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FIELD STUDY OF A VARIABLE-HEIGHT HIGHWAY-NOISE BARRIER

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FINAL REPORT

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PREFACE

The authors would like to take this opportunity to express their appreciation to the many organizations and individuals who contributed to the overall success of the project.

The noise measurements needed to evaluate the barrier performance were carried out using the Transportation Systems Center Mobile Noise Laboratory under the direction of TSC's Edward Rickley. His efforts made it possible to collect and analyze the large amount of data in the program. His recommendations and comments with regard to the measurement plan and with regard to the preparation of this report were greatly appreciated.

Engineering specifications for the noise barrier were prepared by CE Maguire, Inc., 60 First Avenue, Waltham, Massachusetts. In particular, we wish to thank Edward Chisholm of that company for his assistance in preparing the information needed to obtain a construction permit from the Massachusetts DPW.

The noise barrier was constructed by Coronis Construction Company, Inc., 29 Vine Street, Winchester, Massachusetts. Charles Brown provided several changes to the barrier construction which made it easier to seal small gaps in the barrier without increasing its costs.

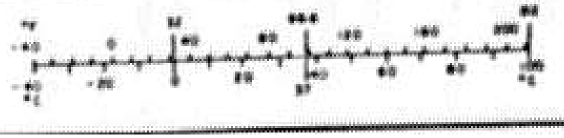
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m³	cubic meters	35	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ILLUSTRATIONS (cont.)

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1. INTRODUCTION

In a recent study, it was estimated that over 70-million people living near highways in the United States are subjected to objectionable noise levels from traffic [1]. Many approaches have been suggested for alleviating this situation. They involve (a) reducing the noise at the source by quieting the individual vehicles, (b) blocking the sound-transmission path by use of roadside barriers or berms, (c) increasing the distance between the roadway and noise-sensitive areas, and (d) increasing the noise-attenuation characteristics of the dwellings in noise-impacted areas. This report focuses on just one of these approaches -- (b) use of roadside barriers.

Roadside-noise barriers have been installed in many parts of the United States [2], in Canada [3], and in other parts of the world [4,5]. However, in spite of these many installations, the performance of a barrier in reducing noise under actual field conditions is not well understood. Many existing design charts, which are based on scale-model laboratory measurements or analytical expressions, tend to be inaccurate in predicting the performance of a barrier. It is believed that this inaccuracy is due to neglect of the effects of the ground surface and atmospheric conditions on the sound propagation. A few recently developed prediction procedures have tried with some success to account for these effects [6,7]. On the whole, however, accurate prediction of roadside-barrier performance remains to be realized.

The purpose of this project was to obtain baseline statistical data which could be used to assess the performance of roadside barriers under actual field conditions. Involved in the project were the design and construction of a temporary variable-height noise barrier; collecting data behind the barrier and at an adjacent open site; and analysis of the data to assess barrier performance.

Past measurements of roadside-barrier performance have been limited. In most cases, the noise levels behind an existing barrier have been measured and compared with levels at a point above or in front of the barrier [8,9]. Unfortunately, in these cases, the performance of the barrier in reducing noise cannot be determined directly since noise levels in the community behind the barrier, without the barrier in place, are not known. The usual practice is to assume that the noise levels measured above or in front of the barrier are unaffected by its presence. These levels are then used to predict the levels in the community without the barrier in place. It follows that errors in prediction of the community-noise levels will transmit directly to errors in the assessment of barrier performance.

In one study of roadside-barrier performance, noise measurements were taken before and after installation of the barrier [3]. This offers a more accurate method for measuring barrier performance, but questions arise as to the similarity of traffic conditions in the two cases.

A few parametric studies have been carried out to determine the effects of barrier height, length, and surface covering on performance [10]. However, these studies have also been limited, in that the supporting measurements were taken using a laboratory-sound source, such as a loudspeaker, rather than actual traffic.

2. SUMMARY

The study described in this report was planned to overcome the shortcomings of past measurement studies. Two adjacent test sites were selected, so that simultaneous measurements could be taken in the open site and behind the barrier. An initial series of measurements, before the barrier was constructed, showed the two sites to be acoustically similar. The barrier was designed so that its height and surface treatment could be changes relatively easily. Measurements were taken for barrier heights of 4, 8, 12, and 16 feet (1.2, 2.4, 3.7, and 4.9 meters, respectively) both with a reflecting surface and a 2-inch (5.1 centimeter) thick absorbing surface. The base of the barrier was 1.2 ft (0.4 m) below the level of the roadway. so that the barrier heights above the level of the roadway were 2.8, 6.8, 10.8, and 14.8 ft (0.9, 2.1, 3.3, and 4.5 m, respectively). Measurement positions were selected at distances of 55, 100, and 200 ft (16.8, 30.5, and 61.0 m, respectively) behind the barrier. At each position microphones were placed on a mast at heights of 3, 8, 13, 18, and 23 ft (0.9, 2.4, 4.0, 5.5, and 7.0 m, respectively) above the road level.

To determine the influence of traffic conditions on barrier performance, measurements were taken at various times of day over a three-day period. Vehicular flow ranged from 2100 to 5400 vehicles per hour with from 90 to 170 heavy trucks and buses per hour, accounting for 4 to 19 percent of the total.

Eight series of measurements, each extending over a two- or three-day period, were needed to study all four barrier heights in combination with the two different barrier surface treatments. During the many measurement sequences, a variety of atmospheric and ground conditions was encountered. Although parameters describing these conditions could not be varied systematically, a study of the data allowed us to draw certain general conclusions.

Table 1 summarizes the results of the measurement program. In this Table, average values for the reduction of L_{10} noise levels* by the barrier are listed. For each value, the average is taken over five or six ten-minute measurement runs encompassing various traffic and atmospheric conditions. For each run the L_{10} noise reduction or "Insertion Loss" was found by taking the L_{10} noise level at a measurement position in the open site and subtracting the L_{10} level at the same position behind the barrier.

Each barrier configuration that was tested had a beneficial effect in reducing noise levels 55, 100, and 200 ft (16.8, 30.5, and 61.0 m, respectively) behind the barrier. In each case, the performance of the barrier increased with barrier height.

Barriers with a sound-absorbing surface were found to be slightly more effective in reducing noise than barriers with a reflecting surface. The average increase in insertion loss for the absorbing barriers was less than ½ dB with the largest increase being approximately 2 dB for the 16-ft (4.88 m) high barrier.

Traffic flow and atmospheric conditions did not have a large effect on the measured values of insertion loss. However, we must point out that the flow of heavy trucks changes only a small amount from measurement run to measurement run, and the prevailing wind was from the barrier toward the road. No measurements were obtained with the wind blowing from the roadway toward the barrier.

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*L_{10} noise level is the sound pressure level (referenced to 20 micro Pascals) that is exceeded 10 percent of the time by a temporally varying noise. In this report all L_{10} noise levels are A-weighted sound pressure levels.

TABLE 1. NOISE REDUCTION BY A 1000-FT LONG BARRIER
AT POINTS 55, 100, and 200 FT FROM THE BARRIER

55 FT FROM BARRIER TO RECEIVER		MEASUREMENT HEIGHT* (ft)				
		3	8	13	18	23
BARRIER HEIGHT (ft)	2.8	4.7	3.3	1.3	0.8	0.8 dB**
	6.8	7.3	7.4	5.4	3.4	1.6 dB
	10.8	10.4	10.5	9.1	6.8	4.1 dB
	14.8	11.8	12.5	11.7	10.8	8.4 dB

100 FT FROM BARRIER TO RECEIVER		MEASUREMENT HEIGHT (ft)				
		3	8	13	18	23
BARRIER HEIGHT (ft)	2.8	2.5	2.6	1.9	1.5	1.1 dB
	6.8	3.3	5.8	5.5	5.0	3.8 dB
	10.8	6.3	9.4	9.2	8.4	6.8 dB
	14.8	8.0	10.3	9.8	10.1	9.6 dB

200 FT FROM BARRIER TO RECEIVER		MEASUREMENT HEIGHT (ft)				
		3	8	13	18	23
BARRIER HEIGHT (ft)	2.8	2.2	2.6	2.6	2.1	1.7 dB
	6.8	2.1	3.5	4.0	4.5	4.8 dB
	10.8	3.7	5.4	6.7	7.4	7.4 dB
	14.8	5.3	6.2	7.2	8.4	8.9 dB

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* All heights are relative to the level of the roadway

** Difference between A-weighted L_{10} noise levels at open site and behind barrier

Barrier located 30 ft from near edge of roadway

3. DESIGN EXPERIMENT

3.1 APPROACH

The primary objective of the program was to design and conduct an experiment in which barrier performance could be measured directly without resorting to any prediction procedure. Thus, experiments in which measured noise levels behind a barrier could be compared with predicted levels at the same site without the barrier in place were ruled out. Experiments in which measurements could be taken before and after barrier construction were also ruled out because a direct comparison of the measured levels would require prediction of the effects of atmospheric conditions, ground cover, and traffic conditions on the observed noise levels. It was assumed that all of these conditions could not possibly be the same during the "before" and "after" measurements.

The experimental approach used in this study was to select two adjacent sites that were acoustically similar. After the sites were chosen, measurements were taken to verify their similarity. The results of these measurements are described in Section 4.2.

After design and construction of the barrier, measured noise levels at positions on the open site could be compared with measured noise levels at corresponding positions behind the barrier to provide a direct measure of barrier insertion loss, which is defined as the difference in noise level at that same position with the barrier in place.

According to current barrier design charts [9], two geometric parameters are of primary importance in determining insertion loss: path-length difference and included horizontal angle. For a given position behind the barrier, these parameters relate directly to barrier height and length. It was considered important to design the experiments so that the effects of these two parameters could be evaluated independently. Thus, in each measurement run, microphones were placed at various heights above ground on two 25-ft (7.62-m) high masts. One mast was placed on the open site, and the second was placed at the corresponding position behind the barrier. Comparison of the data for a given mast position allows a determination of insertion loss as a function of path-length difference for a constant value of included angle. In subsequent runs, the masts were moved to determine the dependence of insertion loss on path-length difference for other included angles. A complete discussion of the measurement procedure is given in Section 5.

3.2 SITE SELECTION AND DESCRIPTION

A measurement site was selected on the west side of Interstate 93 in Andover, Massachusetts. Site selection was based on the following criteria: (a) proximity to a major roadway that is representative of modern design, (b) flatness and absence of nearby reflecting surfaces, (c) ease and convenience of access to the site, (d) openness of the site, and (e) lack of dense vegetation that might influence the measurements.

After the site had been selected, a detailed evaluation was carried out. A description of the site and of the evaluation is presented in Section 4.

3.3 BARRIER DESIGN AND MATERIAL SELECTION

The barrier was to be a temporary structure that would allow for easy removal after the acoustic test series were completed. As the expected life of the barrier was approximately two years, the materials used for the barrier were not treated with preservatives needed for a long service life.

The barrier was located along the southbound side of Interstate 93 in Andover, Massachusetts. The face of the barrier was placed 30 ft (9.14 m) from the edge of the nearest travel lane to adhere to the American Association of State Highway Transportation Officials (AASHTO) requirements for a safety setback to objects that would constitute a danger to out-of-control vehicles. The grade of the existing ground along the centerline of the barrier was approximately 0.7 percent or a difference of 7 ft (2.13 m) in elevation between the beginning and end of the 1000-ft (304.8-m) long barrier.

For financial reasons, the length of the barrier was limited to 1000 ft (304.8 m). This caused some degradation of barrier performance due to noise from traffic beyond the ends of the barrier. The degradation due to finite-barrier length is expected to increase with distance between the barrier and the measurement point. Based on existing design charts for finite-length barriers, the 1000-ft (304.8-m) long barrier will give insertion loss values of 4 dB less than an infinite barrier for a point 50 ft (15.25 m) behind the barrier, 5 dB less for a point 100 ft (30.5 m) behind the barrier, and 7 dB less for a point 200 ft (61 m) behind the barrier. Further discussion of the expected degradation is given in Section 7. The height of the barrier was made to be adjustable, so that the effects of barrier height could be investigated. Heights of 4, 8, 12, and 16 ft (1.22, 2.44, 3.66, and 4.88 m, respectively) above ground level were chosen. Since the ground level along the base of the barrier was approximately 1.2 ft (36.6 cm) below road level, the effective barrier heights to be studied were 2.8, 6.8, 10.8, and 14.8 ft (0.85, 2.07, 3.29, and 4.51 m, respectively).

Barrier material and construction techniques were designed to minimize noise transmission through the barrier and withstand wind loads up to 90 mph (150 km/h). The magnitude and application of the wind loading was as specified in the AASHTO "Specifications for the Design and Construction of Structural Supports for Highway Signs."

Engineering-design specifications for the barrier were prepared by CE Maguire, Inc. A description of their design is included in reference 11.

The supporting elements for the barrier were untreated round timber posts spaced at 8.0 ft (2.44 m) on center. A single unpainted wood beam 16.0-ft (4.88-m) long, 2 in. X 6 in. (5.1 cm X 15.2 cm) was attached to the face of each post to produce a compatible interface for the vertical wall panels. The timber posts supported the main portion of the barrier which was constructed using 4 ft X 8 ft X 5/8 in. (1.22 m X 2.44 m X 1.6 cm) plywood panels (unpainted grade C-D plugged with exterior glue). The plywood panels were mounted with the 8-ft (2.44-m) long edge placed horizontally and the 4-ft (1.22-m) long edge placed vertically. To obtain the required 16-ft (4.88-m) high barrier, four rows of plywood were required. The plywood panels were butted at the center of the 2 in. X 6 in. (5.1 cm X 15.2 cm) interface supports, and were fastened through the post with six 3/8 in. X 6 in. (0.95 cm X 15.2 cm) zinc-plated lag screws with washers (3 screws and washers at each end of the panels). The top of each plywood panel was placed horizontally. The tops of adjacent panels were placed with a slight differential in elevation between them. The introduction to the barrier of a slight sawtoothed top edge was necessary since the timber posts were placed vertically. The sum of the difference in elevations between adjacent panels equaled the approximate 7-ft (2.13-m) difference in elevation between ends of the barrier, or an average of 0.7 inches between adjacent panels.

The center 200 ft (60.96 m) of the barrier consisted of double thickness of plywood with the top of the rear piece of plywood 3 in. (7.6 cm) higher than the front piece. The back-to-back plywood panels were fastened by nails.

The remaining 800 ft (243.8 m) of the barrier consisted of a single thickness of plywood with a 2 in. X 6 in. (5.1 cm X 15.2 cm) stiffener placed horizontally and centered along the top edge of each panel. The stiffener was attached to the vertical 2 in. X 6 in. at each post, and the plywood panels were nailed to the horizontal 2 in. X 6 in. stiffener. To provide an acoustically absorbing face for the barrier, a 4 ft X 8 ft (1.22 m X 2.44 m) piece of glass-fiber insulation board was attached to the front face of each panel using twelve #9 X 3 in. (7.6 cm) zinc-coated wood screws with 2-in. (5.1 cm) diameter X 1/16-in. (0.16 cm) thick polyethylene washers.

Excavated soil was used to fill any openings under the bottom row of panels.

The allowable stresses for the timber elements were determined per the requirements of the American Institute of Timber Construction. The embedment length of the timber posts was determined by the method developed by Rutledge as described in "How to Design Pole-Type Buildings," published by the American Wood Preservers Institute [12].

As the prevalent soil at the site was a very sandy soil, it was easy to auger the holes for the timber posts. The posts were set in the holes and held in place by false-work bracing. The holes were then filled with 3000-psi cement concrete to the level of the existing ground surface.

To verify that sound transmission through the barrier would not significantly influence its performance, transmission-loss (TL) measurements were taken in a two-reverberant-room TL test facility. These measurements showed the TL of the single and double layers of ½-in. (1.3 cm) thick plywood to be:

Octave Band Center Frequency	Single Layer TL in dB	Double Layer TL in dB
125	17.6	18.1
250	18.9	21.8
500	23.1	22.0
1000	25.6	25.6
2000	22.1	27.0
4000	23.5	29.6.

The TL of the double layer of plywood exceeded that of a single layer at most frequencies. This increased TL was expected due to the increased surface density of the double layer. An exception occurred in the 500- and 1000-Hz octave bands where the TL of the double layer was slightly below or equal to the TL of the single layer. This result was due to a reduction in the coincidence frequency* for the double layer. It was shown that the TL of a large flat panel exhibited a sharp dip at this frequency [13].

