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RAILROAD RETARDER NOISE REDUCTION

Study of Acoustical Barrier Configurations

Burlington Northern, Inc.
176 East Fifth Street
St. Paul MN 55101

MAY 1979

FINAL REPORT

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16. Abstract

Field measurements of noise were made near a railroad retarder system without barriers and with acoustical barriers of various configurations. The configurations tested included acoustically reflective and acoustically absorptive barriers with heights of 4 to 12 feet and lengths extending from 0 to 22 feet beyond retarder entrance and exit. Two of the 12 foot high barriers were also tested with a 1 foot inward projecting acoustical panel lip along the top. It was found that the absorptive barriers reduced retarder noise from a few decibels inside the barriers to as much as 25 decibels at 100 feet from the retarder on the system centerline perpendicular to the tracks. Reflective barriers increased noise inside the barriers and at points outside, but near open ends of, the barriers; and reflective barrier noise reduction at 100 feet on the perpendicular centerline was limited to about 16 decibels. Retarder noise was concentrated in a frequency range between 2 and 3 kilohertz. The analytical study presented provides details on the role of observer location as well as the various aspects of barrier configuration.

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PREFACE

This report presents the results of a study to determine the effectiveness of acoustical barriers for abatement of noise produced by operation of a railroad retarder. The work was performed for the U. S. Department of Transportation, Transportation Systems Center (TSC) under contract to the Burlington Northern Railroad, Inc. (BN) who subcontracted the work to the Industrial Acoustics Company, Inc. (IAC). Field testing was done at the Northtown Classification Yard of the Contractor, Burlington Northern, Inc. using Group Retarder No. 3. Field testing was done in June, 1975.

Cars and operational control were provided by BN under the direction of B. G. Anderson, Assistant Vice-President-Engineering. Field data were obtained and reduced by TSC under the direction of E. J. Rickley, Technical Monitor for this program. The existing ("normal") barrier and reconfigurations were designed and constructed by IAC. Data analysis was performed by Uno Ingrad, consultant to IAC and Professor of Physics at Massachusetts Institute of Technology.

Photographs used in this report were provided by Burlington Northern. Detailed descriptions of data acquisition and reduction systems, as well as test procedures, were provided by E. J. Rickley and are included in this report. Detailed measurement data and analyses will be published by TSC in a separate report.

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			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	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
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	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			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	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
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

CONTENTS

CONTENTS (Continued)

TABLES

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

1. INTRODUCTION

The objective of the study described in this report is to develop practical design guides for cost effective application of acoustical barriers to suppress noise caused by operation of railroad retarders.

Noise measurements were made of a retarder in operation without barriers and with barriers of various lengths, heights and acoustical absorption characteristics. Measurements were also made with a one-foot high, inward-leaning acoustical barrier panel added to the top of two of the barrier configurations.

Noise data were analyzed to evaluate the effect of the different barrier configurations on noise at various locations. Results are presented in graphical form of Insertion Loss in decibels. Graphs are also included showing relative A-weighted sound levels in decibels at various locations for the different configurations.

It was found that acoustical barriers, with absorptive surfaces facing the retarder, provided substantial benefit to the areas shielded. Typical Insertion Loss values, in a direction perpendicular to the barrier, were 16 - 22 dB for absorptive barriers 8 to 12 feet high. Corresponding values for reflective barriers were 8 to 13 dB.

It should be noted that the noise involved was concentrated in a relatively narrow band of frequencies, and that nature and geometry of the source are unique. Results cannot, therefore, be directly applied to other sources, with which similar barriers might be more effective or less effective.

Special appreciation is expressed for the cooperation of the Mayors of the adjoining communities:

The Hon. Albert J. Hoffstede of Minneapolis
The Hon. Bruce G. Nawrocki of Columbia Heights
The Hon. William H. Nee of Fridley

who presented special permission for those tests which may have generated noise in excess of the local city ordinance levels.

2. TEST SITE

2.1 General Description

Burlington Northern's Northtown Yard is located in Fridley, Minnesota. Arrangement of the yard and surrounding environs is shown in Figure 2.1.

The Northtown Yard is an automatic classification yard with 63 classification tracks, divided into 8 groups and equipped with an all electric retardation system, manufactured by General Railway Signal Company. Two General Electric 4010 digital computers govern an automatic retarder control, noise abatement system, automatic switching and management information functions. One computer system operates "on line" while the other provides back-up.

Characteristics for each of 63 different routes have been programmed into the computers. These characteristics reflect the grade, curvature, the number of switches and the distance to the clearance point on each of the routes leading to the classification tracks. In addition to track characteristics, the computer programs take into consideration the distance a car must travel after it reaches the tangent point, the weight of the car, the speed it approaches the retarders, the wind, the temperature and humidity conditions and the rollability of the car. These factors determine the speed at which the car must be released from the master and the group retarder to make a damage-free coupling with other cars on the track. Each car passing over the 21.5-foot-high hump has its speed controlled by the 160-ton master retarder and one of the 160-ton group retarders (see Figure 2.2), through the computer programs, as it rolls into the classification track to which it has been assigned.

2.2 Normal Operations

The master and group retarders are equipped with a noise suppression system, consisting of a low pressure pump system which sprays a solution of emulsified oil and water onto the contacting surfaces of the retarder shoe-beams and the wheels of the freight car. The emulsion serves as a friction modifier, changing the dynamic friction characteristics of the contacting surfaces. During extreme cold weather, ethylene glycol replaces the water, and the amount of emulsified oil is reduced to maintain proper flow.

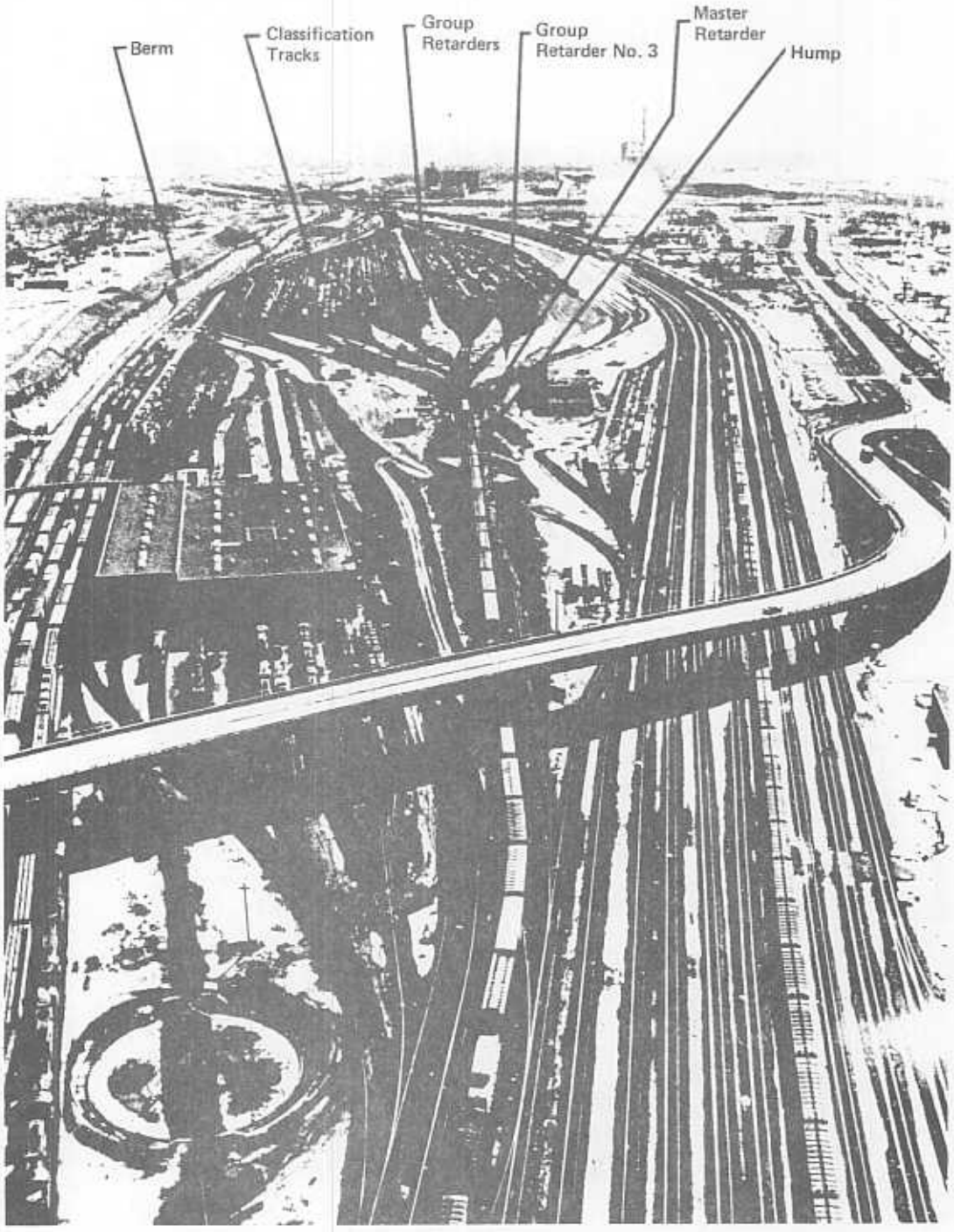

FIGURE 2.1 NORTHTOWN YARD

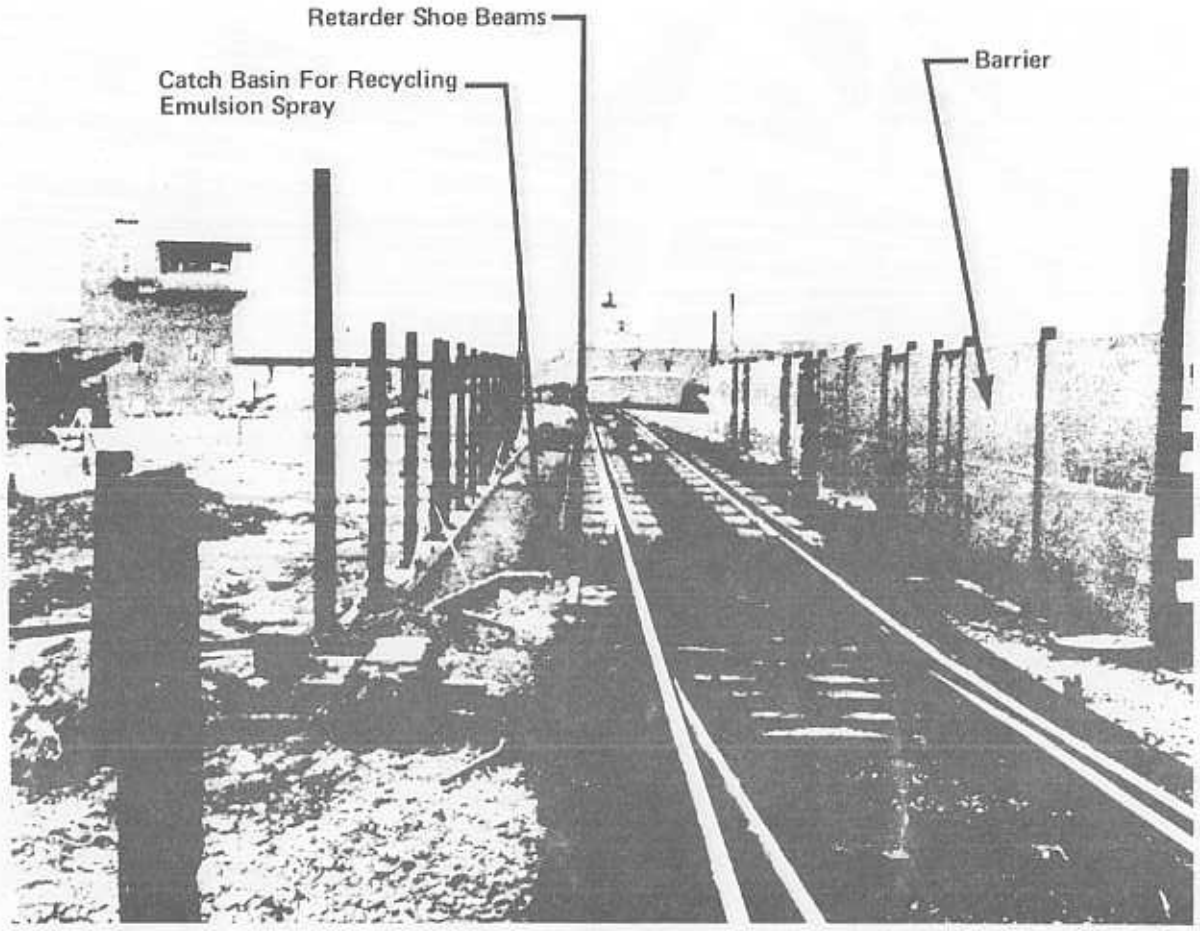

FIGURE 2.2 VIEW, NORTHERLY FROM EXIT END OF GROUP RETARDER NO. 3, WITH WESTERLY BARRIER WALL REMOVED

Control of the emulsion spray is governed by the hump computer, which sends a signal to open a valve at the retarder just prior to car entry. Similarly, another signal shuts off the spray as the car leaves the retarder. Barriers were installed on either side of the retarder to contain the emulsion spray within the catch basin (see Figure 2.2). Since these barriers were constructed with acoustical properties, if a wheel squeal were generated its propagated level would be reduced by the barrier. With the system in normal operation, few cars generate a wheel squeal; and when a squeal is generated, it is of lower intensity and shorter duration than would otherwise occur.

2.3 Operation for Barrier Study

Throughout the barrier test program, the emulsion spray system was disconnected and the computer was programmed to allow cars to leave the master retarder at a much higher speed than normal. In addition, Group Retarder No. 3 was programmed to slow the test cars at a higher than normal rate. In normal operation, a car being operated on Group Retarder No. 3 is slowed over the entire length of the retarder to its required exit speed. For these tests, the retarder was programmed to slow the test cars at a high rate by applying the highest possible retardation force (within safety limitations). This was purposely done to generate a squeal of relatively high intensity with each car to facilitate measurement of noise reduction attributable to the barriers.

2.4 Barrier Description

The acoustical barriers installed for normal operation on BN Group Retarder No. 3 at the Northtown Yard are 8 feet high and 143 feet long, extending approximately 11 feet beyond the retarder on each end. Barrier support is provided by 5-inch, wide-flange columns anchored to concrete footings at 11-foot intervals on each side of the retarder. Column lines are 9 feet-10½ inches from the track centerline. The spaces between columns are spanned by modular acoustical panels, slightly less than 11 feet long by 4 feet wide by 4 inches thick which are nested between the column flanges.

The modular panels are IAC Noishield Regular Panels except that 1.25 mil polyethylene film envelopes are included to protect the acoustical filler material from moisture. Panel faces, separated by 4-inch peripheral and internal steel channels, are perforated 22-gauge steel on one side and solid 18-gauge steel

on the other. Steel parts are galvanized and are joined together by welding and riveting. The perforated (acoustically absorptive or "soft") panel faces are installed facing the retarder in normal operation.

Columns were extended and additional modular panels were used in the study covered by this report in order to provide the various configurations tested.

Additional details of the barriers described above are given in Appendix A. Similar barriers are installed for the other retarders in the Northtown Yard.

3. NOISE MEASUREMENTS

3.1 Scope

The subject study required acquisition, through a field measurement program, of statistical data describing the noise environment associated with operation of railroad retarders without barriers and with barriers of various configurations. The test plan provided for recording data, under controlled conditions, in and around a retarder system equipped with barriers which could be quickly reconfigured to provide a range of geometric and absorptive characteristics. The following discussion of noise measurements follows the test plan precisely except as noted.

3.2 Measurement System Deployment

Locations for 15 microphones were chosen as shown in Figure 3.1. Microphone heights are given in Table 3.1. Microphones 1, 2 and 3 were inside the barrier at a distance of one foot from the acoustical barrier panels. Microphones 4 through 14 were in the relatively obstruction-free yard area west of the retarder; a vertical mast was erected for mounting microphones 12, 13 and 14 at heights of 5, 10 and 20 feet. Microphone 15 was placed in line with microphones 1, 7, 9, 12, 13 and 14 at the BN yard fence line 842 feet east of the barrier centerline; this position was on top of an earth berm 81.41 feet above top of rail. This berm can be seen in the upper left of Figure 2.1. Data from microphone 15 were not included in this study because they are not pertinent to the generalized analysis.

A doppler radar was set up to monitor the speed of test cars entering Group Retarder No. 3.

The manually controlled robot camera shown in Figure 3.1 was triggered when the front end of a test car reached a point exactly 50 feet from the point of entry to the retarder. This provided a photograph for identification of the car and a simultaneous trigger pulse to the TSC measurement van to record a position reference for the recorded noise data.

A weather station was deployed to continuously measure and record temperature, humidity, wind speed and wind direction.

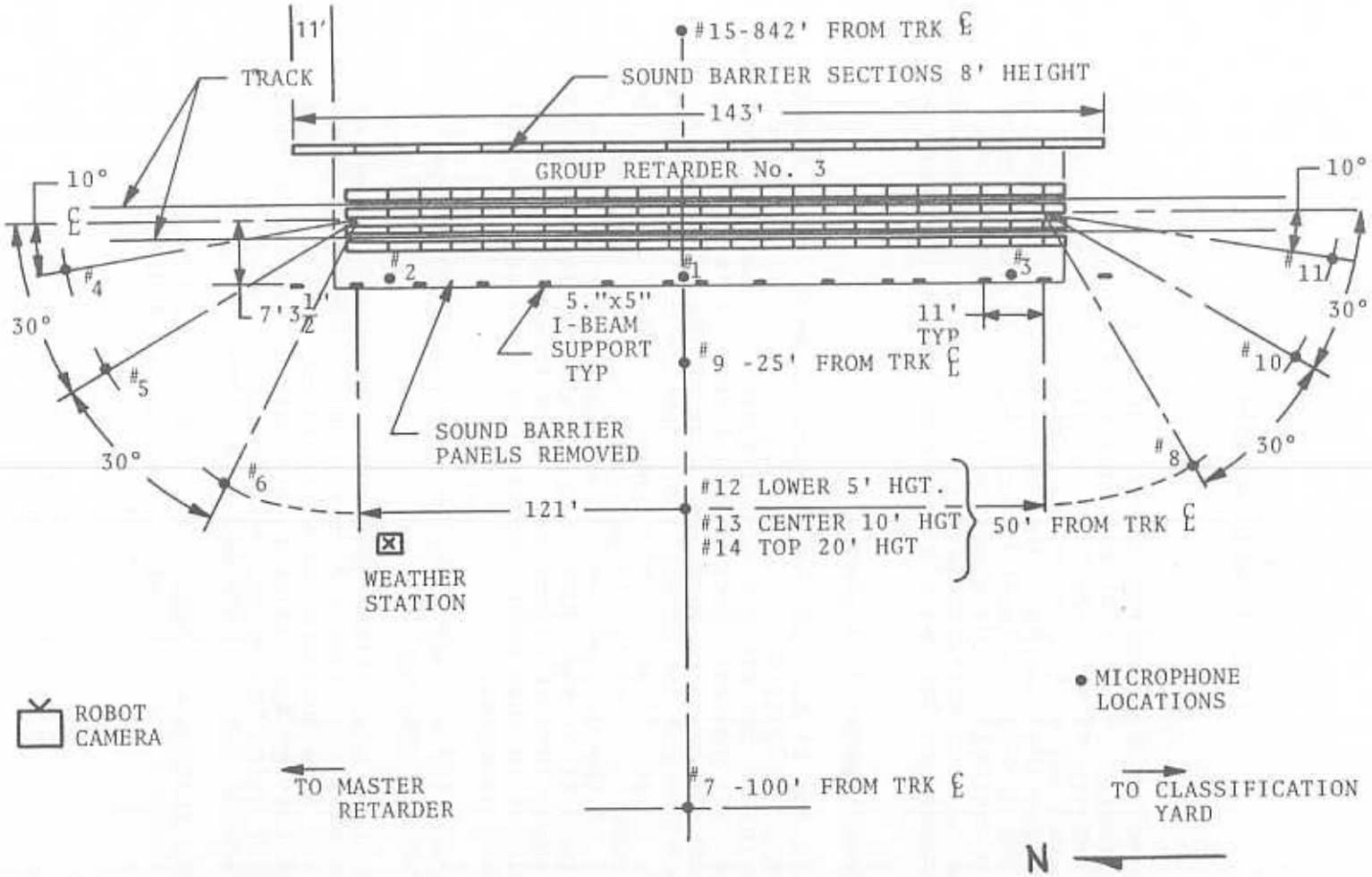

FIGURE 3.1 MEASURING SYSTEM LOCATIONS – BURLINGTON NORTHERN NORTHTOWN YARD, JUNE 1975

TABLE 3.1 MICROPHONE HEIGHT DATA

MICROPHONE NO.	HEIGHT ABOVE GROUND (FT.)	HEIGHT RELATIVE TO TOP OF RAIL AT CENTER OF GROUP NO. 3 RETARDER	
		MAY 29-JUNE 5,1975 (FT.)	JUNE 17-27,1975 (2) (FT.)
1	5.0	2.5	2.5
2	5.0	2.5	2.5
3	5.0	2.5	2.5
4	5.0	4.2	4.4
5	5.0	3.2	3.4
6	5.0	3.3	2.9
7	5.0 (1)	2.2	2.4
8	5.0	2.7	2.3
9	5.0	2.6	2.4
10	5.0	2.0	2.1
11	5.0	2.2	2.3
12	5.0	2.2	1.7
13	10.0	7.2	6.7
14	20.0	17.2	16.7
15	5.0	81.4	81.4

(1) Set at 6.7 ft. June 17-25, 1975

(2) Measurement site regraded by BN

A detailed discussion of the procedures and data acquisition and reduction systems used by TSC in this study is presented in Appendix B.

