacent to the right-of-way of a high speed, high traffic volume expressway.

The purpose of the measurement program was to determine the barrier effect of a row of houses paralleling the roadway, a short distance away. Knowledge of this effect, and its related variables, will ultimately be of value to highway department decision-makers in those instances where it is proposed to remove a row of houses to facilitate widening or other type

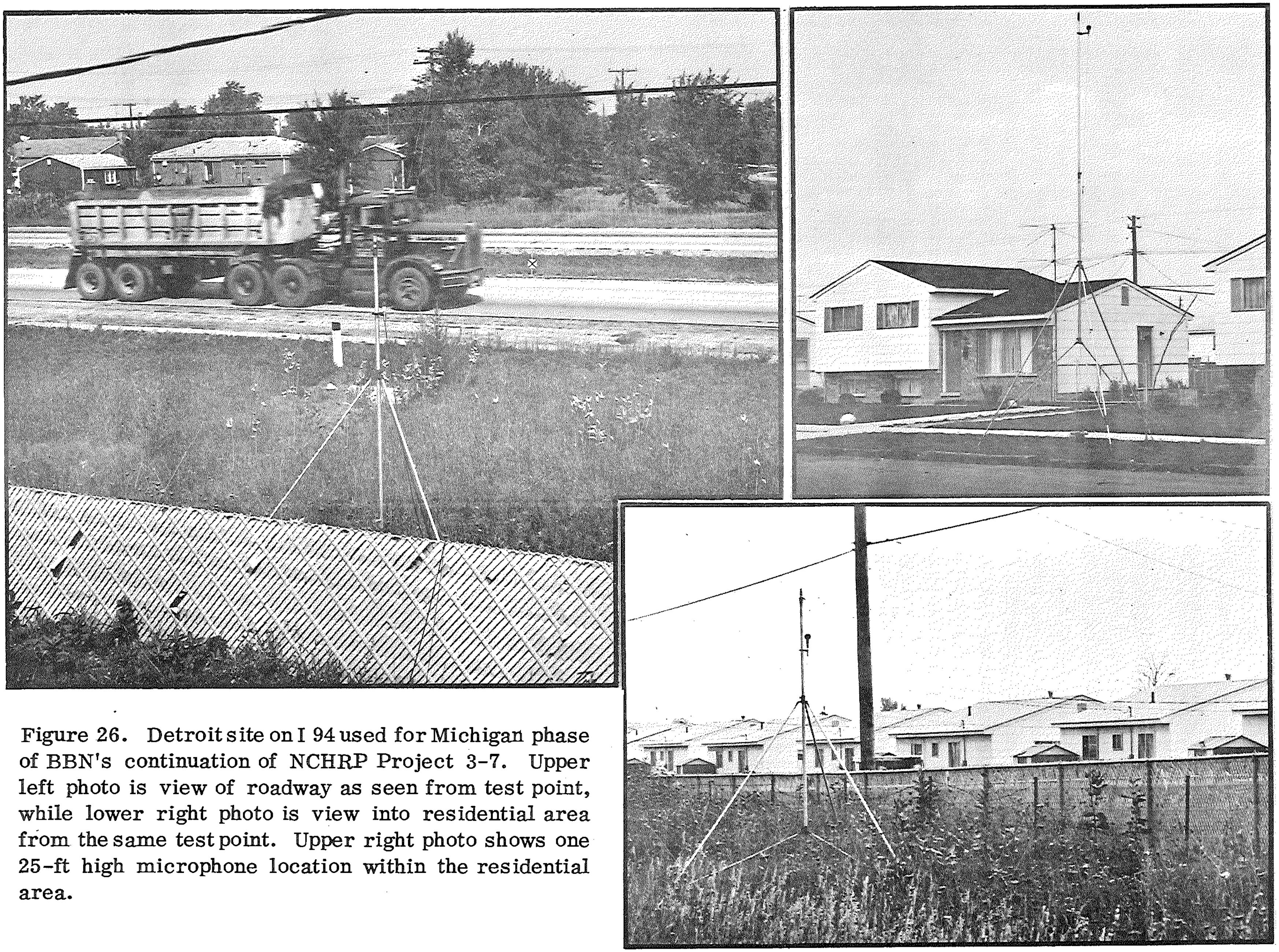


Figure 26. Detroit site on I 94 used for Michigan phase of BBN's continuation of NCHRP Project 3-7. Upper left photo is view of roadway as seen from test point, while lower right photo is view into residential area from the same test point. Upper right photo shows one 25-ft high microphone location within the residential area.

roadway construction. Such a procedure may be found to create an extremely serious impact on the row of houses immediately behind the row being removed. Consequently, the decision-maker should be armed with foreknowledge of such potential impacts to assist him in resolving the problem.

Involvement in this and other studies peripheral to the HPR project have contributed significantly to the growth of experience and knowledge of Michigan's highway noise researchers. This increasing sophistication relative to noise is producing benefits across the whole spectrum of the State's efforts at finding solutions to the noise problem. Consequently, such cooperative endeavors, although not directly applicable to the principal Michigan noise study, are deemed fully justified.

SECTION III

NON-PROGRAMMED NOISE PROBLEM ACTIVITIES

NON-PROGRAMMED NOISE PROBLEM ACTIVITIES

This section of the report has been included on the assumption that highway noise problem activity in Michigan is not unique but rather is typical of what is happening in other states, or will happen in the near future. If that assumption is correct then a review of the Michigan activities could prove of value to the FHWA and to the other states as an indication of the specific problems that should be anticipated and included in future plans for noise abatement. It is very important that every state make liberal provision in any planned noise studies or activities for a great amount of forced time consumption by non-programmed, noise related activities. This has been the experience in Michigan and it is reasonable to expect that the same problem will occur elsewhere. These unplanned expenditures of time have resulted in serious problems in maintaining the proposed schedule of the HPR study being reported in this paper.

If Michigan's experience is typical, then the reader can expect his state to be required to function in at least five distinct areas. It can also be expected that the bulk of this functioning will fall, in the early stages of development, to the state's noise specialists or more likely to those designated to become specialists. In the evolution of the treatment of noise problems, planning, route location, and design groups can be expected to play an increasing role; but not in the beginning.

The five distinct types of activity encountered in Michigan, and that can most likely be anticipated elsewhere, are titled: 1) Project Planning; 2) Environmental Impact Studies; 3) Vehicle Noise Control Legislation; 4) Citizen Noise Complaints and 5) Public Service Activities and Consultations. Each is described in the following:

1. Project Planning

The type of activity required in this category in Michigan is distinct from that of the formal environmental impact study. It has included studies to determine, in advance, the noise effects to be expected as a result of various highway department operations; and in other cases evaluation of noise effects which have already occurred as a result of location, geometrics, or other physical changes.

Included have been studies of: the comparative noise effects of proposed alternate roadway routes; proposed route changes which would result in significant changes in traffic volumes or patterns; road widening projects; projects where significant amounts of vegetation (trees, shrubs, and ground cover) were to be removed from the area between the noise source and receivers; non-Federal participation projects where an environmental impact statement was not required; the noise generation results of non-skid surface treatments; plus the noise effects of other similar activities.

The project planning category as used here also includes activities necessary to implement a computer noise simulation model (or models) and then to train planning, location, and design personnel in its use. Other states are advised to conduct such training programs and initiate them as soon as feasible to ease the pressure on the research, development, or other type personnel who must carry the noise work load in the early stages.

Also, the noise specialists can expect to be called upon to meet with citizen and municipal groups to discuss, predict, reassure, refute, etc., all questions or charges relative to the noise problem under consideration.

In this capacity he will be expected to be conversant with the highway noise effects of grades, interchanges, intersections, pavement surface types, distance, vegetation, barriers, elevation, depression, vehicle speeds, vehicle types, wind effects, temperature effects, etc.--the whole spectrum of the highway noise problem.

2. Environmental Impact Studies

In time, this category of noise work will probably consume more highway department personnel time than all other noise problem activities combined. Hopefully, however, by the time any department reaches the point where all projects being planned require E-I Statements, training programs will have spread the necessary know-how to planning, location, and design engineers. Thus, the work will be distributed among many people in different functional groups, thereby relieving the early workers and at the same time bringing the work to the appropriate operational personnel.

Environmental impact studies conducted to date in Michigan, as in other states, have essentially been conducted without guidance or precedent. Michigan studies have all followed the same general pattern, and all have been performed for projects in the route location phase.

The procedure used has approximated the following:

a) Study the proposed route to locate and identify all potentially noise sensitive areas. These will include such areas as residential, recreational, religious, educational, health service facilities, entertainment, certain business and occupational facilities, animal habitats, and possibly others.

b) After identifying the potentially sensitive areas, make field measurements to determine the existing noise levels in these areas--probably the most man-hour consuming phase of the study. Depending on the nature of the area, and the variability of its characteristic existing noise pattern, it may be necessary to record and analyze many hours of samples taken over a period of days or weeks to insure a valid sample.

Michigan's analysis of such samples is directed to determining L_{10} and L_{50} (dbA levels exceeded 10 percent and 50 percent of the time, respectively) as introduced in the Bolt Beranek and Newman NCHRP Report No. 117.

c) Having identified the sensitive areas and determined their existing noise levels, the next step is to estimate the noise levels which the proposed highway will produce in these areas should it be built. Michigan has obtained these estimates (predictions) by use of a computerized version of the Complete Design Method presented in NCHRP Report No. 117 (this is the computer program discussed at length earlier in this report).

d) Compare predicted noise levels with existing levels, and with design criteria. Although these comparisons will, and should, form the basis for assessing the noise impact on areas adjacent to any proposed highway they have been only qualitatively applied to date in Michigan.

BBN (5) have suggested a quantitative definition of acceptable impact in terms of existing vs. predicted noise levels, and predicted vs. design criteria noise levels, and Michigan has no serious objections to their definitions. The use of these impact determinants, however, has been prevented by the fact that the appropriate highway department divisions are not yet geared to handle the problem; but this deficiency will soon be eliminated.

The computer implementation of the BBN noise design method discussed earlier has been completed and a series of lectures for planning, route location, and design engineers has been scheduled. This lecture series has been designed to give the attending engineers knowledge of the fundamentals of noise, its effects, measurement procedures, methods of control, prediction techniques (shared-time computer terminal in each division) and quantitative methods for determining the noise impact of proposed highways.

Completion of this educational program should equip Michigan's engineers with the tools necessary to evaluate the noise consequences of their designs and to modify those designs accordingly. It is anticipated that this educational program will be completed in March 1972.

3. Vehicle Noise Control Legislation

Efforts towards statutory control of highway vehicle noise in Michigan have not been successful as of this writing; and experience to date in this regard is not such as to generate optimism with respect to the eventual result. Despite this, such efforts must be initiated and continued here and in the other states. Without some control over highway noise sources the task of the highway technologist, attempting to reduce environmental noise, will be extremely difficult if not impossible.

For the benefit of those state highway departments not yet fully committed to the attaining of vehicle noise limits the following dissertation is presented. It is a summing up of Michigan's approach to this problem and the assumptions and philosophy underlying the efforts.

Highway technologists newly involved in the problem of highway noise soon become convinced of one salient fact with respect to their noise attenuation efforts; i.e., it is absolutely essential that statutory limitations on maximum permissible vehicle noise be established. It is more sensible, both environmentally and economically, to moderate noise at the vehicle source than to spend hundreds of thousands of dollars per mile trying to contain and absorb it along the roadway boundaries. Especially when the latter solution means that the millions of roadway users must travel in corridors of ever increasing, ear shattering, stress and fatigue producing noise.

Even with statutory limits some containment and absorption may still be required along roadways adjacent to densely populated residential areas, but certainly nothing on the scale that will be required should vehicles be allowed to continue producing current noise levels and the higher levels predicted for future, higher power, higher volume traffic.

Such legislation should establish statutory upper limits for the maximum noise allowable from motorcylces, automobiles, trucks and all other types of vehicles, powered or drawn, using the highways. It should make allowances for the problem of correcting existing noisy vehicles and should apply more stringent requirements to new vehicles.

Early in the highway noise reduction process it becomes evident that the highway scientist or engineer is the most appropriate initiator of vehicle noise control legislation. He is closest to the problem, has more experience with it and is, therefore, more aware of the realities and difficulties of its solution. Early in his work he will recognize the four principal facets of the solution:

1) Locating the highway to minimize noise impact,
2) Designing the highway to minimize noise radiation.
3) Controlling vehicle noise sources.
4) Controlling land use adjacent to highways.

He will also recognize his inability to deal with the last two except with the assistance of agencies outside his highway organization. The difficulties inherent in effecting land use control are of such magnitude that the highway engineer will realize that his most productive outside effort is likely to be in the area of vehicle noise control and will, therefore, concentrate his early effort in this area.

The first order of business in working towards vehicle noise legislation is awareness of the principles and factors that form the basis for such legislation. In Michigan the principles and factors assumed were:

a) Every citizen has a right to a quiet environment and quiet should not be a purchasable privilege.

b) Modern highways are the most pervasive source of noise in our environment; that is, the noise radiating from them affects more people, more of the time, than any other noise source.

c) The driver of the vehicle in the traffic stream has as much right to quiet as does the citizen living or working adjacent to the highway; thus, containment of noise within the highway boundaries is only a temporary expedient.

d) The adverse effects on humans of noise, while not fully quantified, are well identified qualitatively. They include hearing loss, speech interference, sleep interference, general annoyance and its associated elevated stress levels, and an overall degradation of the quality of life.

e) While moderately high daytime levels of noise from human activity are tolerable to the human organism, quiet for nighttime sleep is an absolute necessity for continued physical and psychological health--human beings cannot continue to live and function without restful sleep.

f) Highway departments will not be able to properly respond to citizen noise complaints or to the demands of environmental impact attenuation requirements without some control over highway noise sources.

g) The noise radiating from highways is produced by vehicles, not by the highway. There are certain features of highways which affect the radiated noise levels. These features: grades, curves, skid resistant surfaces, location, elevation, depression, etc., are being studied to learn ways of moderating their effects.

h) The number of highway vehicles is increasing at a significant rate, and the penetration of this increasing vehicle population into urban and suburban areas is also increasing. Hence, more and more people are being subjected to highway noise.

i) It is the vehicle manufacturer's responsibility to produce quiet vehicles. The methods employed to achieve quiet operation are not appropriate to legislative establishment and therefore legislation should not specify the configuration, materials, or design of any vehicle component, device, structure or system.

j) It is the vehicle user's responsibility to maintain his vehicle in a quiet operating condition, and to operate it in a quiet manner.

k) That because of the costs involved, vehicle manufacturers and users will never make a concerted effort to reduce vehicle noise without the impetus of statute and enforcement.

l) The limits in any proposed bill should be realistic and attainable--neither unreasonably harsh nor excessively lenient. Until very recent times legislation on motor vehicle noise has been vague; employing such terms as "excessive or unusual" as in Michigan's present Section 257.707 of Act 300, P.A. 1949. These ambiguous terms led to difficulty in the courts and the statutes became, for the most part, unenforceable. Consequently, realistic, quantitative statutes are essential.

m) Vehicle noise statutes should include an "operational" section having application to existing vehicles, and a "new vehicle" section whose limits must be met by any vehicle offered for sale for the first time.

n) Limits should be given in A-weighted decibels (dbA) as this is the most practical, quantitative unit commensurate with the current state-of-the-art of noise measurement. It correlates well with human subjective response and is relatively easy to measure.

o) Only total noise radiating from a vehicle should be considered, without any attempt at restricting specific noise sources such as engine, muffler, tires, etc.

p) The levels and measurement methods set forth in any noise control bill should not be based upon any industry standard. Such standards are subject to changes over which the state has no control and, therefore, should be avoided.

q) The provisions of the vehicle noise statutes of California, New York, and other governmental entities, and their experiences in enforcing their bills, should be considered in arriving at the conditions and limits contained in any proposed bill.

r) Reducing highway-generated noise though statutory limits will be greatly enhanced if special noise law enforcement teams and their support equipment are also legislatively provided.

As stated earlier, it is of critical importance to the credibility and acceptance of vehicle noise legislation that the highway technologist propose levels that are feasible, attainable, and economically sensible. It is in this last area, economics, that he can expect the principal challenges to any proposed stringent levels. Opponents will present the familiar arguments that trucking companies, in particular the small operators, will be driven out of business. The same arguments that were presented in years past in opposition to truck load limits, size limits, speed restrictions, seasonal restrictions, driving time limitations on truck drivers, etc.

It will be argued that the expense of installing mufflers, replacing certain tire types, covering open engines, etc. will bankrupt many operators. But this argument is a gross overstatement and cannot be the controlling criteria when considering the contribution made by noisy vehicles to a degraded quality of life for millions of American citizens.

In weighing the arguments of cost to vehicle operators one should compare those costs against the alternative costs of achieving acceptable community noise levels by modifying the highways or by erecting noise barriers between the highway and the community. Too often in the past, legislative committees considering controls on vehicle noise have tended to consider only the potential cost of vehicle modification, ignoring the significantly more expensive alternative of modifying the highway system.

It will be up to the highway engineer to refute such arguments, and failure on his part to do so will result in statutory limits so high as to be meaningless. Allowing trucks to legally generate 92 dbA is an example of such misguided considerations (legal limit of 90 dbA plus a 2 dbA tolerance for measurement site and instrument variations).

Prior to establishing goal noise limits each state should determine the distributions of existing vehicle noise sources on its highways. Such distributions will indicate the number, or percentage, of vehicles to be affected by any proposed levels and thereby help to insure the recommendation of realistic, attainable limits.

Subsequent to determining the vehicle noise distribution on his highways the engineer is advised to confer with vehicle users and manufacturers, with his law enforcement agencies, with the authors of current highway noise studies (or intensively study their reports), with acoustical consultants when indicated, with local environmentalists, with lawyers experienced in environmental matters, and with highway representatives from states already having vehicle noise statutes.

These measures should provide the highway technologist with the ability to prepare and support realistic, meaningful, and defensible vehicle noise legislation--noise limits which if enforced will effect a significant reduction in the noise impact being experienced by the citizens of his state.

Bringing the highway noise problem, as it presently exists, under control requires that legislation be separated into two distinct sections. The first called the "Operational Section" to limit the noise radiation of existing vehicles; and the second, a "New Vehicle Section," to limit and progressively reduce the permissible noise from new vehicles.

Certainly the costs and feasibility of technologically reducing noise from new vehicles are much easier determinations than for the millions of existing vehicles. Despite this, the operational or existing vehicle section should not be considered of lesser importance. Of the millions of vehicles on the highway today, the commercial units which are normally the worst noise offenders are also the longest lived, and therefore their importance to future noise abatement efforts should not be minimized.

To give the reader a feel for noise reductions that are feasible, the following reductions obtained (14) under laboratory or field test conditions are quoted:

13-15 dbA reduction through emplacement of muffler on unmuffled truck.

2-5 dbA incremental reduction through addition of second muffler and tail pipe.

10 dbA reduction in diesel engine noise through redesign of the engine structure to reduce vibration.

7-15 dbA reduction through modification of engine enclosures and addition of second muffler and tail pipe.

7-20 dbA reduction from the use of new rib tires rather than new retread tires.

These reductions are, of course, not directly additive.

It has also been shown that the manner in which a vehicle is operated can significantly affect its noise radiation (14). Under normal acceleration, vehicle noise levels will increase by about 6 dbA, while under maximum acceleration (irresponsible driver mode) they can increase by as much as 15-20 dbA over steady speed driving conditions.

The point is that through proper vehicle maintenance, or minor modification, plus sensible operation, very significant vehicle noise level reductions can be achieved. Consequently, the enactment of vehicle operational noise limits well below present vehicle levels is justified and reasonable.