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*The coincidence frequency is the frequency at which the acoustic wavelength in air equals the wavelength of vibrational bending waves in a flat panel.

In the final barrier design, the panel thickness was increased to 5/8 in. (1.6 cm) to withstand wind loads. The TL of the 5/8-in. (1.6-cm) thick panels used in the barrier was assumed to be equal to, or greater than, values listed above, since the surface density is higher, and the change in coincidence frequency is not large.

The barrier was designed so that an absorptive treatment could be added to cover the entire surface facing the roadway. A 2-in. (5.1-cm) thick semi-rigid glass-fiberboard was selected for the treatment. The absorption coefficients for the board were:

Octave Band Center Frequency (Hz)	Absorption Coefficient
125	0.32
250	0.74
500	0.97
1000	0.98
2000	0.87
4000	0.85.

The glass-fiberboard could be expected to show some effects of deterioration after prolonged exposure to the outdoor environment. It was selected because it gave high sound-absorption coefficients. Deterioration was avoided by storing the glass-fiberboards out of the weather between measurement runs.

3.4 BARRIER CONSTRUCTION

After the preliminary barrier design had been completed, an application for permit to build the barrier was prepared. Copies of the application were sent to the Department of Public

Works for the Commonwealth of Massachusetts and to abutting property owners for their approval on 6 June 1975. A meeting among representatives of the DOT Transportation Systems Center; the Massachusetts DPW; the Federal Highway Administration; the prime contractor, Cambridge Collaborative, Inc.; and the subcontractor, CE Maguire, Inc., was held on 18 June 1975 to discuss the proposed project. After receiving approval from the abutting property owners, a final application for permit was filed with the DPW on 30 June 1975. The Application was approved and a Permit was issued on 6 August 1975.

While the Application for Permit was being processed, the final design drawings were prepared, and an advertisement for bids was placed in the Dodge Bulletin on 18 June 1975. Bids were opened on 4 August 1975. Twelve firms responded to the advertisement, and nine bids were received ranging from $44,900 to $94,257.60. The bid of $44,900 by Coronis Construction Co., Inc., was accepted, and a contract for construction was signed on 3 September 1975.

The following construction sequence was developed and used:

a. Erect timber posts and first 4-ft (1.22-m) stage of plywood paneling;

b. Add glass-fiber to 4-ft (1.22-m) plywood barrier;

c. Add 4-ft (1.22-m) plywood and 4-ft (1.22-m) glass-fiber panels to raise barrier height to 8 ft (2.44 m);

d. Remove all glass-fiber, leaving 8-ft (2.44-m) height of plywood in place;

e. Add 4-ft (1.22-m) plywood panel to raise barrier height to 12 ft (3.66 m);

f. Add 12-ft (3.66-m) of glass-fiber panels to barrier;

g. Add 4-ft (1.22-m) plywood and 4-ft (1.22-m) glass-fiber panels to raise barrier height to 16 ft (4.88 m); and,

h. Remove and store all glass-fiber.

After completion of Step a, each following step required approximately one week for construction and one week for the acoustic testing.

The project was advertised and bid as a lump-sum contract. The total in-place project cost was $45,214.60 or $2.80 per square foot of barrier vertical face area. Construction of the barrier proceeded smoothly without any costly change orders necessitated by construction problems. The completion date indicated in the contract specifications was extended because the time required to perform each set of acoustic tests was longer than anticipated.

The barrier was constructed without adversely affecting either the environment or the traffic flow on adjacent Route I-93. A discussion of the effects of the barrier itself on highway operations is contained in Section 7.

4. SITE EVALUATION

4.1 DESCRIPTION OF SITE

The site selected for the study was a 2000-ft (609.6-m) stretch of property, adjacent to the southbound lanes of Interstate 93, between highway markers 305 and 325. The location for the barrier was between markers 305 and 315. (See Figures 1 through 4.)

The site is a large, flat field bounded on the north and south by tall trees and underbrush. Sixty-five ft (19.81 m) from the nearest traveled lane of the road, and running parallel to it, is a 20-ft (6.10-m) wide line of widely spaced, young, white pines. North along this line, the canopy becomes increasingly mixed with deciduous shrubs and trees. At approximately 90 ft (27.43 m) from the road, there is a chain-link fence, and the ground drops rapidly about 3 ft (0.91 m). Beyond this distance, the terrain is fairly flat with a few saplings scattered about. Ground cover between the highway and treeline is field grass. Beyond the treeline, there is varied ground cover over a fine, sandy soil.

4.2 NOISE SURVEY

Before the barrier was installed, a grid of 14 measurement positions was laid out as shown in Figures 5 and 6 to determine the similarity of the measurement positions. Seven of the microphone positions were along two lines 1000 ft (304.8 m) apart running back from the road at markers 310 and 320 with positions 30, 85, 130, and 230 ft (9.14, 25.91, 39.62, and 70.10 m,

FIG 1 VIEW OF TEST SITE LOOKING
EAST TOWARD I-93 FROM POINT
100 FT FROM ROADWAY

FIG 2 VIEW OF TEST SITE LOOKING EAST TOWARD I-93 FROM POINT 250 FT FROM EDGE OF ROADWAY

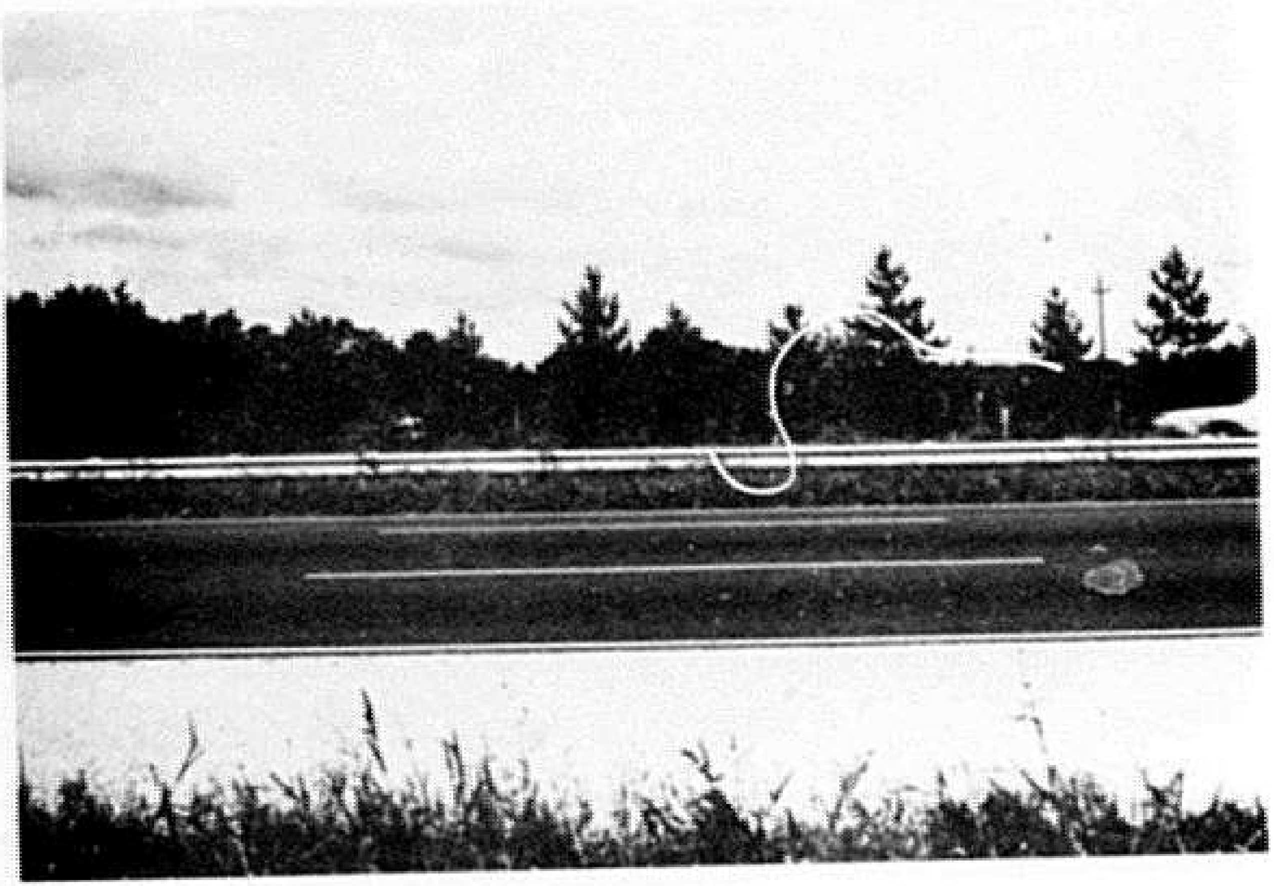
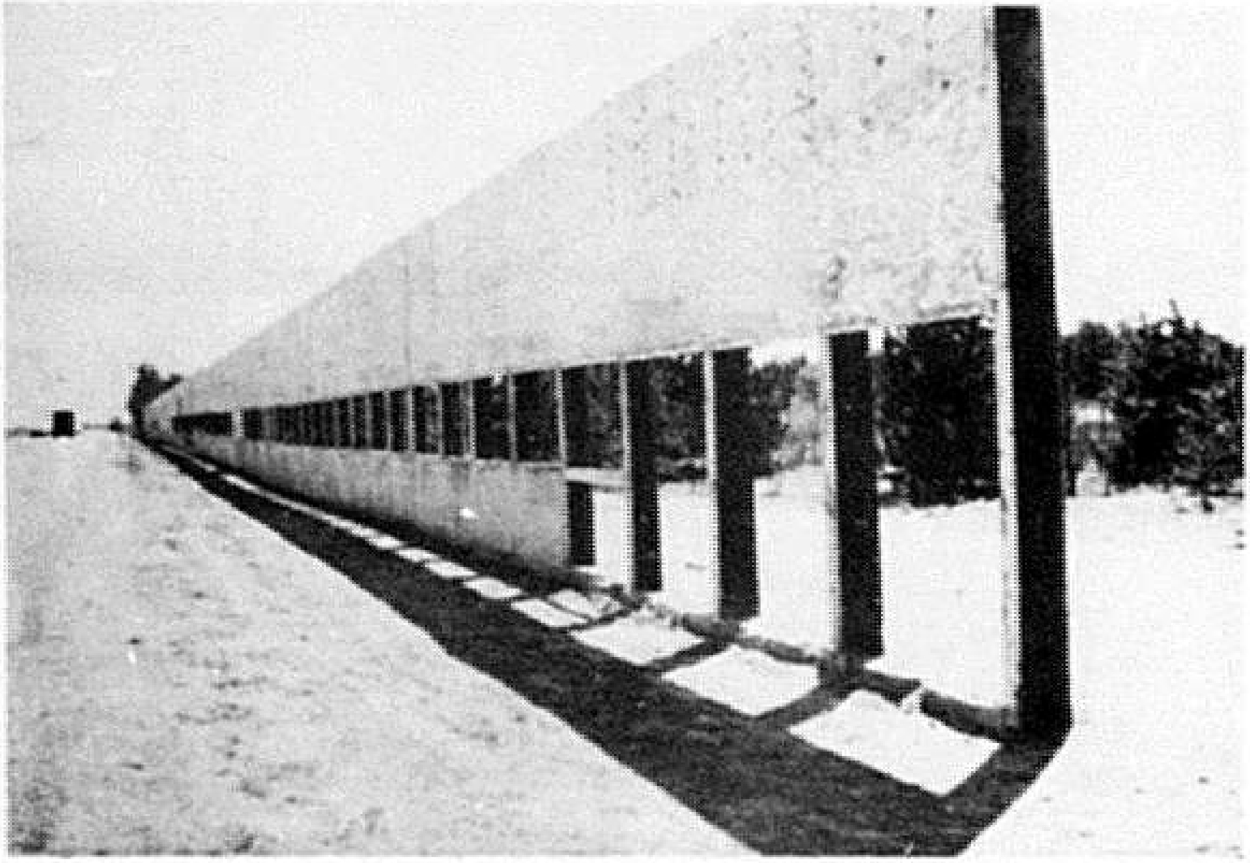
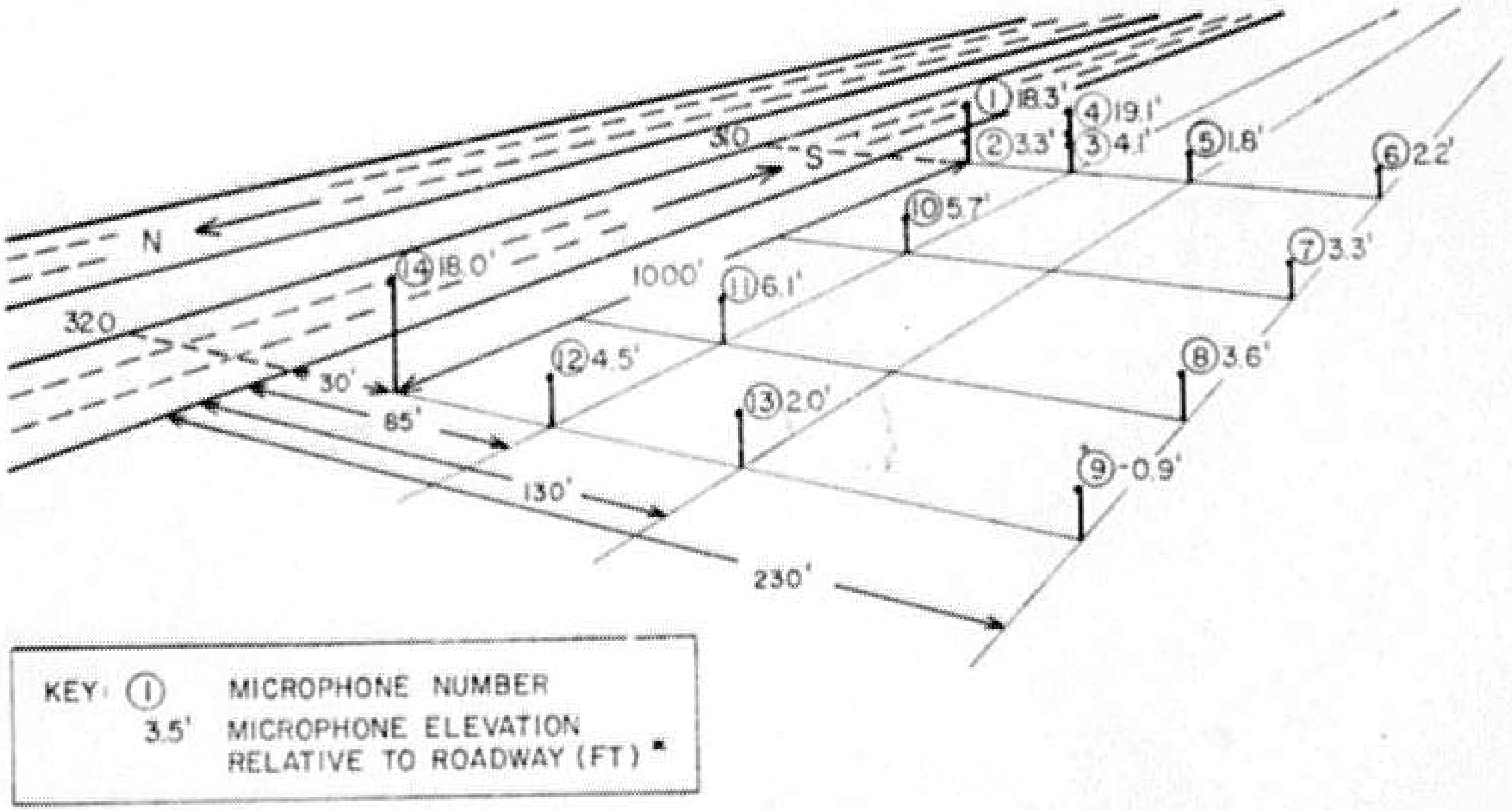