3.3 Barrier Configurations

The test plan included the barrier configurations given in Table 3.2. Configurations 4a and 9a are the "normal" configurations provided by IAC under an earlier contract from BN.

In preparation for the study reported herein, the westerly barrier wall panels were removed and reconfigured with components borrowed from other BN retarders, or fabricated for this study. See Figure 2.2.

Data were gathered for each barrier configuration, including the normal configuration used in operational service by BN, until statistical sets of data had been accumulated.

The easterly barrier was left in place during all tests to avoid possible interference of noise reflections from the westerly barrier wall of the Group 4 retarder, located about 30 feet east of Group Retarder No. 3. Tests 1a through 3 were run with additional acoustically absorptive material, supplementing the absorptive face of the Group Retarder No. 3 easterly barrier, for further assurance of avoiding reflections which would have unrealistically affected the no-barrier baseline noise measurements.

Reconfiguration work and testing had to be carefully scheduled to avoid conflict with the heavy yard operational requirements.

3.4 Operation of Test Cars

High level squeals were desired for this study to minimize the effect of extraneous noise, from other sources in and around the Northtown Yard, on noise measurements. Therefore, the emulsion spray noise suppression system was disconnected, and the computer was programmed for higher than normal car speeds entering Group Retarder 3 and higher than normal retardation force in Group Retarder 3. Also, cars provided by BN were loaded in excess of 80 tons to produce higher noise levels.

TABLE 3.2 BARRIER CONFIGURATIONS

CON-FIG. NO.	WESTERLY BARRIER HT FT.	EXTENSION-FT. ENTRY	EXIT	SEE NOTE	EASTERLY BARRIER HT. FT.	EXTENSION-FT. ENTRY	EXIT	SEE NOTE
1	0	0	0		8	11	11	
1a	0	0	0		8	11	11	(1)
2	4	11	11		8	11	11	(1)
3	6	11	11		8	11	11	(5)
3a	6	11	11	(2)	8	11	11	(2a)
4	8	0	0		8	11	11	
4a	8	11	11	(3)	8	11	11	(3)
5	8	22	22		8	22	11	(6)
6	10	11	11		8	11	11	
7	12	11	11		12	11	11	
7a	12	11	11	(7)	12	11	11	(7)
8	12	11	11	(4)	12	11	11	(4)
8a	12	22	22	(4)	12	22	11	(4)(6)
9	8	11	11	(7)	8	11	11	(7)
9a	8	11	11	(3)	8	11	11	(3)

NOTES:

(1) Absorptive barrier wall was covered with 2-inch thick, 3-pound density fiberglas batts.

(2) Absorptive barrier wall was covered with 1/8-inch thick masonite.

(2a) Lower 6 feet of absorptive wall was covered with 1/8-inch thick masonite.

(3) This is the "normal" configuration.

(4) A 1-foot lip was attached to the top of the barrier wall.

(5) Top 2 feet of absorptive wall was covered with 2-inch thick, 3-pound density, fiberglas batts.

(6) Presence of electric control box prevented extending wall to planned 22 feet.

(7) Lower 4 feet of absorptive wall was covered with 1/8-inch thick masonite; upper panels turned 180 degrees exposing reflective side of panel to inside of barrier.

(8) Effective barrier height above top of rail is reduced by 2 feet, 1 inch. See Appendix A, Figure A1.

Processing of cars through Group Retarder 3 was coordinated by direct radio contact between the Hump Master and the TSC Test Director to insure high quality data acquisition with minimum disruption of normal yard activities. A consist of approximately 25 cars was processed 3 times in succession for each barrier configuration to increase statistical confidence of collected data. Cars, entering the retarder at approximately 20 second intervals, proceeded into two or more tracks to insure that they traveled far enough into the classification yard to avoid resultant impact sounds which might interfere with noise measurements around Group Retarder No. 3. Computer printouts were provided by the BN Signal Group for a record of test car identification, configuration, weight, speed and classification track assignment.

4. RESULTS OF STUDY

4.1 Introduction and Summary

This study is based on noise level data obtained in and around a railroad retarder system without barriers and with acoustical barriers of various geometries and acoustical absorption characteristics. These data were reduced and are analyzed in terms of A-weighted sound levels in decibels.

Results of data analysis in terms of Insertion Loss (IL) are presented in the following subsections 4.2 through 4.6.5. Theoretical considerations regarding the IL results are presented in 4.7. Observations pertinent to barrier application in terms of noise level distribution in and around the barriers are presented in 4.8 and 4.9. Results in terms of IL and noise level distribution are presented in graphical form.

Some of the most important aspects of the results presented can be summarized as follows:

a. IL is markedly higher for an absorptive barrier than for a reflective barrier.

b. In a direction perpendicular to the barrier, typical values of IL are 16-22 dB for absorptive barriers between 8 and 12 feet high. Corresponding values for reflective barriers are 8-13 dB.

c. For a reflective barrier, the IL can be negative within a sector about the entrance and exit of the retarder, the angle of the sector being dependent on barrier height.

d. Barrier IL is dependent on direction to and elevation of the observation point as well as the barrier height.

e. Barrier extensions beyond the retarder improve IL within a sector about the entrance and exit of the retarder, but do not change IL in the direction perpendicular to the barrier.

f. Addition of an inward leaning "lip" along the upper edge of a barrier increases IL in the direction perpendicular to the barrier, but its effect decreases gradually to zero as the observation point is moved toward a direction parallel to the barrier.

g. The fact that substantially greater IL is achieved by an absorptive barrier may perhaps be explained by consideration of the effect of the "duct" which is formed between the barrier and the railroad car. The model of a single source shielded by a single barrier, which has been used in the development of standard prediction schemes, does not consider barrier absorption and is an oversimplification of the present problem.

h. Squeals generated by operation of the retarder in the manner chosen for this study typically lasted about 5 seconds with noise level reaching a maximum value usually when the car was close to the center of the retarder. The somewhat directional sound field, with highest levels in a direction perpendicular to the track, is offset by directional performance of the barriers; with barrier heights above 10 feet, minimum levels occur in the perpendicular direction.

4.2 Relationship Between Noise Reduction and Insertion Loss

We shall describe the noise shielding effect of a barrier in terms of its Insertion Loss (IL) in decibels. Referring to Figure 4.1 the insertion loss at a particular location A is defined as

$$(IL)_A = L_A - L'_A \qquad (4.2.1)$$

where L_A is the A-weighted sound level in decibels at A when no barrier is present, and L'_A is the level at A when the barrier is in place. It is implied that the noise source is the same in the two cases both in terms of strength and location. It should be mentioned in this context that the insertion loss is sometimes defined in terms of the reduction in total radiated acoustic power, but we shall not use this definition here. Our insertion loss, based on the A-weighted sound level, will depend on the location of the observation point, and a complete description of the shielding characteristics of a barrier, therefore, must include information about the insertion loss as a function of location.

It is important to realize that the insertion loss includes not only reflection and absorption effects of the barrier but also any effect the barrier might have on the acoustic power output of the source. In some cases the sound reflected from the barrier back to the source can react on the source in such a way that the acoustic radiation efficiency of the source is changed. It should

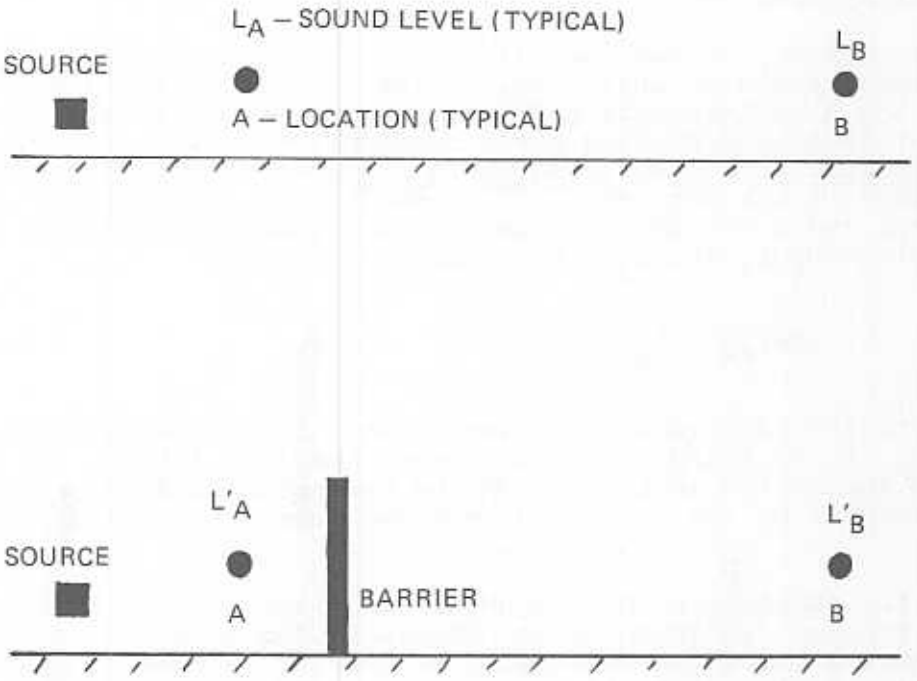

FIGURE 4.1 RELATIONSHIP BETWEEN NOISE REDUCTION AND INSERTION LOSS

Noise Reduction:

$(NR)_{AB} = L_A - L_B$ $\quad (NR)'_{AB} = L'_A - L'_B$

Insertion Loss:

$(IL)_A = L_A - L'_A$ $\quad (IL)_B = L_B - L'_B$

$(IL)_B = (NR)'_{AB} - (NR)_{AB} + (IL)_A$

be pointed out also, that the insertion loss need not necessarily be positive. At certain locations, for example on the source side of the barrier, e.g., location A, the sound reflected from the barrier may cause an increase in the level, rather than a decrease, and the corresponding insertion loss is then negative. In most locations of interest, e.g. location B, however, the insertion loss is generally positive.

Frequently, another quantity, Noise Reduction (NR), is used in the description of shielding. Noise Reduction is the difference between the simultaneously measured sound pressure levels at two different locations, whereas the insertion loss refers to levels at the same location at two different times (before and after the "insertion" of the barrier). If we denote the two different locations by A and B and the two simultaneously measured levels at these points by L_A and L_B the noise reduction is

$$(NR)_{AB} = L_A - L_B \quad . \tag{4.2.2}$$

The noise reduction is caused in part by the geometrical spreading of the sound as it is transmitted from A to B, and in part by sound absorption in the air and by absorption and interference effects caused by the ground surface and other reflecting boundaries.

In the application of the noise reduction concept to the barrier problem, we consider the levels L_A and L_B in Eq. (4.2.2) to represent the values obtained when no barrier is present. When the barrier is in place, the levels at both A and B are generally different from the no-barrier values, and we denote these new levels by L'_A and L'_B. The corresponding noise reduction is then

$$(NR)'_{AB} = L'_A - L'_B \quad . \tag{4.2.3}$$

With reference to the insertion loss definition in Eq (4.2.1) and by using the expression (4.2.2) and (4.2.3) for the noise reduction, we can express the insertion loss at B as follows

$$(IL)_B = (NR)'_{AB} - (NR)_{AB} + (IL)_A \qquad (4.2.4)$$

an expression which we shall use in the analysis of the data.

This new value of the insertion loss includes, in addition to the effects of geometrical spreading, air absorption and ground effects, also the reflection and absorption effects of the barrier. It should be mentioned that the effect of the ground surface in the two cases, with and without the barrier, need not necessarily be the same.

If the point A is chosen to be at our microphone position No. 1, i.e., on the source side of the barrier, we expect the insertion loss $(IL)_A$ at A to be close to zero for the absorptive barrier. The insertion loss $(IL)_B$ at B can then be expressed simply as the difference in the noise reduction values obtained with and without barrier. For a reflecting barrier, on the other hand, the insertion loss at location A can very well be negative, and the insertion loss at B is then somewhat less than the difference in the noise reduction values.

4.3 Squeal Characteristics

The squeal is a high pitched sound with most of its energy contained in a frequency range between 2 kilohertz and 3 kilohertz. It is a result of a friction generated vibration which has its source in the contact between the retarder friction blocks and the wheels of the railroad car. The mechanism of excitation presumably is not unlike the excitation of a violin string.

The duration of the squeal typically is 4-5 seconds, and the peak of the A-weighted sound level measured at a distance of about 5 feet from the rail and 5 feet above the ground level can reach a value of about 140 dBA. However, the level of the squeal can vary greatly from one event to another.

A detailed description of this noise has been given by E. J. Rickley, R. W. Quinn and N. R. Sussan in Report No. DOT-TSC-OST-73-46 entitled: "Noise Level Measurements of Railroads: Freight Yards and Wayside," May, 1974.

4.4 Data Selection

The peak value of the A-weighted sound level in each squeal event has been obtained for a large number of events at different locations about the retarder for a number of different barrier configurations including the case of no barrier.

Out of these data we have selected only the events which were "squeals." This was performed on the basis of the experience gained by the measurement team, that in order to be certain that an event actually represents a squeal, the A-weighted sound level at each of the microphone locations 1, 2 and 3 on the source side of the barrier should exceed 115 dBA. In addition, we have excluded a few events in which the squeal occurred near the entry or exit of the retarder rather than in the center. The exclusions were determined when the levels at location 1 (center of the barrier) were lower than the levels at locations 2 and 3. (See Figure 3.1).

4.5 Determination of the Average Insertion Loss

Using the data thus selected, we have determined the average insertion loss of each barrier configuration, the average being taken over all useful events. The number of such events in each case is larger than 10.

In the expression for the insertion loss at a particular point B, $(IL)_B = L_B - L'_B$, the "no-barrier" value L_B and the "with-barrier" value L'_B were obtained at different times, and the source involved at these times must be assumed to be different in general. Therefore, strictly speaking, one should not be able to use this expression for the insertion loss because of the requirement that the source strength and location be the same in each case. However, if we take an average over many events, this procedure will still be correct as long as the average value of the source strength in the set of events S corresponding to L_B is the same as the average value of the source strength in the set of events S' corresponding to L'_B. A difference between these average values of the source strengths would lead to a systematic error in the analysis, but if the number of events is sufficiently large, the error involved is expected to be small.

It is possible to get an idea of the magnitude of the difference between the average source strength in S and in S' from the measured values of the insertion loss at location 1 in the case of an absorptive barrier. For such a barrier the reflected sound is weak and its contribution to the overall level at location 1 is expected to be negligible. The same is true in regard to any possible effect of the barrier on the radiation efficiency of the source. Therefore, if the source strength is kept constant, the A-weighted sound level at location 1 should be very nearly the same with and without the barrier and the corresponding insertion loss should be close to zero. Although the measured values in the insertion loss at location 1 indeed were quite small, there was a

consistent trend in the data toward a positive insertion loss between 1 and 3 dB for an absorptive barrier. It is difficult to understand such a result, unless we assume that there was a corresponding difference in the average source strength in the sets of events S and S' corresponding to the no-barrier and with-barrier cases. For the no-barrier case, we had only one set of data and most likely the average source strength in this set was 1 to 3 dB higher than in the other sets. We adjusted the no-barrier data accordingly.

With reference to Eq. (4.2.4), the average insertion loss at location B, the average being taken over the events in a set, is

$$(\overline{IL})_B = (\overline{NR})'_{AB} - (\overline{NR})_{AB} + (\overline{IL})_A \qquad (4.5.1)$$

where the bars signify average values. Since the noise reduction (NR) is independent of the source strength, the first two terms in this expression are not affected by shifts in the average values of the source strength from one set of events to another. After having made the correction to the no barrier data as described above, the insertion loss $(IL)_A$ for an absorptive barrier can be set equal to zero, and the insertion loss at location B can then be expressed as the difference between the noise reduction values (based on locations A and B) obtained with and without the barrier present. For the reflective barrier the insertion loss at location 1 turns out to be a small negative quantity, between -1 and -2 dB.

4.6 Discussion of Results - Insertion Loss

The data selected were averaged in accordance with Eq. (4.5.1) and in addition to the average value of the insertion loss, the standard deviation from the average was determined in each case. The results are summarized in graphical form in the various figures in this section. In each figure, we have attempted to demonstrate the effect of a particular parameter on the insertion loss.

4.6.1 Effect of Distance from the Barrier

The insertion loss is expected to decrease with the distance from the barrier at least at locations in the "shadow" zone of the barrier. In Figure 4.2 is shown the measured distance dependence of the insertion loss along the center line perpendicular to

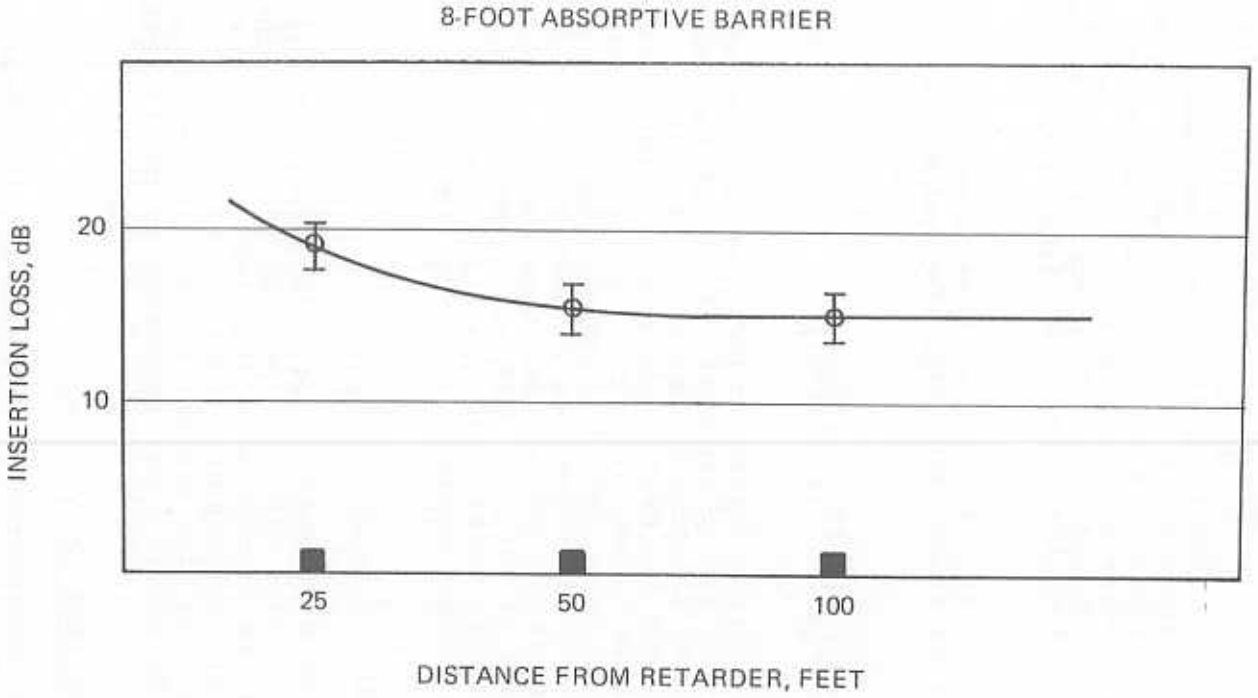

FIGURE 4.2 INSERTION LOSS OF AN 8-FOOT-HIGH ABSORPTIVE BARRIER WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF THE DISTANCE FROM THE RETARDER TO THE OBSERVER AT 90 DEGREES

the retarder for an 8-foot-high absorptive barrier. The insertion loss decreases monotonically with distance, but beyond a distance of 50 feet the decrease is slight. This behavior is consistent with the theoretically predicted distance dependence of the insertion loss for the point source shielded by a single barrier as discussed in the next section. Similar data are shown in Figures 4.3 - 4.6 for all configurations tested. These figures indicate that for barrier heights of more than 8 feet, limiting values of IL would be reached at a distance of more than 100 feet and would be 1 or 2 decibels less than the IL values measured at 100 feet. Although it would have been interesting to have had data beyond a distance of 100 feet, we shall consider the 100 feet data obtained here as representative of the insertion loss of the barrier at locations far away from the barrier. Under anomalous atmospheric conditions, such as created by temperature inversion, for example, the distance dependence of the insertion loss can of course be considerably modified. The considerations presented here refer to the general case where no such anomalies exist, as consistency of the data would indicate was the case in Fridley during the period of data accumulation for this project.