The operational limits proposed by the Michigan Department of State Highways to its Legislature are as follows:

(B) NO MOTOR VEHICLE SHALL BE OPERATED OR DRIVEN UPON THE HIGHWAYS OF THE STATE IN A CONDITION OR MANNER CAUSING IT TO PRODUCE NOISE EXCEEDING THE FOLLOWING NOISE LIMITS:

	POSTED SPEED LIMIT OF 35 MILES PER HOUR OR LESS	POSTED SPEED LIMIT OF OVER 35 MILES PER HOUR
(1) A MOTOR VEHICLE WITH A MANUFACTURER'S GROSS VEHICLE RATING OF 6,000 POUNDS OR MORE, SINGLE OR TOWING ANY SEMITRAILER, POLE TRAILER OR COMBINATION THEREOF.	82 dbA	84 dbA
(2) A MOTORCYCLE, OTHER THAN A MOTOR DRIVEN CYCLE.	78 dbA	82 dbA
(3) ANY OTHER MOTOR VEHICLE AND ANY COMBINATION OF VEHICLES TOWED BY A MOTOR VEHICLE.	74 dbA	78 dbA

Those who might feel that these limits are unrealistically low should be advised that the problems of measuring over-the-road vehicle noise levels dictate the use of a 2 dbA tolerance on readings. Therefore, in actual enforcement practice each of the proposed bill's categories would be in violation only if that category's stated limit is exceeded by 2 dbA or more. Most existing bills have been written without recognizing this requirement and consequently their limits are ineffective in reducing highway noise.

Progressive reduction of the maximum permissible noise from new vehicles is a more difficult determination. The capability, motivation, and eventual accomplishment of vehicle manufacturers in reducing the noise emissions of their products are still unknown quantities. Because the problem is both technological and economic, plotting its future resolution (progressive noise reduction) is a doubly difficult task. Consequently, what is the logical course for highway departments to pursue?

Michigan's proposed phasing down of permissible new vehicle maximum noise levels is based on achieving a current ideal maximum in a reasonable number of years. The New Vehicle section of the highway department's proposed bill is as follows:

(C) NO MOTOR VEHICLE MANUFACTURED OR ALTERED AFTER THE FOLLOWING DATES SHALL PRODUCE NOISE WHICH EXCEEDS THE FOLLOWING NOISE LIMITS:

(1) A MOTOR VEHICLE WITH A GVW RATING OF 6,000 POUNDS OR MORE

(a) Manufactured after July 1, 1972 and before July 1, 1974	88 dbA
(b) Manufactured after July 1, 1974 and before July 1, 1976	86 dbA
(c) Manufactured after July 1, 1976 and before July 1, 1978	83 dbA
(d) Manufactured after July 1, 1978.	80 dbA

(2) A MOTORCYCLE, OTHER THAN A MOTOR DRIVEN CYCLE

(a) Manufactured after July 1, 1972 and before July 1, 1974	88 dbA
(b) Manufactured after July 1, 1974 and before July 1, 1976	84 dbA
(c) Manufactured after July 1, 1976 and before July 1, 1978	80 dbA
(d) Manufactured after July 1, 1978.	75 dbA

(3) ANY OTHER MOTOR VEHICLE

(a) Manufactured after July 1, 1972 and before July 1, 1974	86 dbA
(b) Manufactured after July 1, 1974 and before July 1, 1976	84 dbA
(c) Manufactured after July 1, 1976 and before July 1, 1978	80 dbA
(d) Manufactured after July 1, 1978.	75 dbA

Achieving these limits, especially those in effect after July 1, 1978, will probably require some vehicle redesign. Admittedly this could require a major effort by the manufacturers and also have major financial implications. However, the alternatives in terms of ever increasing noise impacts on the citizens indicate that vehicle redesign is by far the more acceptable of the two choices.

Having prepared his proposed vehicle noise control bill, the highway noise technologist then has the problem of getting it enacted. This will require much effort on his part and he would do well to prepare for it in advance. The many individuals and committees related to the introduction, study, and passage of such a bill will have to be advised, informed, and educated on the specifics of highway noise.

In addition to the many definitions, graphs, charts, etc., supplied to management, legislators, and legislative study committees, magnetic tape recordings of highway noise should prove very beneficial. These tapes as prepared in Michigan included recordings of individual highway trucks, cars, motorcycles, and various traffic stream conditions. Recordings were made for individual vehicles at levels established in other states and cities and these were then audibly compared to the levels proposed for Michigan.

In most states the highway engineer-scientist working for vehicle noise control will be the principal proponent of such legislation. He can expect to encounter little or no public opposition and will probably find his efforts being supported by educators, engineers, scientists, municipal officers, various environmental groups, homeowner groups and various others. He should cooperate with, and develop this support to the utmost to insure the eventual enactment of truly rational and effective laws for controlling and reducing highway vehicle noise.

4. Citizen Noise Complaints

Investigating and responding to citizen noise complaints has proven to be one of the most time consuming functions that Michigan's highway noise scientists have been called on to perform. Many of the Michigan complaints are partially a result of publicity given to this HPR study but, in the main, despite this impetus to complaints, most are legitimate protests from citizens living in areas being heavily impacted by noise from adjacent highways.

Most such complaints have come directly to the highway department from the citizens affected; however, many others have come indirectly through the Governor's office, through State and Federal legislators, through municipal officials, and in one instance through the Federal Highway Administration.

It has been the policy from the beginning of this problem that all such complaints are acknowledged and answered. For the many non-specific noise complaints, a form letter answer (Fig. 27) has normally been used. For more specific protests a response appropriate to the nature of the problem is effected.

COMMISSION:
CHARLES H. HEWITT, CHAIRMAN
LOUIS A. FISHER, VICE CHAIRMAN
E. V. ERICKSON
CLAUDE J. TOBIN

STATE OF MICHIGAN

WILLIAM G. MILLIKEN, GOVERNOR

DEPARTMENT OF STATE HIGHWAYS

STATE HIGHWAYS BUILDING – POST OFFICE DRAWER K – LANSING, MICHIGAN 48904
HENRIK E. STAFSETH, DIRECTOR

Research Laboratory Section
735 East Saginaw Street
Lansing, Michigan 48906

Dear:

Thank you for your letter. We appreciate hearing from those we are attempting to serve whether they are praising, criticizing, questioning or simply commenting on our efforts. It is vitally important that we know the citizen's feelings on any given problem if we are to best serve their interest. Too few people take the time to express their opinions and, as a result, we in public service must often operate in the dark, so to speak, proceeding in the manner and direction that "we think" the citizen would want. Therefore, your letter is doubly welcome.

Highway departments are often severly criticized for building highways near or through high density population areas; but it would not be sensible to do otherwise. Highways are built to serve people, and to accomplish this the roads must reach those they are intended to serve. Because of this the highway designer and builder, although not the principal cause of traffic noise in our society, is the principal recipient of blame for it. The noisy highway vehicles disturbing us all are owned and operated by citizens like yourself, and the locations of highways are dictated by the settlement and living patterns of these same citizens, again like yourself.

Compounding the problem, American's added a net increase of five million new cars and trucks to our highways last year, and it is predicted that the gain will be even higher this year more so in the years to come.

MICHIGAN THE GREAT LAKE STATE

Despite its lack of fault in this matter your highway department is taking the lead in the search for a solution to the problem in Michigan. We have begun an attack on the problem from two fronts:

First, legislation has been prepared and sent to the Governor which, if adopted, will drastically reduce the permissable noise levels of highway vehicles. And second, a study is underway to determine and correct those elements of the highway itself which are contributing to the radiated noise.

Environmental noise has been the most neglected of the many pollutants affecting our lives. Finally, however, that neglect is ending. Many people and organizations at the federal and state levels, and in private industry, are working towards solutions to the problem. And with the amount of effort being expended a solution, or at the least the beginning of a solution, can't be too far away.

You may rest assured that many dedicated and concerned people are aware of your problem and are attempting to eliminate it.

Thank you again for taking the time to give us your thoughts and feelings on this matter.

Very truly yours,

TESTING AND RESEARCH DIVISION

Figure 27. Form letter used as a reply to citizens non-specific noise complaints.

Such response usually consists of an inspection and measurement survey of the subject area to determine the quantitative magnitude of the problem (almost without exception it is a residential area close to a highway which has a high truck population). This may be followed by discussions or correspondence with the area residents, with their spokesmen, with local officials, or in some cases with their state legislators.

The purpose of these communications is to reassure the residents that their problem is recognized and that in conjunction with many others it is under consideration. The continuing efforts by the Department toward legislative reduction of vehicle noise levels is explained. The relationship of their problem to the Michigan noise study, and the many other studies now in progress across the country, is emphasized to again reassure them that in addition to recognizing their noise problem many people and agencies are actively seeking methods for its solution.

Invariably, the citizens raise the question of noise barriers. This requires explaining the problem of funding such structures, and that barriers for highway noise are still in the experimental stage. Also, that questions of barrier performance, durability, safety, esthetics, etc., are as yet unanswered. This, in turn, usually leads to another predictable reaction: a request by the residents that an experimental barrier be installed between the highway and their area. In answer to this request it is necessary to explain that experiments, to be productive of new knowledge, must be very carefully controlled. Specifically, that barrier dimensions and other properties must be varied, the noise sources must be under control and repeatable, the measurement areas must meet many requirements, etc. An old story to researchers but one that is sometimes difficult to explain to laymen.

This procedure, despite its inherent truth and sincerity, does not solve highway noise problems. Because of this the Department has been accused of "sitting on its hands," of trying to "talk the problem away," or "stalling," or being "unresponsive," and in one instance of even having threatened a group spokesman with retaliation for complaints--all untrue charges.

Actually, this whole procedure is an attempt to convince the citizens that:

a) Their problem is recognized and acknowledged.

b) That statutory reduction of permissible noise from vehicles will soon be realized.

c) That the knowledge needed to resolve highway noise problems is being actively sought but is not yet fully attained.

d) That means of funding these certain-to-be-expensive solutions are being sought.

e) That the noise problem, as with the other environmental problems, is the subject of intensive national and international study and will be solved. It will, however, require time which in turn requires the support and understanding patience of all citizens.

In addition to this essentially verbal procedure, more concrete steps have been taken in three separate problem cases. The first was the installation of the stockade type fence discussed earlier in conjunction with the subjective questionnaire.

The second and third instances are in the design proposal stage at this writing. One will constitute a recommendation for a 2,000 ft, corrugated steel barrier of height varying from 6 ft to 12 ft. Esthetics, safety, and cost, as well as noise attenuation, are being emphasized in the design. The site is a very high traffic volume expressway with 30 percent commercial vehicles, most of which are diesel trucks. The roadway is slightly elevated above the adjacent residential area and many of the homes in the area are less than 200 ft from the pavement edge. At one end of the installation the barrier will be carried up a bridge approach and then at reduced height, behind the railing, onto the first six spans of the bridge.

This barrier must be protected by guardrail as it will be erected approximately 17 ft from the roadway edge in a very narrow right-of-way. Also, the problem of noise reflection from the barrier surface to the opposite side of the roadway is not important because that area contains only a water treatment plant which is set back some 600 or more feet from the expressway.

The third case involves a school located 280 ft from the pavement edge of another high traffic volume expressway which has 19 percent commercial vehicles again consisting of mostly diesel trucks. The school and roadway are on essentially flat terrain, both at the same elevation, and with no intervening structures to provide shielding.

The barrier to be erected will be a 10 ft high earth mound with 1 on 2 slopes and approximately 1,850 ft in length. This structure should lower the present L_{10} of 71 dbA and L_{50} of 66 dbA, to 59 dbA and 54 dbA, respectively.

The earth to be used in constructing the mound will be taken from one of the quadrants of a nearby cloverleaf interchange where its removal will solve a sight distance problem for vehicles entering the expressway.

A really important aspect of this whole area of noise complaints for the highway noise worker to recognize is the vast amount of time and effort that he will be called upon to expend. Certainly this has been Michigan's experience. Hundreds of man-hours have been expended in the past year alone, and the portent for the future is for more time and effort to be required, rather than less.

5. Public Service Activities and Consultations

Because of the relative scarcity of technologists experienced in the highway noise subject area, engineers and scientists in the various state highway departments who become involved in, and familiar with the problem, should anticipate many requests for service and advice over and above their routine work assignments.

Complying with these requests in Michigan has led to membership on county environmental planning boards; membership on national and regional noise advisory committees; advisory services to individuals and committees of the state legislature; participation in local school environmental science classes; advisory service to the Governor's Council for Environmental Quality; interviews by local newspapers, television stations and other news media, and similar activities.

In addition, although it has not yet happened in Michigan, the highway noise specialist would be wise to prepare for involvement as an expert witness in litigation relative to noise problems. This possibility has already become fact for the personnel of some states and it should not be lightly dismissed as being a remote possibility.

Again, as with the other non-programmed activities associated with the highway noise problem specifically, and community noise problems in general, the conflict for the highway noise technologist becomes one of finding time to accomplish all of the important and necessary aforementioned services.

Activity to date in the consultation category has not been extensive. In the main it has consisted of phone discussions and written correspondence with personnel of other State of Michigan departments, of highway departments in other states, with municipal officials, with private citizens, and with representatives of commercial organizations.

In one instance, however, the Department advised on a residential area noise problem resulting from operation of a nearby sand mine. It was necessary to make sound level measurements in the residential area, and in and around the mine; plus an inspection and evaluation of the mine operation procedures with respect to the noise ramifications of those procedures.

The problem was satisfactorily resolved by adoption, by the mining firm, of recommendations for some minor changes in sand removal procedures and erection of two sand mound noise barriers.

SECTION IV

RATIONALE FOR CANCELLING PROJECT OBJECTIVES

RATIONALE FOR CANCELLING PROJECT OBJECTIVES

As stated earlier, the situation with respect to highway vehicle noise in the United States has undergone significant change since the proposal for the Michigan study was first prepared in 1967. These changes are such as to dictate an in-depth reevaluation of the overall problem.

The basic test of each original objective in this evaluation was its ability to affirmatively answer the question, "Will its achievement make a significant contribution towards resolution of the highway noise problem?"

In the following text each original objective is considered separately in response to this question.

OBJECTIVE 1

"To assemble a comprehensive bibliography with abstracts of all studies pertinent to the highway noise problem."

This objective constituted the opening phase of the study and efforts had proceeded to the point where some 100 reports had been studied, abstracted and cataloged. At this time the Department of Transportation, through the Highway Research Board, initiated the Transportation Noise Research Information Service (TNRIS) and by so doing obviated any need for Michigan to continue with its work. TNRIS, at last count, has accumulated approximately 4,500 references and was in the process of abstracting, cataloging and publishing them. The TNRIS Development Noise Bulletin containing about 500 abstracts was published in March 1971, the second issue in October 1971, and subsequent issues will be forthcoming on a regular basis. Thus, efforts in the literature compilation area have been terminated in Michigan.

OBJECTIVE 2

"Determine and characterize the sound spectra of the various types of vehicles in the traffic stream."

Studies published in the near past provide a plethora of such spectra. Samplings of Michigan vehicle spectra show them to be, as expected, very similar to the frequency and amplitude distributions found by others, in other areas.

Again no significant contribution can be foreseen by further efforts and, therefore, vehicle spectra characterization has been terminated.

OBJECTIVE 3

"Determine and characterize the composite sound spectra radiating from different highway sites carrying various mixtures of private and commercial vehicles."

Numerous techniques are currently available for characterizing the noise radiation from highway sites. Of these the L system used by Bolt Beranek and Newman appears to have widest acceptance and use. This method characterizes noise on the basis of A-weighted decibels rather than on any differentiated spectral band information.

This is appropriate, at this time, as characterizations based on human subjective response to noise are not well developed in relation to octave or 1/3-octave bands. In addition, the response work that has been done indicates that the significant extra effort required to utilize the Zwicker or Stevens methods is not worthwhile in light of the very small improvement achieved.

These findings, and the ease of use of A-weighted decibels, have probably been the principal determining factors leading to the development and use of dbA-based characterization methods. Certainly these have been the determinants which led Michigan's workers to adopt and use the dbA methods.

For maximum utility and value any highway noise characterization method should be independent of site and traffic variables. Ideally, it is simply a method for arriving at a statistic which appropriately and validly characterizes a continuous, intermittent, or mixed continuous-intermittent noise impinging on a selected observer point.

The L method meets these utility and validity requirements and consequently has received wide acceptance by highway noise workers, including those here in Michigan.

In normal use, and in application to established noise design criteria, as presented in NCHRP Report No. 117, it has been customary to determine L_{10} and L_{50} levels (levels exceeding 10 percent and 50 percent of the time, respectively). In addition to these two statistics, Michigan has found it of value to also determine L_{99} levels (background) and L_1 levels (peak).

In summary, Michigan is extensively utilizing the L level method for all types of noise studies, including those for environmental impact studies, and finds it a very satisfactory tool for such work. Further, in view of this finding it is difficult to rationalize the expenditure of research funds and scientific manpower in attempts to evolve some possibly better system.

Certainly, this is not to imply that the L method is the ultimate in characterization techniques; but at this point in the development of noise measurement and specification methodology it appears an excellent present solution to a part of the problem. Because of its adequacy and the serious deficiencies in other areas of the noise problem, efforts and funds would be more justifiably expended in those other areas of need.

There is a need for the development of a more time-dependent characterization method; one which provides a statistic or statistics related to the impact of various noise levels, over time, on various noise sensitive human activities. The development of such a characterization will, however, require a study of major proportions; one beyond the personnel and facility capabilities of Michigan's small noise research team.

OBJECTIVE 4

> "Develop a computer program of verified accuracy which will predict the noise spectrum that will radiate from a highway under any given set of known conditions."

In 1967, when the proposal for this study was in preparation, there was no known computer program available for predicting highway-generated noise. Because of the obvious impending need for such capability, its development was included as one of the objectives of the study.

Since that time, however, at least five known computer programs have come into being; and three of these programs are now available for use by highway departments. These programs are:

1. The "Statistical Noise Computer Simulation" developed by Bolt Veranek and Newman in their NCHRP Project 3-7 (Report No. 78).

This simulation model is discussed earlier in this report and an expanded version has been included here in total as Appendix C.

2. The Michigan computer implementation of the so-called "Complete Method" of BBN's "Highway Noise - A Design Guide for Engineers," NCHRP Report No. 117 (Appendix B).

In their report BBN have presented two "cookbook" methods enabling non-acousticians (highway designers and planners) to obtain estimates of noise radiating from highways on the basis of the types of information readily available to highway personnel. These two methods, called the "Complete Method" and the "Short Method" are intended to supplement each other.

The short method allows the rapid calculation of L_{10} and L_{50} values for any given site. The method's simplicity and ease of use make it an ideal tool for locating trouble spots (potentially high noise areas) and justifying the elimination from further consideration of other unaffected locations.

The short method, however, is a first approximation, and usually results in higher L_{10} and L_{50} levels than the complete method. For this reason BBN recommends that subsequent to using the short method for screening out non-critical observer points, the complete method be applied to obtain more accurate levels for indicated high noise areas.

To simplify the complete method procedure even further for its designers and planners, Michigan has computer-implemented it for time share terminals.

3. The "HINOI: A digital Computer Program to Aid Highway Noise Design Calculations" by A. Lavin and F. G. Haag, July 1971, is an attempt at implementing BBN's NCHRP Report No. 117. It, however, appears inefficient due to its method of programming. Most of BBN's graphs can be approximated by a single function of several variables and should be implemented as such instead of as a collection of up to six equations per graph.

4. Serendipity, Inc. of Arlington, Virginia under contract DOT-OS-A9-018 with the Office of Noise Abatement, U. S. Department of Transportation, in a series of reports (1-6) has developed noise prediction computer programs for all modes of transportation, including highways.

The reports of Serendipity's work have only recently been made available to highway departments so no further comment can be made on this system at this time, except that it appears to be very detailed and encompassing. Noise workers, however, can look to this system as another tool to aid in their efforts at noise reduction and control.

5. Environmental Systems Laboratory, Inc. of California is reported to have mathematically modeled the highway noise problem, and from that model to have implemented a FORTRAN computer program for predicting highway noise. The program, also reported to have been field validated,

is purportedly capable of producing continuous noise contours, or noise maps, of any highway site.

This reference to the ESL system is qualified by the words, "is reported to" and, "purportedly" because Michigan has no first hand knowledge or experience with the program. The little information that is given relative to the program's existence, and to its capabilities, was gained from a telephone discussion with ESL's Dr. Michael Hogan in March 1971. There is no intent here to imply any questioning of Dr. Hogan's system description. Rather, the qualifiers are inserted simply because Michigan's only exposure to the system has been that verbal description.

On the basis of the existence of the computerized version of BBN's Complete Method noise predictor of NCHRP No. 117, their statistical noise computer simulation of NCHRP No. 78, the DOT noise program, and the plethora of both public and private programs that are sure to be developed in the near future; it has been concluded that for Michigan to expend its personnel and resources developing an additional, new computer program would be an unproductive effort. Objective 4, is therefore recommended for deletion.