FIG 3 VIEW OF TEST SITE LOOKING WEST
FROM EAST SIDE OF I-93



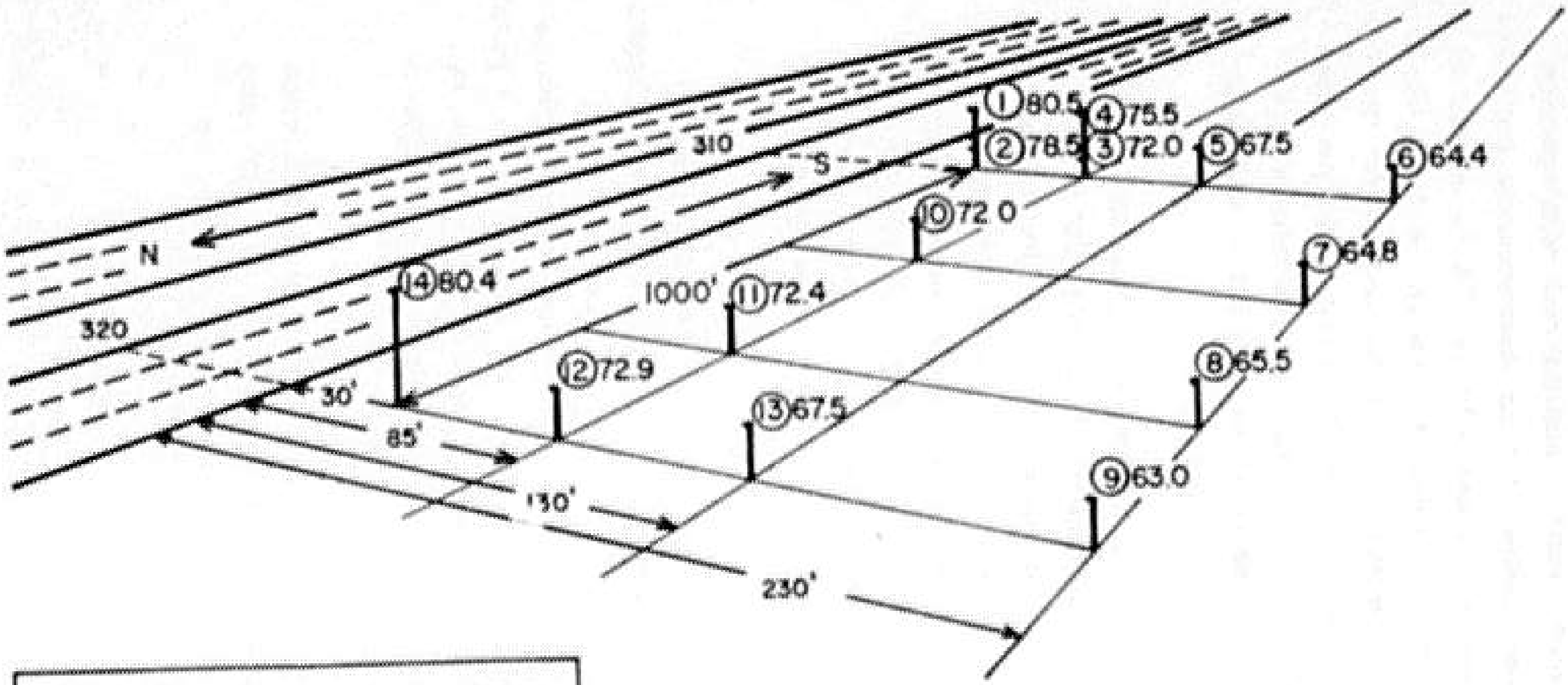
NOTE: SOME PANELS HAVE BEEN REMOVED
FROM BARRIER FOR REPAIR

FIG 4 VIEW OF BARRIER LOOKING SOUTH
FROM SOUTHBOUND BREAK-DOWN LANE



* MICROPHONES 1 AND 14 WERE 20 FT ABOVE THE GROUND SURFACE. ALL OTHER MICROPHONES WERE INITIALLY 4.5 FT ABOVE GROUND LEVEL. AFTER 3 MEASUREMENT RUNS MICROPHONES 5,6,7,8,9 AND 13 WERE SET TO BE 6 FT ABOVE GROUND.

FIG 5 MEASUREMENT POSITIONS FOR THE SITE SURVEY



KEY: ⑫ MICROPHONE NUMBER
72.9 A-WEIGHTED L_{10}- dB

NOTES: RUN 5: 3 SEPT 75, 5:40 P.M.

Duration of Test Sample: 10 min.
Ground/Pavement Surface Conditions: Dry/Dry (light rain on previous evening)
Atmospheric Conditions: Winds Variable: 0-7 mph (avg. 4 mph) from the northwest
Traffic Conditions: Southbound (near) Lanes: 247 vehicles
(15 heavy trucks, 232 passenger cars)
Avg. Speed - 57 mph
Northbound (far) Lanes: 495 vehicles (rush hour)
(20 trucks, 475 passenger cars)

FIG 6 TYPICAL A-WEIGHTED L_{10} LEVELS OBSERVED WHILE EVALUATING SITE SIMILARITY respectively) from the edge of the nearest traveled lane and 4.5 ft (1.37 m) above ground level. Additional microphones were positioned to form two lines of four microphones parallel to the roadway at distances of 85 and 230 ft (25.91 m and 70.10 m, respectively) from the nearest traveled lane and 4.5 ft (1.37 m) above ground level. Two microphones were placed 30 ft (9.14 m) from the nearest traveled lane and 20 ft (6.10 m) above the ground at markers 310 and 320. The remaining microphone was located 85 ft (25.91 m) from the roadway at marker 310 at a height of 18 ft (5.49 m) above the ground.

Measurements were taken over a period of two 10-hour days on September 3 and 4, 1975, by personnel of the TSC Noise Measurement and Assessment Laboratory using the TSC computer-equipped Mobile Noise Measurement and Analysis Laboratory. The measurement procedure was to record simultaneous digital time histories of the A-weighted noise level for all fourteen microphones in 10-minute periods. The time histories were processed by computer to obtain statistical noise levels for each 10-minute data segment.

Thirteen data runs were taken over the two-day period. For each run, meteorological and traffic conditions were recorded. All microphones were calibrated before and after each run. Typical L_{10} noise levels measured during one of the site-evaluation test runs are displayed in Figure 6 along with corresponding traffic and meteorological conditions recorded during the run. A data summary of all 13 test runs, referenced to microphone position 1, is presented in Table 2.

The L_{10} levels for each run were statistically analyzed by computing the average levels at distances of 85, 130, and 230 ft (25.91, 39.62, and 70.10 m, respeccively) from the

TABLE 2. A-WEIGHTED L_{10} DATA FOR SITE SURVEY

Microphone Position	Microphone Height*	Run Number 1	2	3	4	5	6	7	8	9	10	11	12	13
1 (ref.)	20	82.8	83.6	81.9	82.8	80.5	81.8	83.0	82.6	82.8	82.0	81.7	81.6	81.1
2	4.5	-1.6	-1.3	-2.1	-1.6	-2.0	-2.2	-1.1	-2.3	-2.3	-2.1	-2.6	-2.4	-2.5
3	4.5	-7.2	-6.8	-8.6	-8.2	-8.5	-7.6	-7.5	-7.8	-8.2	-9.1	-9.3	-8.4	-9.0
4	20	-3.8	-3.8	-4.2	-4.7	-5.0	-3.5	-3.3	-4.3	-3.8	-4.8	-4.7	-4.2	-4.4
5	4.5	-12.7	-12.2	-14.										
5	6				-12.8	-13.	-12.	-12.	-12.5	-13.9	-13.9	-15.	-13.	-14.5
6	4.5	-15.2	-15.6	-16.4										
6	6				-15.5	-16.1	-15.	-15.5	-15.7	-18.9	-18.9	-19.7	-15.5	-18.4
7	4.5	-14.9	-16.2	-16.2										
7	6				-15.7	-15.7	-14.7	-15.9	-15.9	-17.9	-18.6	-18.9	-15.4	-19.3
8	4.5	-16.0	-17.2	-17.										
8	6				-15.9	-15.	-15.4	-16.6	-15.4	-18.3	-18.2	-18.9	-16.3	-18.8
9	4.5	-18.4	-19.3	-19.8										
9	6				-17.9	-17.5	-17.7	-18.4	-17.8	-19.9				
9**	6										-20.3	-20.4	-17.4	-20.1
10		-7.8	-6.9	-7.9	-6.5	-8.5	-7.3	-7.	-6.2	-7.9	-8.0	-8.6	-8.1	-8.9
11		-5.6	-7.3	-7.7	-7.6	-8.1	-7.9	-6.8	-7.5	-8.1	-8.2	-9.0	-8.2	-9.0
12		-5.9	-7.9	-8.2	-8.5	-7.6	-7.5	-6.	-6.9	-7.2	-7.2	-7.5	-7.3	-8.7
13	4.5	-14.2	-15.	-15.4										
13	6				-13.3	-13.	-12.8	-12.8	-13.4	-14.3	-15.2	-15.6	-14.4	-15.2
14	20	+.4	-.7	-.4	+.1	-.1	+.6	+.5	+.3	-.5	+.2	-.7	+.1	+.5

*In feet above surrounding terrain

**Microphone position moved 50 ft to south to correct partially for 3 ft terrain depression observed at original microphone position 9.

Levels from positions 2-13 relative to reference microphone at position 1.

nearest traveled lane

$$\overline{L_{10}(j,85)} = \frac{1}{N_{85}} \sum_{i=1}^{N_{85}} L_{10}(i,j,85), \qquad (1)$$

where $\overline{L_{10}(j,85)}$ signifies an average L_{10} at 85 ft for run j, N_{85} is the number of microphone positions at 85 ft, and $L_{10}(i,j,85)$ is the L_{10} level 85 ft (25.91 m) from the nearest traveled lane at microphone-position i for run j.

The average L_{10} levels for each run were then analyzed to compute the mean of the differences between L_{10} levels at a particular distance and the average L_{10} level for that distance. The mean of the differences is defined as

$$\overline{\Delta L_{10}(i,85)} = \frac{1}{N_{runs}} \sum_{j=1}^{N_{runs}} \left[L_{10}(i,j,85) - \overline{L_{10}(j,85)} \right], \qquad (2)$$

where N_{runs} is the number of ten-minute runs, and $\overline{\Delta L_{10}(i,85)}$ is the mean difference for position i at 85 ft.

Equations similar to Equations (1) and (2) can be written for positions 130 and 230 ft from the nearest traveled lane.

After three runs, the height of the microphones located 130 and 230 ft (39.62 and 70.10 m, respectively) from the road was increased from 4.5 to 6 ft (1.37 to 1.83 m, respectively) to improve the similarity of the measured noise levels at the different microphone positions. In this configuration, the largest mean difference was -1.6 dB for the measurement position at marker 315 at a distance of 230 ft from the roadway. It was found that the terrain level at this position is 3 ft

(0.92 m) lower than the other 230-ft (70.10-m) positions. By raising the microphone height to compensate for this variation, the mean difference was substantially reduced. The mean differences for all other microphone positions were less than ±0.5 dB. For the purposes of our barrier study, the two sites centered on markers 310 and 320 were acoustically similar.

5. MEASUREMENT PROCEDURES

Noise measurements were taken for the following sequence of barrier configurations:

Test No.	Barrier Height ft	m	Barrier Surface
1	No Barrier		
2	4	1.22	R*
3	4	1.22	A
4	8	2.44	A
5	8	2.44	R
6	12	3.66	R
7	12	3.66	A
8	16	4.88	A
9	16	4.88	R.

For each configuration, measurement runs were carried out over 2- or 3-day periods to establish the dependence of observed noise levels and barrier insertion loss on

a. traffic density,

b. Wind speed and direction, and

c. ground condition

For each run, the following information was collected:

a. traffic counts--separate for cars and trucks and for north- and southbound directions,

b. mean vehicle speed in southbound direction (traffic flow nearest the barrier),

---

*R, reflecting; A, absorbing.

c. wind speed and direction,

d. history of rain or snowfall during past 3 days,

e. time of day and date,

f. description of ground conditions,

g. description of weather and cloud cover,

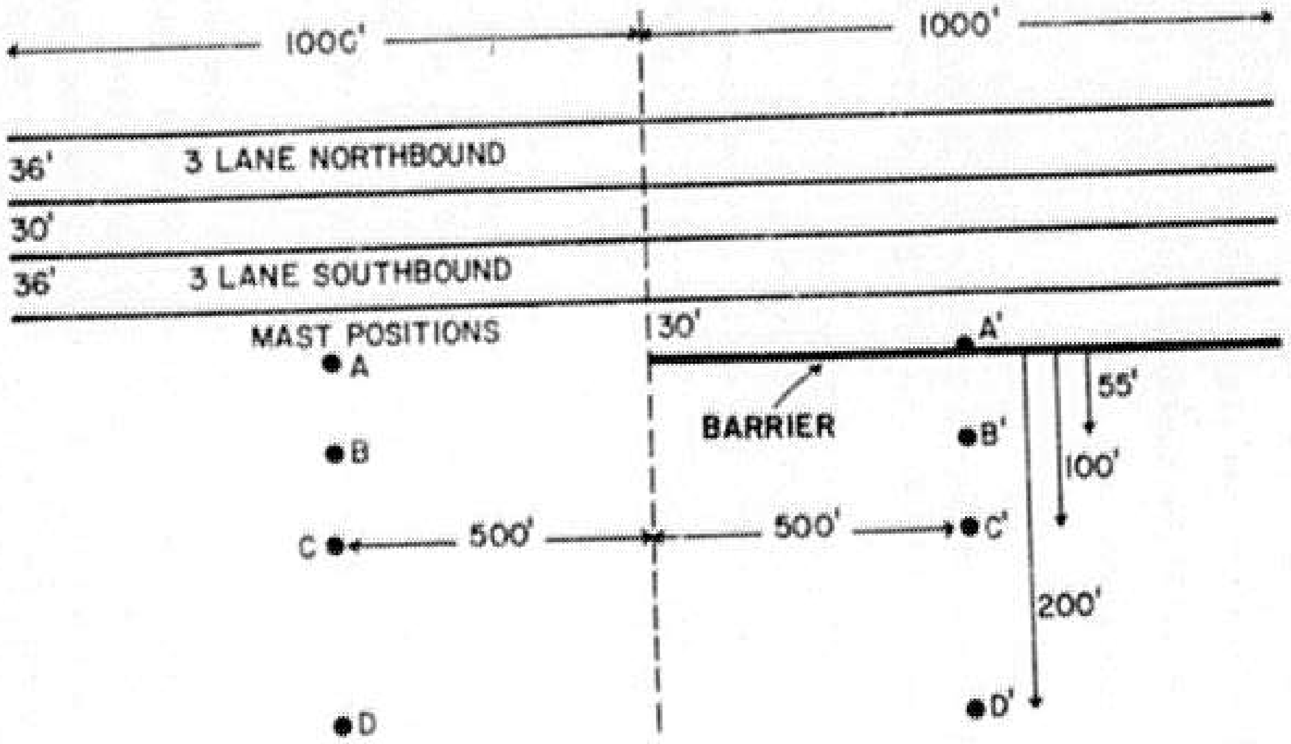
h. temperature and relative humidity, and

i. location of microphones.

The measurements reported here were carried out by TSC personnel using their Mobile Noise Measurement and Analysis Laboratory over a period of October through December, 1975.

The acoustic data were collected using two 25-ft (7.62-m) high masts with microphones located at heights of 3, 8, 13, 18, and 23 ft (0.91, 2.44, 3196, 5.49, and 7.01 m, respectively) above the level of the roadway. With the barriers in place, the masts, one behind the barrier and the other in the open site, were positioned at equal distances from the road as shown in Figure 7. Four reference microphones to monitor traffic-noise similarities between the open site and barrier site were mounted at points on masts 18 ft (5.49 m) above the road level and at points 6 in. (15.24 cm) above the barrier height. The reference microphone masts were 30 ft (9.14 m) from the road as shown in Figure 8.

The microphone masts were 3/4-in. (1.91-cm) diameter poles supported by thin guywires at 10-ft (3.05-m) intervals. Microphones were clamped to the mast at right angles to a line between the mast and the roadway. The distance from the mast to the center of the microphone was 8 in. (20.32 cm). With this configuration, the sound-pressure levels due to the sound



REFERENCE MICROPHONES AT POSITIONS A AND A' ARE 20' ABOVE ROAD LEVEL.
MICROPHONES AT OTHER POSITIONS ARE 3', 8', 13', 18', AND 23' ABOVE ROAD LEVEL.