4.6.2 Effect of Barrier Height and Absorptive Characteristics

In Figures 4.7 - 4.10, we have shown the insertion loss values obtained at locations 7, 6, 5 and 4 as a function of the barrier height for both absorptive and reflective barriers. In each of these figures the open circle data points refer to the absorptive barrier and the filled circles refer to the reflective barriers. The vertical bars through the data points indicate the standard deviation from the mean. For the absorptive barriers, we have data for five different heights, 4, 6, 8, 10 and 12 feet. For the reflective barriers, we have data for only three different heights, 6, 8 and 12 feet.

Considering location 7, 100 feet from the barrier along the center line perpendicular to the retarder (see Figure 4.7), we note that for the absorptive barrier the insertion loss increases with the barrier height and reaches a value of about 21 dB for a barrier height of 12 feet. The rate of increase of the insertion loss per foot of barrier height varies from about 3 dB per foot to about 1.5 - 2 dB per foot as barrier height increases. For the reflective barrier the rate of increase is less and the value of the insertion loss obtained with the 12 foot barrier is only about 12-13 dB.

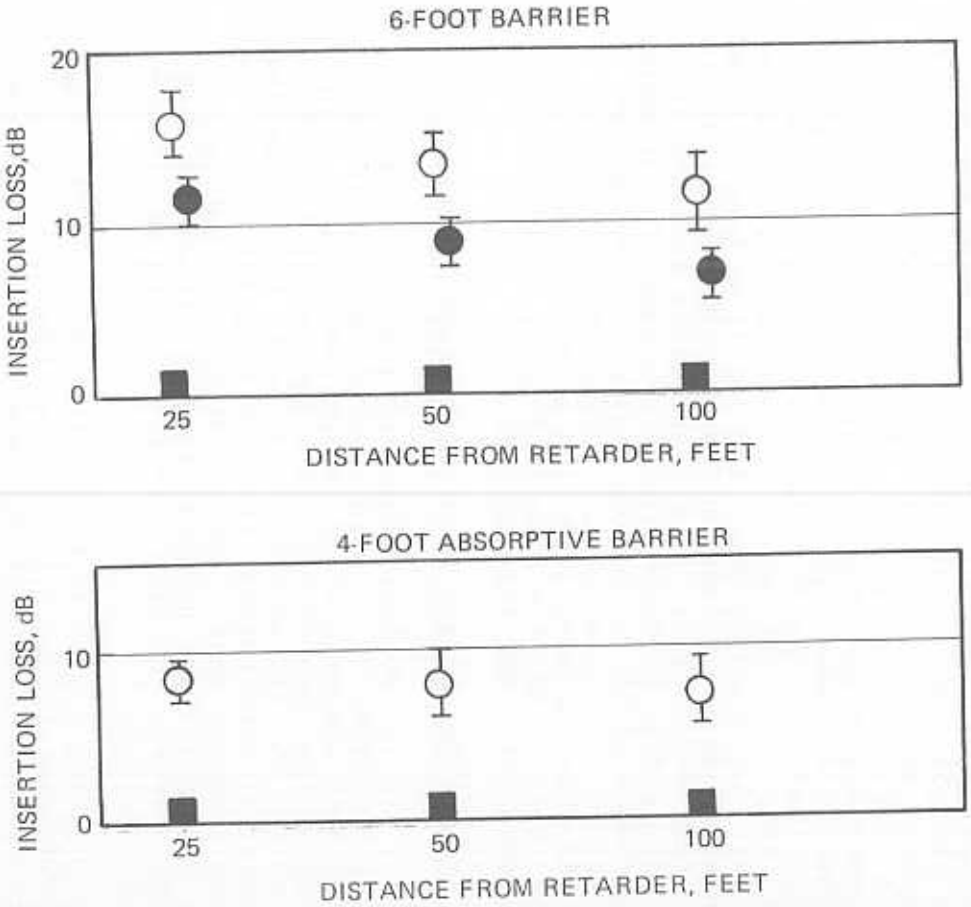

FIGURE 4.3 INSERTION LOSS OF 4-FOOT AND 6-FOOT-HIGH BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF THE DISTANCE FROM THE RETARDER TO THE OBSERVER AT 90 DEGREES

○ – ABSORPTIVE

● – REFLECTIVE

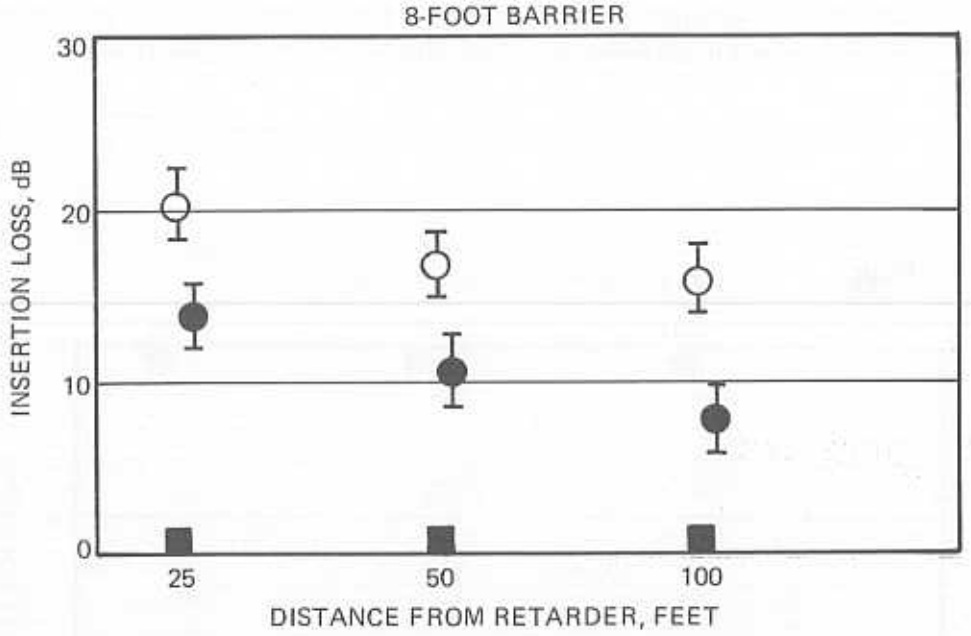

FIGURE 4.4 INSERTION LOSS OF 8-FOOT-HIGH BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF THE DISTANCE FROM THE RETARDER TO THE OBSERVER AT 90 DEGREES

○ – ABSORPTIVE

● – REFLECTIVE

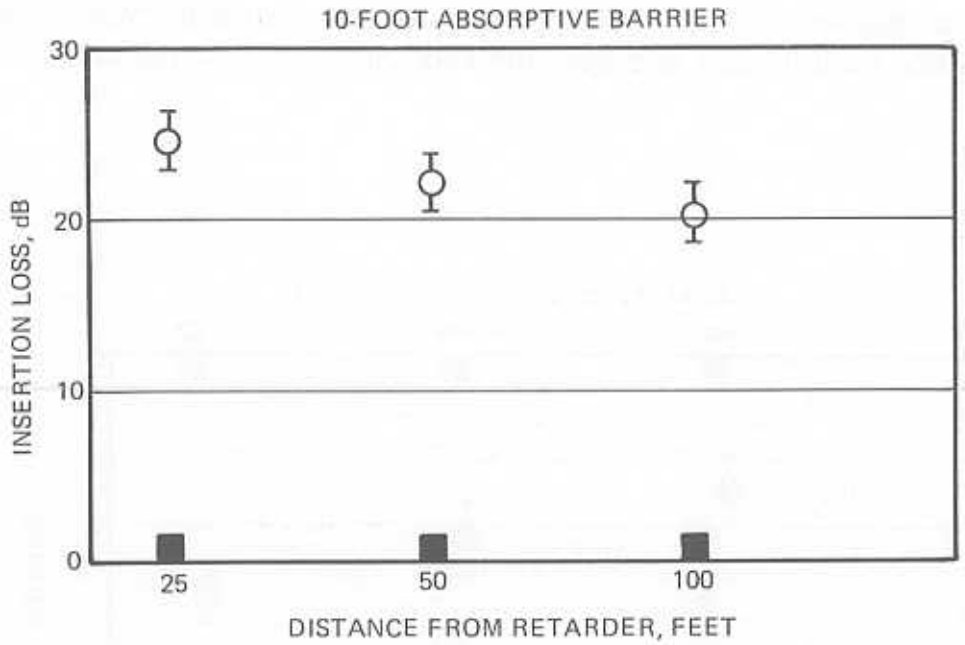

FIGURE 4.5 INSERTION LOSS OF A 10-FOOT-HIGH ABSORPTIVE BARRIER, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF THE DISTANCE FROM THE RETARDER TO THE OBSERVER AT 90 DEGREES

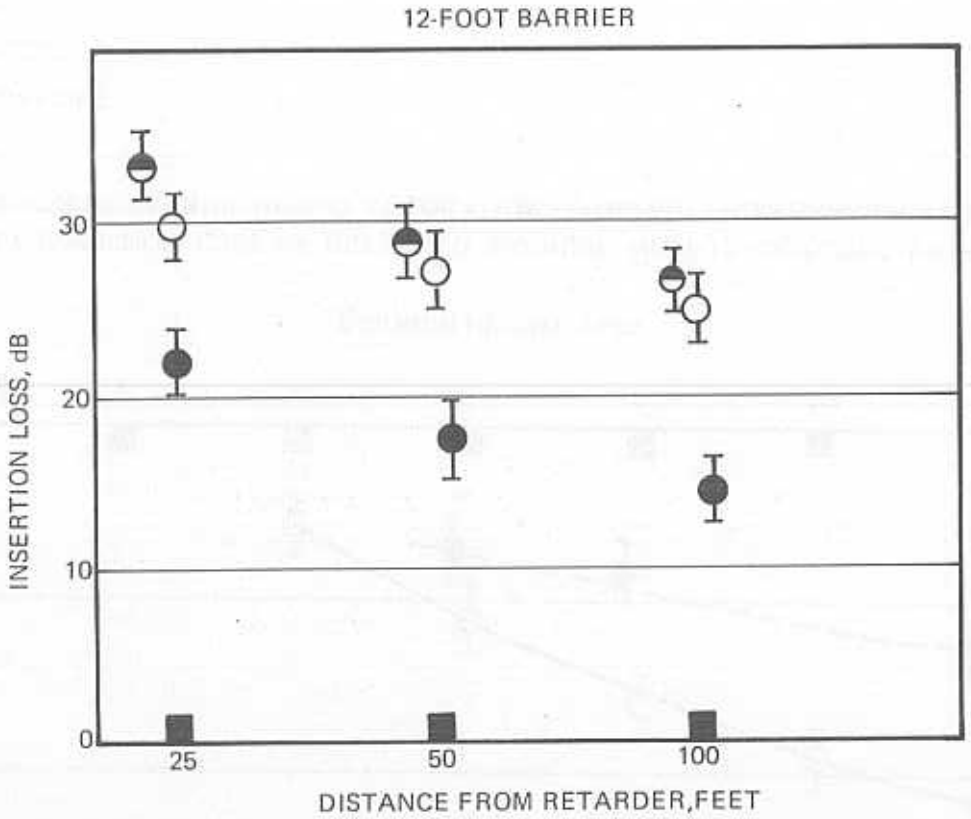

FIGURE 4.6 INSERTION LOSS OF 12-FOOT-HIGH BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF THE DISTANCE FROM THE RETARDER TO THE OBSERVER AT 90 DEGREES

○ – ABSORPTIVE
● – REFLECTIVE
◓ – ABSORPTIVE WITH 1-FT-LIP

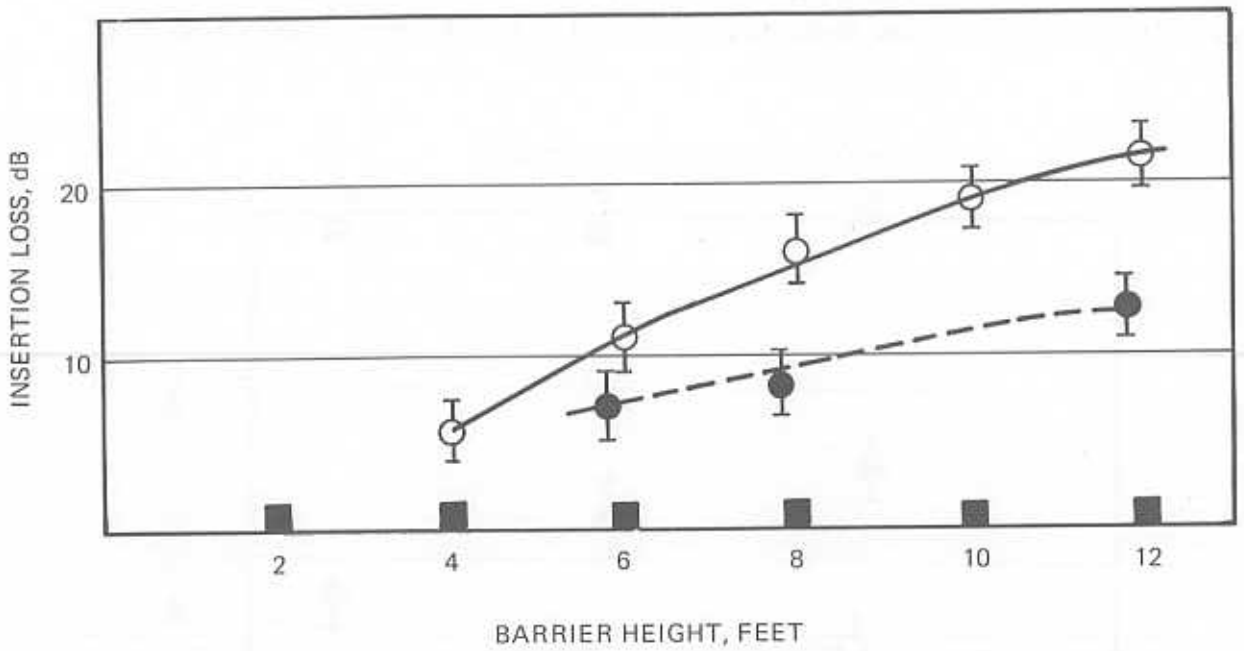

FIGURE 4.7 INSERTION LOSS OF RETARDER BARRIER, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF BARRIER HEIGHT AT LOCATION 7 (100 FEET FROM BARRIER AT 90 DEGREES)

○ – ABSORPTIVE

● – REFLECTIVE

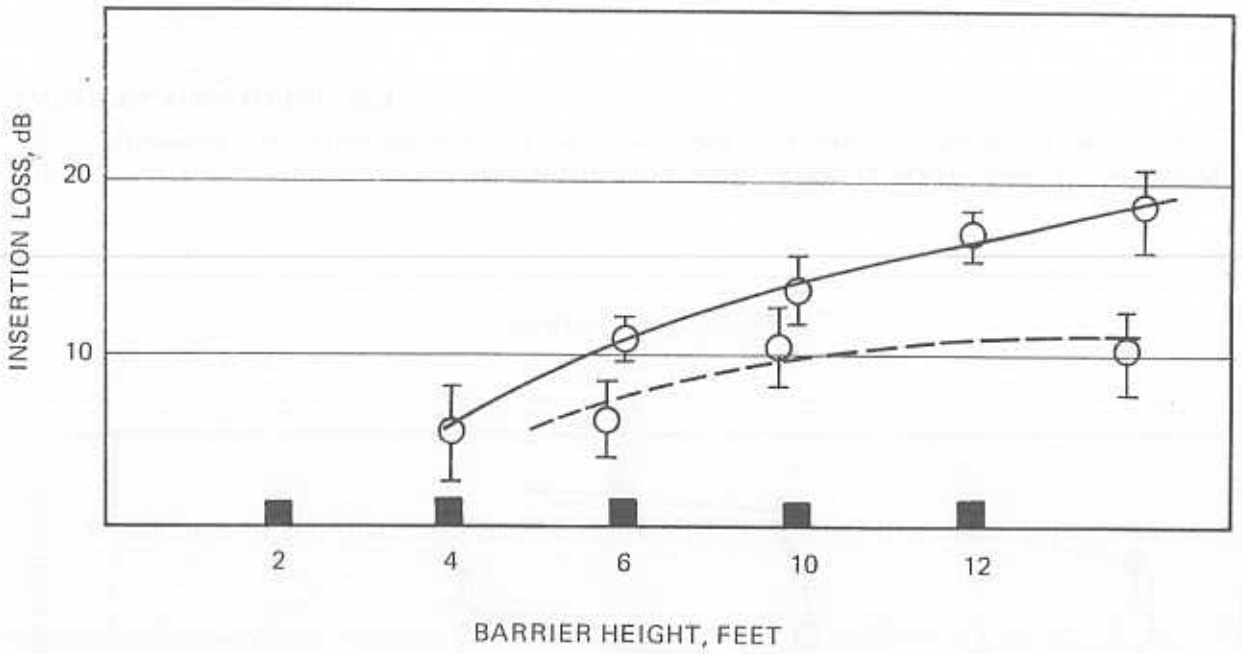

FIGURE 4.8 INSERTION LOSS OF RETARDER BARRIER, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF BARRIER HEIGHT AT LOCATION 6 (ANGULAR LOCATION 60 DEGREES EXTRAPOLATED TO 100 FEET)

○ – ABSORPTIVE

● – REFLECTIVE

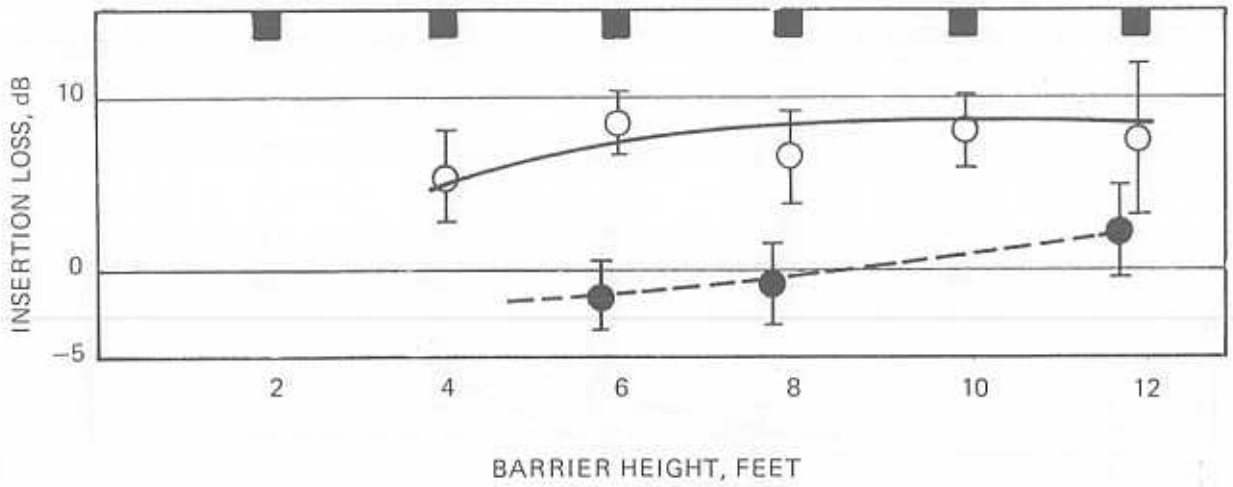

FIGURE 4.9 INSERTION LOSS OF RETARDER BARRIER, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF BARRIER HEIGHT AT LOCATION 5 (ANGULAR POSITION 30 DEGREES EXTRAPOLATED TO 100 FEET)