OBJECTIVE 5

> "To conduct experiments aimed at validating the reputed correlation between the Zwicker Method and human subjective response (perception only). If it is verified that the Zwicker Method does reflect subjective perception of highway noise with good fidelity then it will be possible to estimate the perceptual effects of various noise situations without the need for difficult and complicated human response studies. Simultaneously with the response - Zwicker studies, A-scale weighted decibel readings (dbA) will be taken to determine their correlation with subjective response as at least one report (2) has indicated a good dbA - response relationship."

At the time of proposal preparation the authors were of the opinion that subjective response would be found to correlate much better with Zwicker sones than with dbA or any of the other objective measures. Consequently this objective was included in the proposal to test that hypothesis. The objective statement also included reference to performing correlations with dbA as at least one study (1967) had shown a good relationship between subjective response and that measure. Again, however, on the basis of studies performed by others, Michigan has concluded that such a study program would be redundant. The cost and effort required would be considerable and, because of work by others, the results predictable.

It would be superfluous in this short report to repeat the two excellent existing rationales for the use of dbA as the currently superior measure for highway vehicle noise. These two rationales, which in turn reference numerous studies, are that of D. C. Lavender, "Interpretation of Noise Measurements," Journal of Sound and Vibration (1971), 15(1), pp. 1-9, and that of Galloway, Clark and Kerrick, Highway Noise - Measurement, Simulation, and Mixed Reactions, NCHRP Report No. 78 (1969), pp. 22-29. Review of these two papers by interested readers should convince them that dbA is the best, practical objective measure of highway noise at this time--it is accepted by Michigan as such. This acceptance then raised the question of future Michigan progress in the subjective area. Should the objective be deleted or should further efforts be directed towards some other problem aspect of the subjective response?

In an intensive effort to determine a human response study program which would "make a significant contribution towards resolution of the highway noise problem," scores of hours of meetings and discussions were conducted. Disciplines represented by the attendees at these meetings included physics, electrical engineering, research statistics, psychology, mechanical engineering, and systems science. Despite this considerable array of scientific manpower the meetings produced no feasible alternatives to the original objective. At least none which would accomplish more than to simply provide support for response knowledge or correlation already determined and published in the literature.

OBJECTIVE 6

> "To determine, through experimentation, a practical and economical combination of available materials and configurations for barring or absorbing the noise radiating from any highway site thereby preventing it from entering the areas adjacent to the highway."

Many of the problems and particulars of highway noise barriers are discussed in some detail earlier in this report. It is obvious, however, from review of that material that the experimental barriers originally planned for construction and performance evaluation during this study were not completed.

The reasons for this deficiency are numerous; the principals being insufficient knowledge of the subject at the time of study proposal preparation which, in turn, resulted in a gross underestimate of the funds required.

Table 2, taken from the proposal, shows the factorial barrier experiment as it was originally planned. Examination now discloses certain inadequacies in the design, namely: (a) the "Source Type" categories listed are all point sources while to properly evaluate a barrier one should also use a line source (acoustic power assumed to be evenly distributed along the roadway--high density traffic flow); (b) the heights of 5, 7, and 9 ft are not sufficiently characteristic of practical heights for highway noise, 12 and 15 ft should also be included; (c) the Barrier-to-Sensor distances of 50, 100, and 200 ft are inadequate and should also include 400, 600, 800, and 1,000-ft increments. These changes would increase the scope of a full factorial experiment, with reasonable repetitions, to 12,000 to 15,000 measurements.

The principal problem, however, is not one of number of measurements, but rather one of cost. Consider that a barrier adequate to meet the knowledge needs of noise shielding from point and line sources would have to be on the order of 2,000 ft long. In addition, it would be of adjustable height up to 15 ft; and if the factorial experiment design was to be literally followed, three barrier configurations, constructed in three different materials each, would be required--a total of nine barriers, each 15 ft high and 2,000 ft long.

The cost implications of such a program are immediately obvious, with the total possibly exceeding $1,500,000. In addition, the logistics of such an experiment would be a major expense in itself. And including the cost of land if the experiment were performed at an isolated site, could add significantly to the already excessive cost estimated above.

Assuming, however, that the costs in effort, time, and money were acceptable, is the experiment indicated by the current national and international situation with respect to highway noise barriers? The authors of this paper think not.

At least six barrier types constructed by the Province of Ontario and City of Toronto are now under test. These include standard and lightweight concrete walls, using poured-in-place and precast techniques; concrete block walls; aluminum modular walls; rock filled cribs; and earth mound walls. The State of California is known to have erected and tested a number of barriers of significant lengths along its expressways. In addition, other states are experimenting with various barrier types, materials, and configurations. This activity plus that going on in Europe and elsewhere indicates that a great deal of information on all aspects of barriers will be entering the literature in the near future.

Given this situation as a starting point would make it difficult to design an appropriate (non-redundant) barrier material and configuration study.

By the time a design guidance survey could be completed, an experiment initiated, completed, analyzed and reported, the probability is high that it would be redundant information.

In the light of this accelerating activity and in view of the projected costs, the experiment as proposed is not deemed justified and, therefore, it is suggested for cancellation.

TABLE 2
DESIGN OF NOISE BARRIER STUDY

Variables	Number of each type of variable[1]
Source Type	White Noise, Car, Sports Car, Cycle, Diesel Truck, Truck
Barrier Heights, ft	5, 7, 9
Barrier Material[2]	1, 2, 3
Barrier Configuration[2]	1, 2, 3
Distance (Source to Barrier), ft	25, 75, 125
Distance (Barrier to Sensor), ft	50, 100, 200
Distance (Sensor to Ground), ft	5, 50

[1] A full factorial experiment will require 2,916 measurements.
[2] Specific materials or configurations are, as yet, undetermined.

SECTION V

CONCLUSIONS AND OBSERVATIONS

CONCLUSIONS AND OBSERVATIONS

As a result of the work on this project and in related areas, certain conclusions and observations are indicated. They relate to both current and future development of the highway noise problem and its resolution. Unfortunately, as with most studies relative to new areas of concern, this program terminates with recommendations for further study.

1) In addition to its other content, this report contains a request for FHWA approval to terminate the study on receipt of this report. Section IV contains a rationale for deleting each of the original project objectives, and Section III gives a description of those many noise-related activities that have pre-empted work on the project. Of most significance, of course, were the rationales for not attempting to achieve the original objectives. The reason being, in almost every instance, that the objective has already been achieved by other workers in the field. Coupling this with the great amount of required activity on non-project noise work, plus the limited staff and facilities available, indicates that the most realistic and reasonable way to proceed is to terminate the project. This termination would permit the personnel now involved to direct their efforts to other, more productive, aspects of Michigan's highway noise problem.

2) Probably the greatest accomplishment of this project relates to the education and training of certain Michigan researchers. Prior to the project, this staff had devoted themselves to the many highway problems of a structural, material, or operational nature; but had not been called on to study the problem of noise. Now, however, these technologists are experienced and well versed on the subject and should, with administrative support, be able to proceed towards resolution of the highway noise problem as it exists in this State. Experience and knowledge has been gained on most aspects of the problem including: source characteristics and variables, transmission path variables including effects of interposed obstacles (barriers), receiver or observer characteristics (subjective response), measurement, analysis and characterization techniques, computer modeling and simulation procedures, and many other facets of the problem.

If nothing other than this training and knowledge has been accomplished, the project has been extremely worthwhile. There is no question that the major obstacle to solution of the nation's highway noise problem, has been a glaring highway noise information deficiency throughout the technical community, and particularly with highway technologists. Studies such as this with their inherent educational content will provide long-term benefits to the transportation industry and thereby to the citizens served.

3) Michigan's experience in this field should serve as a lesson and a warning to other states to exercise great care in planning noise studies. The primary error here was the failure to foresee and plan for the great increase in all aspects of the highway noise problem. These many performance areas, detailed in the body of the report, would probably not be appropriate for inclusion in such a study, but because of their priority, frequency and short-time deadlines they consumed much time and effort that had been programmed for the study. Once the noise problem fully descends upon a state agency it should be very pessimistic with respect to being able to assign large amounts of time for the careful, detailed analytical type field and laboratory performance required for research programs.

4) The project has been successful from the Michigan viewpoint despite the fact that all objectives were not completed. The principal accomplishment, as stated earlier, was the realization of an equipped and noise-sophisticated staff of technologists who are already being applied to Michigan's noise problem. In the process of gaining experience and knowledge the staff has made certain accomplishments that would be of value to noise workers in other states, including:

a. Development of field measurement techniques, equipment, and procedures.

b. Development of data reduction and analysis procedures and equipment.

c. Computer implementation of the manual noise prediction method of NCHRP Report No. 117, to facilitate its use by research, planning, and design personnel.

d. Addition of the barrier model to the computerized statistical noise simulation method of NCHRP Report No. 78; plus other lesser changes and improvements to the program.

e. Confirmation of the spectral noise characteristics of highway vehicles--essentially identical to those found elsewhere.

f. An experiment to determine "psychological" shielding effects of a minimal noise barrier.

g. The detailed requirements and difficulties of achieving state-wide vehicle noise control legislation.

5) Finally, the work has disclosed or confirmed the need for further efforts on certain parts of the overall problem. These include: subjective response to time-varying noise; field validation of computer program predictions; development of a noise characterization method more universal

and appropriate than the present L methods; and the evaluation of barrier materials as a function of initial costs, maintenance, and effectiveness. In addition, a comprehensive study is needed to determine the technical and economic trade-offs associated with various proposed statutory vehicle noise limits.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

REFERENCES

1. Zwicker, E., "Ein Verfahren zur Beruchnung der Lautstärke (A Procedure for Calculating Loudness), Acustica, 10, 1960, p. 304.

2. Mills, C. H. G., and Robinson, D. W., "The Subjective Rating of Motor Vehicle Noise," The Engineer, No. 5501, June 1961, p. 211.

3. Galloway, W. J., Clark, W. E., and Kerrick, J. S., "Highway Noise-Measurement, Simulation and Mixed Reactions, "National Cooperative Highway Research Program Report No. 78, Highway Research Board, 1969.

4. Maekawa, Z., "Noise Reduction by Screens," Applied Acoustics, Vol. 1, 1968, pp. 157-73.

5. Gordon, C. G., Galloway, W. J., Kugler, B. A., and Nelson, D. L., "Highway Noise--A Design Guide for Highway Engineers," National Cooperative Highway Research Program Report No. 117, Highway Research Board, 1971.

6. Beranek, L. L., Noise Reduction, McGraw-Hill, New York, 1960.

7. Maryland State Roads Commission, Highway Noise Abatement Project, unpublished.

8. Proudfoot Co., Inc., "Soundblox," The Proudfoot Company, Inc., Bulletin, 9.1/Pr.

9. Reinhold, Günter, and Burger, Wolfgang, "The Functional and Operational Testing of Absorbing Noise Barriers Along an Autobahn, " (in German), Strasse und Autobahn, Heft 1, 1971.

10. Rucker, August and Glück, Karl, "Constructional Protective Measures for the Reduction of Street Traffic Noise," (in German), Strassenbau and Strassenverkenhrstechnik, Heft 47, 1966.

11. Harmelink, M. D., "Noise and Vibration Control for Transportation Systems," Report RR 168, Department of Highways, Ontario, Canada, October 1970.

12. Cook, D. E., and VanHaverbeke, D. F., "Trees and Shrubs for Noise Abatement," Research Bulletin 246, Agricultural Experiment Station, University of Nebraska College of Agriculture, July 1971.

13. Beaton, John L. and Bourget, Louis, "Can Noise Radiation from Highways be Reduced by Design," M & C 636 316-1, Division of Highways, State of California, 1968.

14. Serendipity, Inc., "A Study of the Magnitude of Transportation Noise Generation and Potential Abatement," for U. S. Department of Transportation under Contract DOT-OS-A9-018, 1970-72, Serendipity, Inc., Arlington, Virginia, November 1970.

APPENDIX A

PROPOSED MICHIGAN VEHICLE NOISE CONTROL LEGISLATION

APPENDIX A

PROPOSED MICHIGAN VEHICLE NOISE CONTROL LEGISLATION

Primarily through the efforts of the Michigan Department of State Highways, acting in turn upon a request from the Governor's Office, vehicle noise bills have been introduced in both houses of the Michigan State Legislature. Amendments have been submitted to the bills in both House and Senate, but none of the original bills, or their amendments, are considered satisfactory by the Department of State Highways. Consequently, efforts by the Department are continuing in an attempt to have its vehicle noise bill introduced and hopefully enacted--a bill significantly more stringent than any of those already introduced.

The three subject bills, their proposed amendments and the Michigan Department of State Highways bill are included in this appendix. Specifically included, and in the order presented, are:

1. Department of Highways Proposed Bill.
    a) Proposed Enforcement Teams
    b) Proposed Violation Penalty Clause
2. Senate Bill No. 1017
3. House Bill No. 4115
4. Amendment to 4115
5. House Bill No. 4200
6. Amendment to 4200

MICHIGAN DEPARTMENT OF STATE HIGHWAYS PROPOSED BILL

SECTION 707

(A) NO MOTOR VEHICLE SHALL BE OPERATED OR DRIVEN UPON THE HIGHWAYS OF THE STATE UNLESS AT ALL TIMES EQUIPPED WITH AN ENGINE EXHAUST MUFFLING SYSTEM IN CONSTANT OPERATION AND PROPERLY MAINTAINED TO PREVENT THE ESCAPE OF UNUSUAL OR EXCESSIVE NOISE AND NO SUCH SYSTEM SHALL BE EQUIPPED WITH A CUTOUT, BYPASS OR SIMILAR DEVICE. NO MUFFLING SYSTEM ORIGINALLY INSTALLED ON A VEHICLE SHALL BE MODIFIED IN A MANNER WHICH WILL AMPLIFY OR INCREASE THE EMITTED NOISE TO A LEVEL ABOVE THAT EMITTED BY THE ORIGINAL SYSTEM AND ALL SUCH ORIGINAL SYSTEMS SHALL COMPLY WITH THE REQUIREMENTS OF THIS SECTION.

(B)[1] NO MOTOR VEHICLE SHALL BE OPERATED OR DRIVEN UPON THE HIGHWAYS OF THE STATE IN A CONDITION OR MANNER CAUSING IT TO PRODUCE NOISE EXCEEDING THE FOLLOWING NOISE LIMITS:

	POSTED SPEED LIMIT OF 35 MILES PER HOUR OR LESS	POSTED SPEED LIMIT OF OVER 35 MILES PER HOUR
(1) A MOTOR VEHICLE WITH A MANUFACTURER'S GROSS VEHICLE RATING OF 6,000 POUNDS OR MORE, SINGLY OR TOWING ANY SEMITRAILER, POLE TRAILER OR COMBINATION.	82 dbA	84 dbA
(2) A MOTORCYCLE, OTHER THAN A MOTOR DRIVEN CYCLE.	78 dbA	82 dbA
(3) ANY OTHER MOTOR VEHICLE AND ANY COMBINATION OF VEHICLES TOWED BY A MOTOR VEHICLE.	74 dbA	78 dbA

(C)[2] NO MOTOR VEHICLE MANUFACTURED OR ALTERED AFTER THE FOLLOWING DATES SHALL PRODUCE NOISE WHICH EXCEEDS THE FOLLOWING NOISE LIMITS:

(1) A MOTOR VEHICLE WITH A GVW RATING OF 6,000 POUNDS OR MORE

(a) Manufactured after July 1, 1972 and before July 1, 1974	88 dbA
(b) Manufactured after July 1, 1974 and before July 1, 1976	86 dbA
(c) Manufactured after July 1, 1976 and before July 1, 1978	83 dbA
(d) Manufactured after July 1, 1978.	80 dbA

---

[1] (OPERATIONAL LIMITS - Directed towards existing vehicles. Called operational because compliance with this section is highly dependent upon proper operation. Many vehicles in this category could exceed limits if not operated properly).

[2] (NEW VEHICLE LIMITS - These differ from operation limits in that they cannot legally be exceeded by a vehicle even in its maximum noise producing mode of operation).

(2) A MOTORCYCLE, OTHER THAN A MOTOR DRIVEN CYCLE

(a)	Manufactured after July 1, 1972 and before July 1, 1974	88 dbA
(b)	Manufactured after July 1, 1974 and before July 1, 1976	84 dbA
(c)	Manufactured after July 1, 1976 and before July 1, 1978	80 dbA
(d)	Manufactured after July 1, 1978.	75 dbA

(3) ANY OTHER MOTOR VEHICLE

(a)	Manufactured after July 1, 1972 and before July 1, 1974	86 dbA
(b)	Manufactured after July 1, 1974 and before July 1, 1976	84 dbA
(c)	Manufactured after July 1, 1976 and before July 1, 1978	80 dbA
(d)	Manufactured after July 1, 1978.	75 dbA

(D) THE NOISE LEVEL SHALL BE MEASURED WITH "A" WEIGHTING AT A DISTANCE OF NOT LESS THAN 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL, PURSUANT TO RULES PROMULGATED BY THE DEPARTMENT OF STATE POLICE AND THE STATE HIGHWAY COMMISSION.

(E) THIS SECTION SHALL NOT APPLY TO WARNING DEVICES ON AUTHORIZED EMERGENCY VEHICLES OR TO VEHICLES MOVING UNDER A SPECIAL PERMIT.

PROPOSED NOISE ENFORCEMENT TEAMS

Each team should consist of one Measurement Unit and two Pursuit Units, constituted and operating as follows:

Measurement Unit consisting of one officer in a vehicle equipped with two-way radio, sound level meter, meter calibrator, and tripod mounted microphone.

This unit would be placed at any selected highway site to monitor noise levels of passing vehicles. When a vehicle is detected having a noise level exceeding the statutory limit the unit operator will log the level and vehicle identification and radio ahead to a pursuit unit.

Pursuit Unit will be located down the traffic stream from the measurement unit. It will consist of a radio equipped vehicle manned by one officer. No special equipment is necessary.

Pursuit Units will be responsible for stopping and citing, as necessary, those overloud vehicles detected by the Measurement Unit.

A complete team consisting of one measurement unit and two pursuit units would have a first year cost of approximately $55,000, as follows:

A.	Officer salaries (3)	$39,000
B.	Three radio equipped vehicles	10,500
C.	Sound measurement equipment[3]	1,500
D.	Supplies and miscellaneous	4,000
		$55,000

PROPOSED NOISE VIOLATION PENALTY CLAUSE

Penalty

Any person convicted of a violation of any of the provision of this section declared to constitute a misdemeanor, except for the different penalty expressly provided below for exceeding a noise limit of (B) or (C), shall be punished by a fine of not more than $100 or by imprisonment for not more than 90 days, or by both such fine and imprisonment.

(1) Any person convicted of exceeding a noise limit of this section shall be fined at a rate of $40 for each dbA in excess of the specified limit but not to exceed $500.

(2) In addition to such fines as may be imposed, no person shall operate, and no owner shall permit the operation of a cited vehicle for more than 30 days after the violation unless said motor vehicle shall have been brought into compliance with the regulations of this section.

[3] All participating officers would receive a comprehensive training program (probably one to two weeks) prior to beginning their enforcement activities to ensure thorough familiarization with their equipments and procedures.

SENATE BILL NO. 1017

Referred to Committee on Highways.

A bill to amend section 707 of Act No. 300 of the Public Acts of 1949, entitled as amended

"Michigan vehicle code,"

as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948.