FIG 7 MICROPHONE PLACEMENT FOR BARRIER INSERTION-LOSS TESTS (PLAN VIEW)

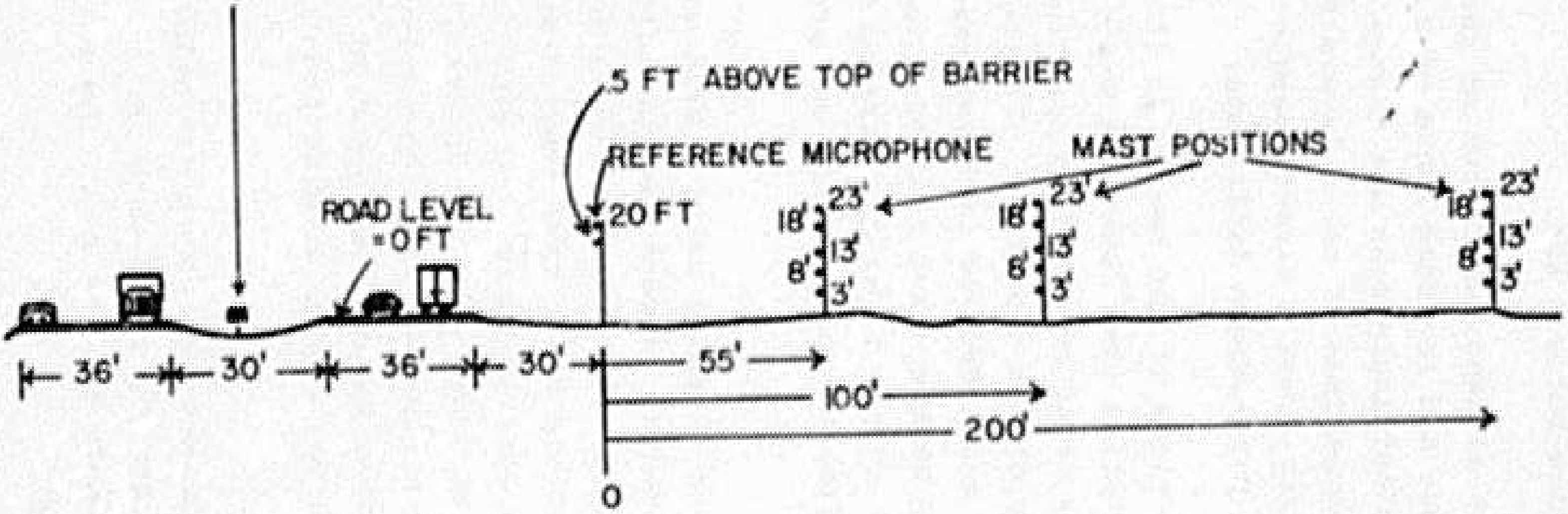


FIG 8 MICROPHONE PLACEMENT FOR BARRIER INSERTION - LOSS TESTS (ELEVATION)

scattered from the cylindrical mast are more than 20 dB below measured levels at all frequencies below 4 kHz.

The use of microphone masts allowed separation of the effects of path-length difference and included angle on barrier insertion loss. Since the included angle does not change with the height of the microphone, comparison of noise levels for similar positions on the two masts gives a direct measure of insertion loss as a function of path-length difference.

For each test run, the positions of the two 25-ft (7.62-m) multiple microphone masts were varied (see Positions B-B', C-C', A-A'). The reference microphone masts remained in position to monitor traffic-noise similarity at the two sites. Usually, six 10-minute measurements were conducted for each barrier-mast configuration. For a particular barrier-mast configuration, the measurement runs were spread out over a three-day testing period to maximize the variety of traffic, meteorological, and ground conditions encountered.

Wind direction and speed were measured using a wind vane and cup anemometer at a point situated between the two adjacent sites, set back approximately 300 ft (91.4 m) from the barrier sites, to avoid any influence this structure might have exerted on local wind patterns. During the barrier tests, the wind direction varied from northeast to south with the "prevailing winds" coming primarily from the northwest. Average wind-velocity vectors perpendicular to the roadway ranged from approximately -1 to +14 mph (positive sign indicating wind blowing from the microphones toward the road).

Ground conditions at the adjacent sites were essentially identical. Because of this fact and the difficulty in obtaining meaningful ground-impedance measurements, the soil conditions were analyzed by simple inspection. Although ground conditions were predominantly dry and dusty during the October and November tests, December saw a variety including dry, wet, frozen, and snow-covered surfaces.

Traffic counts were recorded manually during each test run for both directions of traffic flow, and vehicle speeds in the southbound lanes were sampled using radar techniques. Average traffic speeds passing the barrier ranged from 54 to 59 mph with a standard deviation of approximately 6 mph. Traffic volumes during the 10-minute test samples varied from 350 vehicles during off-peak runs to 900 vehicles during rush-hour traffic. Heavy trucks and buses accounted for 4 to 19 percent of this population. This large variation in percentage of truck and bus population is misleading, however, since the level of truck and bus activity was fairly constant throughout the day while the passenger-car population fluctuated significantly. Typically, 15 to 35 heavy vehicles passed the barrier every 10 minutes.

6. DATA EVALUATION AND RESULTS

6.1 L_{10} LEVELS MEASURED AT OPEN SITE

To assess the acoustic performance of the barriers studied, simultaneous measurements were taken behind the barrier and at the adjacent open site. Average L_{10} levels measured at the open site are displayed in Figure 9. The average is taken over more than sixty 10-minute measurement runs encompassing various traffic and atmospheric conditions. It is of interest to note that the noise levels at the lower microphone position decline more rapidly as one moves away from the roadway than do the levels at the higher microphone positions, while at 100 and 200 ft (30.05 and 61.0 m, respectively) behind this line, approximately 6 dB separate these positions. This difference in attenuating rates with distance is primarily due to ground effects.

Stated simply, ground effect is the reduction or increase in noise levels (as compared to free-space propagation levels) resulting from the interference of sound waves reflected off the ground. As shall be seen in subsequent sections, this ground-effect phenomenon has a pronounced effect on barrier performance.

6.2 L_{10} LEVELS MEASURED BEHIND BARRIER

Average L_{10} levels for the different barrier heights are displayed in Figure 10. An interesting feature of these data is that the noise levels at the lower microphone positions decrease relatively slowly as one moves away from the roadway.

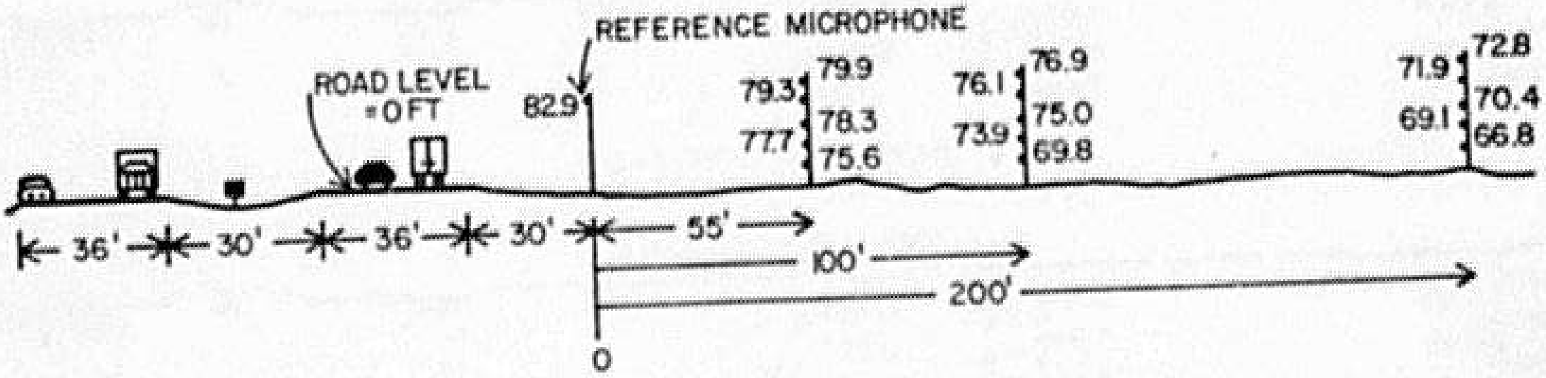
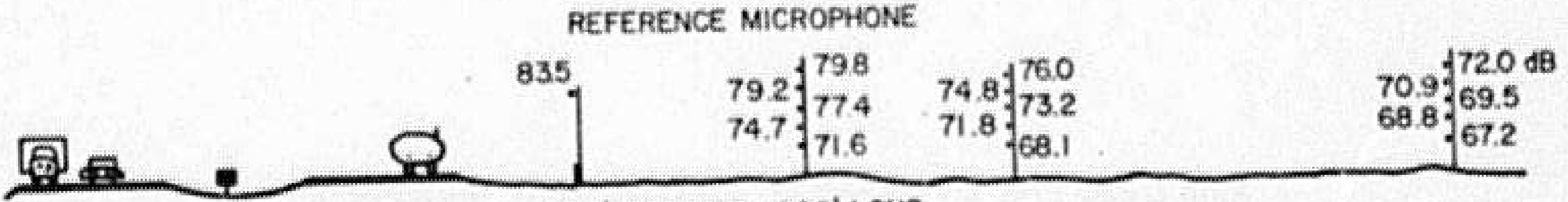
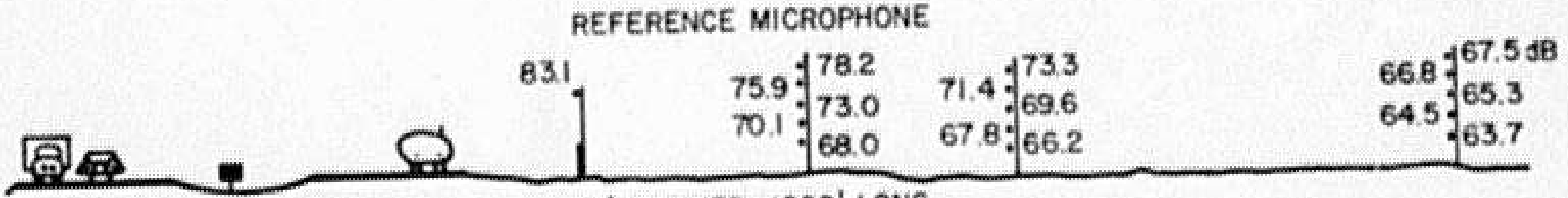


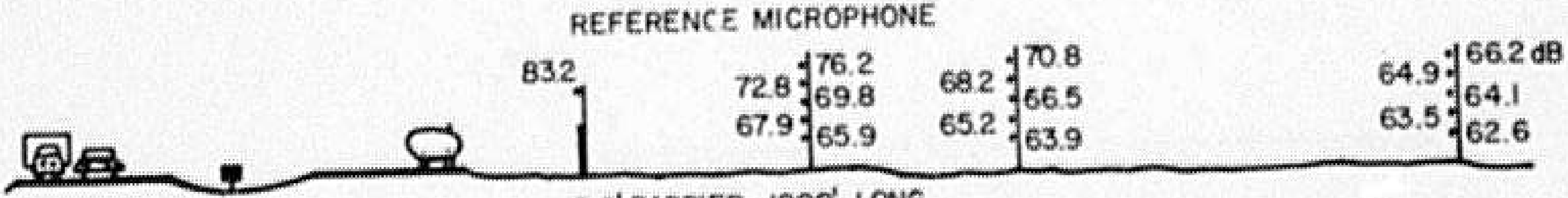
FIG 9 AVERAGE A-WEIGHTED L_{10} LEVELS AT THE OPEN SITE



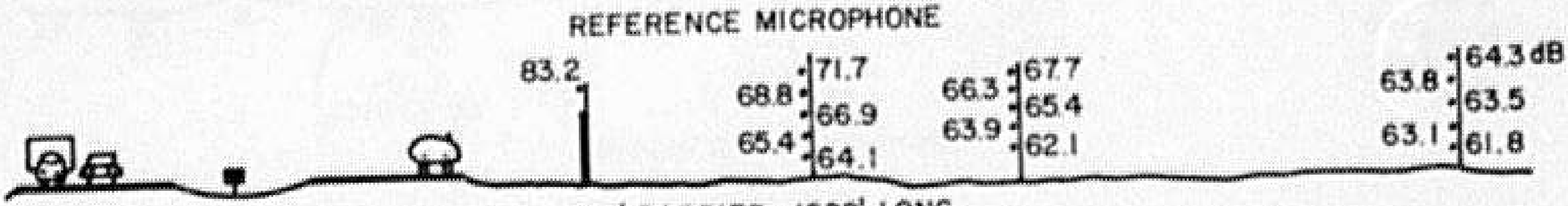
2.8' BARRIER, 1000' LONG



6.8' BARRIER, 1000' LONG



10.8' BARRIER, 1000' LONG



14.8' BARRIER, 1000' LONG

FIG 10 AVERAGE A-WEIGHTED L_{10} LEVELS MEASURED BEHIND THE BARRIER FOR DIFFERENT BARRIER HEIGHTS

This trend is due to a compensating interaction of reduced attenuation by the barrier as the distance increases and increased attenuation with distance from the noise source. However, in all cases the noise levels behind the barrier decrease as the barrier height is reduced.

6.3 BARRIER L_{10} INSERTION LOSS

An important observation can be made when one compares corresponding noise levels at the open site and behind the barrier. The noise reductions caused by the "insertion" of the barrier, observed at the mast position 100 ft and 200 ft (30.48 and 60.96 m, respectively) behind the barrier are smaller at the low microphone positions than at the higher ones (see Figure 11). This effect is contrary to the barrier insertion-loss prediction techniques in common use, which state that the barrier's insertion loss will increase with increasing path-length difference of Fresnel number (decreasing receiver height).

Figures 12, 13, and 14 show the measured values for insertion loss as a function of path-length difference for points 55, 100, and 200 ft (16.8, 30.1, and 61.0 m, respectively) behind the barrier. The path-length difference, which is used in the NCHRP Report 144 design chart [9], is the path-length difference between straight-line propagation from the effective traffic-noise-source location to the measurement point and propagation from the effective source location along straight lines to the top of the barrier and to the measurement point as shown in Figure 15. The included angle, which is a second parameter used in the NCHRP 144 design chart to determine barrier