○ – ABSORPTIVE

● – REFLECTIVE

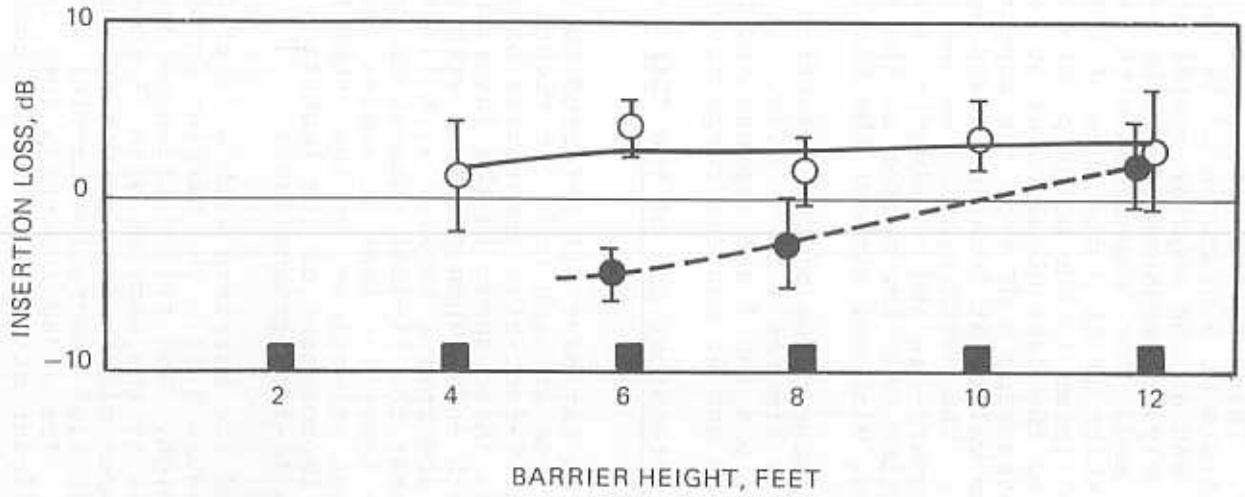

FIGURE 4.10 INSERTION LOSS OF RETARDER BARRIER, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF BARRIER HEIGHT AT LOCATION 4 (ANGULAR LOCATION 10 DEGREES EXTRAPOLATED TO 100 FEET)

○ – ABSORPTIVE

● – REFLECTIVE

Similar insertion loss curves, showing the effect of barrier height for both absorptive and reflective barriers, are given in Figures 4.8, 4.9 and 4.10. These curves refer to the locations 6, 5 and 4. These locations are at a distance of 50 feet from the entrance of the retarder and at the angular coordinates 60, 30 and 10 degrees, respectively, as measured from the center of the retarder at the entrance end. For comparison with the results obtained at location 7, which is at a distance of 100 feet from the retarder, and for use later in the polar presentation of the data, we have extrapolated the data obtained at 50 feet to a distance of 100 feet by subtracting 2 dB from the insertion loss at location 6, 1 dB from the values at location 5 and zero dB from the values at location 4. The extrapolation values are approximations based on inverse-square-law and considering length of the paths from a source location near the center of the retarder to the measurement positions, with and without the barrier in place.

To show the angular dependence of the insertion loss, we have replotted the data in Figures 4.11 - 4.15. In these figures, the locations 4, 5, 6 and 7 are represented by the angular coordinates 10, 30, 60 and 90 degrees respectively.

4.6.3 Effect of Barrier Extensions and of the "Lip" along the Top Edge of the Barrier

The data presented so far have all referred to a barrier with 11-foot-long extensions, one at each end. In Figure 4.16 is shown the insertion loss of the 8-foot-high absorptive barrier with no extensions at either end. Also shown is the insertion loss with 22-foot extensions on both ends. When compared with the insertion loss of the 8-foot-high absorptive barrier with 11-foot extensions (Figure 4.13), we note that the 11-foot extensions provide a significant increase of the insertion loss at angles less than 60 degrees. The use of 22-foot extensions, on the other hand, does not lead to a corresponding improvement of the insertion loss over that of the barrier with 11-foot extensions.

The results obtained for barriers with a "lip" along the upper edge are shown in Figure 4.17. The barrier involved here is absorptive and 12 feet high. The filled triangle data points indicate the insertion loss of the barrier with 11-foot extensions and a 1-foot lip. The open circle data points in the same figure also refer to the 12-foot high absorptive barrier with a lip but with 22-foot extensions. The added insertion loss resulting from the extensions is significant at all angles. To obtain the effect of the lip alone, we have to compare these results with those of the 12-foot-high barrier in Figure 4.11. We find that

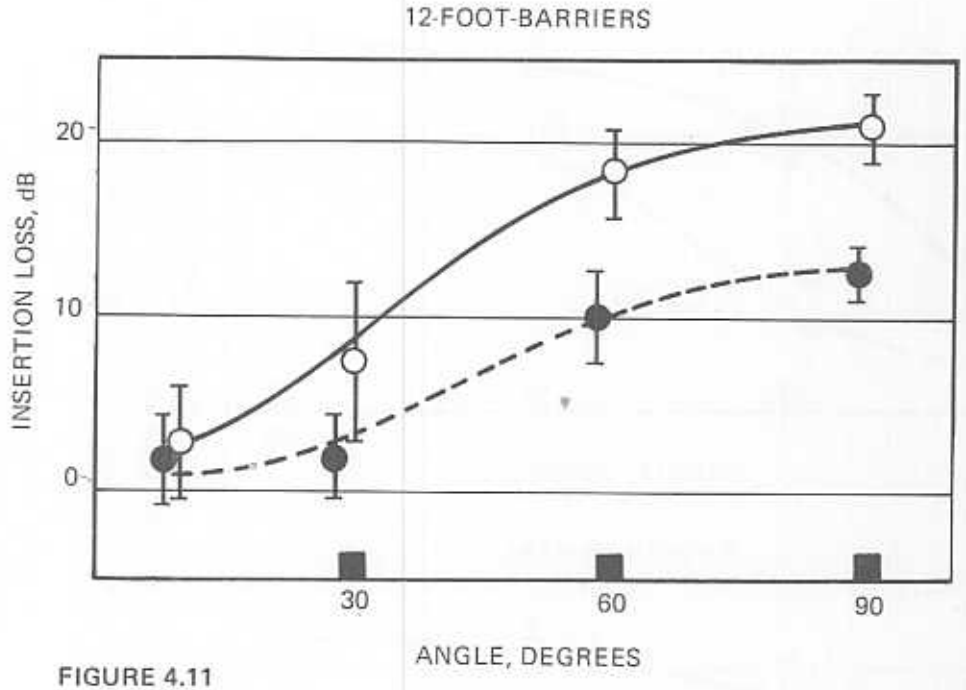

FIGURE 4.11

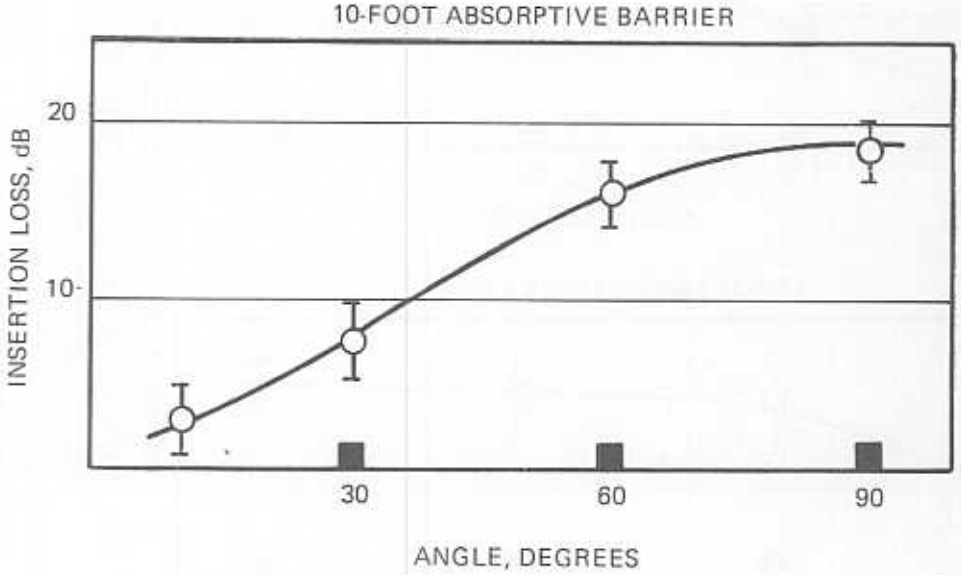

FIGURE 4.12

FIGURE 4.11 and 4.12 INSERTION LOSS OF 12-FOOT AND 10-FOOT-HIGH BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF ANGULAR LOCATION AT 100-FOOT EQUIVALENT DISTANCE

○ – ABSORPTIVE
● – REFLECTIVE

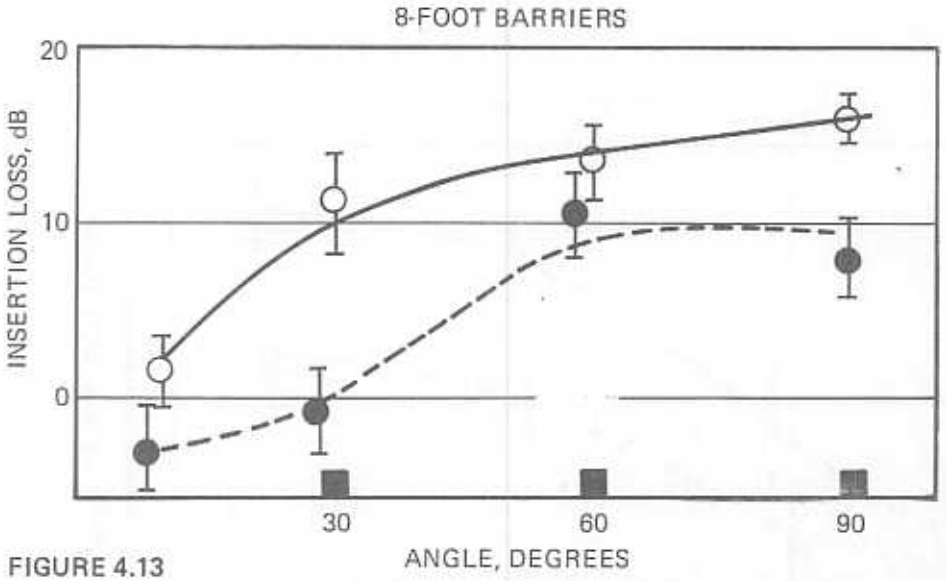

FIGURE 4.13

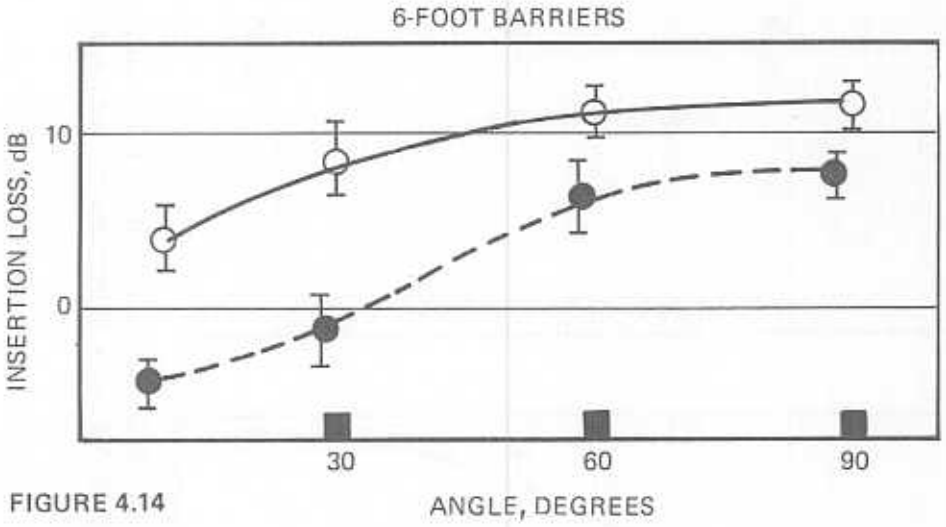

FIGURE 4.14

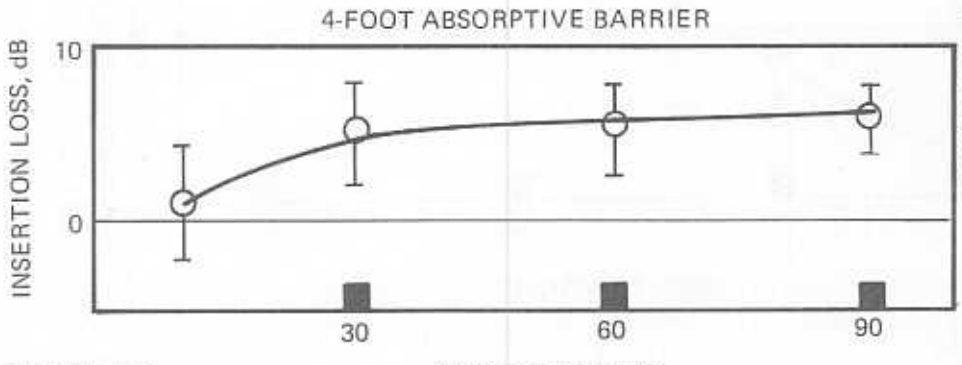

FIGURE 4.15

FIGURES 4.13, 4.14 and 4.15 INSERTION LOSS OF 8-FOOT, 6-FOOT, AND 4-FOOT HIGH BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF ANGULAR LOCATION AT 100-FOOT EQUIVALENT DISTANCE

○ – ABSORPTIVE

● – REFLECTIVE

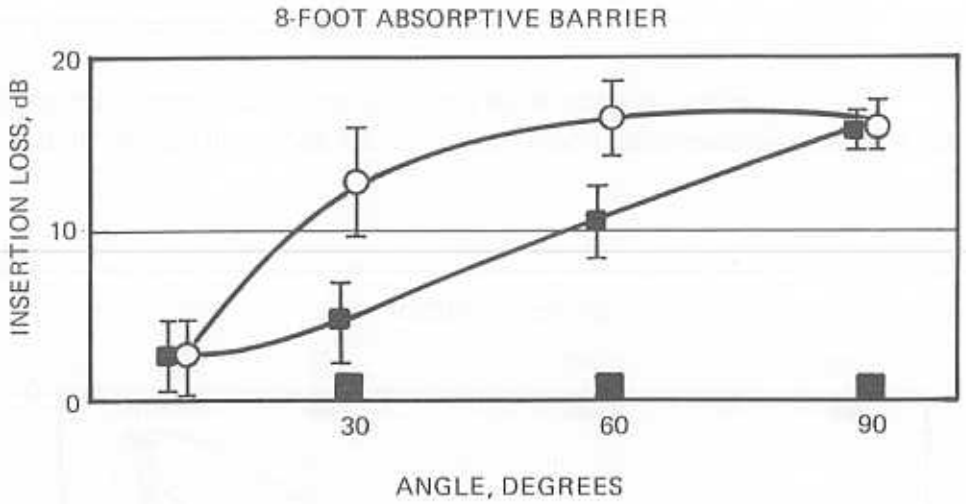

FIGURE 4.16 THE INSERTION LOSS OF AN 8-FOOT-HIGH ABSORPTIVE BARRIER AS A FUNCTION OF ANGULAR LOCATION AT 100-FOOT EQUIVALENT DISTANCE

■ – NO EXTENSIONS – LENGTH: 121 FEET

○ – WITH 22-FOOT EXTENSIONS – LENGTH: 165 FEET

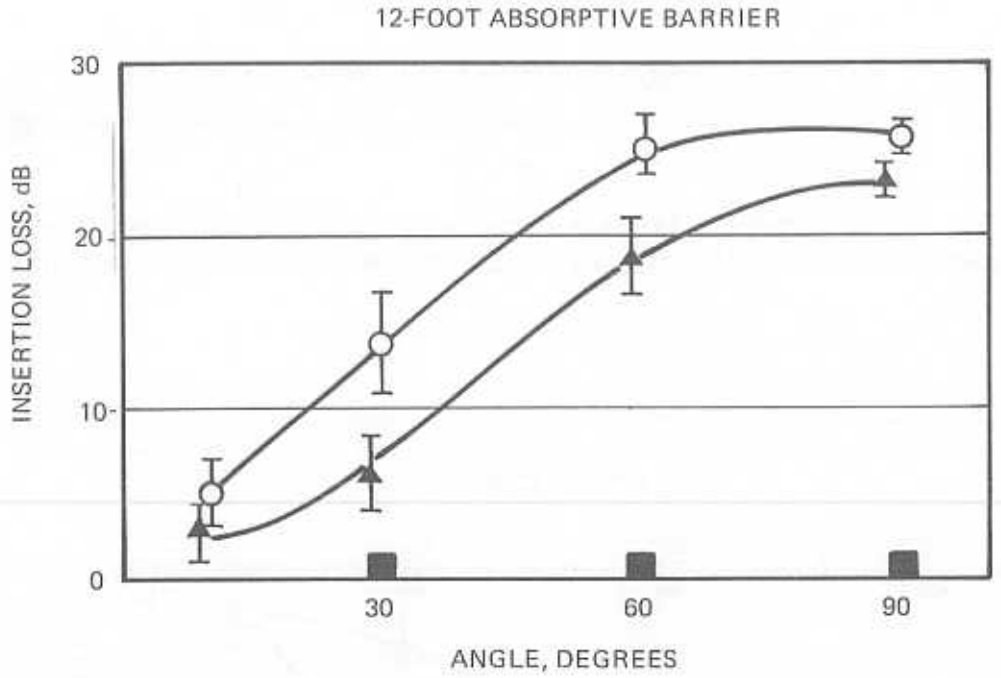

FIGURE 4.17 THE INSERTION LOSS OF A 12-FOOT-HIGH ABSORPTIVE BARRIER AS A FUNCTION OF ANGULAR LOCATION AT 100-FOOT EQUIVALENT DISTANCE

▲ – WITH 11-FOOT EXTENSIONS AND A 1-FOOT LIP

○ – WITH 22-FOOT EXTENSIONS AND A 1-FOOT LIP

the effect of the lip is small at all angles except in the vicinity of 90 degrees, where an increase of about 2 dB is obtained.

4.6.4 Miscellaneous Insertion Loss Results

The results described so far all refer to observation points 5 feet above the ground level. Higher microphone positions were available only at locations 13 and 14. Insertion loss values at these locations have been shown for the 8-foot-high absorptive barrier in Figure 4.18, where the value at location 12, 5 feet above ground, is also shown. As expected, the insertion loss decreases with the elevation of the observation point.

Although we naturally are mainly interested in the insertion loss data at locations outside the retarder barriers, we have included for completeness, in Figures 4.19 and 4.20, the insertion loss as a function of barrier height at locations 2 and 3 which are both on the rail side of the barrier. It is not surprising that the insertion loss at these locations is generally negative when the barrier is reflective.