THE PEOPLE OF THE STATE OF MICHIGAN ENACT:

Section 1. Section 707 of Act No. 300 of the Public Acts of 1949, as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948, is amended to read as follows:

Sec. 707. (A) A MOTOR VEHICLE SHALL NOT BE OPERATED UPON A HIGHWAY WHICH PRODUCES NOISE EXCEEDING THE FOLLOWING NOISE LIMITS:

		SPEED LIMIT OF 35 MILES PER HOUR OR LESS.	SPEED LIMIT OF MORE THAN 35 MILES PER HOUR.
(1)	A MOTOR VEHICLE WITH A MANUFACTURER'S GROSS VEHICLE RATING OF 6,000 POUNDS OR MORE TOWING ANY SEMITRAILER POLE TRAILER OR TRAILER OR COMBINATION THEREOF.	88 dbA	90 dbA
(2)	A MOTOR VEHICLE WITH A MANUFACTURER'S GROSS VEHICLE RATING OF MORE THAN 6,000 POUNDS.	86 dbA	88 dbA
(3)	A MOTORCYCLE	82 dbA	86 dbA
(4)	ANY OTHER MOTOR VEHICLE AND ANY COMBINATION OF VEHICLES TOWED BY A MOTOR VEHICLE.	76 dbA	82 dbA

(B) A MOTOR VEHICLE MANUFACTURED OR ALTERED AFTER THE FOLLOWING DATES SHALL NOT PRODUCE NOISE WHICH EXCEEDS THE FOLLOWING NOISE LIMITS:

(1) A MOTORCYCLE MANUFACTURED AFTER JULY 1, 1971, AND BEFORE JULY 1, 1973.	88 dbA
(2) A MOTORCYCLE MANUFACTURED AFTER JULY 1, 1973.	86 dbA
(3) A MOTOR VEHICLE WITH A GROSS VEHICLE RATING OF 6,000 POUNDS OR MORE MANUFACTURED AFTER JULY 1, 1971, AND BEFORE JULY 1, 1973.	88 dbA
(4) A MOTOR VEHICLE WITH A GROSS VEHICLE WEIGHT OF 6,000 POUNDS OR MORE MANUFACTURED AFTER JULY 1, 1973.	84 dbA
(5) ANY OTHER MOTOR VEHICLE MANUFACTURED AFTER JULY 1, 1973.	84 dbA

(C) THE NOISE LEVEL SHALL BE MEASURED WITH "A" WEIGHTING AT A DISTANCE OF NOT LESS THAN 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL, PURSUANT TO RULES PROMULGATED BY THE DEPARTMENT OF STATE POLICE AND THE STATE HIGHWAY COMMISSION. THIS SECTION SHALL NOT APPLY TO WARNING DEVICES ON AUTHORIZED EMERGENCY VEHICLES OR TO VEHICLES MOVING UNDER A SPECIAL PERMIT.

(D) A PERSON SHALL NOT HAVE A CAUSE OF ACTION PURSUANT TO THIS SECTION AGAINST A MANUFACTURER OF A VEHICLE OR A COMPONENT PART THEREOF BECAUSE OF A BREACH OF EXPRESS OR IMPLIED WARRANTY UNLESS THE MANUFACTURER DID NOT COMPLY WITH NOISE LIMIT STANDARDS OF THIS ACT APPLICABLE TO MANUFACTURERS AND IN EFFECT AT THE TIME THE VEHICLE OR COMPONENT PART WAS FIRST SOLD FOR PURPOSES OTHER THAN RESALE.

(E) WHEN A PERSON IS CONVICTED OF VIOLATING THIS SECTION WITHIN 1 YEAR OF PURCHASE OF A NEW VEHICLE, THE SELLER SHALL REIMBURSE THE PERSON THE AMOUNT OF THE FINE AND COSTS IMPOSED AND SHALL CORRECT THE VIOLATION TO COMPLY WITH THIS SECTION WITHIN 30 DAYS OF NOTIFICATION OR MAKE FULL REFUND OF THE PURCHASE PRICE INCLUDING TAXES AND ALL OTHER CHARGES OF THE VEHICLE.

HOUSE BILL NO. 4115

Referred to Committee on Conservation and Recreation.

A bill to amend section 707 of Act No. 300 of the Public Acts of 1949, entitled as amended

"Michigan vehicle code,"

as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948.

THE PEOPLE OF THE STATE OF MICHIGAN ENACT:

Section 1. Section 707 of Act No. 300 of the Public Acts of 1949, as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948, is amended to read as follows:

Sec. 707. (a) ~~Every~~ ALL motor ~~vehicle~~ VEHICLES AND MOTORIZED CONSTRUCTION EQUIPMENT,~~-including-every-motorcycle or-motor-driven-cycle,~~ shall at all times be equipped with a muffler in good working order and in constant operation to prevent excessive or unusual noise and annoying smoke ~~and-no-person-shall-remove,-destroy-or-damage-any-or-all of-the-baffles-contained-in-such-muffler,-nor-shall-any person-use-a-muffler-cutout,-by-pass,-or-similar-device-upon a-motorcycle-or-motor-driven-cycle-on-any-highway-or-street.~~

(B) AN EXHAUST SYSTEM CONSISTING OF 1 OR MORE PIPES WITHOUT BAFFLES OR SOUND ABSORBING MEANS, WHETHER STRAIGHT OR CURVED AND WHETHER OF CONSTANT OR VARYING CROSS SECTION, SHALL BE DEEMED NOT TO CONTAIN AN EFFECTIVE MUFFLER.

(C) IT IS UNLAWFUL TO HAVE ANY DEVICE ON A MUFFLER WHICH PERMITS AN ADJUSTMENT TO BE MADE OF THE NOISE LEVEL OR TYPE OF SOUND EMITTED

(D) IT IS UNLAWFUL TO MODIFY OR REMOVE PARTS OF A STANDARD MUFFLER, OR TO UTILIZE TRUMPET OR OTHER AMPLIFIERS AS PART OF THE EXHAUST SYSTEM OF A MOTOR VEHICLE.

(E) IF NOISE IS IN EXCESS OF THE ACCEPTABLE SOUND LEVEL, AS HEREIN DEFINED, AND SHALL EMANATE FROM A VEHICLE, SUCH EVIDENCE SHALL CONSTITUTE AND BE ADMITTED AS PRESUMPTIVE EVIDENCE THAT IT WAS PRODUCING EXCESSIVE NOISE.

(F) NO PERSON SHALL SELL, GIVE FOR USE UPON, INSTALL OR USE ON ANY MOTOR VEHICLE OPERATED IN THIS STATE, ANY TYPE OF MUFFLER THAT SHALL CAUSE THE NOISE EMITTED BY THE MOTOR OF SUCH VEHICLE TO BE ABOVE THE ACCEPTABLE SOUND LEVEL OR IN VIOLATION OF THIS SECTION.

(G) AS USED IN THIS SECTION "ACCEPTABLE SOUND LEVEL" REFERS TO A SOUND LEVEL WHICH HAS A VALUE OF 90 DECIBELS OR LESS. SOUND LEVEL MEANS THE NOISE EMANATING FROM ANY MOTOR VEHICLE AND MEASURED IN ACCORDANCE WITH THE LATEST STANDARDS PUBLISHED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS.

~~(b)~~ (H) The engine and power mechanism of every motor vehicle shall be so equipped and adjusted as to prevent the escape of excessive fumes or smoke.

AMENDMENT TO HOUSE BILL NO. 4115

A bill to amend section 707 of Act No. 300 of the Public Acts of 1949, entitled as amended

"Michigan vehicle code,"

as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948.

THE PEOPLE OF THE STATE OF MICHIGAN ENACT:

Section 1. Section 707 of Act No. 300 of the Public Acts of 1949, as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948, is amended to read as follows:

Sec. 9a (1) "DECIBEL" MEANS A UNIT OF SOUND PRESSURE LEVEL ON A LOGARITHMIC SCALE MEASURED RELATIVE TO THE THRESHOLD OF SOUND PRESSURE NEEDED FOR HUMAN HEARING, OR 10^{-16} SCALE WATTS PER SQUARE CENTIMETER.

(2) "dbA" MEANS DECIBELS MEASURED ON THE A-WEIGHTED SCALE.

Sec. 707. (a) ~~Every~~ A PERSON SHALL NOT OPERATE A motor vehicle, ~~including-every~~ motorcycle, ~~or~~ motor driven cycle, OR MOTORIZED CONSTRUCTION EQUIPMENT UNLESS IT IS ~~shall-at-all-times-be~~ equipped with a muffler in good working order and in constant operation, AND UNLESS IT IS EQUIPPED AND ADJUSTED to prevent excessive SMOKE or ~~unusual~~ noise IN EXCESS OF THE STANDARDS OF THIS SECTION. ~~-and-annoying-smoke,-and-no~~ A person shall NOT remove, destroy or damage ~~any-or-all-of-the-baffles~~ A BAFFLE ~~contained~~ in ~~such~~ THE muffler. ~~,nor-shall-any~~ A person SHALL NOT use a muffler cutout, bypass or similar device upon a motorcycle or motor driven cycle on ~~any~~ A highway or street.

(b) ~~The engine and power mechanism of every motor vehicle shall be so equipped and adjusted as to prevent the escape of excessive fumes or smoke.~~ A PERSON SHALL NOT SELL, TRANSFER, INSTALL, CAUSE TO BE INSTALLED, OR ALTER UPON A VEHICLE AN EXHAUST SYSTEM OR SOUND MUFFLING DEVICE, OR A PART THEREOF, WHICH WILL PERMIT THE VEHICLE TO EMIT NOISE OR SMOKE IN VIOLATION OF THE STANDARDS OF THIS SECTION.

(C) A PERSON SHALL NOT OPERATE A MOTOR VEHICLE WITH A MANUFACTURER'S GROSS WEIGHT RATING OF 6,000 POUNDS OR MORE IN A MANNER AS TO EXCEED 86 dbA AT A DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL AT SPEEDS OF 35 MILES PER HOUR OR LESS, OR 88 dbA AT A DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL AT SPEEDS OF MORE THAN 35 MILES PER HOUR.

(D) A PERSON SHALL NOT OPERATE A MOTOR VEHICLE WITH A MANUFACTURER'S GROSS WEIGHT RATING OF LESS THAN 6,000 POUNDS, A MOTORCYCLE OR A MOTOR DRIVEN CYCLE IN A MANNER AS TO EXCEED 82 dbA AT A DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL AT SPEEDS OF 35 MILES PER HOUR OR LESS, OR 86 dbA AT A DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL AT SPEEDS OF MORE THAN 35 MILES PER HOUR.

(E) A PERSON SHALL NOT OPERATE MOTORIZED CONSTRUCTION EQUIPMENT IN A MANNER AS TO EXCEED 88 dbA AT ANY POINT ON THE BOUNDARY OF THE CONSTRUCTION SITE.

(F) A PERSON SHALL NOT SELL, TRANSFER OR OFFER FOR SALE A MOTOR VEHICLE, MOTORCYCLE, MOTOR DRIVEN CYCLE OR MOTORIZED CONSTRUCTION EQUIPMENT WHICH PRODUCES NOISE GREATER THAN THE FOLLOWING LIMIT AT A DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL.

(1) MANUFACTURER'S GROSS WEIGHT RATING OF 6,000 POUNDS OR MORE:

(i) MANUFACTURED BEFORE JANUARY 1, 1973........86 dbA

(ii) MANUFACTURED ON OR AFTER JANUARY 1, 1973..84 dbA

(2) MANUFACTURER'S GROSS WEIGHT RATING OF LESS THAN 6,000 POUNDS:

(i) MANUFACTURED BEFORE JANUARY 1, 1970........88 dbA

(ii) MANUFACTURED ON OR AFTER JANUARY 1, 1970 AND BEFORE JANUARY 1, 1973.....................86 dbA

(iii) MANUFACTURED ON OR AFTER JANUARY 1, 1973 AND BEFORE JANUARY 1, 1975.....................84 dbA

(iv) MANUFACTURED ON OR AFTER JANUARY 1, 1975..82 dbA

(G) THE NOISE LIMITS PROVIDED IN THIS SECTION SHALL INCLUDE ALL ELEMENTS OF NOISE, SUCH AS ENGINE NOISE, TIRE NOISE, AND ANY OTHER NOISE EMITTED BY A VEHICLE, EXCEPT THE HORN. A HORN OR OTHER WARNING DEVICE SHALL NOT EXCEED NOISE LIMITS ESTABLISHED BY RULE PURSUANT TO THIS SECTION.

(H) WHEN MORE THAN 1 VEHICLE IS COUPLED TOGETHER, OR TRAILERS OR SIMILAR ATTACHMENTS ARE COUPLED TOGETHER, ALL VEHICLES, TRAILERS OR ATTACHMENTS WHICH ARE COUPLED TOGETHER CONSTITUTE 1 VEHICLE FOR THE PURPOSES OF THIS SECTION.

(I) IN A PROSECUTION UNDER THIS SECTION, A SHOWING THAT AN EXHAUST SYSTEM OR SOUND MUFFLING DEVICE DID NOT MEET THE STANDARDS OF THIS SECTION WHEN INSTALLED BY ANOTHER PERSON, AND THAT THE DEFENDANT DID NOT HAVE REASON TO BELIEVE AT THE TIME OF INSTALLATION OR A SUBSEQUENT TIME THAT THE SYSTEM OR DEVICE DID NOT MEET THE STANDARDS, CONSTITUTES AN AFFIRMATIVE DEFENSE.

(J) THE DEPARTMENT OF STATE POLICE SHALL PROMULGATE RULES FOR THE ENFORCEMENT OF THIS SECTION. WHERE NOISE LIMITS HAVE BEEN PROVIDED FOR A MEASURING DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL, THE DEPARTMENT SHALL ESTABLISH A TABLE OF EQUIVALENTS, SO THAT THE ACTUAL MEASUREMENT MAY BE TAKEN AT ANY DISTANCE. THE DEPARTMENT SHALL REPORT TO THE GOVERNOR AND THE LEGISLATURE ANNUALLY THE STATUS OF THE NOISE CONTROL PROGRAM, DEVELOPMENTS IN NOISE CONTROL TECHNOLOGY AND RECOMMENDATIONS FOR THE IMPROVEMENT OF THE STANDARDS AND THEIR ENFORCEMENT.

HOUSE BILL NO. 4200

Referred to Committee on Conservation and Recreation.

A bill to amend section 707 of Act No. 300 of the Public Acts of 1949, entitled as amended "Michigan vehicle code," as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948.

THE PEOPLE OF THE STATE OF MICHIGAN ENACT:

Section 1. Section 707 of Act No. 300 of the Public Acts of 1949, as amended by Act No. 134 of the Public Acts of 1969, being section 257.707 of the Compiled Laws of 1948, is amended to read as follows:

Sec. 707. (a) ~~Every~~ ALL motor ~~vehicle~~ VEHICLES, including every motorcycle or motor driven cycle WHEN BEING OPERATED ON A HIGHWAY OR ROAD AND MOTORIZED CONSTRUCTION EQUIPMENT, shall at all times be equipped with a muffler in good working order and in constant operation to prevent excessive or unusual noise and annoying smoke, ~~-and-no person-shall-remove,-destroy-or-damage-any-or-all-of-the baffles-contained-in-such-muffler,-nor-shall-any-person use-a-muffler-cutout,-bypass-or-similar-device-upon-a-motor cycle-or-motor-driven-cycle-on-any-highway-or-street.~~

(B) AN EXHAUST SYSTEM CONSISTING OF 1 OR MORE PIPES WITHOUT BAFFLES OR SOUND ABSORBING MEANS, WHETHER STRAIGHT OR CURVED AND WHETHER OF CONSTANT OR VARYING CROSS SECTION, SHALL BE DEEMED NOT TO CONTAIN AN EFFECTIVE MUFFLER

(C) IT IS UNLAWFUL TO HAVE ANY DEVICE ON A MUFFLER WHICH PERMITS AN ADJUSTMENT TO BE MADE OF THE NOISE LEVEL OR TYPE OF SOUND EMITTED.

(D) IT IS UNLAWFUL TO MODIFY OR REMOVE PARTS OF A STANDARD MUFFLER, OR TO UTILIZE TRUMPET OR OTHER AMPLIFIERS AS PART OF THE EXHAUST SYSTEM OF A MOTOR VEHICLE.

(E) IF NOISE IS IN EXCESS OF THE ACCEPTABLE SOUND LEVEL, AS HEREIN DEFINED, AND SHALL EMANATE FROM A VEHICLE, SUCH EVIDENCE SHALL CONSTITUTE AND BE ADMITTED AS PRESUMPTIVE EVIDENCE THAT IT WAS PRODUCING EXCESSIVE NOISE.

(F) NO PERSON SHALL SELL, GIVE FOR USE UPON, INSTALL OR USE ON ANY MOTOR VEHICLE OPERATED IN THIS STATE, ANY TYPE OF MUFFLER THAT SHALL CAUSE THE NOISE EMITTED BY THE MOTOR OF SUCH VEHICLE TO BE ABOVE THE ACCEPTABLE SOUND LEVEL OR IN VIOLATION OF THIS SECTION.

(G) AS USED IN THIS SECTION "ACCEPTABLE SOUND LEVEL" REFERS TO A SOUND LEVEL WHICH HAS A VALUE OF 90 DECIBELS OR LESS. SOUND LEVEL MEANS THE NOISE EMANATING FROM ANY MOTOR VEHICLE AND MEASURED IN ACCORDANCE WITH THE LATEST STANDARDS PUBLISHED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS.

~~(b)~~ (H) The engine and power mechanism of every motor vehicle shall be so equipped and adjusted as to prevent the escape of excessive fumes or smoke.

AMENDMENT TO HOUSE BILL NO. 4200

Sec. 707. (A) NO PERSON SHALL OPERATE EITHER A MOTOR VEHICLE OR COMBINATION OF VEHICLES INCLUDING EVERY MOTORCYCLE OR MOTOR DRIVEN CYCLE WHEN BEING OPERATED ON A HIGHWAY OR ROAD AND MOTORIZED CONSTRUCTION EQUIPMENT OF A TYPE SUBJECT TO REGISTRATION AT ANY TIME OR UNDER ANY CONDITION OF GRADE, LOAD, ACCELERATION OR DECELERATION IN SUCH A MANNER AS TO EXCEED THE FOLLOWING NOISE LIMIT FOR THE CATEGORY OF MOTOR VEHICLE BASED ON A DISTANCE OF 50 FEET FROM THE CENTER OF THE LANE OF TRAVEL WITHIN THE SPEED LIMITS SPECIFIED IN THIS SECTION:

	SPEED LIMIT OF 35 MPH OR LESS	SPEED LIMIT OF MORE THAN 35 MPH
(1) ANY MOTOR VEHICLE WITH A MANUFACTURER'S GROSS VEHICLE WEIGHT RATING OF 6,000 POUNDS OR MORE AND ANY COMBINATION OF VEHICLES TOWED BY SUCH MOTOR VEHICLE ON AND AFTER JANUARY 1, 1973..................	86 dbA	90 dbA
(2) ANY MOTORCYCLE OTHER THAN A MOTOR DRIVEN CYCLE.............	82 dbA	86 dbA
(3) ANY OTHER MOTOR VEHICLE AND ANY COMBINATION OF VEHICLES TOWED BY SUCH MOTOR VEHICLE AND MOTORIZED CONSTRUCTION EQUIPMENT..	76 dbA	82 dbA

(B) THE DEPARTMENT SHALL ADOPT RULES ESTABLISHING THE TEST PROCEDURES AND INSTRUMENTATION TO BE UTILIZED.

(C) THIS SECTION APPLIES TO THE TOTAL NOISE FROM A VEHICLE OR COMBINATION OF VEHICLES AND SHALL NOT BE CONSTRUED AS LIMITING OR PRECLUDING THE ENFORCEMENT OF ANY OTHER PROVISIONS OF THIS ACT RELATING TO MOTOR VEHICLE EXHAUST NOISE.

(D) FOR THE PURPOSE OF THIS SECTION, A TRUCK, TRUCK-TRACTOR OR BUS THAT IS NOT EQUIPPED WITH AN IDENTIFICATION PLATE OR MARKING BEARING THE MANUFACTURER'S NAME AND MANUFACTURER'S GROSS VEHICLE WEIGHT RATING SHALL BE CONSIDERED AS HAVING A MANUFACTURER'S GROSS VEHICLE WEIGHT RATING OF 6,000 POUNDS OR MORE IF THE UNLADEN WEIGHT IS MORE THAN 5,000 POUNDS.

(E) NO PERSON SHALL HAVE A CAUSE OF ACTION RELATING TO THE PROVISIONS OF THIS SECTION AGAINST A MANUFACTURER OF A VEHICLE OR A COMPONENT PART THEREOF ON A THEORY BASED UPON BREACH OF EXPRESS OR IMPLIED WARRANTY UNLESS IT IS ALLEGED AND PROVED THAT SUCH MANUFACTURER DID NOT COMPLY WITH NOISE LIMIT STANDARDS OF THIS ACT APPLICABLE TO MANUFACTURERS AND IN EFFECT AT THE TIME SUCH VEHICLE OR COMPONENT PART WAS FIRST SOLD FOR PURPOSES OTHER THAN RESALE.