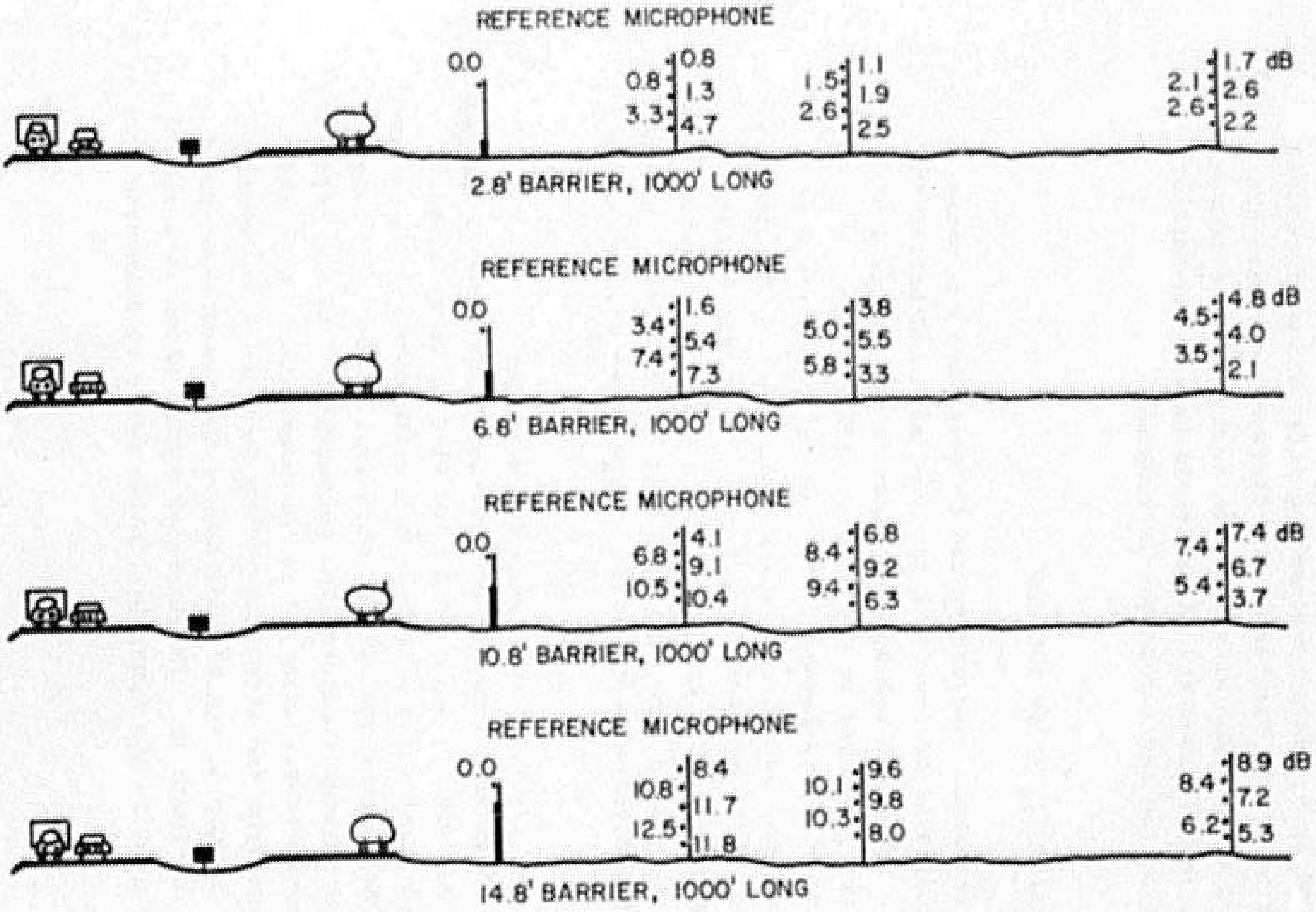


FIG 11 AVERAGE BARRIER INSERTION LOSSES BASED ON A-WEIGHTED L_{10} LEVELS

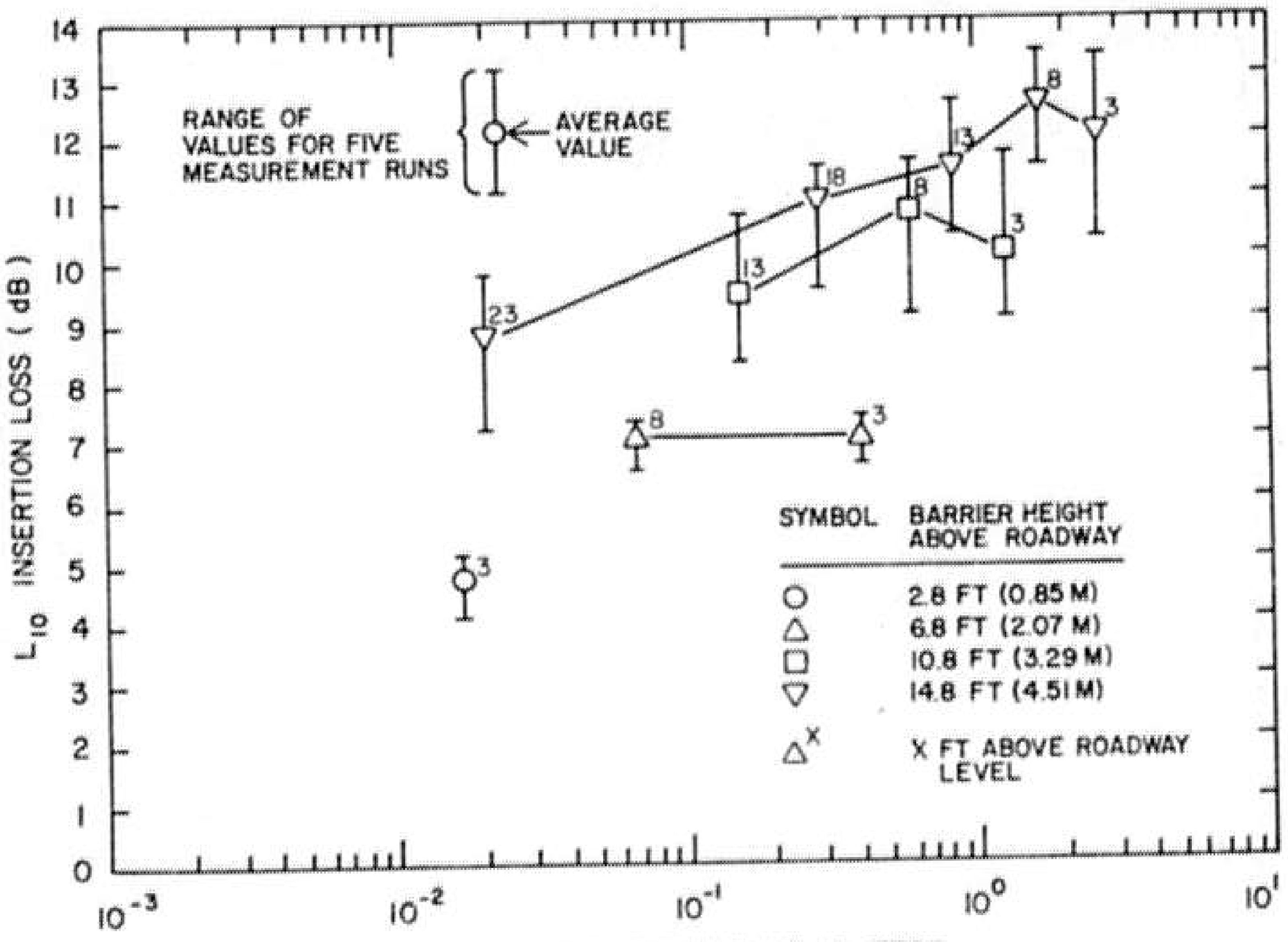


FIG 12 MEASURED INSERTION LOSS 55' BEHIND BARRIER ($\alpha = 169°$)

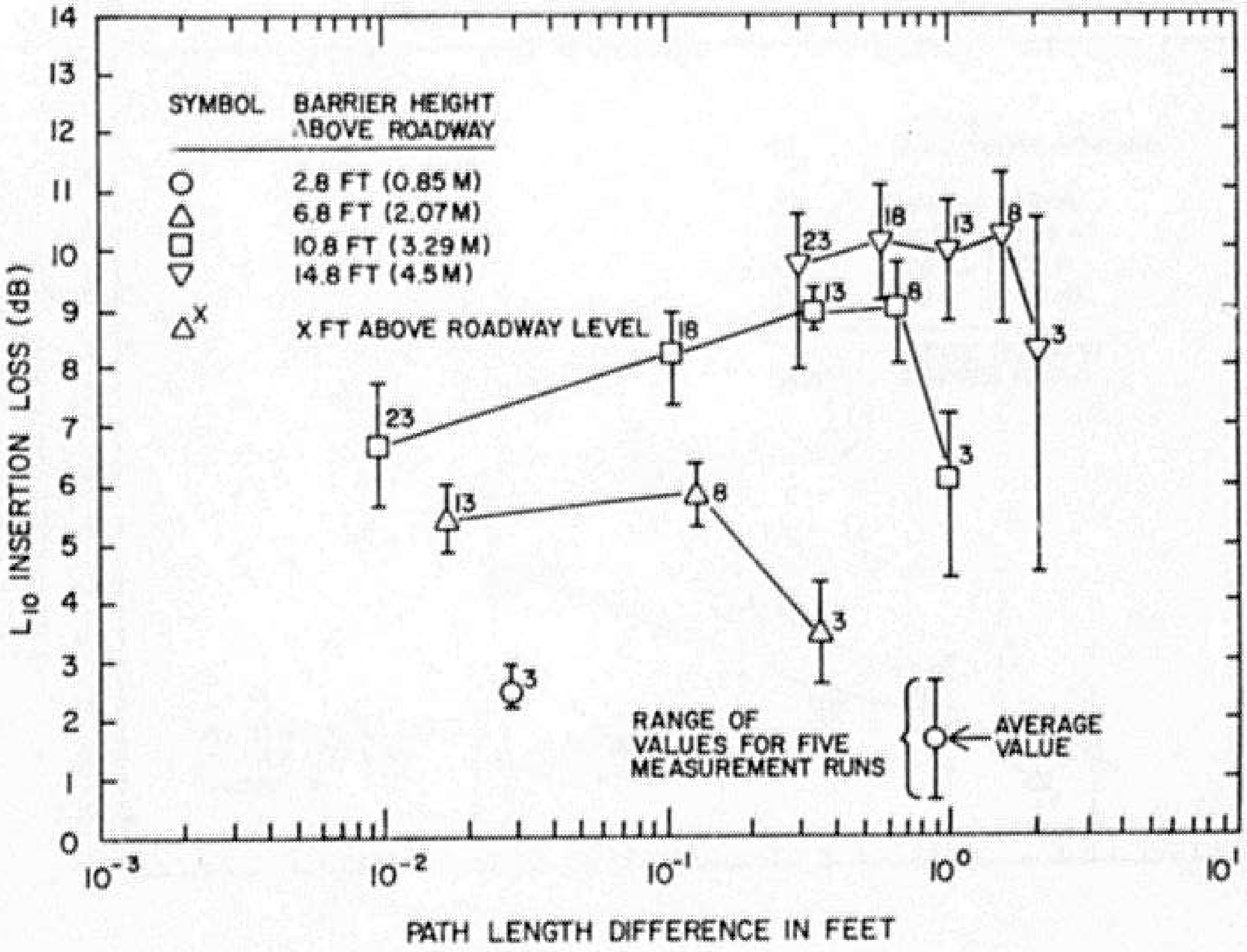


FIG 13 MEASURED INSERTION LOSS 100' BEHIND BARRIER ($\alpha = 157°$)

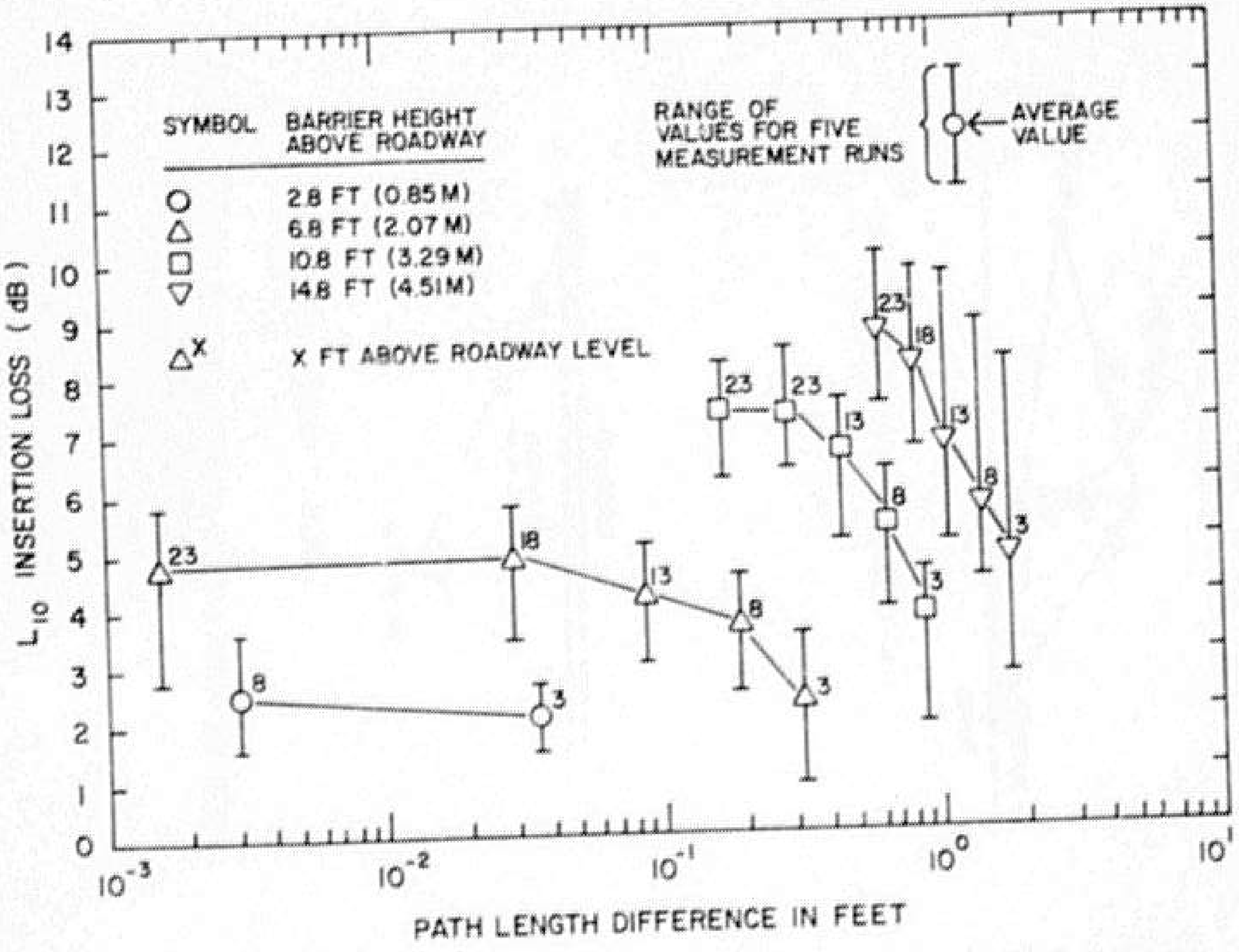
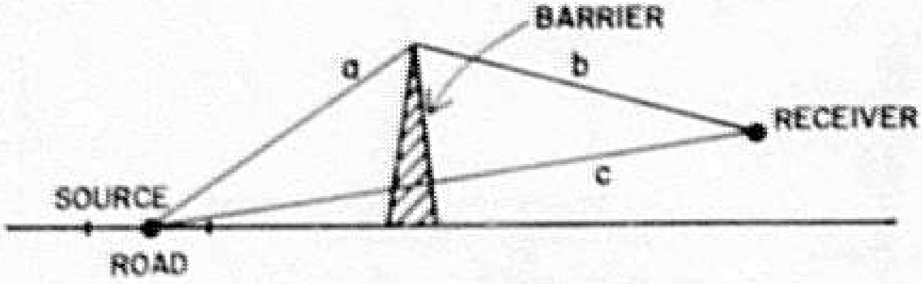
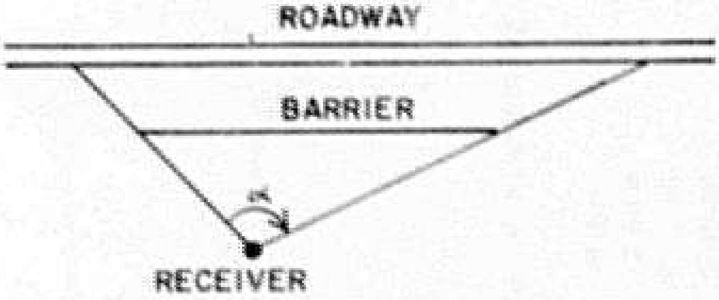


FIG 14 MEASURED INSERTION LOSS 200' BEHIND BARRIER ($\alpha = 137°$)



PATH LENGTH DIFFERENCE = a+b-c



INCLUDED ANGLE = α°

FIG 15 DETERMINATION OF PATH LENGTH DIFFERENCE AND INCLUDED ANGLE performance, is given in the figures. Note that we have presented our data in such a way that the included angle is constant for the data within a given plot.

6.4 L_{10} INSERTION LOSS OF BARRIER WITH ABSORPTION TREATMENT

Average insertion-loss values observed behind a barrier treated with acoustically absorptive materials are compared to average insertion-loss values behind the reflective barrier in Figures 16 through 18. It can be seen that the insertion-loss characteristics are similar for both barrier configurations. The difference in measured insertion-loss between the two conditions is usually less than 1 dB for barrier heights 10.8 ft (3.3 m) and below. The difference for the 14.8-ft (4.5-m) barrier is approximately 1 to 2 dB.

6.5 COMPARISON OF L_{10}, L_{50}, AND L_{eq} BARRIER INSERTION LOSS

Figure 19 shows a comparison among average L_{10}, L_{eq}, and L_{50} insertion-loss measurements at 50, 100, and 200 ft (16.8, 30.5, and 61.0 m, respectively) behind the 14.8 ft (4.5 m) barrier. The L_{eq} insertion-loss values lie approximately 0.5 dB lower than the L_{10} values, while the L_{50} insertion-loss data lie approximately 1 to 2 dB below L_{10} values. The reduction of insertion loss at the lower microphone positions is characteristic of L_{10}, L_{eq}, and L_{50} insertion-loss measurements alike.