To supplement the data at the locations about the entrance end of the retarder we show in Figure 4.21 the insertion loss at location 8 which is at the exit end of the retarder. The results in this figure refer to absorptive barriers and should be compared with the results obtained at the symmetrically located position 6 (see Figure 4.8). The insertion loss at 8 is somewhat smaller than at 6. The reason for this difference is presumably that the effective source location is not quite in the center of the retarder, i.e., at location 1, but displaced toward location 2.

In Figure 4.22 we have plotted the measured A-weighted sound level as a function of the distance from the retarder in the case when no barrier is present. As can be seen, the decrease of the level with distance is close to that corresponding to spherical divergence, i.e., 6 dB decrease per doubling of distance.

4.6.5 Summary of Insertion Loss Data - Polar Plots

Most of the insertion loss results discussed so far have been summarized in Figures 4.23 - 4.26, in which the insertion loss is plotted as a function of the angular position of the observation point. The data correspond to a distance of 100 feet from the retarder, but can be considered to represent the angular distribution of the insertion loss far away from the retarder, as indicated previously in this report. Figure 4.23 includes the data

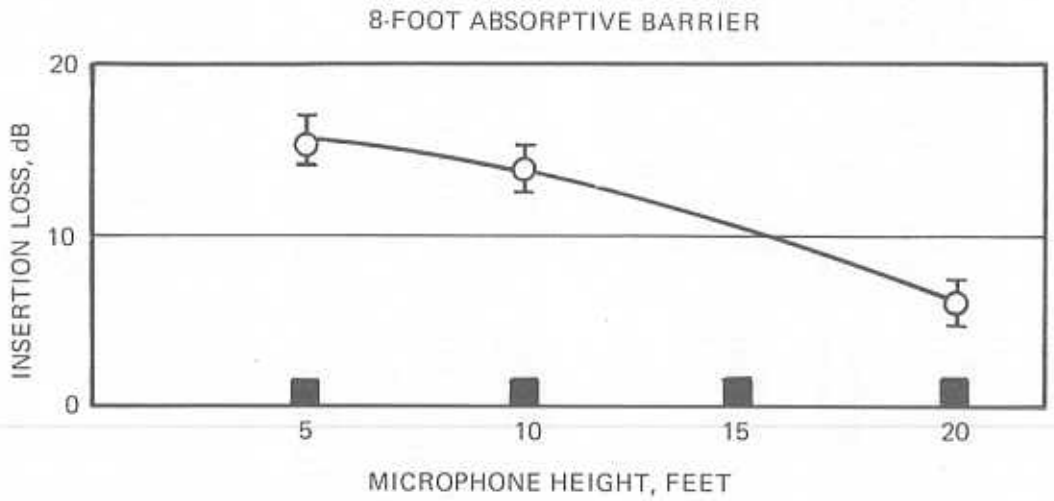

FIGURE 4.18 INSERTION LOSS OF AN 8-FOOT-HIGH ABSORPTIVE RETARDER BARRIER AT 50 FEET FROM THE RETARDER AT LOCATIONS 12, 13 and 14 AT HEIGHTS 5, 10 and 20 FEET ABOVE GROUND

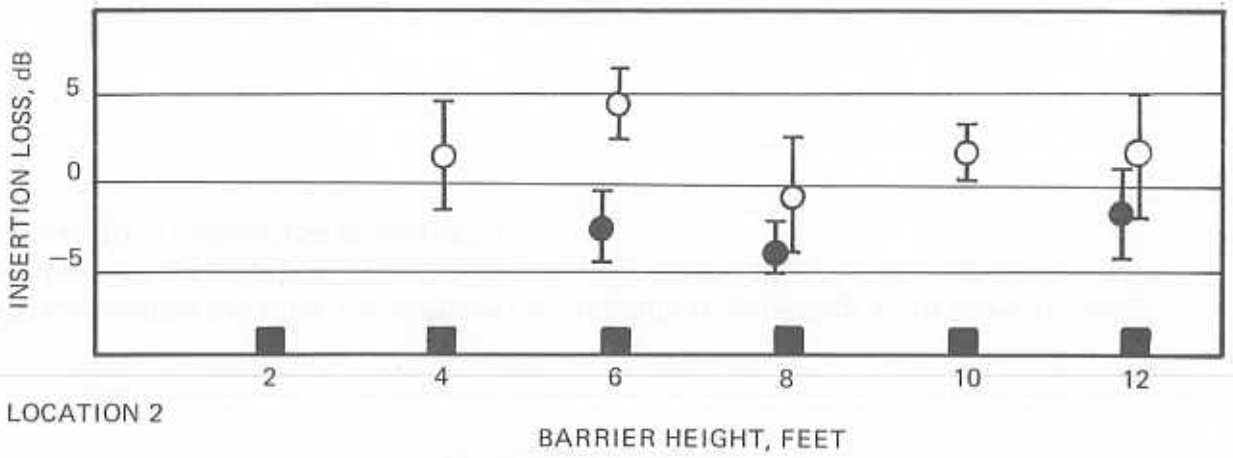

FIGURE 4.19

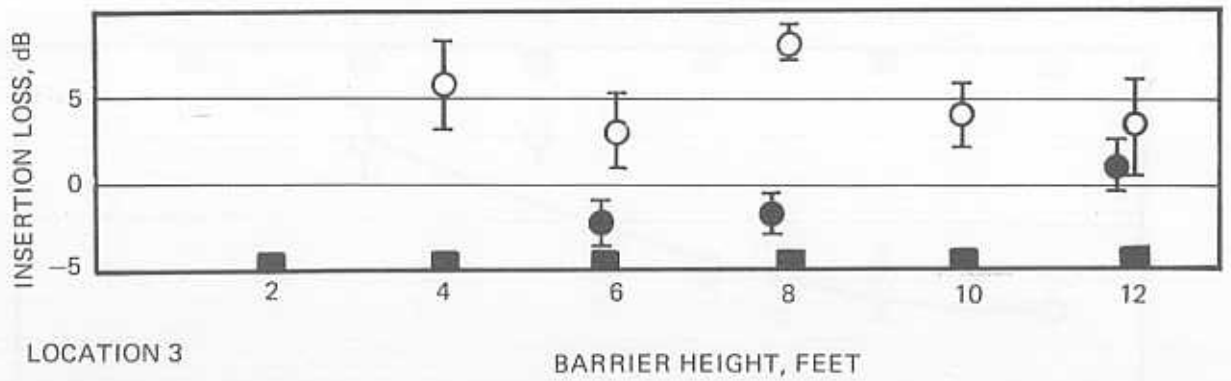

FIGURE 4.20

FIGURE 4.19 and 4.20 INSERTION LOSS OF RETARDER BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF BARRIER HEIGHT AT LOCATIONS 2 and 3 (WITHIN THE BARRIER NEAR ENTRY AND EXIT END RESPECTIVELY)

○ – ABSORPTIVE
● – REFLECTIVE

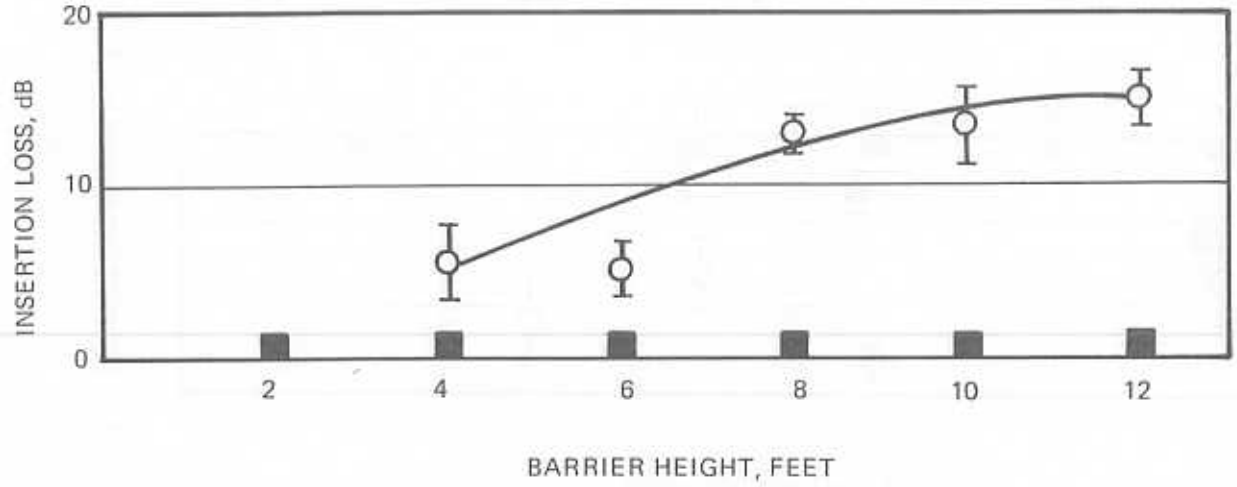

FIGURE 4.21 INSERTION LOSS OF ABSORPTIVE RETARDER BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AS A FUNCTION OF THE BARRIER HEIGHT AT LOCATION 8 (EXIT END OF RETARDER, ANGULAR LOCATION 60 DEGREES)

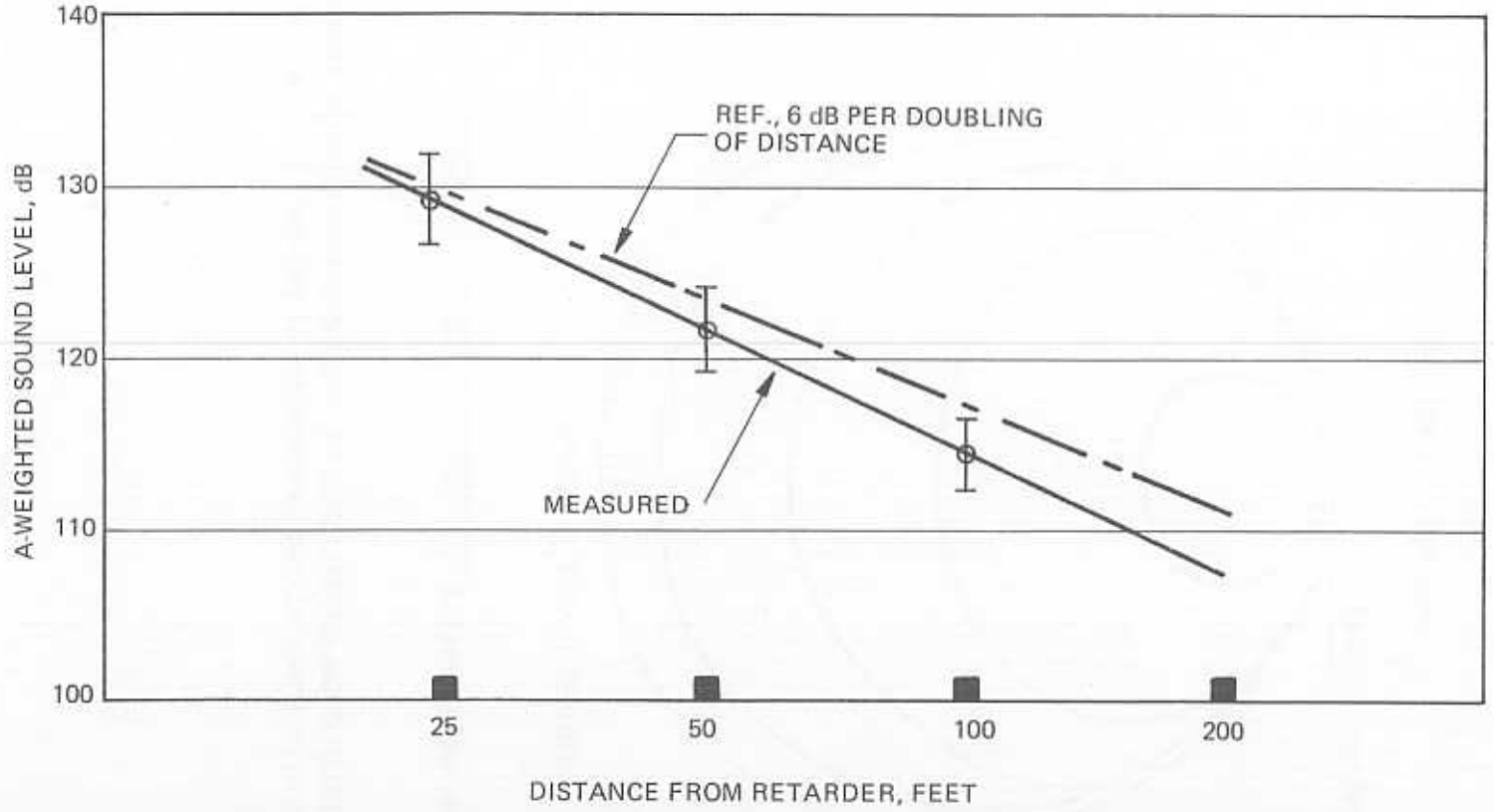

FIGURE 4.22 A-WEIGHTED SOUND LEVEL VS. DISTANCE FROM THE RETARDER IN THE PERPENDICULAR DIRECTION WHEN NO BARRIER IS PRESENT

NOTE: THESE SOUND LEVELS REPRESENT A FORCED CONDITION FOR THOSE TESTS AND ARE NOT REPRESENTATIVE OF NORMAL OPERATION OF THE GROUP 3 RETARDER AT THE BN NORTHTOWN YARD

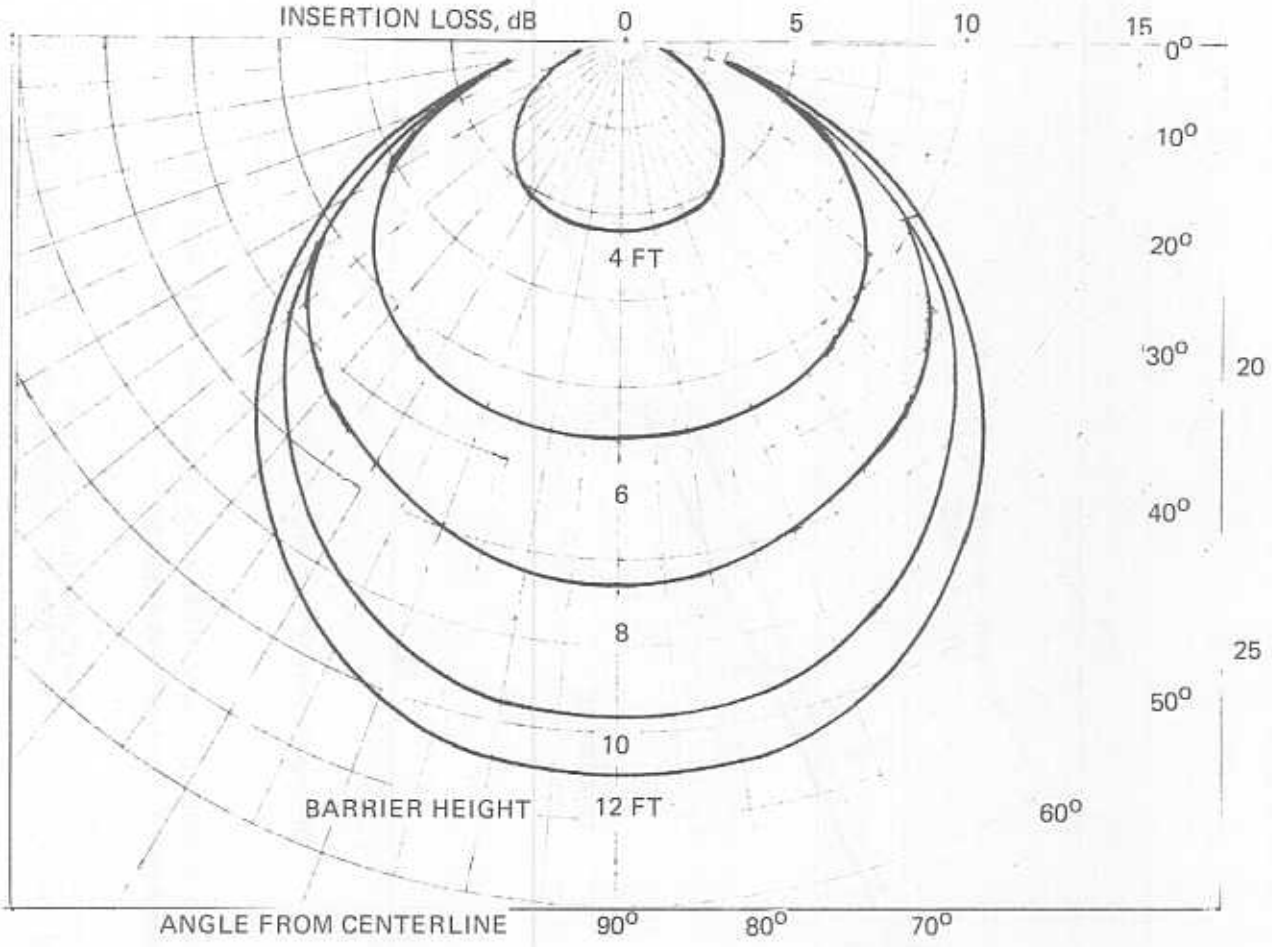

FIGURE 4.23 THE DIRECTIONAL DEPENDENCE OF THE INSERTION LOSS OF ABSORPTIVE RETARDER BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AT 100-FOOT EQUIVALENT DISTANCE

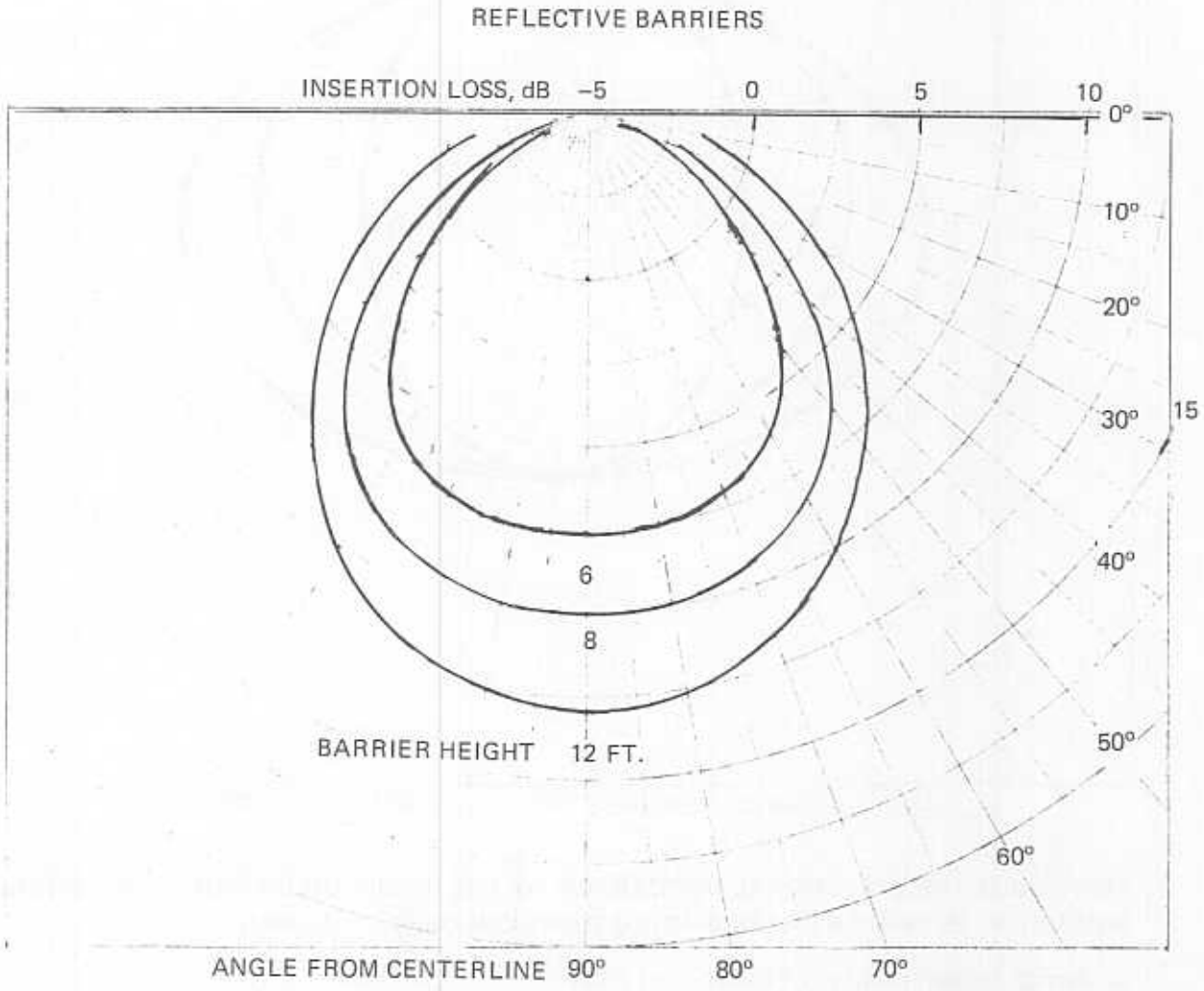

FIGURE 4.24 THE DIRECTIONAL DEPENDENCE OF THE INSERTION LOSS OF REFLECTIVE RETARDER BARRIERS, WITH 11-FOOT-LONG EXTENSIONS, AT 100-FOOT EQUIVALENT DISTANCE