Sec. 707A. (A) NO PERSON SHALL SELL OR OFFER FOR SALE A NEW MOTOR VEHICLE WHICH PRODUCES A MAXIMUM NOISE EXCEEDING THE FOLLOWING NOISE LIMIT AT A DISTANCE OF 50 FEET FROM THE CENTERLINE OF TRAVEL UNDER TEST PROCEDURES ESTABLISHED BY THE DEPARTMENT:

(1) ANY MOTORCYCLE MANUFACTURED BEFORE JANUARY 1, 1970.................................... 92 dbA

(2) ANY MOTORCYCLE, OTHER THAN A MOTOR DRIVEN CYCLE, MANUFACTURED ON OR AFTER JANUARY 1, 1970, AND BEFORE JANUARY 1, 1973........................ 88 dbA

(3) ANY MOTORCYCLE, OTHER THAN A MOTOR DRIVEN CYCLE, MANUFACTURED ON OR AFTER JANUARY 1, 1973... 86 dbA

(4) ANY MOTOR VEHICLE WITH A GROSS VEHICLE WEIGHT RATING OF 6,000 POUNDS OR MORE MANUFACTURED ON OR AFTER JANUARY 1, 1968, AND BEFORE JANUARY 1, 1973...................................... 88 dbA

(5) ANY MOTOR VEHICLE WITH A GROSS VEHICLE WEIGHT RATING OF 6,000 POUNDS OR MORE MANUFACTURED ON OR AFTER JANUARY 1, 1973....................... 86 dbA

(6) ANY OTHER MOTOR VEHICLE MANUFACTURED ON OR AFTER JANUARY 1, 1968, AND BEFORE JANUARY 1, 1973.. 86 dbA

(7) ANY OTHER MOTOR VEHICLE MANUFACTURED AFTER JANUARY 1, 1973............................ 84 dbA

(B) TEST PROCEDURES FOR COMPLIANCE WITH THIS SECTION SHALL BE ESTABLISHED BY THE DEPARTMENT, TAKING INTO CONSIDERATION THE TEST PROCEDURES OF THE SOCIETY OF AUTOMOTIVE ENGINEERS.

APPENDIX B

COMPUTER PROGRAM FOR THE NOISE PREDICTION METHOD FOR NCHRP REPORT NO. 117

COMPUTER PROGRAM FOR THE NOISE PREDICTION METHOD OF NCHRP REPORT NO. 117

Flow charts of the mainline program (Fig. 28) and the three subroutines (Fig. 29) and the entire program listing are included in this appendix.

Assuming that time share capability is not available to all users, the program can be modified to run on batch processing.

The WRITE and FORMAT statements which request the insertion of certain data can be deleted for batch processing. Care should be taken when deleting WRITE statements having line numbers which are addressed from other parts of the program.

Also, the file statement at the beginning will need to be changed to the proper card reader and printer numbers and the free field format (/) on the READ statements must be modified.

Since this was written for a Burroughs B5500, other CPU's will require the usual changes to cover the few differences in the many versions of FORTRAN IV that exist.

Inquiries regarding this program
should be directed to:
Highway Research Laboratory
735 East Saginaw Street
Lansing, Michigan 48906
Tel. 517-373-2730

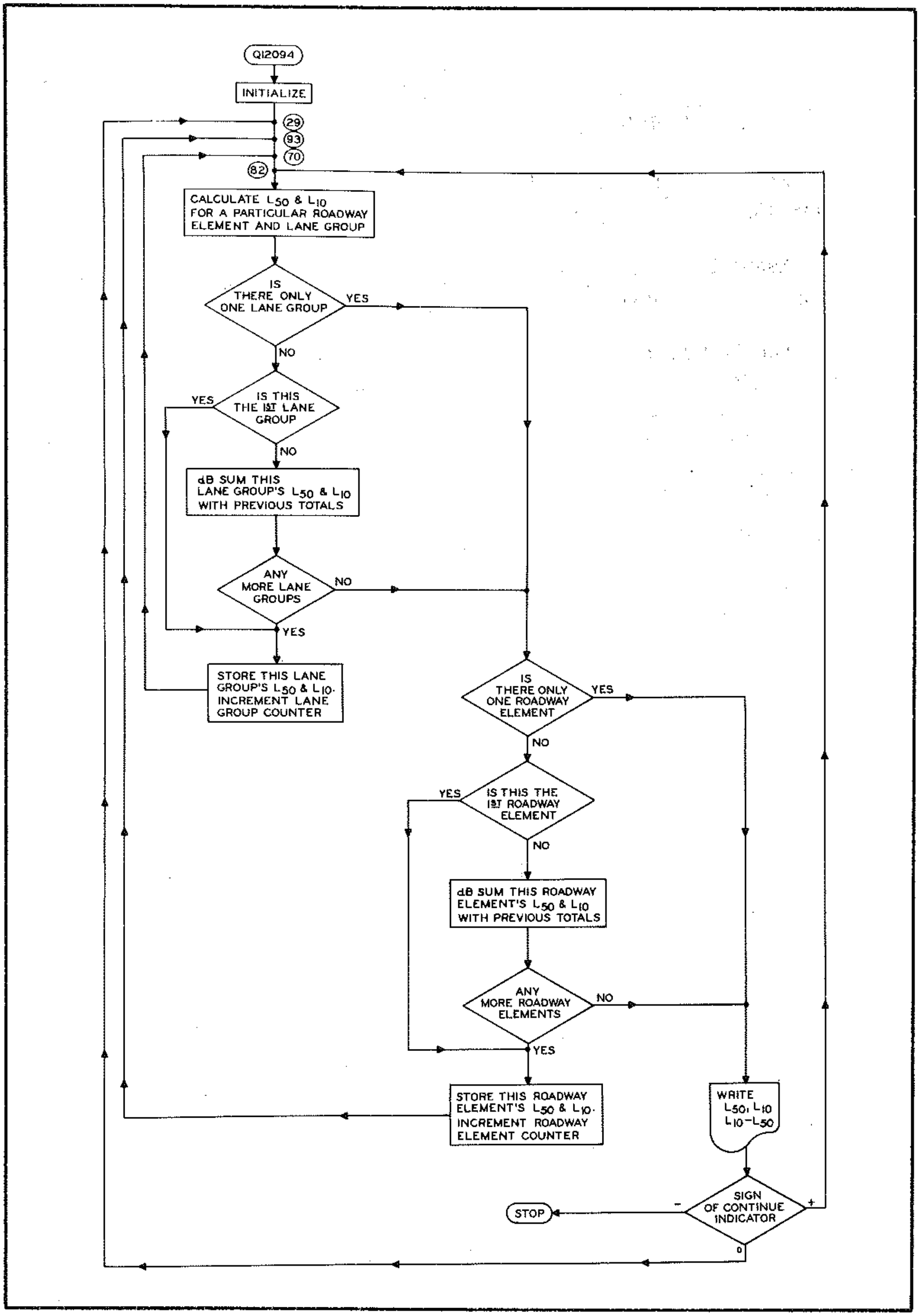


Figure 28. Computer program flow diagram for calculating L levels by the "Complete Method" of NCHRP Report No. 117.

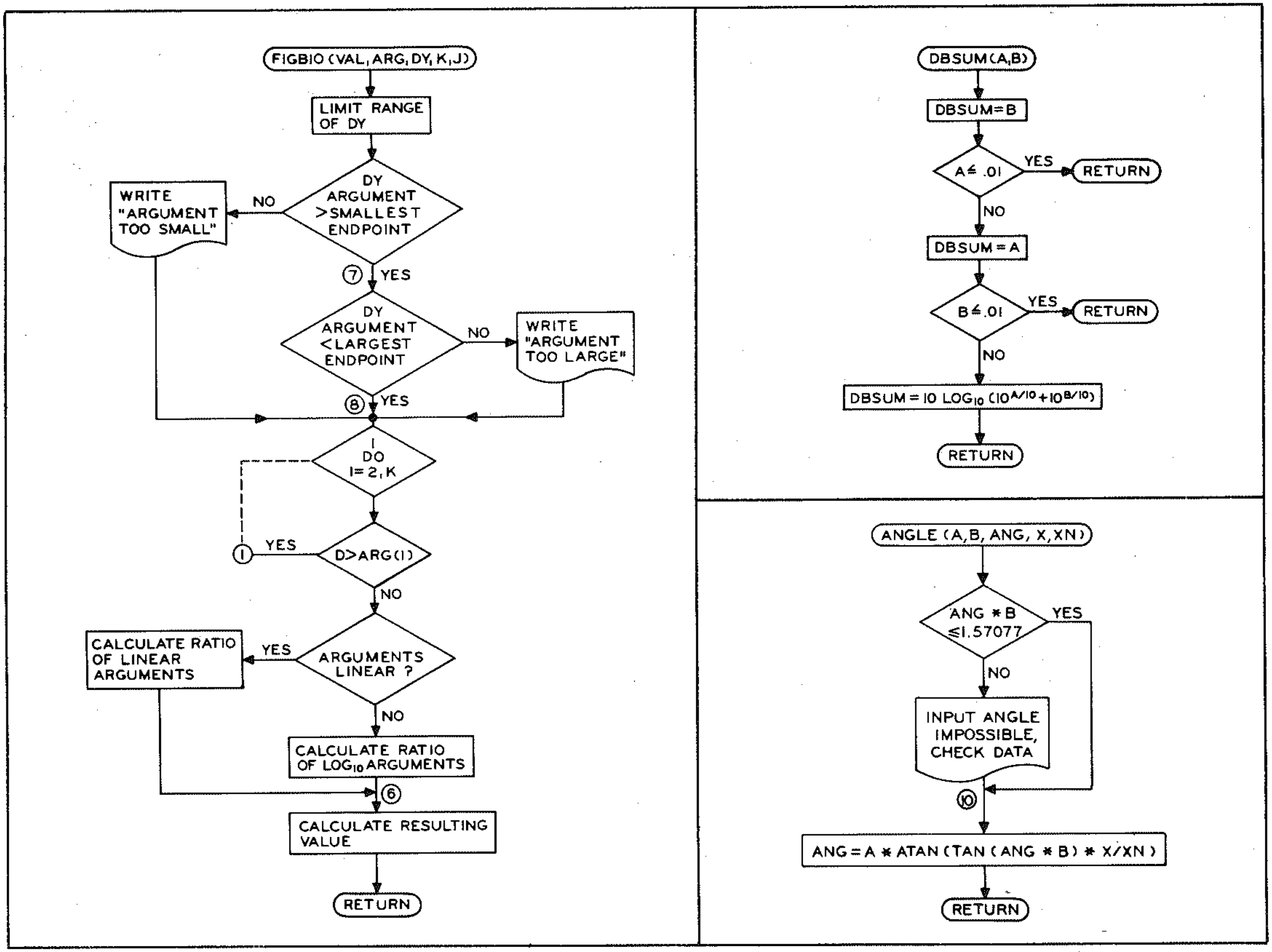


Figure 29. Flow diagrams for subroutines of NCHRP 117 "Complete Method" computer program. At left is the "Table Look-up Function" subroutine, above right the "db Sum" subroutine and below right the "angle increment" subroutine.

```
FILE  2=Q12OUT,UNIT=REMOTE
      DIMENSION VAL(9),ARG(9),A1(5),V12(5),V14(5),V18(5)
      DIMENSION V11(5),V13(5),V16(5)
      DIMENSION A5(7),V5(7),A6(7),V6(7),D1(7),D2(7),DEL(7)
      DIMENSION A2(10),V25(10),V210(10),V215(10)
      REAL MED
      DATA (VAL(I),I=1,9)/10.87,8.19,5.63,4.00,3.00,2.13,
     *1.50,1.26,1.13/
      DATA (ARG(I),I=1,9)/300.,600.,1500.,3000.,6000.,
     *15000.,40000.,100000.,800000./
      DATA (A1(I),I=1,5)/30.,100.,300.,1000.,3000./
      DATA (V11(I),I=1,5)/8.,0.,-7.,-15.,-22./
      DATA (V12(I),I=1,5)/6.5,-.5,-7.,-15.,-22./
      DATA (V13(I),I=1,5)/6.,-.7,-7.,-15.,-22./
      DATA (V14(I),I=1,5)/5.5,-1.,-7.,-15.,-22./
      DATA (V16(I),I=1,5)/4.,-1.5,-7.,-15.,-22./
      DATA (V18(I),I=1,5)/2.5,-2.,-7.5,-15.,-22./
      DATA (A5(I),I=1,7)/-60.,-20.,20.,40.,60.,70.,80./
      DATA (V5(I),I=1,7)/-.78,-2.03,-4.06,-5.62,-7.82,-9.55,-12.66/
      DATA (A6(I),I=1,7)/0.,10.,20.,40.,60.,100.,160./
      DATA (V6(I),I=1,7)/-16.25,-12.34,-9.68,-6.56,
     *-4.68,-2.34,-.31/
      DATA(A2(I),I=1,10)/.1,.2,.3,.4,.5,.6,.7,.8,.9,1./
      DATA(V25(I),I=1,10)/0.,3*-1.,2*-2.,-3.,2*-4.,-5./
      DATA(V210(I),I=1,10)/0.,2*-1.,-2.,2*-3.,-4.,-6.,-7.,-10./
      DATA (DEL(I),I=1,7)/.01,.03,.1,.3,1.,4.,30./
      DATA(V215(I),I=1,10)/0.,-1.,2*-2.,-3.,-4.,-5.,-7.,-10.,-15./
      DATA (D1(I),I=1,7)/-2.,-2.5,-3.75,-6.25,-10.16,-15.,-15./
      DATA (D2(I),I=1,7)/-5.,-5.63,-6.88,-8.28,-10.62,-15.,-15./
      WRITE(2,85)
85    FORMAT("*****  *****  *****  *****  *****  *****",
     *"  *****"/"* CAUTION, METHOD NOT VALIDATED, READ REPORT  *"
     */"* NCHRP 117, PROGRAM VERSION NO. 2, 8/1/72.    *"/
     *"*****  *****  *****  *****  *****  *****  *****")
C
C  PLEASE REPORT ANY PROBLEMS TO G.H.GROVE
C  AT THE MICHIGAN DEPT OF STATE HIGHWAYS
C  T & R LAB IN LANSING, THANK YOU.
C
29    INRE=1
      C1=.017453;C2=57.29578;C3=.0087265;C4=114.59156
      WRITE(2,91)
91    FORMAT(/"INSERT NRE= # OF ROADWAY ELEMENTS")
      READ(2,/)NRE
93    J=1
      WRITE(2,13)INRE
13    FORMAT("INSERT N= # OF LANE GROUPS FOR ROAD ELEMENT #",I2)
      READ(2,/)N
70    WRITE(2,12)J
12    FORMAT(/"INSERT ADT,PCADT,TMIX,ST,SA,HD,DN,RL,BL,FLO,P,"/,
     *"DEL3,DEL5,DEL7 FOR LANE GROUP ",I2)
      READ(2,/)ADT,PCADT,TMIX,ST,SA,HD,DN,RL,BL,FLO,P,DEL3,DEL5,DEL7
      IF(J.EQ.1)DN1=DN
      IF(N.NE.2) GO TO 98
      WRITE(2,99)
99    FORMAT("INSERT MED")
      READ(2,/)MED
98    CONTINUE
C  CALC. VEHICLE VOLUMES.
      V=ADT*PCADT*.01
      VT=TMIX*V*.01
      VA=V-VT
C  DEL2 - ELEMENT CORRECTION.
82    IF(RL.GE.2.)GO TO 40
      DEL2=0.
      GO TO 42
40    IF(ICON.EQ.1)GO TO 160
      WRITE(2,32)
32    FORMAT("INSERT THETA")
      READ(2,/)THETA
160   CONTINUE
      IF(RL.GT.2.) GO TO 41
      DEL2=FIGR10(V5,A5,THETA,7,1)
      GO TO 42
41    DEL2=FIGR10(V6,A6,THETA,7,1)
42    IF(P.GT.2.)GO TO 63
C  DE - EQUIVALENT LANE DISTANCE CALC.
      DF=DN+12.*P-12.
      GO TO 64
63    DF=DN+12.5*P-12.
64    DE=SQRT(DN*DF)
C  DEL1 - DISTANCE CORRECTION.
      IF(P-2.)190,191,192
190   DEL1=FIGR10(V11,A1,DN,5,0);GO TO 61
191   DEL1=FIGR10(V12,A1,DN,5,0);GO TO 61
192   IF(P-4.)193,194,195
193   DEL1=FIGR10(V13,A1,DN,5,0);GO TO 61
194   DEL1=FIGR10(V14,A1,DN,5,0); GO TO 61
195   IF(P.GT.6.)GO TO 196
      DEL1=FIGR10(V16,A1,DN,5,0);GO TO 61
196   DEL1=FIGR10(V18,A1,DN,5,0)
C  DEL4 - VERTICAL CORRECTION.
61    IF(HD.EQ.0.AND.BL.EQ.0.OR.J.NE.1.OR.ICON.EQ.1) GO TO 120
      WRITE(2,119)
119   FORMAT("INSERT HO")
      READ(2,/)HO
120   IF(HD)53,43,44
53    IF(J.GT.1.OR.ICON.EQ.1) GO TO 110
      WRITE(2,14)
14    FORMAT("INSERT H1,DS")
      READ(2,/)H1,DS
110   CONTINUE
      HH=(H1-HO)*(H1-HO)
      DL =DE-DS+SQRT(HH+DS*DS)-SQRT(HH+DE*DE)
      IF(DL.LT..01) GO TO 43
      DEL4=FIGR10(D1,DEL,DL,7,0)
      GO TO 47
44    IF(J.GT.1.OR.ICON.EQ.1) GO TO 111
      WRITE(2,11)
11    FORMAT("INSERT H2,DC")
      READ(2,/)H2,DC
111   CONTINUE
      A=SQRT(H2*H2+(DE-DC)*(DE-DC))
      B=SQRT(HO*HO+DC*DC)
      D=SQRT((H2+HO)*(H2+HO)+DE*DE)
      DL=A+B-D
      IF(DL.LT..01)GO TO 43
      DEL4=FIGR10(D2,DEL,DL,7,0)
47    DL4=AMIN1(DEL4+5.,0.)
      GO TO 98
```

```
43    DELA=0.
      DLA=0.
C  DEL6 = BARRIER CORRECTION.
48    DELA=0.
      DL6=0.
      IF(RL.EQ.0.) GO TO 33
      IF(J.GT.1.OR.ICON.EQ.1) GO TO 112
      WRITE(2,39)
39    FORMAT("INSERT H,DR")
      READ(2,/)H,DR
112   CONTINUE
      A=SQRT(H*H+(DE-DR)*(DE-DR))
      B=SQRT((H-HO)*(H-HO)+DR*DR)
      D=SQRT(HO*HO+DE*DE)
      DL=A+B-D
      IF(DL.LT..01) GO TO 33
34    DEL6=FIGB10(D1,DEL,DL,7,0)
      DL6=AMIN1(DEL6+5.,0.)
37    IF(RL-2.)33,38,38
38    IF(J.GT.1.OR.ICON.EQ.1) GO TO 113
      WRITE(2,73)
73    FORMAT("INSERT ALPHA")
      READ(2,/)ALPHA
113   CONTINUE
      IF(RL-2.)74,75,76
74    A=ALPHA/180.
      GO TO 77
75    A=ALPHA/(90.-THETA)
      GO TO 77
76    A=ALPHA/THETA
77    IF(A.LE..1) GO TO 89
      IF(DEL6.GT.-5.) GO TO 86
      IF(DEL6.GT.-10.) GO TO 87
      VU=FIGB10(V210,A2,A,10,1)
      VL=FIGB10(V215,A2,A,10,1)
      GO TO 88
89    DEL6=0.
      DL6=0.
      GO TO 33
86    VU=0.
      VL=FIGB10(V25,A2,A,10,1)
      GO TO 88
87    VU=FIGB10(V25,A2,A,10,1)
      VL=FIGB10(V210,A2,A,10,1)
88    AL=.1*AINT(10.*A)
      AU=AL+.1
      DEL6=(A-AL)*(VL-VU)/(AU-AL)+VU
      DL6=AMIN1(DEL6+5.,0.)
33    IF(RL.EQ.2.AND.BL.EQ.2.AND.ICON.NE.1.AND.J.EQ.1)GO TO 199
      GO TO 179
199   WRITE(2,185)
185   FORMAT("INSERT BETA");READ(2,/)BETA
C  CALC. L50 & L10.
179   S=DEL1+DEL2+DEL5+DEL7
      SDEL=S+AMAX1(DEL4+DEL6,-15.)
      SDELT=S+DEL3+AMAX1(DL4+DL6,-15.)
      AT=VT*DE/ST
      IF(AT.LT.300.) GO TO 49
      AA=VA*DE/SA
      AL10A=FIGB10(VAL,ARG,AA,9,0)
      AL10T=FIGB10(VAL,ARG,AT,9,0)
      YA=.119*VA/SA
      UA=VA*SA*SA*TANH(YA)
      AL50A=10.*ALOG10(UA)-1.
      YT=.119*VT/ST
      UT=VT*TANH(YT)/ST
      AL50T=10.*ALOG10(UT)+65.
      OL50A=AL50A+SDEL
      OL50T=AL50T+SDELT
      OL10A=OL50A+AL10A
      OL10T=OL50T+AL10T
      IF(FLO.GT.0.) GO TO 51
      OL10A=OL10A+2.
      OL10T=OL10T+4.
51    AL50=DBSUM(OL50A,OL50T)
      AL10=DBSUM(OL10A,OL10T)
      GO TO 52
49    V=VA+15.*VT
      AAT=V*DE/SA
      WRITE(2,90)
90    FORMAT(/"*** TWILIGHT ZONE - ALL VEHICLES NOW CARS ***")
      AL10V=FIGB10(VAL,ARG,AAT,9,0)
      YA=.119*V/SA
      UA=V*SA*SA*TANH(YA)
      AL50V=10.*ALOG10(UA)-1.
      AL50=AL50V+SDEL
      AL10=AL50+AL10V
      IF(FLO.GT.0.) GO TO 52
      AL10=AL10+2.
52    CONTINUE
      IF(N.EQ.1)GO TO 72
      IF(J.EQ.1)GO TO 65
      AL50=DBSUM(AL50,XX)
      AL10=DBSUM(AL10,YT)
C  CHECK IF ANY MORE LANE GROUPS.
      IF(J.EQ.N)GO TO 72
65    XX=AL50
      YY=AL10
      J=J+1
      IF(N.NE.2)GO TO 70
      DN=DN+MED+12.*P
      GO TO 42
C  CHECK IF ANY MORE ROADWAY ELEMENTS.
72    IF(NRE.EQ.1)GO TO 92
      IF(INRE.EQ.1)GO TO 67
      AL50=DBSUM(AL50,RODL5)
      AL10=DBSUM(AL10,RODL1)
      IF(INRE.EQ.NRE)GO TO 92
67    RODL5=AL50
      RODL1=AL10
      INRE=INRE+1
      GO TO 93
C  OUTPUT RESULTING L50 & L10 VALUES.
92    IF(ICON.EQ.1)GO TO 161
      WRITE(2,23)AL50,AL10,DN1
23    FORMAT(/"*********************"/"L50=",F5.1," L10=",
     -F5.1," DN1=",F7.1/"*********************"/)
C  CHECK IF ANY MORE PROBLEMS TO BE SOLVED.
      WRITE(2,26)
26    FORMAT("INSERT 2,1,0,-1 FOR CONTINUE,ITERATE,NEW,STOP")
```

```
      READ(2,/)ICON
      IF(ICON.GT.1)GO TO 187
      IF(ICON)28,29,30
30    WRITE(2,141)
141   FORMAT("INSERT DESIRED L10");READ(2,/)AL10D
      DX=0.;DELDN=100.
161   DXN=AL10-AL10D
      IF(ABS(DXN).LT..1)GO TO 162
      IF(DELDN.LT.5.)GO TO 162
      IF(DXN*DX.LT.0.)DELDN=.5*DELDN
      DXX=SIGN(DELDN,DXN)
      DNN=DN1+DXX
      XXX=DNN
      IF(HD)146,145,144
144   DC=DC+DXX
      XXX=DC
      GO TO 145
146   DS=DS+DXX
      XXX=DS
145   IF(RL.EQ.0.)GO TO 181
      DBN=DB+DXX;XXX=DBN
181   IF(XXX.LE.0.)GO TO 180
      IF(RL-2.)151,149,150
150   CALL ANGLE(C4,C3,THETA,DN1,DNN)
151   IF(RL.EQ.2.)CALL ANGLE(C4,C3,ALPHA,DB,DBN)
      GO TO 148
149   CALL ANGLE(C2,C1,THETA,DN1,DNN)
      IF(RL.EQ.2.)GO TO 198
148   DN=DNN;DN1=DNN;DX=DXN
      IF(RL.NE.0.)DB=DBN
171   J=1;INHE=1
      GO TO 82
198   ALB=ALPHA+BETA
      CALL ANGLE(C2,C1,ALB,DN1,DNN)
      CALL ANGLE(C2,C1,BETA,DN1,DNN)
      ALPHA=ALB-BETA
      GO TO 148
162   ICON=0
      GO TO 92
180   WRITE(2,203)
203   FORMAT("TRY CLOSER L10 AFTER RESET OF SITE DATA")
      ICON=0
      GO TO 29
187   WRITE(2,17)
17    FORMAT("INSERT DN")
      READ(2,/)DN
      DN1=DN
      GO TO 171
28    STOP
      END
      FUNCTION FIGR10(VAL,ARG,DY,K,J)
      DIMENSION VAL(1),ARG(1)
C  INTERPOLATES ON EITHER A LINEAR OR SEMILOG GRID.
C  IN THE CALL, SET J=1 FOR LINEAR, =0 FOR SEMILOG.
      D=AMAX1(AMIN1(DY,ARG(K)),ARG(1))
      IF(DY.GE.ARG(1)) GO TO 7
      WRITE(2,20)
20    FORMAT("*** ARGUMENT LIMITED AT LOW END ***")
      WRITE(2,22)DY,ARG(1),ARG(K)
22    FORMAT("DY=",F6.2," ARG(1)=",F6.2," ARG(K)=",F6.2)
```

```
      GO TO 8
7     IF(DY.LE.ARG(K)) GO TO 8
      WRITE(2,21)
21    FORMAT("*** ARGUMENT LIMITED AT HIGH END ***")
      WRITE(2,22)DY,ARG(1),ARG(K)
8     DO 1 I=2,K
      IF(D.GT.ARG(I)) GO TO 1
      IF(J.EQ.1) GO TO 9
      FIGR10=ALOG10(D)-ALOG10(ARG(I-1))
      F=ALOG10(ARG(I))-ALOG10(ARG(I-1))
6     FIGR10=FIGR10*(VAL(I)-VAL(I-1))/F+VAL(I-1)
      RETURN
9     FIGR10=D-ARG(I-1)
      F=ARG(I)-ARG(I-1)
      GO TO 6
1     CONTINUE
      RETURN
      END
      FUNCTION DBSUM(A,B)
C  CALCULATES THE DB SUM OF A & B.
      DBSUM=B
      IF(A.LE..01)RETURN
      DBSUM=A
      IF(B.LE..01)RETURN
      DBSUM=10.*ALOG10(10.**(.1*A)+10.**(.1*B))
      RETURN
      END
      SUBROUTINE ANGLE(A,B,ANG,X,XN)
20    FORMAT("INPUT ANGLE PHYSICALLY IMPOSSIBLE,CHECK DATA.")
      IF(ANG*B.LE.1.57077)GO TO 10
      WRITE(2,20)
10    ANG=A*ATAN(TAN(ANG*B)*X/XN)
      RETURN
      END
```