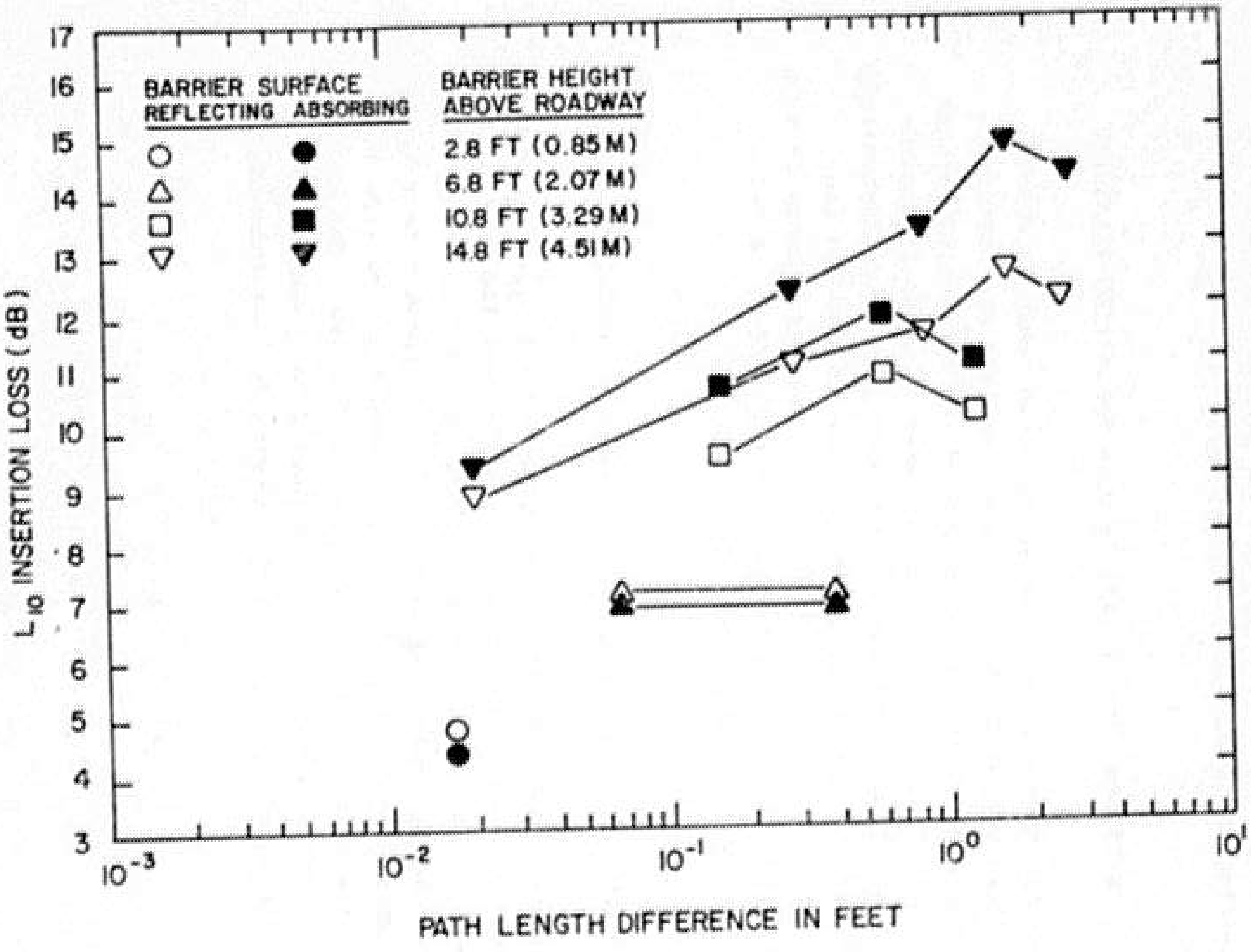


FIG 16 EFFECTS OF ABSORPTIVE TREATMENT 55' BEHIND BARRIER

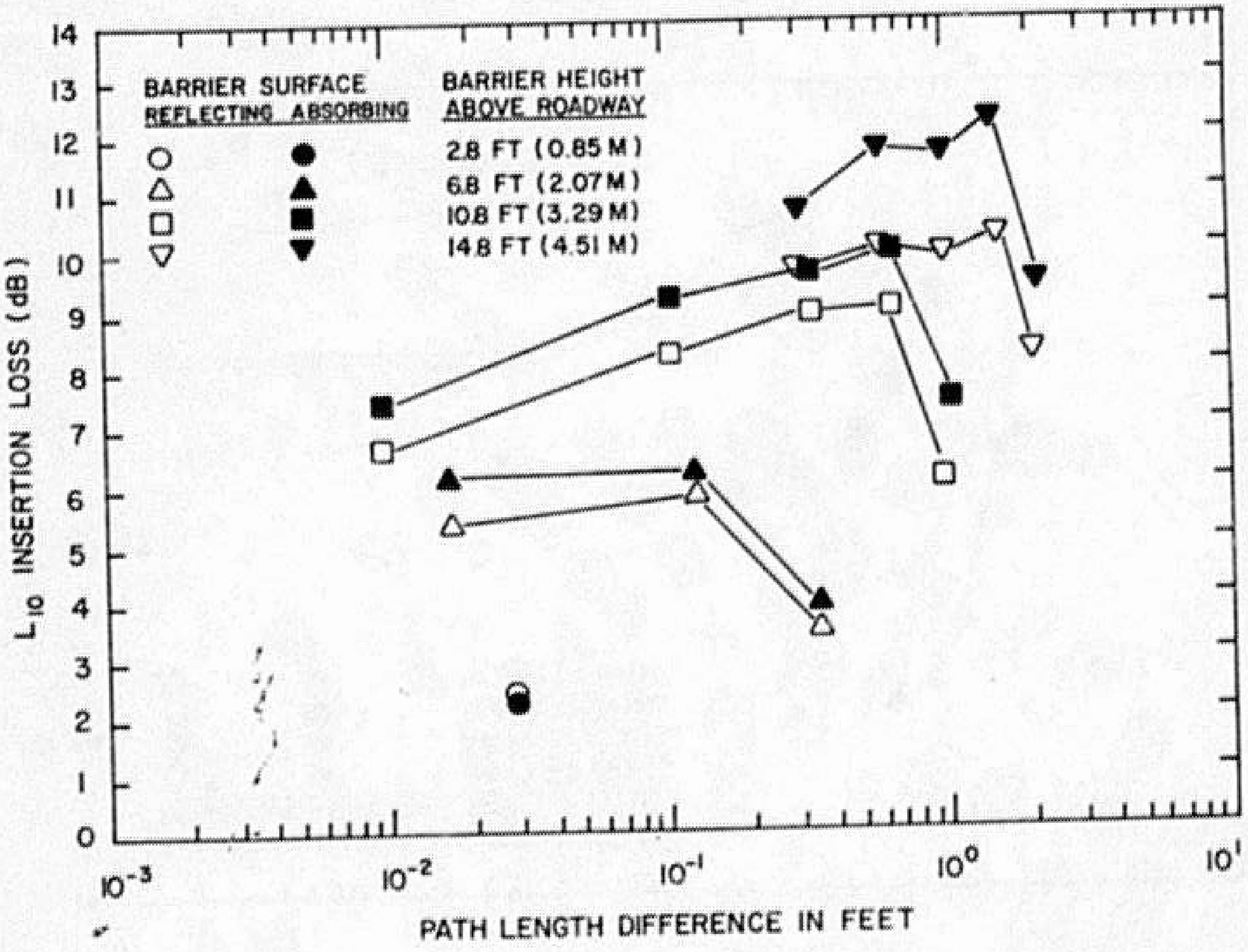


FIG 17 EFFECTS OF ABSORPTIVE TREATMENT 100' BEHIND BARRIER

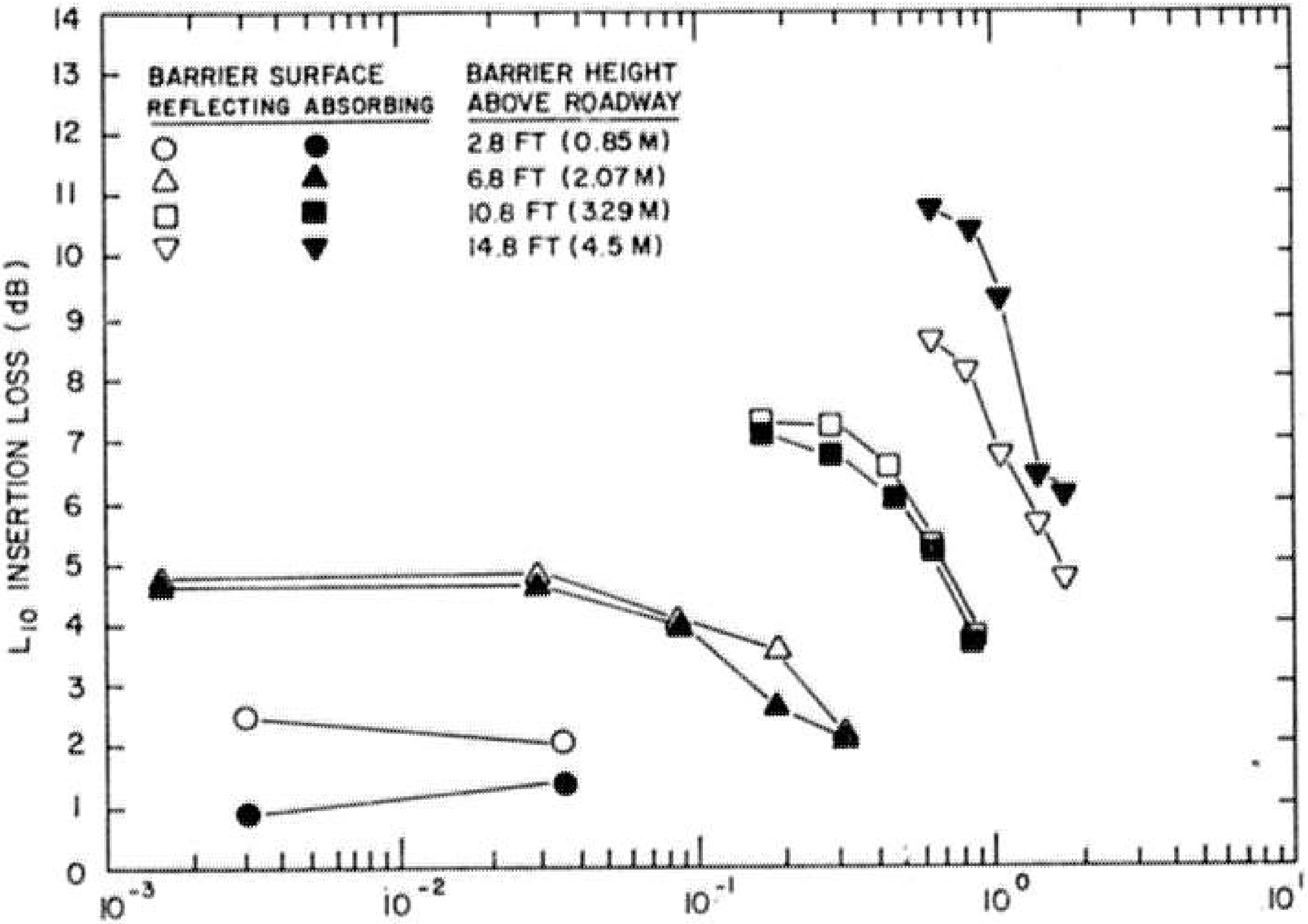


FIG 18 EFFECTS OF ABSORPTIVE TREATMENT 200' BEHIND BARRIER

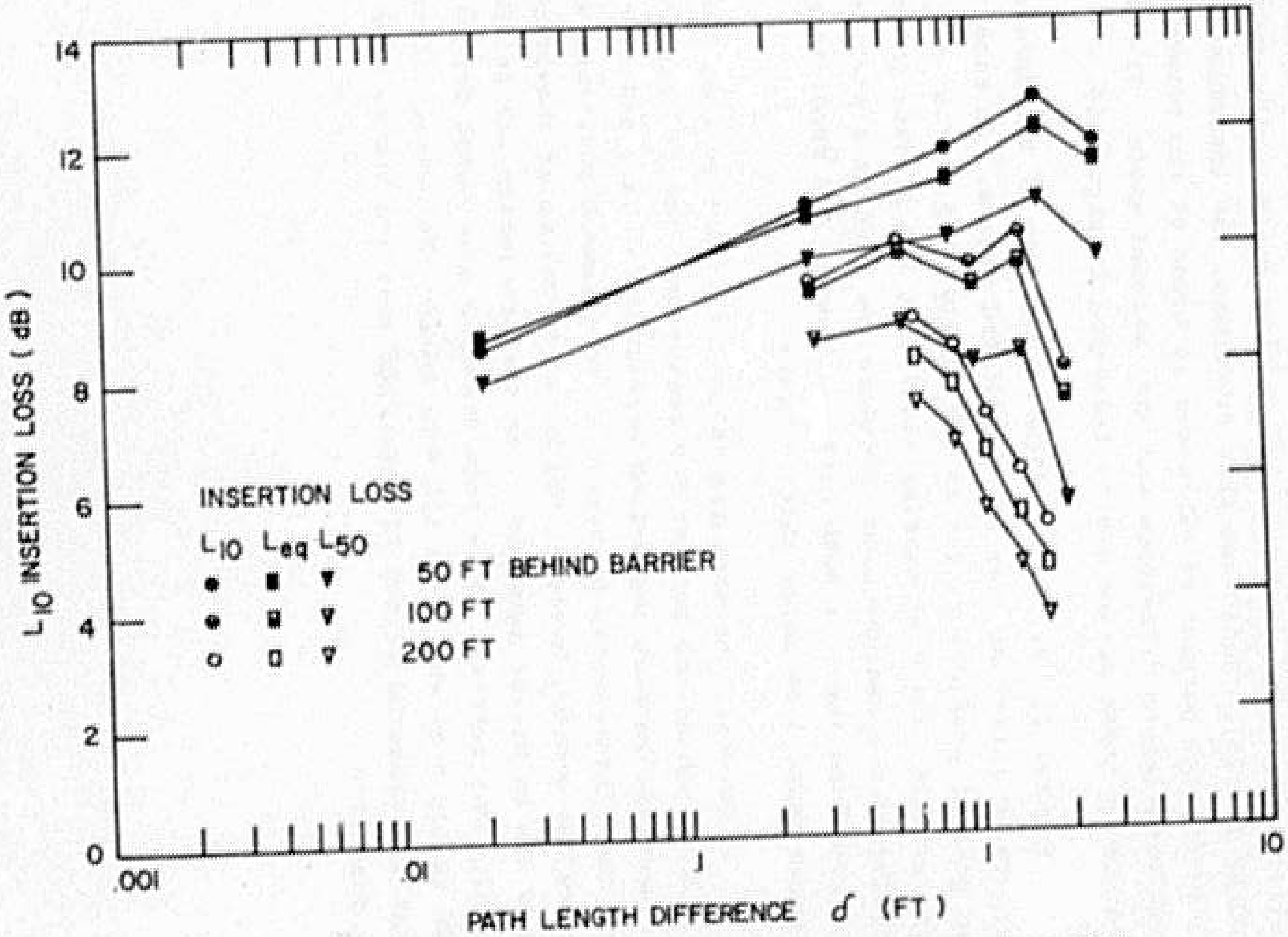


FIG 19 COMPARISON OF L_{10}, L_{eq}, AND L_{50} INSERTION LOSS FOR THE 14.8 FT HIGH BARRIER

6.6 COMPARISON OF DATA WITH DESIGN-GUIDE PREDICTIONS

The procedure most commonly used to predict noise-barrier effectiveness is set out in the highway design-guide reports, NCHRP 144 [9]. Following this procedure, the insertion loss for the barrier is expressed in terms of two parameters: the path-length difference and the included angle. The calculation of these parameters is indicated in Figure 15.

Figures 20, 21, and 22 show comparisons of the measured values of insertion loss with predicted values. In each figure, we present predictions for an infinitely long barrier and for the 1000-ft (304.8-m) barrier studied in the present program. Following the design-guide procedure, we present a prediction of insertion loss for both cars and trucks: the prediction for trucks being 3 dB below that for cars.

In general, the measured values of insertion loss 200 ft (61.0 m) behind the barrier for measurement points near the ground fall between the values predicted for cars and trucks for the finite-length barrier. At measurement positions well above the ground, however, the measured values of insertion loss are in better agreement with the prediction for an infinitely long barrier. This same trend is also noted for points 100 ft (30.5 m) and 55 ft (16.8 m) behind the barrier, except that the measured values of insertion loss are higher than would be predicted.