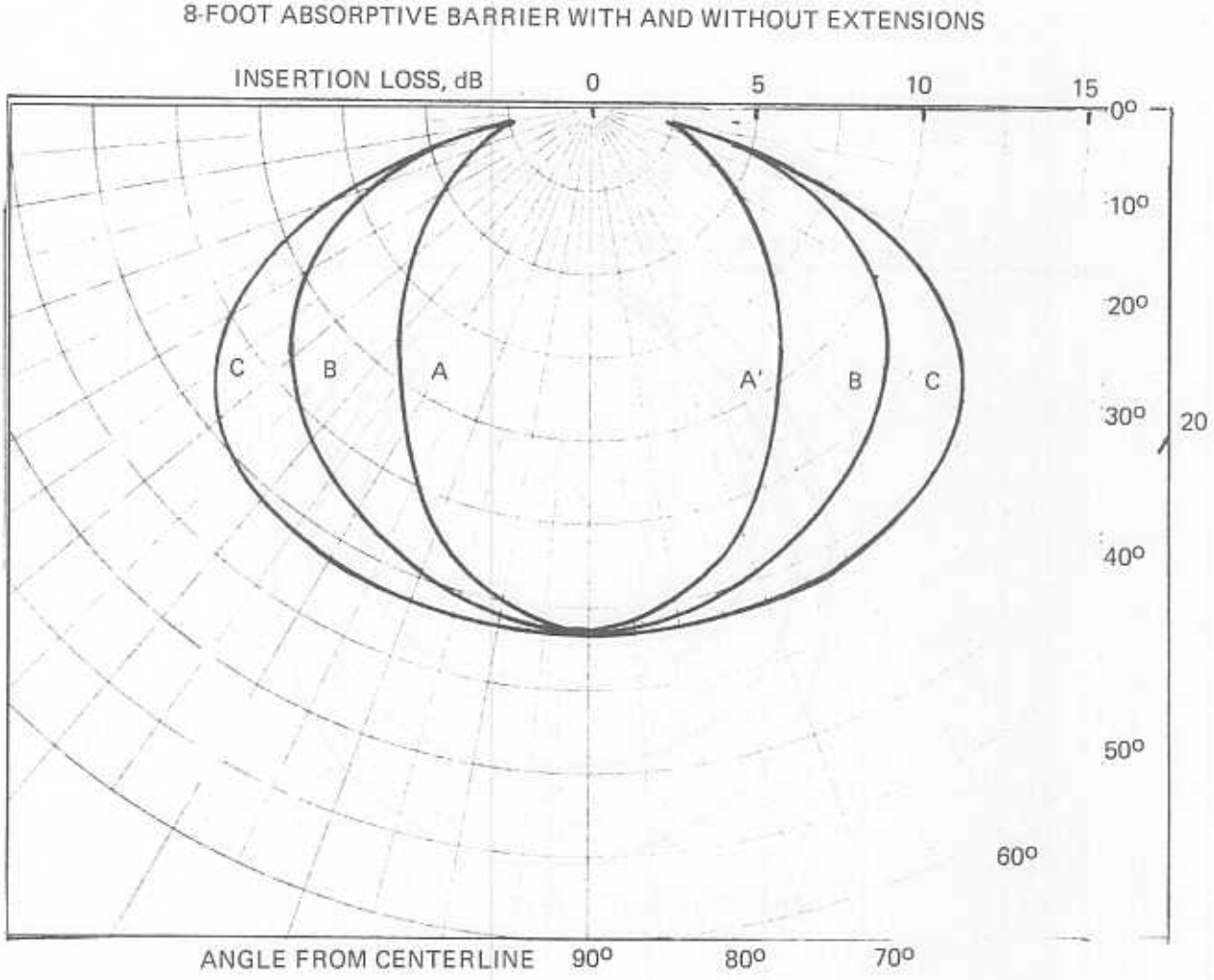

FIGURE 4.25 THE DIRECTIONAL DEPENDENCE OF THE INSERTION LOSS OF AN 8-FOOT-HIGH ABSORPTIVE RETARDER BARRIER AT 100-FOOT EQUIVALENT DISTANCE

A – WITH NO EXTENSIONS, LENGTH 121 FEET
B – WITH 11-FOOT EXTENSIONS, LENGTH 121 + 22 FEET
C – WITH 22-FOOT EXTENSIONS, LENGTH 121 + 44 FEET

12-FOOT ABSORPTIVE BARRIER – EXTENSIONS AND LIP

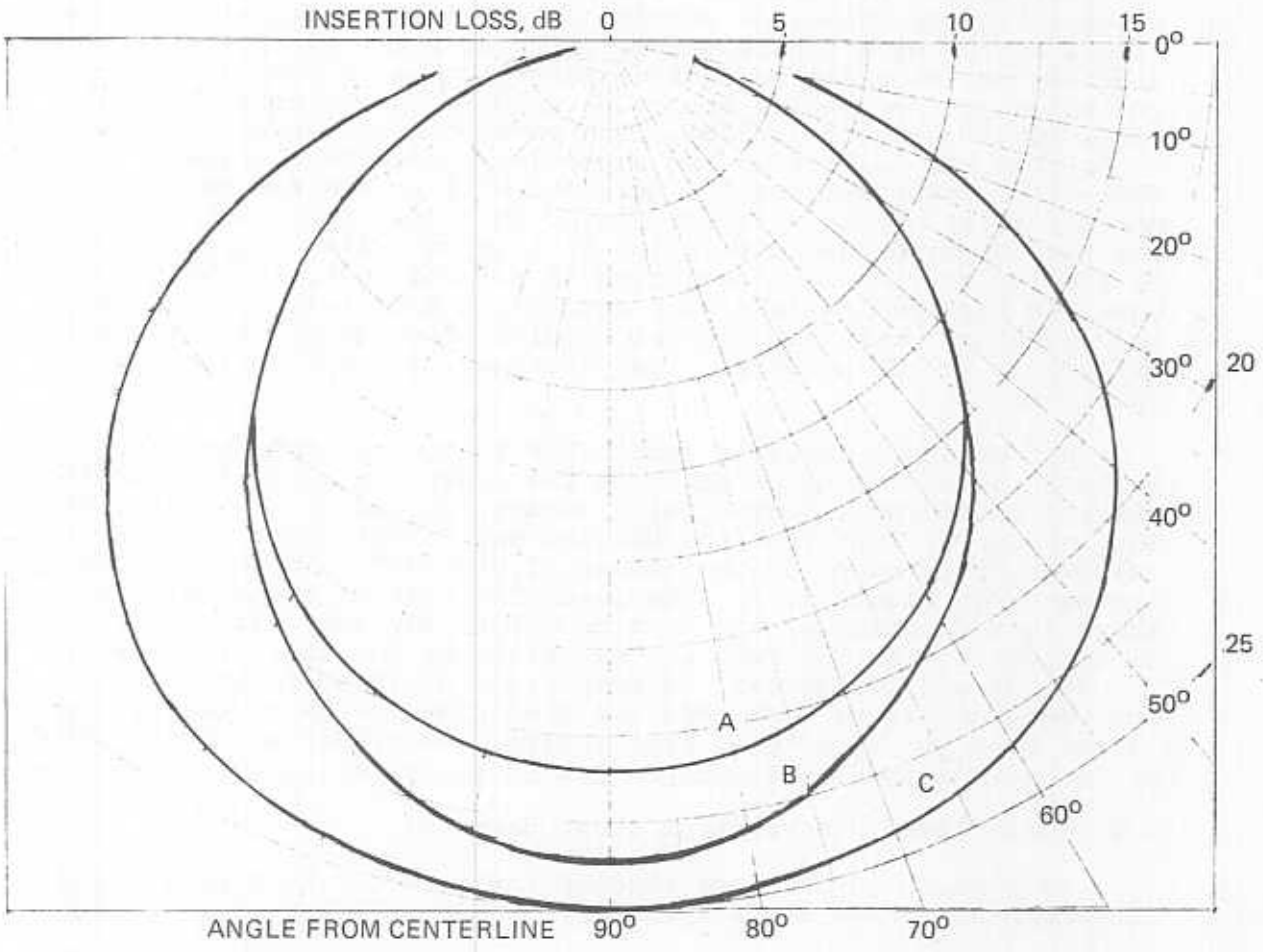

FIGURE 4.26 THE DIRECTIONAL DEPENDENCE OF THE INSERTION LOSS OF A 12-FOOT-HIGH ABSORPTIVE RETARDER BARRIER AT 100-FOOT EQUIVALENT DISTANCE

A – WITH 11-FOOT EXTENSIONS, LENGTH 121 + 22 FEET
B – WITH 11-FOOT EXTENSIONS AND A 1-FOOT LIP
C – WITH 22-FOOT EXTENSIONS AND A 1-FOOT LIP

for the absorptive barriers and Figure 4.24 for the reflective. Figure 4.25 contains the results for the 8-foot-high barrier with and without extensions; and, in Figure 4.26 are shown the results for the 12-foot-high absorptive barrier with extensions and a 1-foot lip.

4.7 Theoretical Considerations - Insertion Loss

Numerous studies of the problem of acoustic shielding by barriers have been described in the literature by many investigators. However, the schemes for predicting the noise shielding characteristics of barriers that have emerged from these studies refer to rather idealized situations, such as the shielding of a single source by a single barrier with no other additional reflecting or absorbing boundaries present. As we have already indicated, these schemes cannot be expected to be directly applicable to the present problem. The basic reason for this appears to be that the noise from the squealing wheels must travel in the duct-like region between the retarder barrier and the railroad car before it can be diffracted over the edge of the barrier. The transmission characteristics of this duct-like region should be similar to the characteristics of a lined duct, in the case when the barrier is lined with absorption material. This model is consistent with the observed results which show a significant difference in the insertion loss of absorptive and reflective barriers.

Although not directly applicable to the retarder barriers, we have included a calculation of the insertion loss of a single barrier shielding a single point source located in the center of the barrier, 4 feet from the barrier and 2 feet above ground. The calculation is based on the scheme of Maekawa*, and the results are shown in Figure 4.27. The insertion loss of the barrier is shown as a function of the barrier height for some different directions to the observer as expressed by the angle coordinates 90, 60, 30 and 10 degrees. A comparison of these results with the measured values shows that the predicted values generally are larger than the measured. Furthermore, the predicted values include no additional attenuation due to absorptivity of the barrier.

4.8 Noise Level Distribution about Barriers

As a railroad car goes through the retarder, a squeal noise is generated, which lasts typically for about 5 seconds. During

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*"Noise Reduction by Screens," Applied Acoustics, Volume 1, Pages 157-173, 1968.

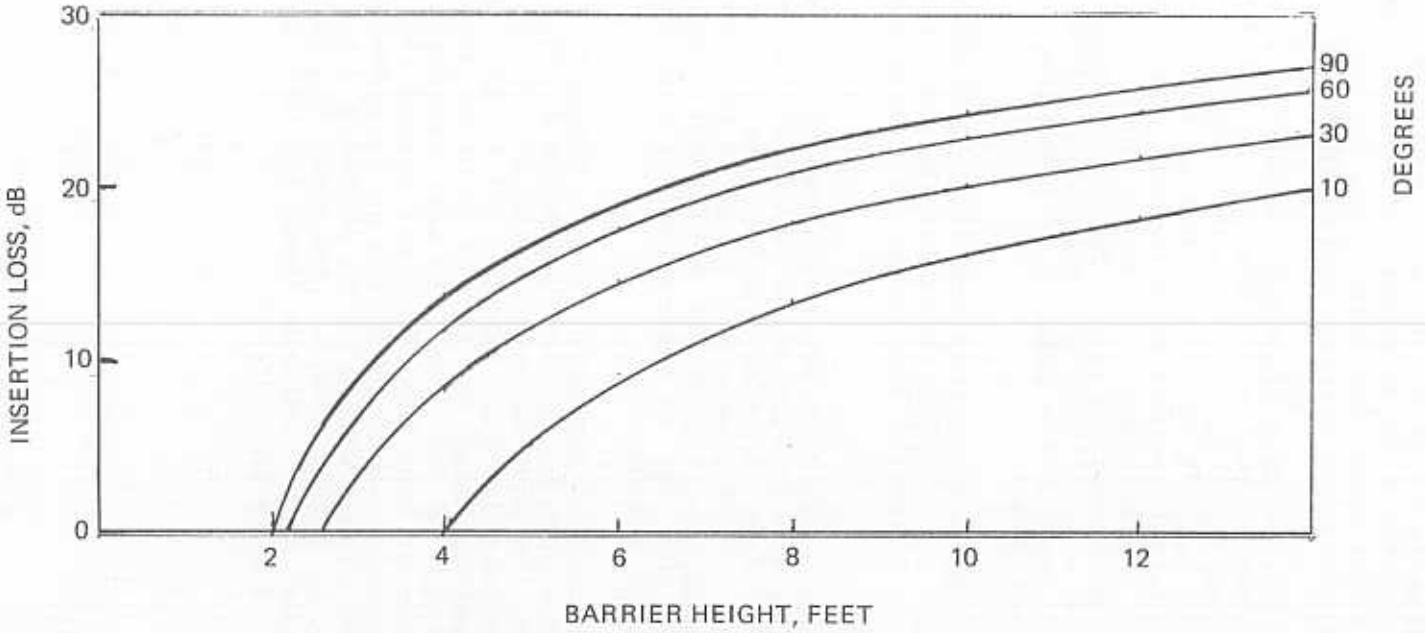


FIGURE 4.27 PREDICTED INSERTION LOSS OF A SINGLE BARRIER SHIELDING A SINGLE POINT SOURCE

SOURCE ELEVATION: 2 FEET — OBSERVER ELEVATION: 5 FEET
SOURCE-BARRIER DISTANCE: 4 FEET — OBSERVER-BARRIER DISTANCE: 100 FEET

THE 90 DEGREE DIRECTION (TO THE OBSERVER) CORRESPONDS TO THAT PERPENDICULAR TO THE BARRIER.

NOTE: ABSORPTIVITY OF THE BARRIER IS NOT A PARAMETER OF THE PREDICTION SCHEME.

this time, the noise level varies and reaches a maximum value usually when the car is close to the center of the retarder. Records of the variation of the noise level with time were obtained during the measurements at Northtown for a large number of events. From these records the maximum noise level was determined and tabulated for various microphone positions and barrier configurations.

As in the analysis of IL, we have selected for analysis only those events in which the source level was a maximum in the vicinity of the center of the retarder; that is, in which the level at microphone location 1 was at least 5 dB larger than at locations 2 and 3. The sound levels analyzed represent a forced condition for these tests and are not representative of normal operation of Group Retarder 3 at the BN Northtown Yard. Absolute levels are not used in Figures 4.28 - 4.36; however, a point of reference is provided in each figure for the purpose of comparing Figures 4.28 - 4.36 with each other.

Average values and standard deviations are given in Figures 4.28 - 4.36 for distribution of relative noise levels about the barriers. In each figure is indicated the number of events considered in the analysis.

These comparative noise level data are organized as follows. In Figure 4.28, we start by showing the noise levels at the monitoring microphone 1 for different barrier configurations, including the case of no barrier. These levels are found to be approximately independent of the barrier height but are slightly higher (1-2 dB) for a hard barrier than for an absorptive. The standard deviation is seen to be about 5-7 dB.

Figure 4.29 shows the comparative noise levels obtained at various microphone locations when no barrier was present. Microphone 7, at an angular position θ=90 degrees, is located a distance of 100 feet from the retarder rail center, and to make the data comparable, we have extrapolated the levels at other angular positions to the same distance of 100 feet. In this extrapolation we made use of the data at the locations 25, 50 and 100 feet in the 90-degree direction, which indicated an inverse-square law dependence of the level with distance (6 dB decrease per doubling of distance). It is interesting to note that the noise field is somewhat directional with a maximum level in the direction perpendicular to the rail (θ=90 degrees).

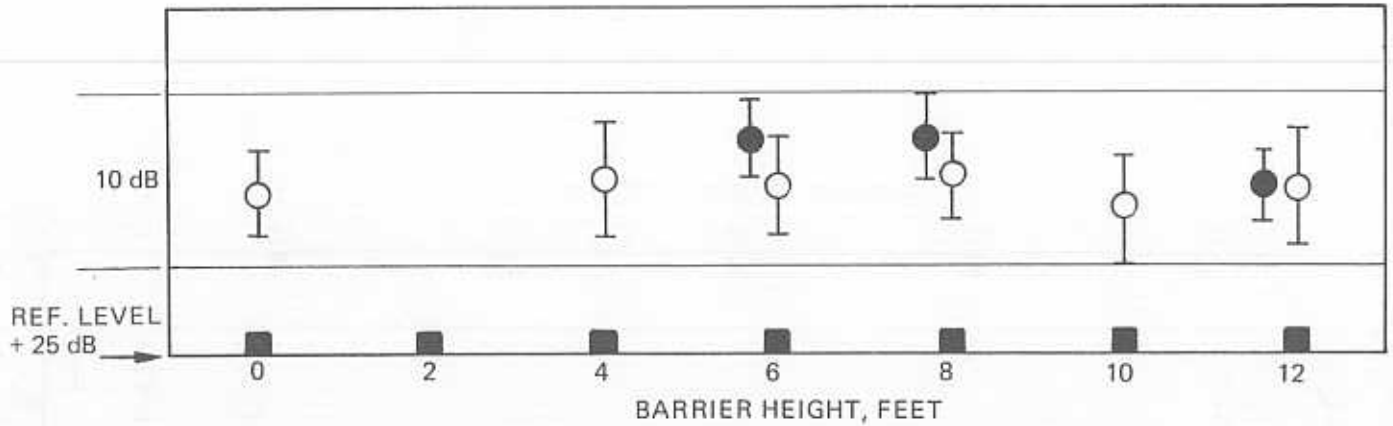


FIGURE 4.28 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF BARRIER HEIGHT AT MICROPHONE 1 (INSIDE BARRIER)

○ – ABSORPTIVE BARRIERS ● – REFLECTIVE BARRIERS

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: SEE FOLLOWING FIGURES.
ERROR BARS REPRESENT ONE STANDARD DEVIATION.