APPENDIX C

COMPUTER PROGRAM FOR THE STATISTICAL METHOD OF NOISE SIMULATION OF NCHRP REPORT NO. 78 AS MODIFIED BY MICHIGAN DEPARTMENT OF STATE HIGHWAYS

```
11  PATH  0.     100.   0.   ⎫
11  PATH  0.     200.   0.   ⎪
                             ⎬50 CARDS, ONE FOR EACH 100 FEET.
11  PATH  0.    4900.   0.   ⎪
11  PATH  0.    5000.   0.   ⎭

12ØBSERV  100.  2450.   0.
13ØFFSET    6.  0.
13ØFFSET   -6.  0.
14BARLØC  11.   6.      0.    75.    3.     50.    50.
21AIRATN  0.    0.       .3    .6     .6    1.2    2.4    5.2

31SØURCE  67.   68.     65.   63.    63.    58.    50.    42.    50.    50.
31SØURCE  78.   83.     84.   80.    75.    72.    63.    54.    50.     0.
41  MIX   80.   20.
41  MIX   80.   20.
43  SPEED 60.   60.

44DENSTY  100.  100.

 2SNPSHT  40.
 4NØPUNC
 6NØTRAC

 1RUN
```

Input data for sample problem (each card has "I2,6A1,2X,10F7.1" format.

```
H I G H W A Y   T R A F F I C   N O I S E   S I M U L A T I O N      HSHD

PATH POINT (X,Y,Z) =      0.0  100.0     0.0
PATH POINT (X,Y,Z) =      0.0  200.0     0.0
PATH POINT (X,Y,Z) =      0.0  300.0     0.0
PATH POINT (X,Y,Z) =      0.0  400.0     0.0
PATH POINT (X,Y,Z) =      0.0  500.0     0.0
PATH POINT (X,Y,Z) =      0.0  600.0     0.0
PATH POINT (X,Y,Z) =      0.0  700.0     0.0
PATH POINT (X,Y,Z) =      0.0  800.0     0.0
PATH POINT (X,Y,Z) =      0.0  900.0     0.0
PATH POINT (X,Y,Z) =      0.0 1000.0     0.0
PATH POINT (X,Y,Z) =      0.0 1100.0     0.0
PATH POINT (X,Y,Z) =      0.0 1200.0     0.0
PATH POINT (X,Y,Z) =      0.0 1300.0     0.0
PATH POINT (X,Y,Z) =      0.0 1400.0     0.0
PATH POINT (X,Y,Z) =      0.0 1500.0     0.0
PATH POINT (X,Y,Z) =      0.0 1600.0     0.0
PATH POINT (X,Y,Z) =      0.0 1700.0     0.0
PATH POINT (X,Y,Z) =      0.0 1800.0     0.0
PATH POINT (X,Y,Z) =      0.0 1900.0     0.0
PATH POINT (X,Y,Z) =      0.0 2000.0     0.0
PATH POINT (X,Y,Z) =      0.0 2100.0     0.0
PATH POINT (X,Y,Z) =      0.0 2200.0     0.0
PATH POINT (X,Y,Z) =      0.0 2300.0     0.0
PATH POINT (X,Y,Z) =      0.0 2400.0     0.0
PATH POINT (X,Y,Z) =      0.0 2500.0     0.0
PATH POINT (X,Y,Z) =      0.0 2600.0     0.0
PATH POINT (X,Y,Z) =      0.0 2700.0     0.0
PATH POINT (X,Y,Z) =      0.0 2800.0     0.0
PATH POINT (X,Y,Z) =      0.0 2900.0     0.0
PATH POINT (X,Y,Z) =      0.0 3000.0     0.0
PATH POINT (X,Y,Z) =      0.0 3100.0     0.0
PATH POINT (X,Y,Z) =      0.0 3200.0     0.0
PATH POINT (X,Y,Z) =      0.0 3300.0     0.0
PATH POINT (X,Y,Z) =      0.0 3400.0     0.0
PATH POINT (X,Y,Z) =      0.0 3500.0     0.0
PATH POINT (X,Y,Z) =      0.0 3600.0     0.0
PATH POINT (X,Y,Z) =      0.0 3700.0     0.0
PATH POINT (X,Y,Z) =      0.0 3800.0     0.0
PATH POINT (X,Y,Z) =      0.0 3900.0     0.0
PATH POINT (X,Y,Z) =      0.0 4000.0     0.0
PATH POINT (X,Y,Z) =      0.0 4100.0     0.0
PATH POINT (X,Y,Z) =      0.0 4200.0     0.0
PATH POINT (X,Y,Z) =      0.0 4300.0     0.0
PATH POINT (X,Y,Z) =      0.0 4400.0     0.0
PATH POINT (X,Y,Z) =      0.0 4500.0     0.0
PATH POINT (X,Y,Z) =      0.0 4600.0     0.0
PATH POINT (X,Y,Z) =      0.0 4700.0     0.0
PATH POINT (X,Y,Z) =      0.0 4800.0     0.0
PATH POINT (X,Y,Z) =      0.0 4900.0     0.0
PATH POINT (X,Y,Z) =      0.0 5000.0     0.0

OBS. POINT (X,Y,Z) =    100.0 2450.0     0.0

LANE OFFSET (H,V) =      6.0     0.0

LANE OFFSET (H,V) =     -6.0     0.0

   HB      HR      HO      B1      BARR LENGHT

   11.0    6.0     0.0    75.0     3.0    50.0    50.0

AIR ATTEN., 63-8000 HZ
   0.00    0.00    0.30    0.60    0.60    1.20    2.40    5.20

VEHICLE CATAGORY  1SPECTRUM, 63-8000 HZ
  67.00  68.00  65.00  63.00  63.00  58.00  50.00  42.00
REF. DIST. (FT) =     50.0
REF. SPEED (MPH) =    50.00

VEHICLE CATAGORY  2SPECTRUM, 63-8000 HZ
  78.00  83.00  84.00  80.00  75.00  72.00  63.00  54.00
REF. DIST. (FT) =     50.0
REF. SPEED (MPH) =     0.00

MIX FOR LANE  1  80.00  20.00

MIX FOR LANE  2  80.00  20.00

SPEED IN MPH FOR LANES 1-NL
   60.0   60.0

DENSITY IN VPH FOR LANES 1-NL
 100.00 100.00

SNAPSHOTS = 40

RUN =  RUN
```

Output listing for the problem input.

```
*******************************************************************
   DBA       DBC                  BANDS 63 - 8000 HZ
  77.27     83.65      76.03  78.58  78.07  74.79  72.41  68.27  60.01  51.99 NO BARRIER
  67.41     78.51      73.87  74.51  71.40  65.20  59.94  52.74  41.49  30.48 BARRIER

VEHICLE POPULATION FOR LANES 1 - NL
 1   16.0   11.0
 2    4.0    1.0

TRAFFIC SPAN (FT) FOR LANES 1 - NL
 1095.3  821.8
*******************************************************************
   DBA       DBC                  BANDS 63 - 8000 HZ
  79.29     85.80      77.07  80.66  80.96  77.28  73.68  70.03  61.45  53.07 NO BARRIER
  70.42     80.93      75.17  77.03  75.02  68.44  61.77  55.13  43.53  32.11 BARRIER

VEHICLE POPULATION FOR LANES 1 - NL
 1   15.0   10.0
 2    1.0    2.0

TRAFFIC SPAN (FT) FOR LANES 1 - NL
  907.5  242.2
*******************************************************************
   DBA       DBC                  BANDS 63 - 8000 HZ
  77.15     83.63      75.17  78.51  78.64  75.04  71.72  67.94  59.44  51.13 NO BARRIER
  67.29     78.15      72.91  74.26  71.71  65.16  59.04  52.16  40.69  29.42 BARRIER

VEHICLE POPULATION FOR LANES 1 - NL
 1   10.0    8.0
 2    2.0    0.0

TRAFFIC SPAN (FT) FOR LANES 1 - NL
  604.8  378.1
*******************************************************************
```

NOTE:

"ONLY FIRST 3 AND LAST 2 SNAPSHOTS, OF TOTAL OF 40, ARE SHOWN."

```
*******************************************************************
   DBA       DBC                  BANDS 63 - 8000 HZ
  81.45     88.05      78.24  82.84  83.68  79.77  75.14  71.98  63.15  54.45 NO BARRIER
  72.14     82.52      76.05  78.75  77.04  70.19  62.63  56.42  44.59  32.90 BARRIER

VEHICLE POPULATION FOR LANES 1 - NL
 1    4.0    7.0
 2    4.0    1.0

TRAFFIC SPAN (FT) FOR LANES 1 - NL
  774.3  269.0
*******************************************************************
   DBA       DBC                  BANDS 63 - 8000 HZ
  80.46     87.03      77.58  81.83  82.52  78.67  74.38  71.05  62.31  53.72 NO BARRIER
  71.07     81.54      75.37  77.74  75.89  69.10  61.84  55.48  43.74  32.16 BARRIER

VEHICLE POPULATION FOR LANES 1 - NL
 1   10.0    6.0
 2    2.0    2.0

TRAFFIC SPAN (FT) FOR LANES 1 - NL
  616.5  457.9
*********************************************************  **********************

MEAN=   79.18  85.69

DEV=     2.40   2.48

MIN=    72.28  78.44

MAX=    84.65  91.25

MEAN SPECTRUM FOR SNAPSHOTS
   76.9   80.5   80.8   77.1   73.5   69.9   61.4   53.0

DISTRIBUTION OF SNAPSHOT DBA VALUES
72          0       0.00
73          1       2.50
74          1       2.50
75          1       2.50
76          5      12.50
77          4      10.00
78          7      17.50
79          7      17.50
80          9      22.50
81          2       5.00
82          1       2.50
83          0       0.00
84          1       2.50
85          0       0.00
```

Output listing for the problem input (cont.).

```
        B 5 5 0 0     F O R T R A N     C O M P I L A T I O N

FILE  2=QC12090,UNIT=READER
FILE  3=QP12090,UNIT=PRINTER
C  HIGHWAY TRAFFIC NOISE SIMULATION MODIFIED
C     **********WITH NOISE REDUCTION BARRIER**********G,H,GROVE*********
C     **********(METHOD OF Z. MAEKAWA)**********

      COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL/BLK2/DENSTY(10),VELCTY
     1(10),FLOW(10)  /BLK3/CSPECT(8,10),SOTST(10),SSPEED(10)
     2/BLK4/PVECT(10,10),NC,NM   /BLK5/AIRATN( 8),GRDATN( 8),NB
     3/BLK6/NS,IOFLAG,PFLAG   /BLK7/POSITN(3),OBSERV(3)
      COMMON/BLK11/HR,HR,HD,R1,H2,H3,BL
C
C  INITIALIZE THE PARAMETERS
C
      NP=0; NC=0;NL=0; NM=0; NS=0
C
C  SET UP NUMBER OF RANDS AND PRINT HEADING
C
      NB=8
      WRITE(3,65)
   65 FORMAT("1"," H I G H W A Y   T R A F F I C   N O I S E   S I M U L A
C
     1 T I O N     MSHO")
C  READ DAYA
C
  100 CALL HRBINP(IEFLAG)
      GO TO(900,910,920,930,940,950,110),IEFLAG
  110 IEFLAG=0
      IF(NP-2)111,111,112
  111 WRITE(3,50)
   50 FORMAT("0","*******PATH ILL-DEFINED")
      IEFLAG=1
  112 IF(NS-2)113,113,114
  113 WRITE(3,51)
   51 FORMAT("0","*********TOO FEW SNAPSHOTS")
      IEFLAG=1
  114 IF(NC)115,115,116
  115 WRITE(3,52)
   52 FORMAT("0","***** NO VEHICLE CLASSES")
      IEFLAG=1
  116 IF(NL)117,117,118
  117 WRITE(3,53)
   53 FORMAT("0","***** NO LANES DEFINED")
      IEFLAG=1
  118 IF(NM-NC)119,120,120
  119 WRITE(3,54)
   54 FORMAT("0","***** TOO FEW MIX SPECS")
      IEFLAG=1
  120 TEMP1=0.0
      TEMP2=0.0
      TEMP3=0.0
      DO 121 I=1,NL
      TEMP1=DENSTY(I)+TEMP1
      TEMP2=FLOW(I)+TEMP2
  121 TEMP3=VELCTY(I)+TEMP3
      IF(TEMP3)122,122,123
  122 WRITE(3,55)
   55 FORMAT("0","***** NO LANE SPEED INFO")
      IEFLAG=1
  123 IF(TEMP1)124,124,140
  124 IF(TEMP2)125,125,130
  125 WRITE(3,56)
   56 FORMAT("0","***** NO LANE FLOW OR DENSITY INFO")

      IEFLAG=1
      GO TO 200
  130 DO 131 I=1,NL
  131 DENSTY(I)=FLOW(I)/VELCTY(I)
      GO TO 200
  140 DO 141 I=1,NL
  141 FLOW(I)=DENSTY(I)*VELCTY(I)
C
C  WAS ERROR CONDITION FOUND
  200 IF(IEFLAG)201,280,201
  201 WRITE(3,57)
   57 FORMAT("0","RUN ABORTED",/,"1")
      GO TO 100
C
C  PERFORM A RUN
C
  280 IF(IOFLAG)290,300,290
  290 WRITE(3,66)(FLOW(I),I=1,NL)
      WRITE(3,67)(DENSTY(I),I=1,NL)
      WRITE(3,68)(VELCTY(I),I=1,NL)
      DO 295 I=1,NL
      TESTRN=RANF(1)
      WRITE(3,70) TESTRN
   70 FORMAT("0",F10.5)
      CALL GETGAP(I,TESTGP)
  295 WRITE(3,69) TESTGP
   69 FORMAT("0","TEST GAP = ", F10.3)
   66 FORMAT("0","FLOW IN VPH = ",10F8.2)
   67 FORMAT("0","DENSITY IN VPM = ",10F8.2)
   68 FORMAT("0","SPEED IN FPS = ",10F8.2)
  300 CALL RUNSIM
C
C  ADVANCE PRINTER PAGE FOR NEXT LOOP
C
  400 WRITE(3,58)
   58 FORMAT("1")
      GO TO 100
C
C  END OF RUNS
  900 WRITE(3,59)
   59 FORMAT("0","DONE",/,"1")
      GO TO 1000
C
C  INPUT ERROR CONDITIONS
C
  910 WRITE(3,64)
   64 FORMAT("0","*****INPUT CARD OF UNDEFINED TYPE")
      GO TO 201
  920 WRITE(3,60)
   60 FORMAT("0","***** GEOMETRY INPUT ERROR")
      GO TO 201
  930 WRITE(3,61)
   61 FORMAT("0","***** PROPAGATION CONDITIONS ERROR")
      GO TO 201
  940 WRITE(3,62)
   62 FORMAT("0","***** VEHICLE CLASS ERROR")
      GO TO 201
```