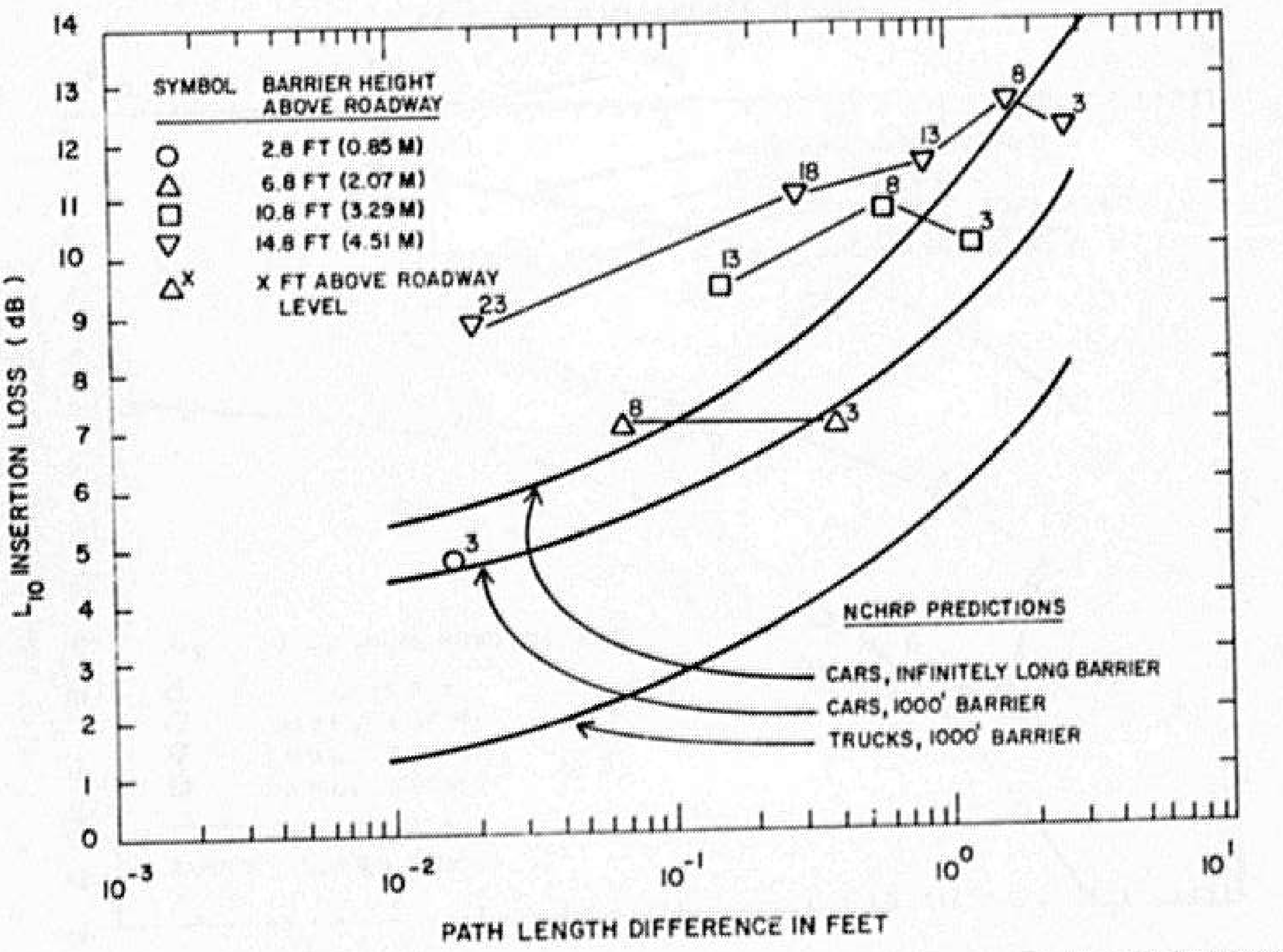


FIG 20 COMPARISON OF NCHRP PREDICTIONS WITH MEASUREMENTS 55' BEHIND BARRIER

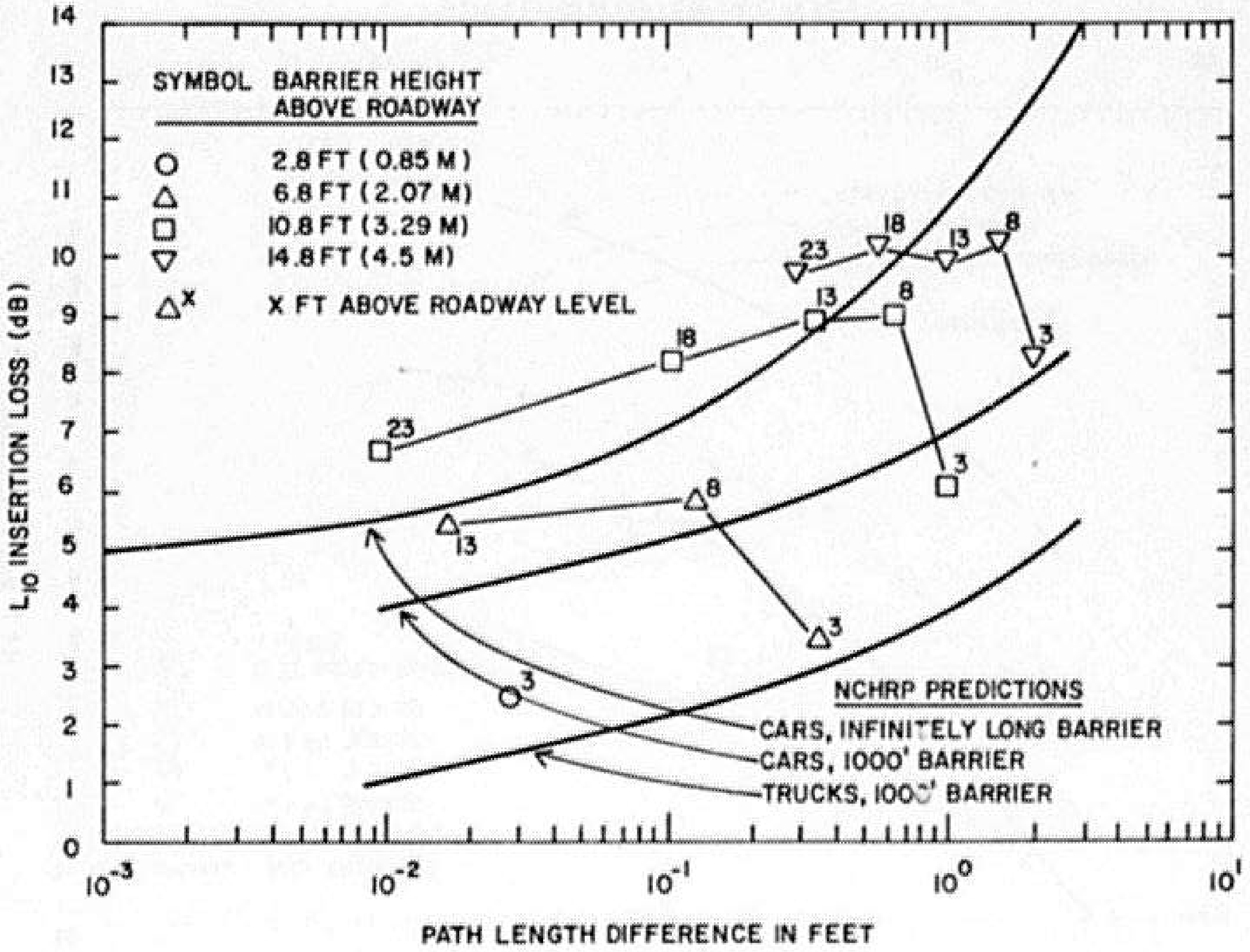


FIG 21 COMPARISON OF NCHRP PREDICTIONS WITH MEASUREMENTS 100' BEHIND BARRIER

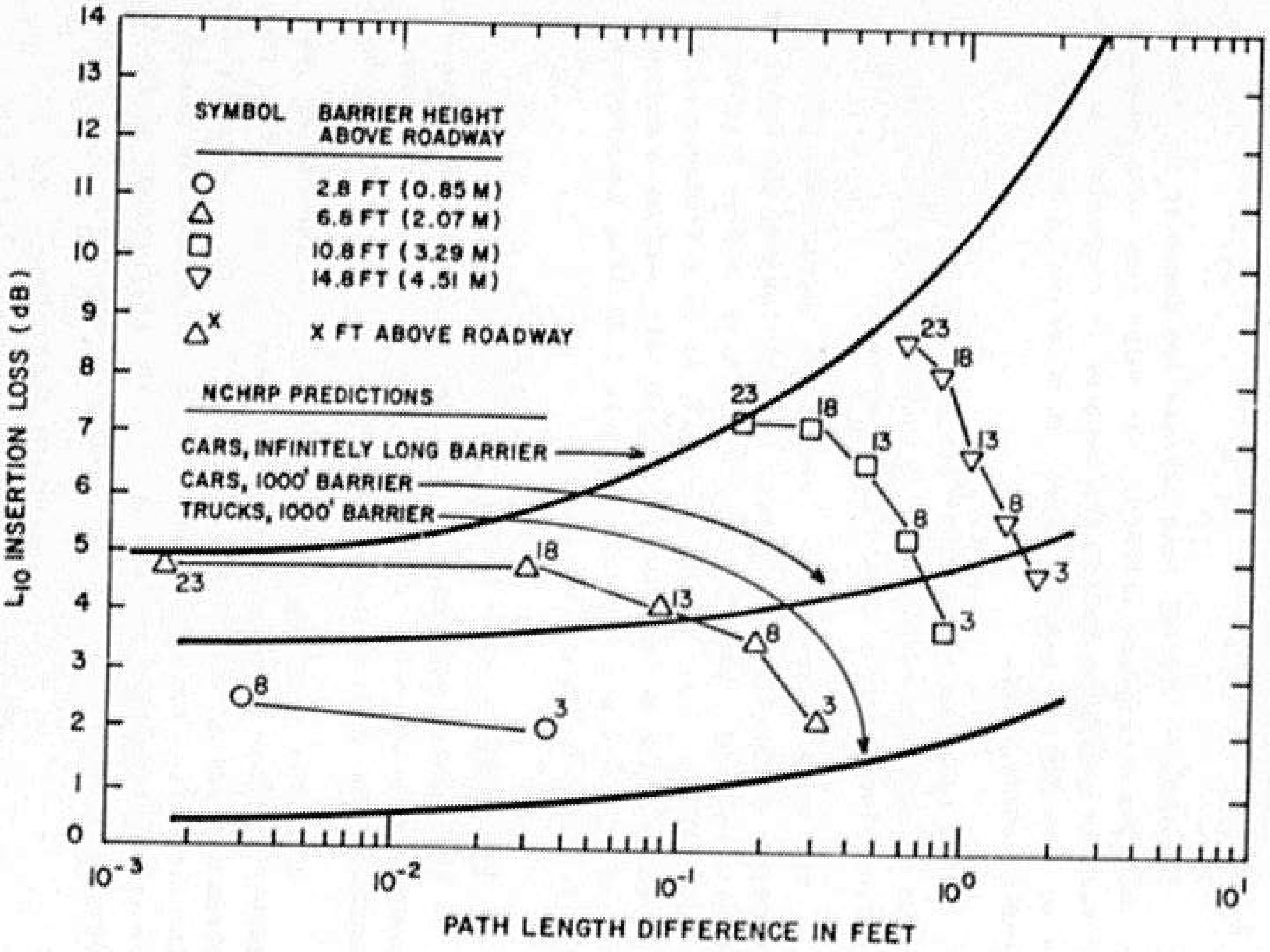


FIG 22 COMPARISON OF NCHRP PREDICTIONS WITH MEASUREMENTS 200' BEHIND BARRIER

7. CONCLUSIONS

7.1 BARRIER PERFORMANCE

The 1000-ft (305-m) long barrier was found to be effective in reducing noise from traffic. The noise reduction measured at various positions behind the barrier is summarized in Table 1. In no case did the barrier cause an increase in measured traffic-noise levels.

As a rule the noise reduction provided by the barrier was found to increase with barrier height. Even a low 2.8-ft (0.85 m) barrier provided some reduction in noise.

The noise reduction provided by the barrier was found to decrease as the distance between the barrier and the measurement point increased. For example, the 14.8-ft (4.5-m) high barrier reduced noise levels approximately 11 dB at a distance of 55 ft (16.8 m) behind the barrier, approximately 9 dB at a distance of 100 ft (30.5 m), and approximately 7 dB at a distance of 200 ft (61.0 m) behind the barrier.

Inadequacies of Current Design-Guide Prediction

The results presented in Section 6 show that the procedure presented in the NCHRP 144 Design Guide [9] tends to underestimate the performance of highway barriers in reducing noise.

At high-microphone positions, the effectiveness of the 1000-ft (305-m) long barrier was found to be as great as that predicted for an infinitely long barrier. This indicates that the correction for finite-barrier length used in the design guide significantly underestimates the performance of finite-length barriers.

At low-microphone positions, the effectiveness of the 1000-ft (305-m) long barrier was found to be in better agreement with predictions from the design-guide procedure. However, this agreement is considered to be the result of counteracting errors in the design-guide prediction. Of the factors not included in the design-guide prediction procedure, ground effect appears most likely to account for the discrepancy between measured and predicted insertion loss. Traffic and wind conditions varied considerably during the tests, accounting possibly for the spread of data, but not for the systematic difference between measured and predicted values of insertion loss.

Ground effect is the effect of the interference between sound waves coming directly from the noise source(s) and those reflected off the ground. For traffic noise, the overall influence of the ground effect is to cause an excess attenuation, such that A-weighted noise levels decrease with increasing distance from the roadway at a rate greater than 3 dB per distance doubling. Although the amount of excess attenuation varies with the type of ground and with the noise source and receiver heights, an overall propagation loss of 4.5 dB per distance doubling is generally used for flat terrain near highways.

The influence of ground effect on barrier performance is twofold. First, the excess attenuation due to ground effect decreases the level of noise from traffic that is beyond the ends of a finite-length barrier. Thus, the correction for finite-barrier length that is used in the design-guide prediction procedure is too great, and results in predictions that underestimate the performance of a finite-length barrier. Second, the excess attenuation due to ground effect can be expected to be less behind the barrier than in an open site due to the increased height of the effective noise source along the top edge of the barrier. This results in what appears to be reduced barrier performance at lower microphone elevations.

At high-microphone heights for the 1000-ft (305-m) long barrier, the first effect discussed above is dominant, so that the design-guide procedure significantly underestimates the barrier performance. At low heights, the two effects tend to be equal and to cancel, so that the design-guide prediction is in reasonable agreement with the data. However, this agreement is only for the particular length of barrier under study. A longer barrier would not be significantly more effective in reducing noise up to 200 ft (61.0 m) behind the barrier.

7.2 EFFECTS ON HIGHWAY OPERATIONS

In analyzing the effects of the barrier on highway operations, thought must be given to those effects which pertain only to this experimental barrier and those which apply to barriers in general.

Visual: The raw plywood surfaces used on the temporary barrier studied in this project are not aesthetic. The large plain surface was distracting to passing motorists. Many found occasion to stop to ask its purpose. However, the height of the barrier was not overwhelming; the top of the highest barrier had an elevation of only 15 degrees to the automotive driver and less to the truck driver. Graffiti was a major problem. Slogans and slurs appeared regularly. However, permanent barriers could have a less suitable surface; earth berms and irregular concrete structures and special "non-stick" coatings make spray cans less effective.

Audible: The barrier was sufficiently far from the roadway that there were no noticeable increases in vehicle-interior noise when passing the barrier.

Traffic Flow: Though the barrier was visually distracting, radar measurements indicated that traffic did not decrease speed in passing the barrier.

Safety: The barrier was set back from the road at a distance recommended by AASHTO standards, giving 30 ft of space for the stopping of errant vehicles.

The barrier did provide a wind break. Motorists passing the barrier ends during high cross winds may receive deflecting gusts. It was noticed that lightweight vehicles traveling southbound had a tendency to be moved toward the median on very windy days with the wind coming from the northwest.

The deposition of snow in the lee of the barrier was a problem. Since the snowfall was so light during the winter of 1976-76, problems could hardly have been expected. There was always ample "off road" space for piling the snow plowed from the shoulder.

The lack of service stations on I-93 has given motorists the need for improvised facilities. The privacy offered by the barrier was an attraction. As a result, vehicles left the shoulder and re-entered the highway near the barrier more frequently than at other points along the road.