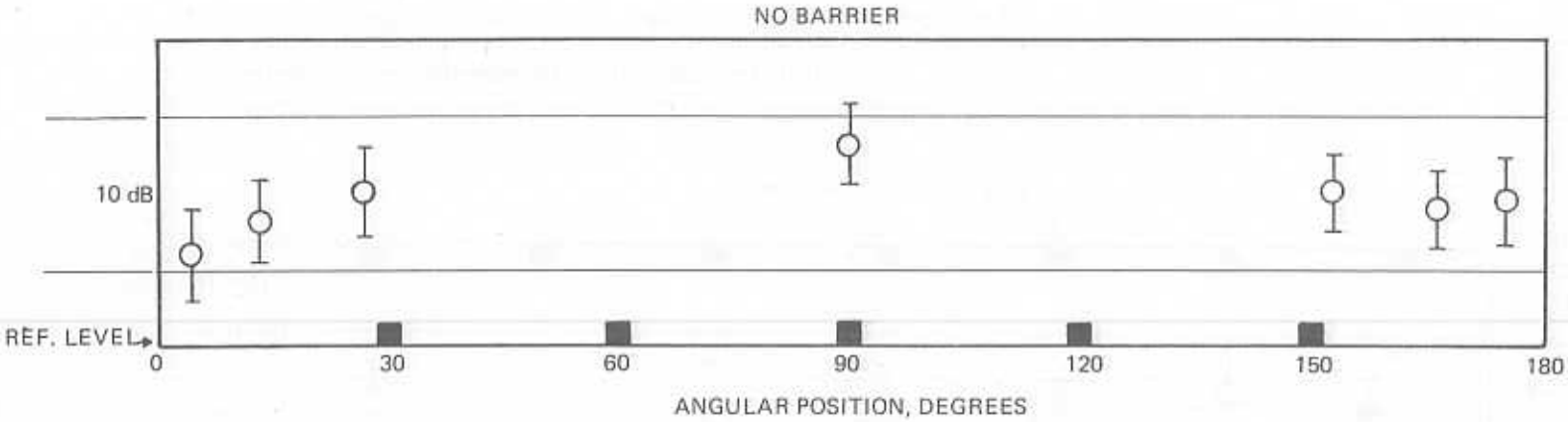


FIGURE 4.29 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION (NO BARRIER)

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: 32
THE ERROR BARS REPRESENT ONE STANDARD DEVIATION.

ANGLE 0 CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

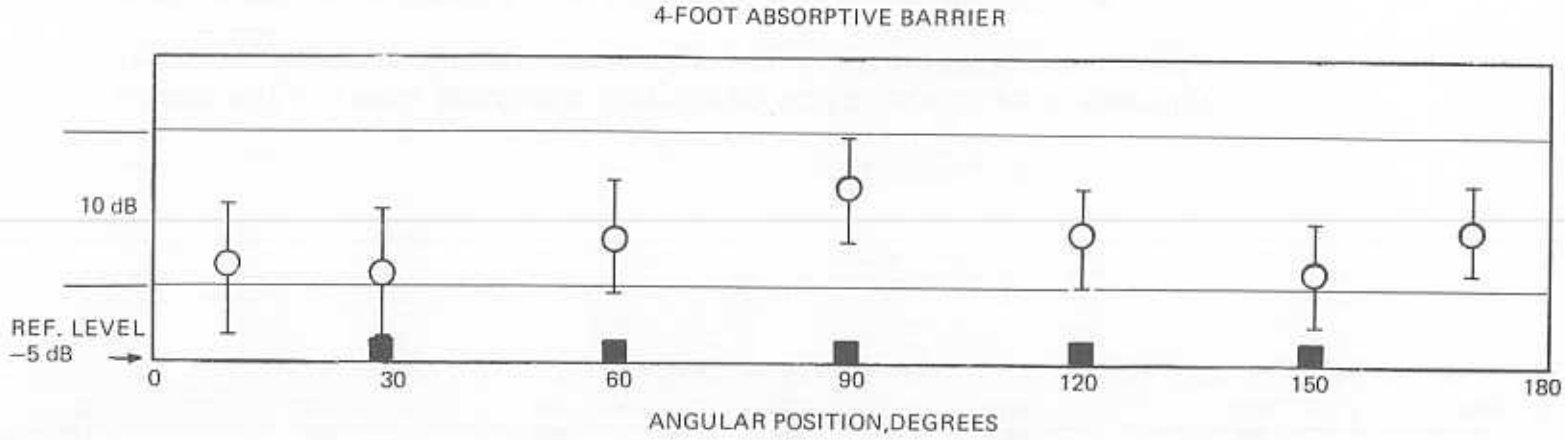


FIGURE 4.30 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 4-FOOT-HIGH ABSORPTIVE BARRIER WITH 11-FOOT EXTENSIONS

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: 31
THE LENGTH OF THE ERROR BARS CORRESPOND TO ONE STANDARD DEVIATION.

ANGLE O CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

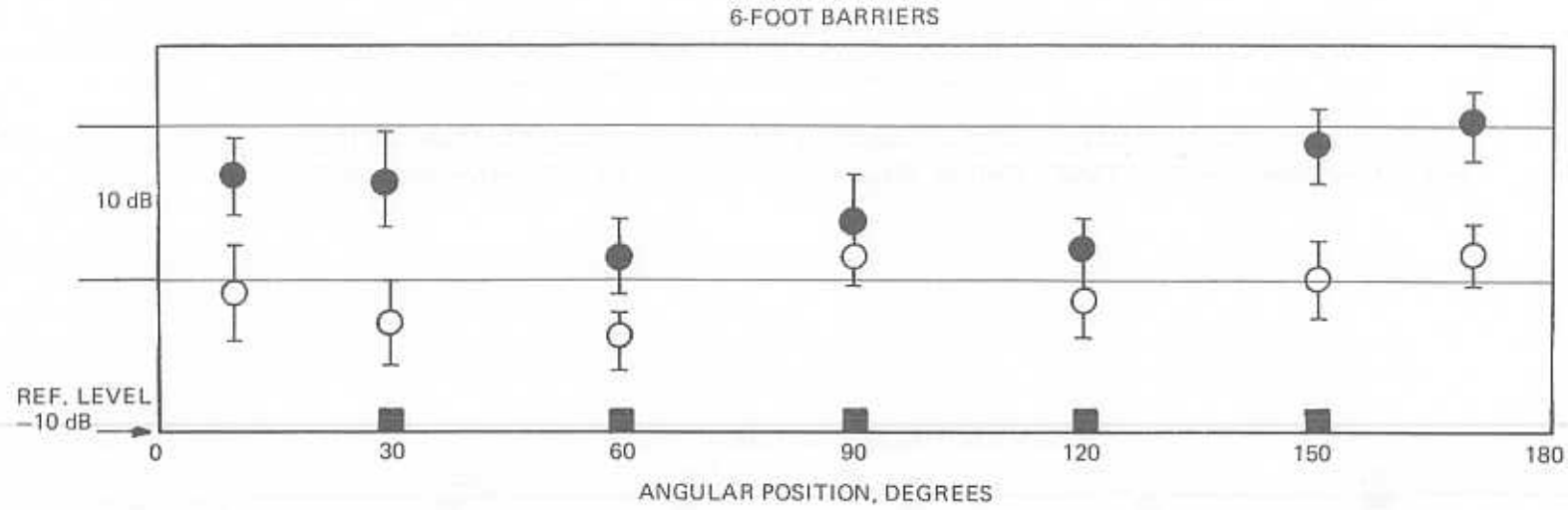


FIGURE 4.31 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 6-FOOT-HIGH BARRIERS WITH 11-FOOT EXTENSIONS

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: O ABSORPTIVE 30, ● REFLECTIVE 39.
THE ERROR BARS REPRESENT ONE STANDARD DEVIATION.

ANGLE O CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

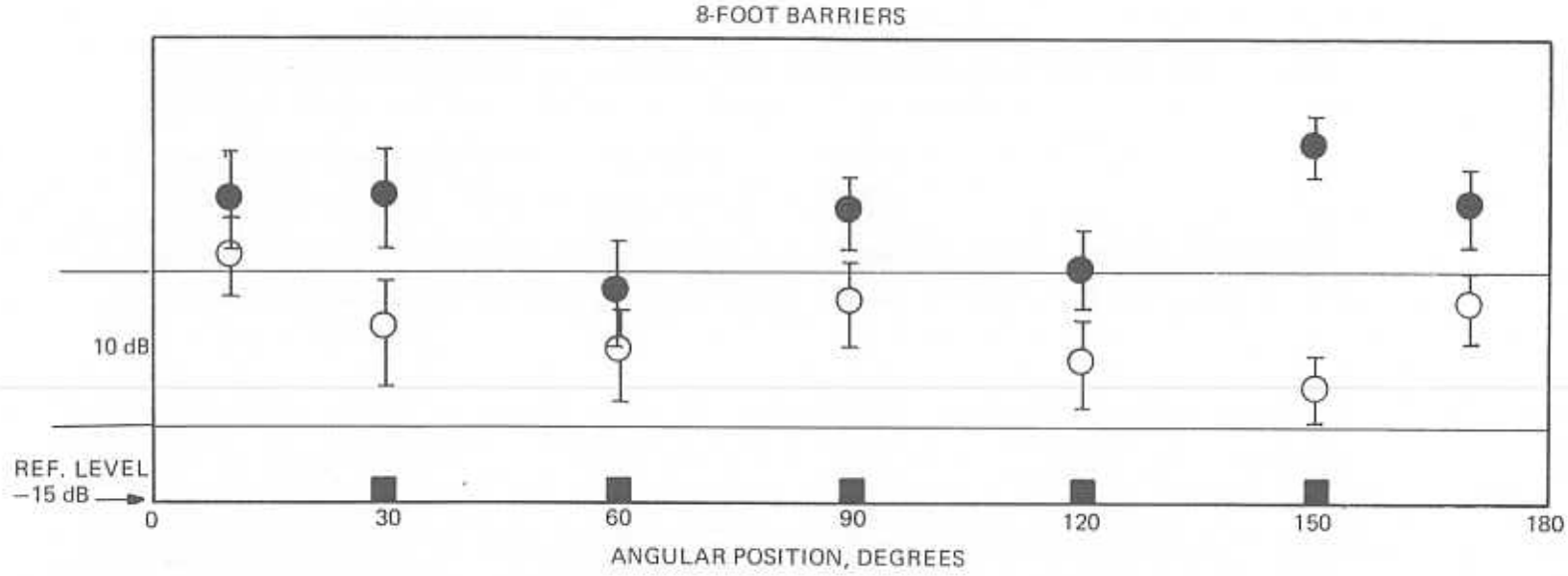


FIGURE 4.32 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 8-FOOT-HIGH BARRIERS WITH 11-FOOT EXTENSIONS

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: O ABSORPTIVE 40, ● REFLECTIVE 35.
THE ERROR BARS REPRESENT ONE STANDARD DEVIATION.

ANGLE O CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

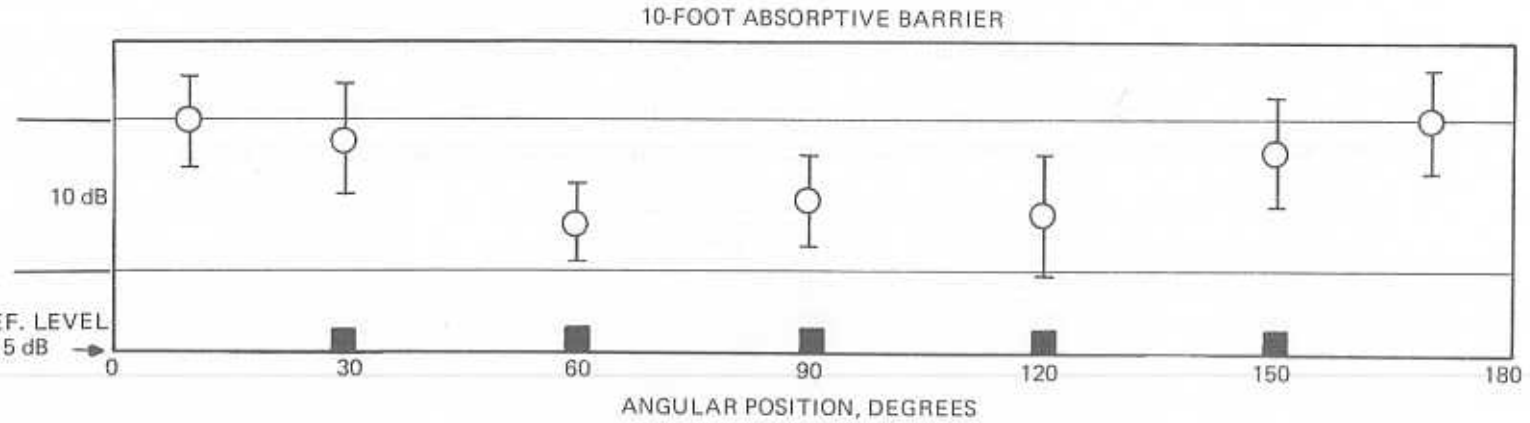


FIGURE 4.33 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 10-FOOT-HIGH ABSORPTIVE BARRIER WITH 11-FOOT EXTENSIONS

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT : 37
THE ERROR BARS REPRESENT ONE STANDARD DEVIATION.

ANGLE 0 CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

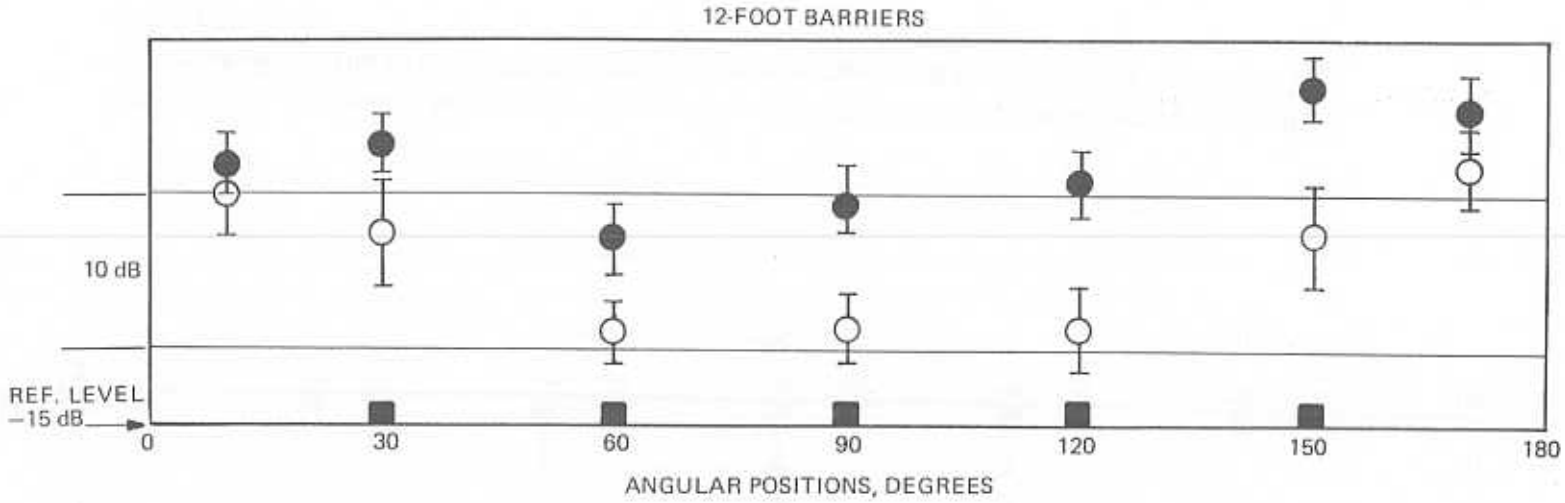


FIGURE 4.34 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 12-FOOT-HIGH BARRIERS WITH 11-FOOT EXTENSIONS

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: O ABSORPTIVE 14, ● REFLECTIVE 23.
THE ERROR BARS REPRESENT ONE STANDARD DEVIATION.

ANGLE O CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

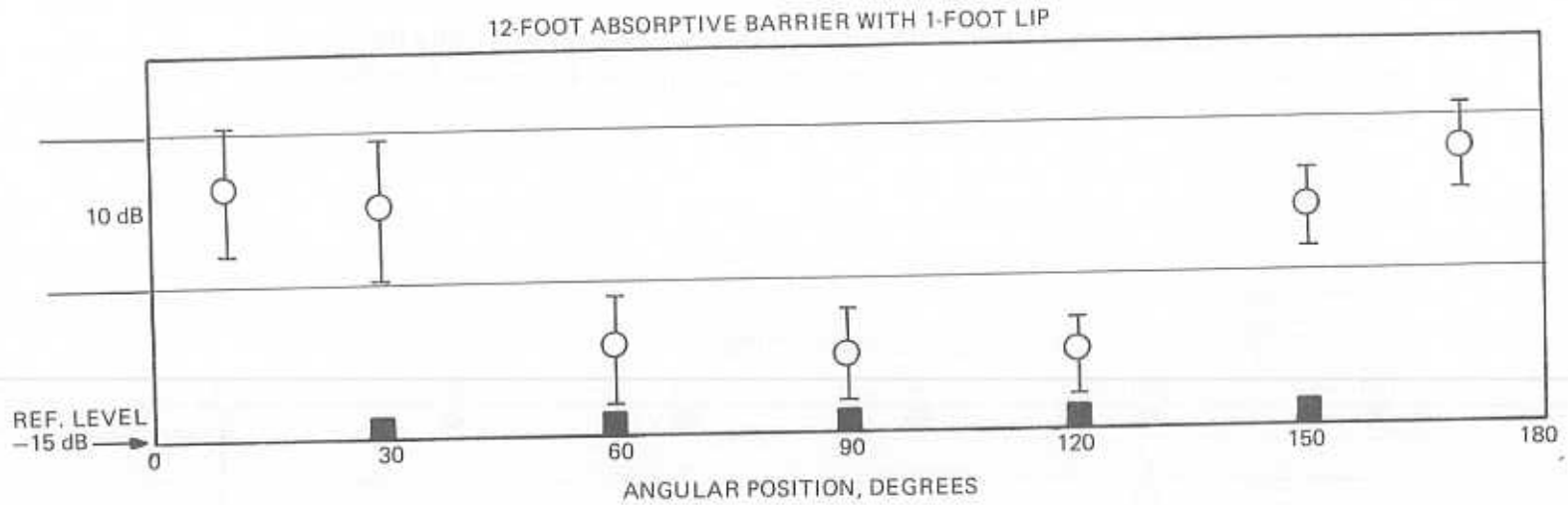


FIGURE 4.35 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 12-FOOT-HIGH ABSORPTIVE BARRIER WITH 11-FOOT EXTENSIONS AND 1-FOOT LIP

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: 31
ERROR BARS REPRESENT ONE STANDARD DEVIATION.

ANGLE 0 CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

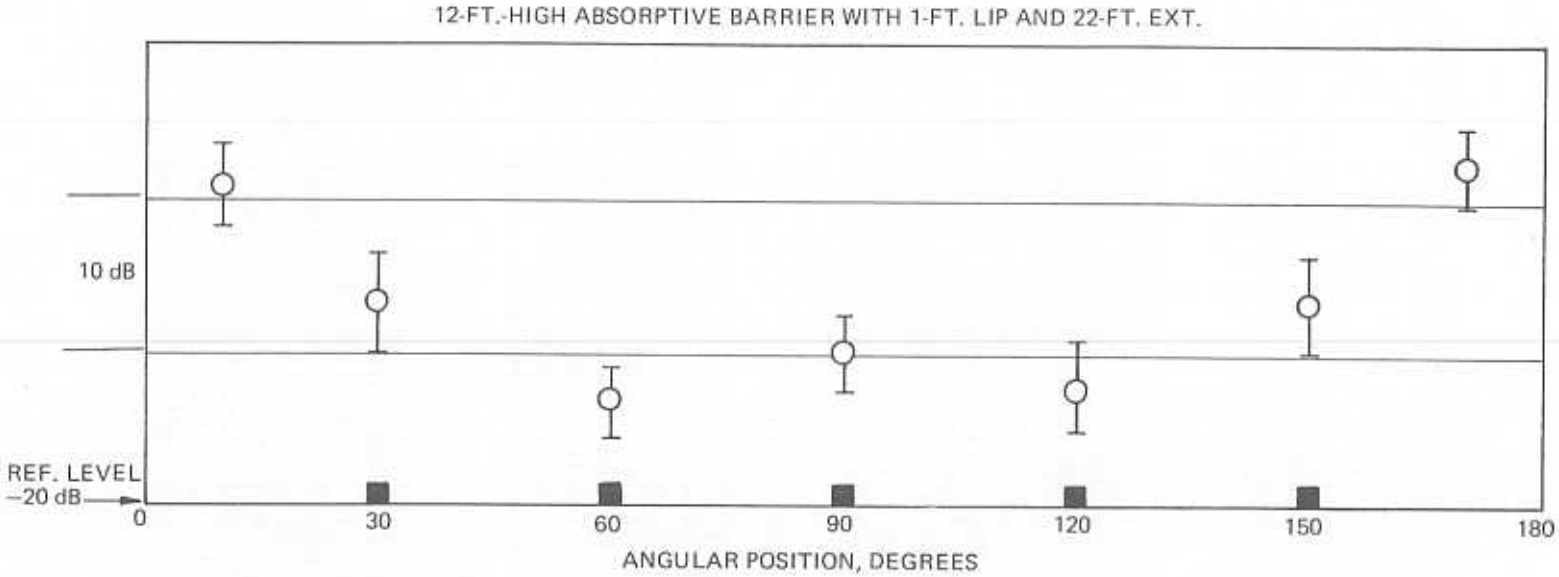


FIGURE 4.36 AVERAGE MEASURED A-WEIGHTED SOUND LEVELS AS A FUNCTION OF THE ANGULAR POSITION WITH 12-FOOT-HIGH ABSORPTIVE BARRIER WITH 22-FOOT EXTENSIONS AND 1-FOOT LIP

ANGLE 0 CORRESPONDS TO ENTRY AND 180 TO EXIT END OF BARRIER.
90-DEGREE DATA MEASURED AT 100 FEET, AND OTHER DATA EXTRAPOLATED TO 100 FEET.