Program listing for the MDSH modification of BBN's Highway Noise Simulation Model of NCHRP Report No. 78 (Burroughs B5500 - FORTRAN IV - card input - printer output).

```
  950 WRITE(3,63)
   63 FORMAT("0","***** TRAFFIC INFO ERROR")
      GO TO 201
C
 1000 STOP
      END

      SUBROUTINE HRBINP(EFLAG)
C   REMARKS
C       HRBINP READS CARDS OF FIVE MAJOR TYPES
C           1   CONTROL
C                   RUN                     01
C                   SNAPSHOTS               02
C                   PUNCH                   03
C                   NOPUNCH                 04
C                   TRACE                   05
C                   NOTRACE                 06
C                   CLEAR                   07
C           2   GEOMETRY
C                   PATH                    11
C                   OBSERV                  12
C                   LANELOC                 13
C                   BARLOC                  14
C           3   PROPAGATION CONDS,
C                   AIRATTEN                21
C                   SHIFLOC                 22
C           4   VEHICLE CATAGORY
C                   SOURCE                  31
C           5   TRAFFIC CHARACTERISTICS
C                   MIX                     41
C                   FLOW                    42
C                   SPEED                   43
C                   DENSITY                 44
C
C     THE FOLLOWING ARRAYS ARE USED
C       PATH- (3 X NP) DEFINING ROADWAY CENTERLINE POINTS (IN FT)
C       CSPECT- (8 X NC) DEFINING SOURCE REFERENCE SPECTRA FOR 8 BANDS
C         63-8000 HZ  ( IN DB RF 0.0002 MICROBAR)
C       PVECI- (NC X NL) DEFINING POPULATION MIXES FOR LANES (IN PCT)
C       OFFSET- (2 X NL) DEFINING LANE POSITION REFERRED TO PATH
C         CENTERLINE (HORIZ, VERT IN FT., PLUS TOWARD OBSERVER AND UP)
C
C       THE FOLLOWING VECTORS ARE USED
C         SSPEED-(NC) DEFING REFERENCE SPEED FOR CLASSES (FPS)
C         SDIST-(NC) DEFINING REFERENCE DISTANCE FOR CLASSES (FT)
C         DENSTY -(NL) DEFINING VEH/MILE FOR LANES
C         VELCTY-(NL) DEFINING SPEED FOR LANES (FT/SEC)
C         FLOW-(NL) DEFINING FLOW FOR LANES (VEH/HR)
C         OBSERV-(3) X,Y,Z FOR OBS. POINT (FT)
C         AIRATN-(8 ) AIR ATTEN FOR 63-8000 HZ
C               (IN DB/1000 FT, -FOR LOSS)
C         GRDATN-(8 ) SHIELDING FOR 63-8000 HZ (DB)
C       THE FOLLOWING SINGLE PARAMETERS ARE SET
C         NS - NO. OF SNAPSHOTS PER RUN
C         NP - NO. OF POINTS IN PATH
C         NL - NO. OF LANES
C         NM - NO. OF LANE MIX SPECS
C         NC - NO. OF VEHICLE CLASSES
C
C         PFLAG - TO PUNCE EACH SNAPSHOT DATA
C         IOFLAG - FOR TRACING SIMULATION
```

```
C
      COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL/BLK2/DENSTY(10),VELCTY
     1(10),FLOW(10)   /BLK3/CSPECT(8,10),SDIST(10),SSPEED(10)
     2/BLK4/PVECT(10,10),NC,NM    /BLK5/AIRATN( 8),GRDATN( 8),NB
     3/BLK6/NS,IOFLAG,PFLAG    /BLK7/POSITN(3),OBSERV(3)
      COMMON/BLK11/HR,HR,HO,B1,H2,H3,BL
      INTEGER EFLAG
      DIMENSION VARS(10),IDENT(6)
C
C  READ A DATA CARD
C
  100 READ(2,1) IOCODE,IDENT,VARS
    1 FORMAT(I2,6A1,2X,10F7.1)
  110 IF(IDCODE-10)200,111,111
  111 IDCODE=IDCODE-10
      IF(IDCODE-10)300,112,112
  112 IDCODE=IDCODE-10
      IF(IDCODE-10) 400,113,113
  113 IDCODE=IDCODE-10
      IF(IDCODE-10)500,114,114
  114 IDCODE=IDCODE-10
      GO TO 600
C
C  PROCESS A CONTROL COMMAND
C
  200 IF(IDCODE.GT.0)GO TO 201
      EFLAG=2
      GO TO 900
  201 GO TO(210,220,230,240,250,260,270,100,290),IDCODE
  210 WRITE(3,50) IDENT
   50 FORMAT("0","RUN = ",6A1)
      EFLAG=7
      IF(PFLAG) 211,212,211
  211 WRITE(4,51) IDENT
   51 FORMAT("RUN = ",6A1)

  212 GO TO 900
C         SNAPSHOTS
  220 NS=VARS(1)
      WRITE(3,52) NS
   52 FORMAT("0","SNAPSHOTS = ",I2)
      GO TO 800
C
C         PUNCH AND NOPUNCH SETTINGS
  230 PFLAG=1
      WRITE(3,53)
   53 FORMAT("0","PUNCH RESULTS")
      GO TO 800
  240 PFLAG=0
      GO TO 800
C
C         TRACE AND NOTRACE SETTINGS
  250 IOFLAG=1
      GO TO 800
  260 IOFLAG=0
      GO TO 800
C
C         CLEAR COMMAND
  270 NP=0; NL=0;NC=0; NM=0
      GO TO 800
C
```

```
C         STOP COMMAND
  290 EFLAG=1
      GO TO 900
C
C         PROCESS A GEOMETRY INPUT CARD
  300 IF(IDCODE.GT.0) GO TO 301
  302 EFLAG=3
      GO TO 900
  301 GO TO(310,320,330,340,302,302,302,302,302),IDCODE
C
C         PATH INPUT
  310 NP=NP+1
      DO 311 I=1,3
  311 PATH(I,NP)=VARS(I)

      WRITE(3,54)(PATH(I,NP),I=1,3)
   54 FORMAT("0","PATH POINT (X,Y,Z) = ",3F7.1)
      GO TO 800
C
C         OBSERV POINT INPUT
  320 DO 321 I=1,3
  321 OBSERV(I)=VARS(I)
      WRITE(3,55)(OBSERV(I),I=1,3)
   55 FORMAT("0","OBS. POINT (X,Y,Z) = ",3F7.1)
      GO TO 800
C
C         LANE LOCATION INPUT
  330 NL=NL+1
      DO 331 I=1,2
  331 OFFSET(I,NL)=VARS(I)
      WRITE(3,56)(OFFSET(I,NL),I=1,2)
   56 FORMAT("0","LANE OFFSET (H,V) = ",2F7.1)
      GO TO 800
C         BARRIER INPUTS
  340 HB=VARS(1)
      HR=VARS(2)
      HD=VARS(3)
      B1=VARS(4)
      BL=VARS(5)
      H2=VARS(6)
      H3=VARS(7)
      WRITE(3,560)
  560 FORMAT("0",3X,"HB      HR      HD      B1      BARR LENGHT")
      WRITE(3,561)HB,HR,HD,B1,BL,H2,H3
  561 FORMAT("0",7F7.1)
      GO TO 800
C
C         SOUND PROPAGATION CONDITIONS
  400 IF(IDCODE.GT.0)GO TO 401
  402 EFLAG=4
      GO TO 900
  401 GO TO(410,420,402,402,402,402,402,402,402),IDCODE
C
C         AIR ATTEN SPECTRUM INPUT
  410 DO 411 I=1,NB
  411 AIRATN(I)=VARS(I)
      WRITE(3,57)(AIRATN(I),I=1,NB)
   57 FORMAT("0","AIR ATTEN., 63-8000 HZ",/," ",8F7.2)
      GO TO 800
C
C         SHIELDING CONSTANT SPECTRUM INPUT
  420 DO 421 I=1,NB
  421 GRDATN(I)=VARS(I)
      WRITE(3,58)(GRDATN(I),I=1,NB)
   58 FORMAT("0","SHIELDING ATTEN., 63-8000 HZ",/," ",8F7.2)
      GO TO 800
C
C         PROCESS A VEHICLE CLASS INPUT CARD
  500 IF(IDCODE.GT.0)GO TO 501
  502 EFLAG=5
      GO TO 900
  501 GO TO(510,502,502,502,502,502,502,502,502),IDCODE
C
C         SOURCE SPECTRUM, DISTANCE,AND SPEED
  510 NC=NC+1
      DO 511 I=1,8
  511 CSPECT(I,NC)=VARS(I)
      SDIST(NC)=VARS(9)
      SSPEED(NC)=VARS(10)*5280.0/3600.0
      WRITE(3,59)NC,(CSPECT(I,NC),I=1,8),SDIST(NC),VARS(10)

   59 FORMAT("0","VEHICLE CATAGORY ",I2,"SPECTRUM, 63-8000 HZ",/," ",
     18F7.2,/," ","REF. DIST. (FT) = ",F7.1,/," ",
     2"REF. SPEED (MPH) = ",F7.2)
      GO TO 800
C
C         TRAFFIC INPUT CARD
  600 IF(IDCODE.GT.0) GO TO 601
  602 EFLAG=6
      GO TO 900
  601 GO TO(610,620,630,640,602,602,602,602,602),IDCODE
C
C         TRAFFIC MIX INPUT FOR A LANE
  610 NM=NM+1
      DO 611 I=1,NC
  611 PVECT(I,NM)=VARS(I)
      WRITE(3,60)NM,(PVECT(I,NM),I=1,NC)
   60 FORMAT("0","MIX FOR LANE ",I2,10F7.2)
      GO TO 800
C
C         TRAFFIC FLOW INPUT
  620 DO 621 I=1,NL
  621 FLOW(I)=VARS(I)
      DO 622 I=1,NL
  622 DENSTY(I)=0.0
      WRITE(3,61)(FLOW(I),I=1,NL)
   61 FORMAT("0","FLOW IN VPH FOR LANES 1-NL",/," ",10F7.1)
      GO TO 800
C
C         TRAFFIC SPEED INPUT
  630 DO 631 I=1,NL
  631 VELCTY(I)=VARS(I)*5280.0/3600.0
      WRITE(3,62)(VARS(I),I=1,NL)
   62 FORMAT("0","SPEED IN MPH FOR LANES 1-NL",/," ",10F7.1)
      GO TO 800
C
C         TRAFFIC DENSITY INPUT
  640 DO 641 I=1,NL
      DENSTY(I)=VARS(I)
  641 FLOW(I)=0.0
      WRITE(3,63)(DENSTY(I),I=1,NL)
   63 FORMAT("0","DENSITY IN VPM FOR LANES 1-NL",/," ",10F7.2)
      GO TO 800
```

```
  800 GO TO 100
  900 RETURN
      END


      SUBROUTINE RUNSIM
C  TO PERFORM A SIMULATION RUN CONSISTING OF  NS  SNAPSHOTS
C   USING THE DATA PREPARED IN COMMON
      COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL/BLK2/DENSTY(10),VELCTY
     1(10),FLOW(10)  /BLK3/CSPECT(8,10),SDTST(10),SSPEED(10)
     2/BLK4/PVECT(10,10),NC,NM   /BLK5/AIRATN( 8),GRDATN( 8),NB
     3/BLK6/NS,IOFLAG,PFLAG   /BLK7/POSITN(3),OBSERV(3)
     4/BLK9/RPREV(3),R1,R2/BLK10/LPREV(3),L1,L2
      COMMON/BLK11/HB,HR,HD,B1,H2,H3,BL
      INTEGER R1,R2,RLAST,TYPE,VTYPE
      REAL LPREV
      DIMENSION SPECTR( 8),SPEC1( 8),TOTSPC( 8),FOOT(3),SPAN(10),
     2POP(10,10),AVER(2),SD(2),VMIN(2),VMAX(2),TOT(2),S(50),VALUES(100)
      DIMENSION SPECTB( 8),SPEC2( 8),VALUEB(100)
C
C        CLEAR MEAN SPECTRUM VECTOR
      DO 97 I=1,NB
   97 TOTSPC(I)=0.0
C
C
C        FIND MINIMUM DISTANCE TO ROADWAY CENTERLINE
C
      CALL MINDST(FOOT,I1,I2)
      IF(IOFLAG)98,99,98
   98 WRITE(3,3) FOOT,I1,I2
    3 FORMAT(" ","FOOT = ",3F7.1,"I1,I2",2I6)
C
C        START OF DO LOOP FOR EACH SNAPSHOT
   99 DO 200 K=1,NS
      DO 500 I=1,NL
      SPAN(I)=0.0
      DO 500 J=1,NC
      POP(J,I)=0.0
  500 CONTINUE
      DBVAL=0.0
      DBVALB=0.0
      DO 10 I=1,NB
      SPECTB(I)=0.0
   10 SPECTR(I)=0.0
C
C        START OF DO LOOP FOR EACH LANE
      DO 100 LANE=1,NL
      CALL GETGAP(LANE,FIRSTI)
      SPAN(LANE)=SPAN(LANE)+FIRSTI
      PREVLG=0.0
      PREVRG=0.0
      FRIGHT=FIRSTI+RANF(1)
      DO 601 I=1,3
  601 RPREV(I)=FOOT(I)
      R1=I1; R2=I2
      CALL RTPOS(FRIGHT,LANE,RLAST)
      IF(RLAST.EQ.2)GO TO 300
      DO 602 I=1,3
  602 LPREV(I)=RPREV(I)
      L1=R2;L2=R1
      CALL LFTPOS(FIRSTI,LANE,LLAST)
      IF(LLAST.EQ.2)GO TO 300
```

```
C
C        START OF DO LOOP FOR EACH 4-VEHICLE SEQUENCE ON A LANE
   50 OLDVAL=DBVAL
      DO 150 M=1,4
C        PLACE VEHICLE TO RIGHT OR LEFT DEPENDING UPON  N
      N=MOD(M,2)+1
      IF(N.EQ.2)GO TO 70
      IF(LLAST.EQ.2)GO TO 300
C
C        DRAW VEHICLE TYPE,SPEED, AND INTERVEHICLE INTERVAL
      TYPE=VTYPE(LANE)
      SPEED=VSPEED(LANE)
      SPAN(LANE)=SPAN(LANE)+PREVLG
      CALL GETGAP(LANE,GAP)
      PREVLG=GAP
      CALL LFTPOS(GAP,LANE,LLAST)
      GO TO 75
C
   70 IF(RLAST.EQ.2)GO TO 150
      TYPE=VTYPE(LANE)
      SPEED=VSPEED(LANE)
      SPAN(LANE)=SPAN(LANE)+PREVRG
      CALL GETGAP(LANE,GAP)
      PREVRG=GAP
      CALL RTPOS(GAP,LANE,RLAST)
   75 IF(IOFLAG)74,74,73
   73 WRITE(3,4)TYPE,SPEED,POSITN,GAP
    4 FORMAT(" ","TYPE=",I4,"  SPEED=",F5.0,"  POSITION=",3F7.1,
     1 /," ","GAP=",F7.1)
C        MODIFY VEHICLE SPECTRUM AND ADD TO EXISTING SPECTRUM
   74 CALL CNTRIB(TYPE,SPEED,LANE,SPEC1,SPEC2)
      POP(TYPE,LANE)=POP(TYPE,LANE)+1.0
      DO 76 I=1,NB
      SPECTB(I)=DBSUM(SPEC2(I),SPECTB(I))
   76 SPECTR(I)=DBSUM(SPEC1(I),SPECTR(I))
  150 CONTINUE
C        COMPUTE DBA
      DBVAL=DBA(9,8,SPECTR)
      DBVALB=DBA(9,8,SPECTB)
      IF(0.5-ABS(DBVAL-OLDVAL))50,80,80
C        CHECK WHETHER ANY CLASS VEHICLE AT THIS LAST POSITION WOULD
C        CONTRIBUTE AS MUCH AS 1 DBA TO SUM
   80 HYPOTH=0.0
      DO 90 ICAT=1,NC
      CALL CNTRIB(ICAT,SPEED,LANE,SPEC1,SPEC2)
      TEMP1=DBA(9,8,SPEC1)
      IF(TEMP1-HYPOTH)90,90,85
   85 HYPOTH=TEMP1
      IMX=ICAT
   90 CONTINUE
      CALL CNTRIB(IMX ,SPEED,LANE,SPEC1,SPEC2)
      DO 91 I=1,NB
   91 SPEC1(I)=DBSUM(SPEC1(I),SPECTR(I))
      CHDBA=DBA(9,8,SPEC1)
      IF(CHDBA.GE.(DBVAL+1.0))GO TO 50
  100 CONTINUE
C        STORE VALUES FOR STATISTICAL COMPUTATIONS
      DO 180 I=1,NB
  180 TOTSPC(I)=TOTSPC(I)+SPECTR(I)
      S(K)=1.0
```

```
      VALUES(K)=DBVAL
      VALUEB(K)=DBVALB
      KN=K+NS
      VALUES(KN)=DA(9 ,NB,SPECTR)
      VALUEB(KN)=DA(9,NB,SPECTB)
      IF(PFLAG)190,202,190
  190 WRITE(3,9)(SPECTR(I),I=1,NB)
      WRITE(3,9)(SPECTB(I),I=1,NB)
    9 FORMAT(9X,8F7.2)
C        PRINT SNAPSHOT RESULTS
  202 WRITE(3,1)
    1 FORMAT(" ",".................................................
     1...................",/,
     2" ",3X,"DBA       DBC                BANDS 63 - 8000 HZ")
      WRITE(3,2)(VALUES(I),I=K,KN,NS),(SPECTR(I),I=1,NB)
      WRITE(3,67)(VALUEB(I),I=K,KN,NS),(SPECTB(I),I=1,NB)
    2 FORMAT(" ",2(F7.2,2X), 8F7.2,"NO BARRIER")
   67 FORMAT(" ",2(F7.2,2X), 8F7.2,"BARRIER")
      WRITE(3,13)
      DO 201 J=1,NC
  201 WRITE(3,14)J,(POP(J,I),I=1,NL)
   13 FORMAT("0","VEHICLE POPULATION FOR LANES 1 - NL")
   14 FORMAT(" ",I2,10F7.1)
  200 WRITE(3,12)(SPAN(I),I=1,NL)
   12 FORMAT("0","TRAFFIC SPAN (FT) FOR LANES 1 - NL",/," ",10F7.1)
      WRITE(3,18)
   18 FORMAT(" ",".................................................
     1.......................")
      CALL TALLY(VALUES,S,TOT,AVER,SD,VMIN,VMAX,NS,2)
      WRITE(3,5)AVER