7.3 ECONOMICS OF BARRIER CONSTRUCTION

Permanent noise-attenuation barriers should be designed considering the following three items: (1) adequate noise reduction; (2) aesthetically pleasing; and (3) economical. The barrier selection process should involve all three of the above selection criteria on an equally weighted basis.

Various barrier configurations were developed using five common construction materials for the structural elements. The five were earth, aluminum, concrete, wood, and steel. Each material would provide sufficient sound transmission loss so that noise levels behind the barrier would be a function of barrier height and not barrier material. Estimated construction costs have been computed for each of 15 different barrier types (see Table 3 and Figures 23, 24, and 25). The unit prices used in computing these costs are applicable to eastern Massachusetts only. For comparison purposes, the approximate costs of barrier types 3 through 15 are based on a 16-ft-high barrier.

Barrier types 1 and 2 show the change in cost per linear ft per ft of barrier height that would occur if the barrier height was reduced to 8 or 12 ft.

The approximate costs shown in Table 3 do not include engineering or utility relocation costs.

a. Earth Berm

1) Major advantages -- low maintenance costs; low construction costs; long service life; could be made very attractive with proper landscaping.

2) Major disadvantages -- for each ft of barrier height, the earth berm requires 4 ft of width. (For a 16-ft-high barrier, 64 ft is the minimum width at the base.) In urban areas, the cost of the additional right of way necessary to construct the barrier could be prohibitive.

b. Aluminum

1) Major advantages -- low maintenance costs; long service life.

2) Major disadvantage -- very high construction cost.

c. Concrete (Precast)

1) Major advantages -- low maintenance costs combined with moderate construction costs; ability to be formed to take any texture and shape. Coloring may be added to enhance beauty; long service life.

2) Major disadvantage -- aesthetics.

d. Wood

1) Major advantages -- low construction costs; easy replacement of damaged portions of barrier.

2) Major disadvantages -- high maintenance costs; short service life.

e. Steel

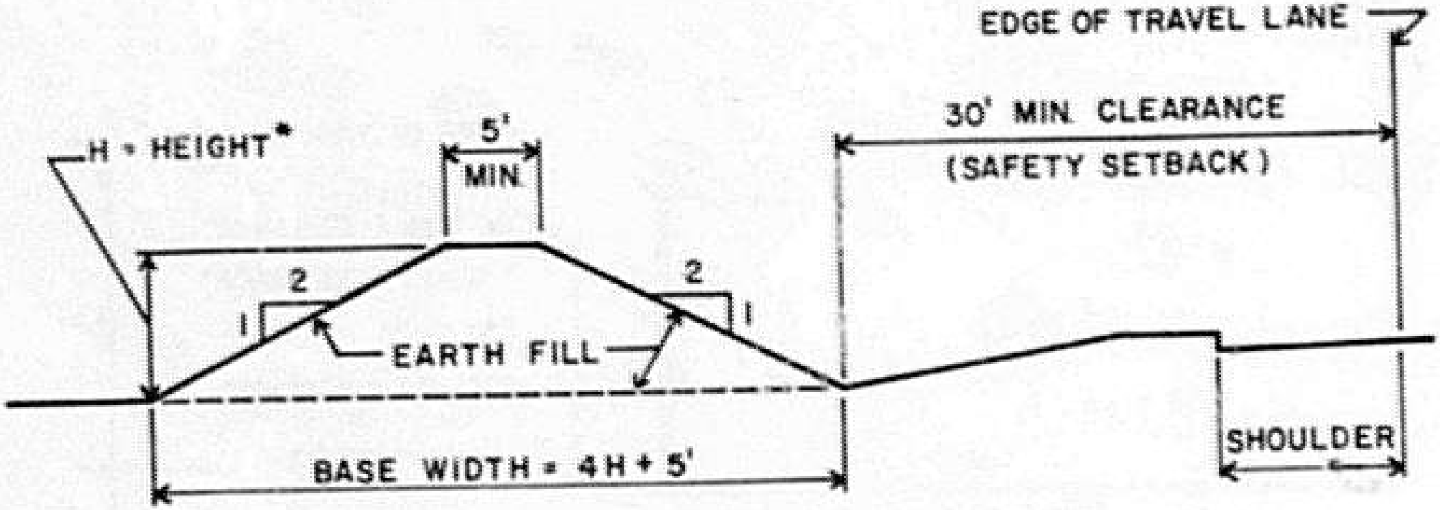
1) Major advantages -- none.

2) Major disadvantages -- high maintenance costs combined with moderately high construction costs.

TABLE 3. COMPARATIVE COSTS OF BARRIER TYPES

TYPE	DESCRIPTION	BARRIER HEIGHT (ft)	SUPPORT	APPROX. COST* PER LINEAR FT PER FT OF BARRIER HEIGHT (dollars)
1	Earth Berm	8	--	2.46
2	Earth Berm	12	--	2.78
3	Earth Berm	16	--	3.12
4	Aluminum Wall	16	Aluminum wide flange shape 18 ft on center	15.72
5	Precast Concrete Wall	16	Self-supporting 8-ft-long panels	7.00
6	Wood Wall	16	Timber posts 8 ft on center	3.00
7	Steel Wall	16	Steel H piles 18 ft on center	6.80
8	6' Earth Berm with 10' Aluminum Wall	16	See Type 4	11.01
9	6' Earth Berm with 10' Precast Concrete Wall	16	See Type 5	4.92
10	6' Earth Berm with 10' Wood Wall	16	See Type 6	3.04
11	6' Earth Berm with 10' Steel Wall	16	See Type 7	5.42
12	10' Earth Berm with 6' Aluminum Wall	16	See Type 4	7.91
13	10' Earth Berm with 6' Precast Concrete Wall	16	See Type 5	3.89
14	10' Earth Berm with 6' Wood Wall	16	See Type 6	3.14
15	10' Earth Berm with 6' Steel Wall	16	See Type 7	4.57

* <u>Initial</u> Construction Costs <u>only</u>.



*H = 8' – TYPE 1 – BASE WIDTH = 37"
H = 12' – TYPE 2 – BASE WIDTH = 53"
H = 16' – TYPE 3 – BASE WIDTH = 69"

FIG 23 TYPICAL CROSS-SECTION, HIGHWAY-NOISE BARRIERS TYPE 1 THRU 3

NOTE:

CHAIN LINK FENCE WILL DISCOURAGE VANDALS FROM ATTACKING THE BARRIER FROM THE HIGHWAY. SEE FIGURE 25 FOR ALTERNATE SECTION.

*ALUMINUM
PRECAST CONCRETE
WOOD
STEEL

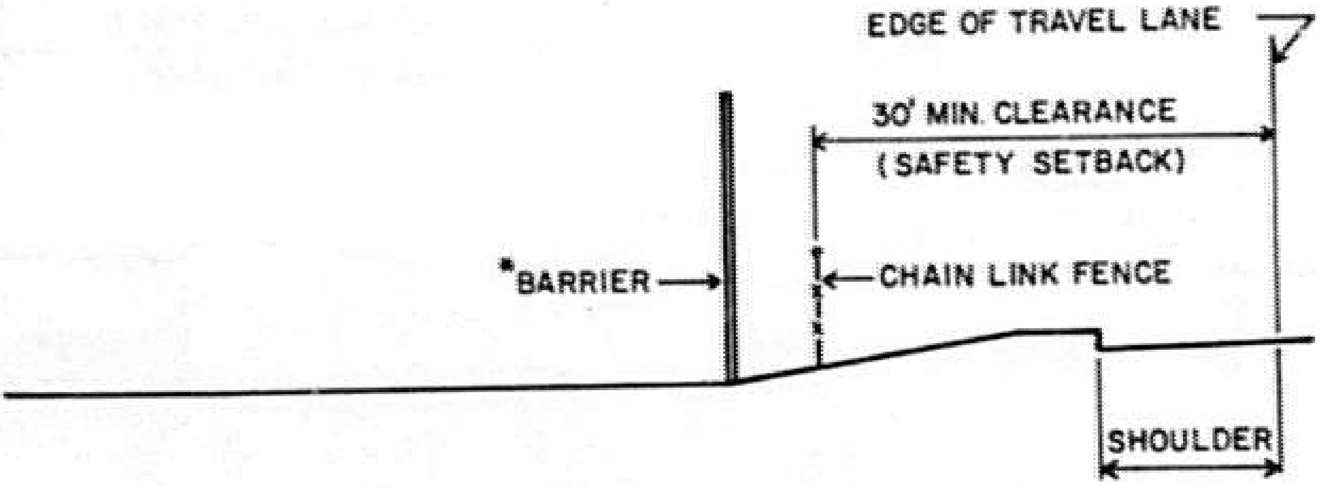


FIG 24 PREFERRED TYPICAL CROSS-SECTION, HIGHWAY-NOISE BARRIERS TYPE 4 THRU 7

NOTE:

THIS BARRIER CONFIGURATION SHOULD BE USED ONLY WHERE THERE WILL BE LITTLE DANGER OF VANDALISM ORIGINATING FROM THE HIGHWAY. SEE FIGURE 24 FOR PREFERRED SECTION.

*ALUMINUM
PRECAST CONCRETE
WOOD
STEEL

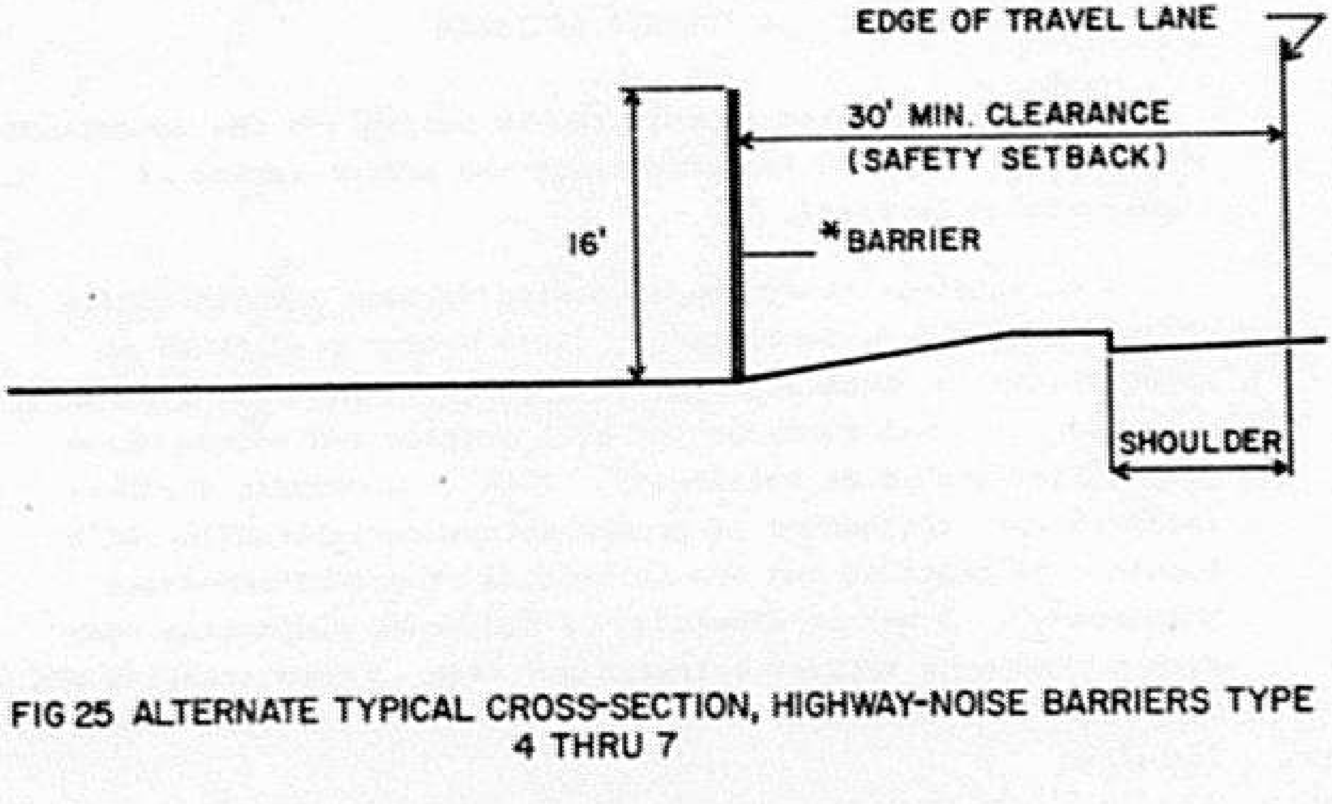


FIG 25 ALTERNATE TYPICAL CROSS-SECTION, HIGHWAY-NOISE BARRIERS TYPE 4 THRU 7

First-cost economics would indicate that most permanent noise-attenuation barriers should be of wood construction. However, because of its relatively short anticipated service life, the wood barrier should be eliminated for permanent-barrier construction. Consideration of first costs plus maintenance costs over the entire service life would definitely favor the selection of precast concrete for a permanent-barrier installation.

Combining earth berms with the other four structural materials makes aluminum and steel more competitive with precast concrete although these metal barriers will still be more expensive.

7.4 RECOMMENDATIONS FOR FURTHER RESEARCH

The work presented in this report brings out the importance of the ground surface in determining the effectiveness of highway-noise barriers.

A classification system involving various terrain configurations should be developed to allow better prediction of noise levels in areas adjacent to roadways. Acoustic impedances of various terrain surfaces for both grazing and normal noise propagation should be catalogued. This will require further research into the nature of ground-structure interaction with acoustic propagation and new techniques of ground-impedance measurement. A better knowledge of how sound propagates away from a road over various terrains may lead to more creative and less expensive solutions to highway-noise control than currently feasible.

APPENDIX

REPORT OF INVENTIONS

This report presents test results for a highway noise barrier that was designed and built in Andover, Massachusetts. After a diligent review of the work performed under this contract, it was found that no new inventions, discoveries, or improvements of inventions were made.

REFERENCES

1 Environmental Protection Agency, "Background Document for Proposed Medium and Heavy Truck Noise Regulations," Sect. 2, Rept. No. EPA-550/9-74-018, Oct. 1974.

2 Earnhart, G.A., Rupert, H.M., and Reagan, J.A., "Fundamentals and Abatement of Highway Traffic Noise - Noise Barrier Design and Example Abatement Measures," Vol. 2, Rept. No. FHWA/HHI/HEV-74/0000-1, NTIS PB 235 253, Apr. 1974.

3 Harmelink, M.D. and Hajek, J.J., "Noise Barrier Evaluation and Alternatives for Highway Noise Control," Canadian Ministry of Transportation and Communications, Ontario, Rept. No. RR180, Sept. 1972.

4 Scholes, W.E., et al., "Performance of a Motorway Noise Barrier at Heston," Applied Acoustics, Vol. 7, No. 1, 1974.

5 Reinhold and Burger, "Die Funktionelle und Betriebliche Erprobung Absorbierender Larmochutzwande an einer Autobahn (The Functional and Operational Investigation of Absorbing Barriers on a Highway)," Strasse und Autobahn 1, 35-43, (Kirschbaum, Bonn, Germany), (1971).

6 Jonasson, H.G., "Sound Reduction by Barriers on the Ground," J. Sound and Vibration, Vol. 22, No. 1, 113-126, 1972.

7 Scholes, W.E., Salvidge, A.C., and Sargent, J.W., "Motorway Noise Propagation and Screening," J. Sound and Vibration, Vol. 38, No. 3, 281-303, 1975.

8 Simpson, M.A., "Noise Barrier Attenuation Theory and Field Experience," FHWA Rept. No. DOT-FH-11-8287, 1976.

REFERENCES (cont.)

9 Kugler, B.A., and Pierson, A.G., "Highway Noise - A Field Evaluation of Traffic Noise Reduction Measures," NCHRP Rept. 144, 1973.

10 Scholes, W.E., Salvidge, A.C., and Sargent, J.W., "Field Performance of a Noise Barrier," J. Sound and Vibration, Vol. 16, No. 4, 627-642, 1971.

11 Rickley, Edward, et al., "Roadside Barrier Effectiveness Noise Measurement Program," Rept. No. DOT-TSC-OST-77-53, Oct. 1977.

12 Patterson, Donald, "How to Design Pole-Type Buildings," 4th edition, American Wood Preservers Institute, 1965.

13 Ver, I.L. and Holmer, C.I., "Interaction of Sound Waves with Solid Structures," Chapter 11 in <u>Noise and Vibration Control</u>, L.L. Beranek, editor; McGraw-Hill, New York, N.Y., 1971.

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