      WRITE(3,6) SD
      WRITE(3,7) VMIN
      WRITE(3,8) VMAX
    5 FORMAT("0","MEAN= ",3F7.2)
    6 FORMAT("0","DEV=  ",3F7.2)
    7 FORMAT("0","MIN=  ",3F7.2)
    8 FORMAT("0","MAX=  ",3F7.2)
      DO 210 I=1,NB
  210 TOTSPC(I)=TOTSPC(I)/NS
      WRITE(3,15)(TOTSPC(I),I=1,NB)
   15 FORMAT("0","MEAN SPECTRUM FOR SNAPSHOTS",/," ", 8F7.1)
C        CALC HISTOGRAM
      WRITE(3,17)
   17 FORMAT("0","DISTRIBUTION OF SNAPSHOT DBA VALUES")
      CUT=0.5
  220 CUT=CUT+1.0
      IF(CUT-VMIN(1))220,220,221
  221 COUNT=0.0
      DO 224 I=1,NS
      IF(VALUES(I)-CUT)224,222,222
  222 IF(VALUES(I)-(CUT+1.0))223,224,224
  223 COUNT=COUNT+1.0
  224 CONTINUE
      PCT=(COUNT/NS)*100.0
      IMID=CUT-0.5
      NUM=COUNT
      WRITE(3,16) IMID,NUM,PCT
   16 FORMAT(" ",I2,8X,I3,F10.2)
      CUT=CUT+1.0
      IF(VMAX(1)-(CUT-1.0))400,221,221
```

```
  400 RETURN
  300 WRITE(3,11)
   11 FORMAT("0","****** INSUFFICIENT ROADWAY LENGTH, RUN ABORTED")
      GO TO 400
      END



      SUBROUTINE MINDST(FOOT,I1,I2)
      COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL
     2/BLK7/POSITN(3),OBSERV(3)
     3/BLK9/RPREV(3),R1,R2  /BLK10/LPREV(3),L1,L2
      INTEGER R1,R2
      REAL LPREV,LV1,LV2
      DIMENSION FOOT(3),V1(3),V2(3),D(3)
      DMIN=1.0E40
      DO 100 J=1,NP
      SUM=0.0
      DO 21 I=1,3
      T=PATH(I,J)-OBSERV(I)
   21 SUM=SUM+T*T
      VL=SQRT(SUM)
      IF(VL-DMIN)22,100,100
   22 DMIN=VL
      I1=J
  100 CONTINUE
      I2=I1+1
      R1=I1; R2=I2
      IF(R2-NP)101,101,900
  101 L1=R1; L2=L1-1
      IF(L2)900,900,110
  110 LV1=0.0;LV2=0.0; DV1=0.0;DV2=0.0
      DO 200 I=1,3
      V1(I)=PATH(I,L2)-PATH(I,L1)
      V2(I)=PATH(I,R2)-PATH(I,R1)
      LV1=LV1+V1(I)*V1(I)
      LV2=LV2+V2(I)*V2(I)
      D(I)=OBSERV(I)-PATH(I,R1)
      DV1=DV1+D(I)*V1(I)
  200 DV2=DV2+D(I)*V2(I)
      DO 105 I=1,3
  105 FOOT(I) = PATH(I,R1)
      IF(DV1-10.0)210,210,250
  210 IF(DV2-10.0)220,220,290
  220 RETURN
  250 IF(DV2-10.0)280,280,260
  260 IF(DV1-DV2)290,290,280
  280 I1=L2;I2=L1
      C=DV1/LV1
      DO 285 I=1,3
  285 FOOT(I)=PATH(I,L1)+C*V1(I)
      RETURN
  290 C=DV2/LV2
      DO 295 I=1,3
  295 FOOT(I)=PATH(I,R1)+C*V2(I)
      RETURN
  900 WRITE(3,1)
    1 FORMAT("0","*****PERPENDICULAR OUT OF BOUNDS***")
      RETURN
      END
```

```
      SUBROUTINE TALLY(A,S,TOTAL,AVER,SD,VMIN,VMAX,NO,NV)
      DIMENSION A(100),S( 50),TOTAL(2),AVER(2),SD(2),VMIN(2),VMAX(2)
      DO 1 K=1,NV
      TOTAL(K)=0.0
      AVER(K)=0.0
      SD(K)=0.0
      VMIN(K)=1.0E40
    1 VMAX(K)=-1.0E40
      SCNT=0.0
      DO 7 J=1,NO
      IJ=J-NO
      IF(S(J))2,7,2
    2 SCNT=SCNT+1.0
      DO 6 I=1,NV
      IJ=IJ+NO
      TOTAL(I)=TOTAL(I)+A(IJ)
      IF(A(IJ)-VMIN(I))3,4,4
    3 VMIN(I)=A(IJ)
    4 IF(A(IJ)-VMAX(I))6,6,5
    5 VMAX(I)=A(IJ)
    6 SD(I)=SD(I)+A(IJ)*A(IJ)
    7 CONTINUE
      DO 8 I=1,NV
      AVER(I)=TOTAL(I)/SCNT
    8 SD(I)=SQRT(ABS((SD(I)-TOTAL(I)*TOTAL(I)/SCNT)/(SCNT-1.0)))
      RETURN
      END
      SUBROUTINE CNTRIB(TYPE,SPEED,LANE,SPECTR,SPECTB)
      COMMON /BLK3/CSPECT(8,10),SDIST(10),SSPEED(10)
     1/BLK7/POSITN(3),OBSERV(3)/BLK5/AIRATN(8),GRDATN(8),NB
      COMMON/BLK11/HR,HR,HD,B1,H2,H3,BL
      INTEGER TYPE
      DIMENSION SPECTR( 8),SPECTB( 8),BCONST( 8)
      D=0.0
      DO 3 I=1,3
      T=POSITN(I)-OBSERV(I)
    3 D=D+T*T
      D=SQRT(D)
C
C         PICK UP REFERENCE DISTANCE
      DZERO=SDIST(TYPE)
C
C         SPEED CORRECTION BASED ON 30 LOG V1/V0 RELATION
C         WHERE REFERENCE SPEED IS VZERO
      VZERO=SSPEED(TYPE)
      IF(VZERO)6,6,5
    5 VCONST=30.0*ALOG10(SPEED/VZERO)
      GO TO 7
    6 VCONST=0.0
C
C         STANDARD ATTENUATION DEPENDENT UPON DISTANCE
    7 ACONST=(D-DZERO)/1000.0
      DCONST=20.0*(ALOG10(DZERO)-ALOG10(D))
C         BARRIER ATTEN.
      CALL SCREEN(LANE,BCONST)
C         ADJUSTED SPECTRUM
      DO 10 I=1,NB
      SPECTR(I)=CSPECT(I,TYPE)+VCONST+DCONST+ACONST+AIRATN(I)
   10 SPECTB(I)=SPECTR(I)-BCONST(I)
      RETURN
      END
```

```
      REAL FUNCTION DBA(BO,NB,SPECTR)
      DIMENSION SPECTR( 8)
      INTEGER BO
      IX=1
      IF(NB-12)50,50,60
   50 IX=3
   60 K=BO
      DBA=0.0
      DO 200 I=1,NB
      GO TO(1,1,1,1,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20, 1,22,
     123,24,25,26,27,27,27,30,1,1,1,1,1,1 ),K
  100 DBA=DBSUM(DBA,(SPECTR(I)+WEIGHT))
  200 K=K+IX
      RETURN
C
C         WEIGHTING VALUES
    1 WEIGHT=0.0
      GO TO 100
    5 WEIGHT=-40.3
      GO TO 100
    6 WEIGHT=-36.2
      GO TO 100
    7 WEIGHT=-32.5
      GO TO 100
    8 WEIGHT=-28.9
      GO TO 100
    9 WEIGHT=-25.3
      GO TO 100
   10 WEIGHT=-21.8
      GO TO 100
   11 WEIGHT=-18.8
      GO TO 100
   12 WEIGHT=  -16.0
      GO TO 100
   13 WEIGHT=   -13.1
      GO TO 100
   14 WEIGHT=      -10.8
      GO TO 100
   15 WEIGHT=    -8.6
      GO TO 100
   16 WEIGHT=    -6.5
      GO TO 100
   17 WEIGHT=    -4.8
      GO TO 100
   18 WEIGHT=    -3.3
      GO TO 100
   19 WEIGHT=     -1.9
      GO TO 100
   20 WEIGHT=    -0.8
      GO TO 100
   22 WEIGHT=    0.6
      GO TO 100
   23 WEIGHT=     1.1
      GO TO 100
   24 WEIGHT=     1.4
      GO TO 100
   25 WEIGHT=    1.5
      GO TO 100
   26 WEIGHT=    1.7
      GO TO 100
```

```
27 WEIGHT=    1.8
   GO TO 100
30 WEIGHT=    1.9
   GO TO 100

   END

   REAL FUNCTION DBSUM(A,B)
   DBSUM=B
   IF(A-0.01)30,30,10
10 DBSUM=A
   IF(B-0.01)30,30,20
20 DBSUM=10.0*ALOG10(10.0**(0.1*A ) + 10.0**(0.1*B ))
30 RETURN
   END

   SUBROUTINE GETGAP(LANE,G)
   COMMON/BLK2/DENSTY(10),VELCTY(10),FLOW(10)
   F=RANF(1)
   G=((ALOG(1.0-F))/(0.0-DENSTY(LANE)))*5280.0
   RETURN
   END

   SUBROUTINE LFTPOS(GGAP,LANE,LAST)
   COMMON/BLK1/PAYH(3,200),OFFSET(2,10),NP,NL  /BLK7/POSITN(3),
  1OBSERV(3)/BLK10/LPREV(3),L1,L2
   INTEGER FAR,OK
   REAL LPREV,NEWGAP
   LAST=1; NEAR=L1; FAR=L2
   XDIFF=ABS(PATH(1,FAR) - PATH(1,NEAR))
   YDIFF=ABS(PATH(2,FAR) - PATH(2,NEAR))
   VLN=SQRT((XDIFF*XDIFF) + (YDIFF*YDIFF))
   C1=YDIFF/VLN
   C2=XDIFF/VLN
   POSITN(1)=LPREV(1)  + OFFSET(1,LANE)*C1
   POSITN(2)=LPREV(2) +OFFSET(1,LANE)*C2
   POSITN(3)=LPREV(3)+OFFSET(2,LANE)
   NEWGAP=GGAP
15 GAP=NEWGAP
200 CALL MOVE(LPREV,L1,L2,GAP,NEWGAP,OK)
   IF(OK.EQ.1)GO TO 30
20 L1=L2; L2=L2-1
   IF(L2)25,25,15
25 LAST=2
30 RETURN
   END

   SUBROUTINE RTPOS(GGAP,LANE,LAST)
   COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL
  1/BLK7/POSITN(3),OBSERV(3)/BLK9/RPREV(3),R1,R2
   INTEGER R1,R2,OK,FAR
   REAL NEWGAP
   LAST=1; NEAR=R1; FAR=R2
   XDIFF=ABS(PATH(1,FAR) - PATH(1,NEAR))
   YDIFF=ABS(PATH(2,FAR) - PATH(2,NEAR))
   VLN=SQRT((XDIFF*XDIFF) + (YDIFF*YDIFF))
   C1=YDIFF/VLN
   C2=XDIFF/VLN
   POSITN(1)=RPREV(1)  + OFFSET(1,LANE)*C1
   POSITN(2)=RPREV(2) +OFFSET(1,LANE)*C2
   POSITN(3)=RPREV(3)+OFFSET(2,LANE)
   NEWGAP=GGAP
15 GAP=NEWGAP
200 CALL MOVE(RPREV,R1,R2,GAP,NEWGAP,OK)
   IF(OK.EQ.1)GO TO 30
20 R1=R2; R2=R2+1
   IF(R2-NP)15,15,25
25 LAST=2
30 RETURN
   END

   SUBROUTINE MOVE(R,P1,P2,DELTA,NEWGAP,OK)
   COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL
   INTEGER P1,P2,OK
   REAL NEWGAP,R(3),U(3),LENGTH
   OK=1  ;  NEWGAP=0.0
   SUM=0.0
   DO 10 I=1,3
   T=PATH(I,P2)-R(I)
10 SUM=SUM+T*T
   LENGTH=SQRT(SUM)
   IF(DELTA-LENGTH)20,30,30
20 SUM=0.0
   DO 21 I=1,3
   T=PATH(I,P2)-PATH(I,P1)
   U(I)=Y
21 SUM=SUM+T*T
   UL=SQRT(SUM)
   DO 25 I=1,3
25 R(I)=DELTA*U(I)/UL+R(I)
   RETURN
30 NEWGAP=DELTA-LENGTH
   OK=2
   DO 31 I=1,3
31 R(I)=PATH(I,P2)
   RETURN
   END

   REAL FUNCTION DA(IO,N,SPCTRM)
   DIMENSION SPCTRM( 8)
   DA=0.0
   DO 4 J=1,N
   IF(SPCTRM(J))4,4,3
 3 DA=DA+10.0**(.1*SPCTRM(J))
 4 CONTINUE
   IF(DA)6,6,5
 5 DA=10.0*ALOG10(DA)
 6 RETURN
   END

   REAL FUNCTION VSPEED(LANE)
   COMMON /BLK2/DENSTY(10),VELCTY(10),FLOW(10)
   VSPEED=VELCTY(LANE)
   RETURN
   END

   INTEGER FUNCTION VTYPE(LANE)
   COMMON /BLK4/PVFCT(10,10),NC,NM
   FRACT=RANF(1)
   FRACY=100.0*FRACT
   SUM=0.0
```

```
      DO 100 I=1,NC
      SUM=SUM+PVECT(I,LANE)
      IF(SUM-FRACT)100,100,200
  100 CONTINUE
      VTYPE=NC
      GO TO 300
  200 VTYPE=I
  300 RETURN
      END


      REAL FUNCTION RANF(X)
      DATA I/2407/
      W=1025*I+101
      I=AMOD(W,2**36)
      RANF=I/2.**36
      RETURN
      END


      REAL FUNCTION DBATN(A,B)
      DBSUM=B
      IF(A-0.01)30,30,10
   10 DBSUM=A
      IF(B-0.01)30,30,20
   20 DBATN=-10.*ALOG10(10.**(-.1*A)+10.**(-.1*B))
   30 RETURN
      END


      REAL FUNCTION LNGTH(X,Y)
      LNGTH=SQRT(X*X+Y*Y)
      RETURN
      END


      REAL FUNCTION ATN(VAL,ARG,DUMMY,KK)
      DIMENSION VAL(1),ARG(1)
      DUM=AMAX1(AMIN1(DUMMY,ARG(KK)),ARG(1))
      DO 1 I=2,KK
      IF(DUM.GT.ARG(I)) GO TO 1
      ATN=ALOG10(DUM)-ALOG10(ARG(I-1))
      F=ALOG10(ARG(I))-ALOG10(ARG(I-1))
      ATN=ATN*(VAL(I)-VAL(I-1))/F+VAL(I-1)
      RETURN
    1 CONTINUE
      RETURN
      END

      SUBROUTINE SCREEN(LANE,BCONST)
C        ******** CALC ATTENUATION DUE TO NOISE BARRIER, ********
C        INPUT PARAMETERS ***
C          HB - BARRIER HEIGHT (FT).
C          HR - RECEIVER HEIGHT (FT).
C          HD - ROAD LEVEL TO RECEIVER LEVEL DIST (FT).
C          B1 - BARRIER TO RECEIVER DIST (FT).
C          BL - BARRIER LENGTH (1.=INF, 2.=SEMI, 3.=FINITE).
C          H2 - BARRIER LENGTH TO LEFT OF RECEIVER (FT).
C          H3 - BARRIER LENGTH TO RIGHT OF RECEIVER (FT).
C          OBSERV(1) - X POSITION FOR REC. LOC. (FT).
C          OFFSET(1,LANE) - HORIZ. LANE POSITION WRT CL. (FT).
C          OFFSET(2,LANE) - VERT. LANE POSITION WRT CL. (FT).
C          LANE - LANE NUMBER FROM 1 TO NL.
C        OUTPUT PARAMETERS ***
C          BCONST - BARRIER ATTENUATION VECTOR (DB).
      COMMON/BLK1/PATH(3,200),OFFSET(2,10),NP,NL
      COMMON/BLK5/AIRATN( 8),GRDATN( 8),NB
      COMMON/BLK7/POSITN(3),OBSERV(3)
      COMMON/BLK11/HB,HR,HD,B1,H2,H3,BL
      REAL N,LA,L,L3
      DIMENSION BCONST(8),F(8),SR(2),SO(3,2),OR(3,2),DEL(3,2),H(3)
      DIMENSION ARG(6),N(3,2),AN(3,2),L3(3),LA(3,2),Z(2,2),L(3,8),VAL(6)
      DATA (F(I),I=1,8)/63.,125.,250.,500.,1000.,2000.,4000.,8000./
      DATA (ARG(I),I=1,6)/0.,.01,.05,.2,.4,1./
      DATA (VAL(I),I=1,6)/5.,6.,7.,9.,10.4,13./
      HS=OFFSET(2,LANE)
      AB=OBSERV(1)-OFFSET(1,LANE)
      A1=AB-B1
C        CHECK TYPE OF ROADWAY.
      IF(HD)100,200,300
C        SETUP FOR ELEVATED ROADWAY.
  100 C=HS-HD+HR
      D=HB-HD+HR
      HRS=HD+HR
      HBS=HB-HD-HR
      GO TO 400
C        SETUP FOR DEPRESSED ROADWAY.
  300 HS=HS-HD
C        SETUP FOR AT-GRADE ROADWAY.
  200 C=HS+HR
      D=HB+HR
      HRS=HR-HS
      HBS=HB-HS
C        CALC PATH DIFF FOR DIFFRACTION, GND REFLECTION.
  400 HBR=HB-HR
      SO(1,1)=LNGTH(A1,HBS)
      SO(1,2)=SO(1,1)
      OR(1,1)=LNGTH(B1,HBR)
      OR(1,2)=LNGTH(B1,D)
      SR(1)=LNGTH(AB,HRS)
      SR(2)=LNGTH(AB,C)
      DO 450 J=1,2
  450 DEL(1,J)=SO(1,1)+OR(1,J)-SR(J)
C        CHECK BARRIER LENGTH.
      IF(BL-2.) 410,510,610
C        CALC ATTENUATION FOR INF BARRIER.
  410 DO 500 I=1,NB
      DO 502 J=1,2
      N(1,J)=F(I)*DEL(1,J)/564.
      IF(N(1,J)-1.)520,530,530
  530 AN(1,J)=13.0103+10.*ALOG10(N(1,J))
      GO TO 502
  520 AN(1,J)=ATN(VAL,ARG,N(1,J),6)

  502 CONTINUE
      L3(1)=DBATN(AN(1,1),AN(1,2))
  500 BCONST(I)=AMIN1(L3(1),25.)
      RETURN
C        CALC ATTENUATION FOR SEMI-INF BARRIER.
C        (PRESENTLY NOT OPERATIONAL.)
  510 CONTINUE
C        CALC PATH DIFF AROUND ENDS FOR FINITE BARRIER.
  610 H(2)=H2
      H(3)=H3
```

```
      DO 651 J=1,2
      Z(1,J)=A1+SR(J)/AB
      Z(2,J)=B1+SR(J)/AB
      DO 651 K=2,3
      SO(K,J)=LNGTH(H(K),Z(1,J))
      OR(K,J)=LNGTH(H(K),Z(2,J))
  651 DEL(K,J)=SO(K,J)+OR(K,J)-SR(J)
C         CALC ATTENUATION FOR FINITE BARRIER.
      DO 700 I=1,NB
      DO 680 K=1,3
      DO 670 J=1,2
      N(K,J)=F(I)*DEL(K,J)/564.
      IF(N(K,J)-1.)620,630,630
  630 AN(K,J)=13.0103+10.*ALOG10(N(K,J))
      GO TO 670
  620 AN(K,J)=ATN(VAL,ARG,N(K,J),6)
  670 CONTINUE
      L3(K)=DBATN(AN(K,1),AN(K,2))
      IF(K-2)661,662,662
  662 L3(K)=DBATN(L3(K),L3(1))
  661 CONTINUE
  680 CONTINUE
      BCONST(I)=DBATN(L3(1),L3(2))
  700 BCONST(I)=AMIN1(DBATN(BCONST(I),L3(3)),25.)
      RETURN
      END
```