NUMBER OF EVENTS CONSIDERED AT EACH DATA POINT: 38
THE ERROR BARS REPRESENT ONE STANDARD DEVIATION.

In Figures 4.30 - 4.36, we have shown the noise levels around the retarder when barriers were present. To be consistent with the procedure used in the evaluation of the insertion loss, we have again extrapolated (see page 30) the levels at microphones 4, 5, 6 and 8, 10, 11 to a distance of 100 feet from the entrance and exit ends of the retarder, respectively. The angular positions of the microphones are measured with respect to origins at the center of the rail in the entrance and exit planes of the retarder.

The results indicate that the angular variation of the noise level depends on the barrier height and is different for hard and absorptive barriers. For barrier heights above 10 feet, the level distribution has a minimum in the direction perpendicular to the barrier. This means that the angular dependence of the insertion loss is such that it more than compensates for the somewhat larger radiation in the perpendicular direction. Data of this kind are useful in the "optimum" design of barriers. For example, if a certain minimum noise reduction is required in all directions around a retarder, it may be desirable to use a barrier with a larger length-to-height ratio than that used in the tests.

4.9 Comments on Noise Level Fluctuations

From the data presented, it is apparent that the standard deviation of the noise levels is substantially larger than the standard deviation of the insertion loss. The reason is no doubt that the noise levels include the fluctuations of the source as well as of the atmosphere, whereas in the insertion loss data the fluctuations in the source levels are to a great extent eliminated. (The analysis of the insertion loss was based on the difference between levels belonging to the same event.)

Even if the source level fluctuations could be eliminated, the atmospheric fluctuations along the acoustic transmission path would result in fluctuations in the measured insertion loss. Ordinarily, when we deal with a broad band noise, such as jet noise, and consider the insertion loss averaged over a comparatively broad frequency band, the fluctuations caused by the atmosphere are comparatively small. In this particular case, however, the bulk of the noise is concentrated in a rather narrow frequency band and under such conditions the fluctuations can be considerable. The fluctuations are produced to a great extent by the interference of sound "rays" which have travelled along different paths to the microphone. For example, the direct ray

from the top of the barrier to the microphone can interfere with the ray that has been reflected from the ground. If the atmospheric fluctuations in the sound speed along the two paths produce a phase shift between the two rays of 180 degrees, destructive interference and a corresponding fluctuation in the level will occur. The magnitude and frequency of such fluctuations vary with the distance from the barrier. For further details of this problem see "On the Effect of Atmospheric Turbulence on Sound Propagated Over Ground," U. Ingard and G. Maling, J.A.S.A., 35, 1056-1058, 1963.

The temporal fluctuations of the source level itself and the variation of the source level from one event to the next are contained in the standard deviation of the measured noise levels but are to a great extent eliminated from the level difference in "simultaneous" measurements, such as used in the insertion loss analysis. It appears that the source level fluctuations are larger than the fluctuations caused by the atmosphere irregularities. This can be seen by comparing the standard deviations at microphones1 and 7 when no barrier is present. If the fluctuations were dominated by atmospheric effects the fluctuations at 7, which is 100 feet further from the source than 1, would be expected to be considerably larger than at 1. The data indicate no such pronounced difference in the standard deviations at the two locations.

5. COST ESTIMATES

Cost estimates are given in Table 5.1 for the configurations tested.

TABLE 5.1 BARRIER COST ESTIMATES

Barrier Configuration	Panels & Trim	5WF16 Supports	Installation Dollars	Installation Man Hrs.	Total Dollars
1	$ 8,500.	$ 1,400.	$ 3,000.	120	$12,900.
1a	(4)	(4)	(4)	(4)	(4)
2	12,000.	2,100.	5,100.	220	19,200.
3	13,500.	2,400.	6,500.	265	22,400.
3a	(4)	(4)	(4)	(4)	(4)
4	11,500.	1,700.	5,200.	225	18,400.
4a	13,500.	2,700.	6,500.	275	22,700.
5	15,500.	3,100.	6,700.	280	25,300.
6	16,500.	3,200.	7,700.	320	27,400.
7	20,000.	3,900.	8,900.	395	32,800.
7a	(4)	(4)	(4)	(4)	(4)
8	22,500.	3,900.	10,700.	475	37,100.
8a	25,500.	4,200.	11,700.	520	41,400.
9	(4)	(4)	(4)	(4)	(4)

NOTES
(1) Refer to drawings and specifications presented in Appendix A and to Table 3.2 for description of barrier configurations.
(2) Component costs are F.O.B. Industrial Acoustics Company, Inc., 1160 Commerce Ave.,Bronx, New York 10462 - basis June, 1976.
(3) Installation costs are for the Northtown, Minnesota area under normal working conditions and include an IAC supervisor and estimated equipment costs - basis June, 1976.
(4) No estimate - not a practical configuration.
(5) Cost of placing a 5WF16 support post would be approximately $200 per post. This is based on BN estimates for a post set 6 feet into a 14 inch diameter augured hole cased by a spiral paper tube form and anchored by concrete poured into the form to ground level. Buried depth required depends on soil conditions, wind load and frost line.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Assessment of Performance

The absorptive barrier configurations investigated can provide substantial far-field reduction of noise caused by operation of a railroad retarder. Insertion losses measured in this study for the 12-foot-high barrier with lip and with 22-foot extensions were

a. more than 25 dB on the barrier transverse centerline (i.e., perpendicular to the tracks),

b. more than 23 dB in the 60 degree sectors centered on the transverse centerline,

c. more than 13 dB in the 120 degree sectors centered on the transverse centerline.

Corresponding insertion losses for the "normal" 8-foot-high barrier with 11-foot extensions beyond the end of the retarder were

1. more than 20 dB on the transverse centerline,

2. more than 13 dB in the 60 degree sectors,

3. more than 10 dB in the 120 degree sectors.

With open ended barriers, there is the possibility of increasing noise at angles approaching a line parallel to the track. To put it another way, one could possibly achieve negative insertion loss at some locations by funneling the noise out of the open ends of the barrier. The study shows that this did, indeed, happen with reflective barriers. The study also shows that it did not happen with absorptive barriers; in fact, the absorptive barriers provide some reduction of noise even inside the barriers. At points outside the barriers, absorptive barriers were up to 10 dB more effective than reflective barriers.

Referring to Figures 4.25 and 4.26, it is seen that barrier extensions beyond the end of the retarder can be very beneficial in those cases where the area to be protected lies in a direction more than about 20 degrees away from the transverse centerline. The importance of increased barrier height, where the area to be protected is within about 45 degrees of the transverse, is evident from Figure 4.23.

Barrier effectiveness, as determined by this study, is less than would be estimated from available prediction schemes which assume a single point source shielded by a single barrier with no other reflecting (or absorbing) boundaries present. The difference is marked with the reflective barriers studied, insertion loss on the transverse centerline being less than half of what would be predicted. With the absorptive barriers studied, this difference is much less and diminishes as barrier height increases. These results are consistent with analytical considerations if one takes into account the significance of the reflecting boundary introduced by the side of the railroad car. This, in effect, elevates the height of the source. Absorption of acoustical energy partially offsets this effect when an absorptive barrier is used; but this, of course, is not the case with a reflective barrier.

6.2 Effects of Barrier on System Operations

Negative effects inherent in use of the barriers investigated are as follows:

a. Signal personnel are restricted in performing repair or replacement of retarder parts in that access can be gained only by use of doors located in the barrier opposite the retarder mechanism, through the open ends of the barrier, through use of a crane, or by removal of the barrier panels.

b. Derailments in the retarder are more difficult to clean up, and damage to the barriers usually occurs during derailments.

c. Personnel working within the barrier confines cannot be readily seen by the Hump Control Operator. To eliminate the possibility of injury, special precautions must be taken above and beyond those normally required.

Positive effects of barriers, beyond those associated with control of retarder noise propagation to the community, are as follows:

1. Retarder noise is decreased in the area around the retarder. Although this may not be of significant benefit in the Northtown Yard, it could well be in cases where personnel need to work close to an operating retarder, particularly if no other type of retarder noise suppression is in use.

2. Barriers serve to contain the emulsified oil spray used as part of the computerized retarder noise suppression system in use at the Northtown Yard.

3. Barriers provide weather protection, acting as a wind break for personnel working within their confines.

6.3 Recommendations for further Testing under this Contract

Statistical data of high quality have been obtained on all planned configurations necessary for completion of the study required under Contract No. DOT-TSC-1035. Therefore, no further testing of the barriers constructed, under this contract, is recommended.

6.4 Recommendations for Future Studies

It is recommended that consideration be given to analytical, model and field test studies as outlined in the following paragraphs.

6.4.1 Effect of Barrier Absorptive Characteristics

The fact that absorptive barriers can provide significantly better noise reduction than reflective barriers has been well established by the present study. While the difference cannot be calculated by any available prediction scheme, we believe the effect is related to ducting of the sound between the barrier and the side of the railroad cars. We would also expect that, even in the absence of a reflecting wall presented by the source, barrier absorptivity would play a role and this has been recognized in work by Maekawa. A systematic study to extend the theory of noise shielding by barriers would take into account the degree of absorptivity and the duct effect for sources with a range of source geometries and acoustical characteristics such as frequency distribution and directionality of the produced sound field. Such a program would provide valuable data for application to transportation noise problems other than the rather unique problem presented by railroad retarders. Economical implementation would begin with analytical study and laboratory model testing before verification in full-scale field tests.

6.4.2 Field Measurement Techniques

In regard to field measurement of barrier insertion loss, we suggest that the method of cross correlation measurements and coherence functions be explored. It appears that, by means of this

technique, the role of extraneous noise can be substantially reduced. It is also possible that the noise path over the barrier could be at least approximately established which would illuminate the role of barrier length-height ratio in the angular distribution of the radiated sound.

6.4.3 Extrapolation of Noise to Distant Locations

When it comes to extrapolating the noise level data to distant locations the effects of geometrical spreading as well as the attenuation due to various absorption effects, both in the atmosphere and by the ground, must be considered. The absorption effects are frequency dependent and extensive studies of these have been made. It is recommended that these results be reviewed and summarized in convenient form for the use in retarder barrier evaluations. Such a summary should include, for example, the frequency weighted attenuation to provide the A-weighted sound level of the noise as a function of distance.

6.4.4 Effect of Length-Height Increases

The configurations tested show diminishing insertion loss returns as length or height dimensions are increased beyond those of the "normal" BN Northtown Barriers. See Figures 4.23, 4.25 and 4.26.

The configurations tested do not, however, exhaust the possibilities of extending barrier applicability by use of even greater lengths or heights. It would appear that extensions of length more than 22 feet past the retarder section, by providing more insertion loss at angles less than 90 degrees, would make barriers applicable in some cases where the barriers investigated are not. There may also be cases, particularly with locations to be protected significantly higher than the retarder, where the additional insertion loss to be gained with barrier heights of more than 12 feet would be attractive. Note that cars are higher than a 12-foot barrier (Figures 6.1 and 6.2). A field test program, covering greater barrier lengths and heights, is indicated, provided that

a. There are enough sites which could benefit, and

b. There are not more apparently cost-effective, or more operationally practical, means of achieving the required results.

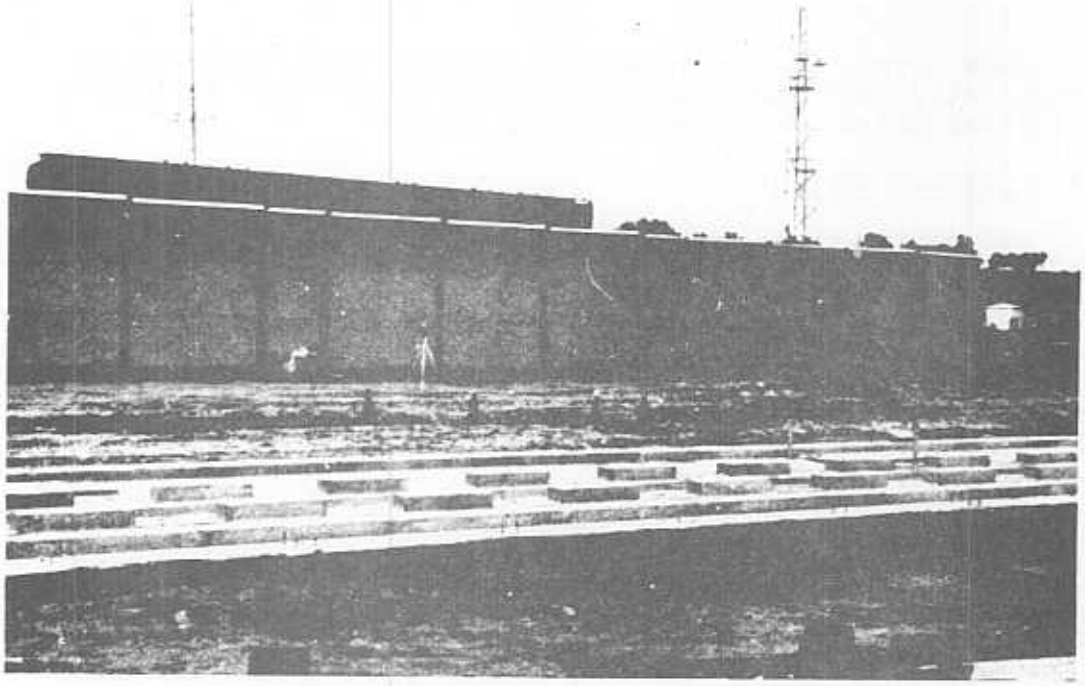


FIGURE 6.1 12-FOOT BARRIER – VIEW EASTERLY FROM MICROPHONE NO. 7

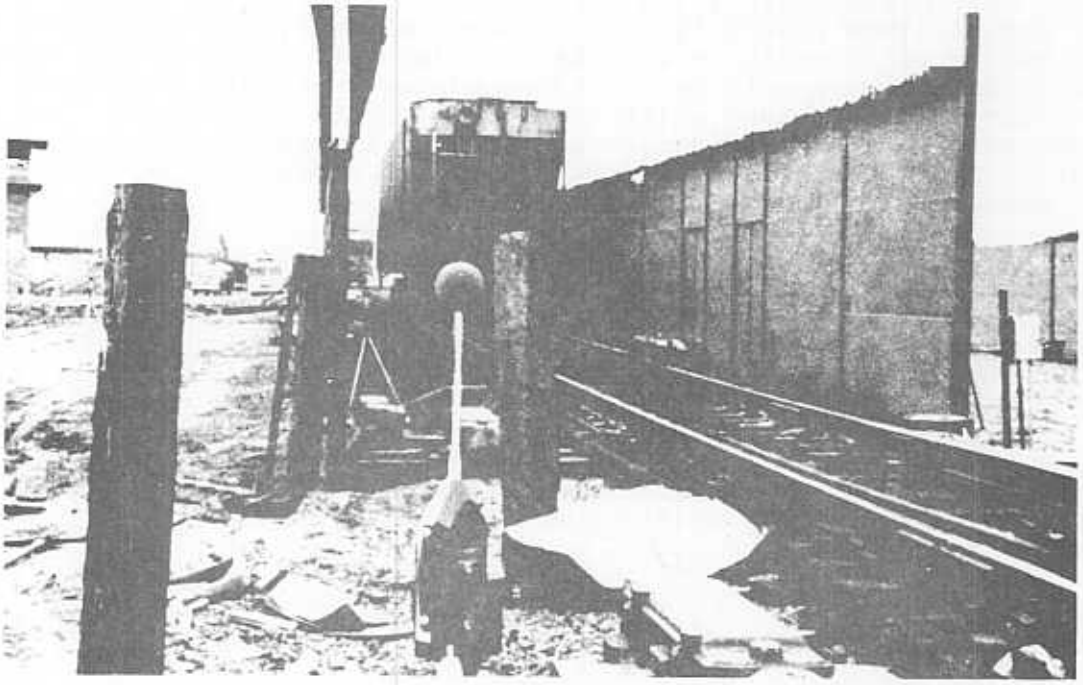


FIGURE 6.2 12-FOOT BARRIER WITH 1-FOOT LIP – VIEW NORTHERLY FROM MICROPHONE NO. 11

Such tests, if they appear to be warranted, might be most economically programmed as a tentative second phase to follow an initial phase of laboratory model testing.

6.4.5 Optimum Barrier

Definition of an "optimum barrier" must consider cost and operational factors as well as level of insertion loss adequate to the application. If the barrier configurations investigated in this program cover the range of insertion loss requirements for railroad retarders, an optimum configuration for a particular site can be chosen from the data presented in this report. If the range has not been covered, a follow-on program, covering one or more of the above recommendations, may be indicated.

From a purely acoustical viewpoint, the best barrier performance achievable would be independent of angle to the observer and of a magnitude consistent with the high transmission loss inherent in construction of the acoustical panels used. Length and height of such a barrier would be impractical from structural and cost viewpoints. A more practical approach to an acoustically optimum barrier would be a roofed (tunnel) barrier with extensions or other means to control noise radiated from the ends. A tunnel barrier, in a railroad retarder application, would introduce problems of maintenance, work required in the event of a derailment or the need to replace a section of track, and safety (Hump Foreman's view of the retarder). It would be worthwhile to investigate a tunnel barrier only in the event that acoustical requirements beyond those achieved in this investigation are of a magnitude which apparently cannot be satisfied by moderate height-length increases discussed in paragraph 6.4.4 above, or some other more cost-effective or operationally practical means.

It is anticipated that experience with the operational retarder barriers at the BN Northtown Yard will provide valuable information regarding improvement of design details and materials of construction for improved cost of barrier installation and maintenance.

We suggest that consideration be given to defining the practical optimum railroad retarder barrier based on experience with the barrier used for investigation and a survey of acoustical requirements for other existing and planned sites.

APPENDIX A: ENGINEERING PLANS

The facility used for this study was an 8-foot-high acoustically absorptive barrier designed, manufactured and installed by IAC Inc. for Burlington Northern's Northtown freight classification yard. Barrier components and design are applications of standard products and methods of the manufacturer.

A special reinforced concrete foundation was designed by Burlington Northern to support the retarders, to provide a catch basin for recycling the emulsion spray, and to support the barriers. It is shown in Figure A.1. The method devised by BN for setting posts to retain extension panels (resting on grade) is shown in Figure A.2.

A plan view of Group Retarder No. 3 Barrier, which was used for this study, is shown in Figure A.3. Some barrier construction details are shown in Figure A.4.

Acoustical panels used in this application are IAC "Noishield" with a 1.25-mil polyethylene film envelope protecting the absorptive fill from moisture and weather conditions. Standard "Noishield" materials and design are indicated in attached sheets MDS 1110.0 and MDS 1030.0 from IAC Bulletin 6.0502.2. These materials are all steel except for the fill which is a mineral wool material with a UL fire hazard classification per ASTM specification E-84 as follows:

Flame Spread	- 15
Smoke Developed	- 0
Fuel Contributed	- 0

The polyethylene film is one of a number of impervious films which can be effectively applied by the manufacturer for applications where moisture soaking of the fill would otherwise occur or where loss of particles of fill materials must be minimized. Flammability and toxicity of the polyethylene are consistent with that found in a commercial grade of polyethylene film.

Absorption coefficients of the various absorptive and reflective barrier panel facings used in this study are given in Table A.1.

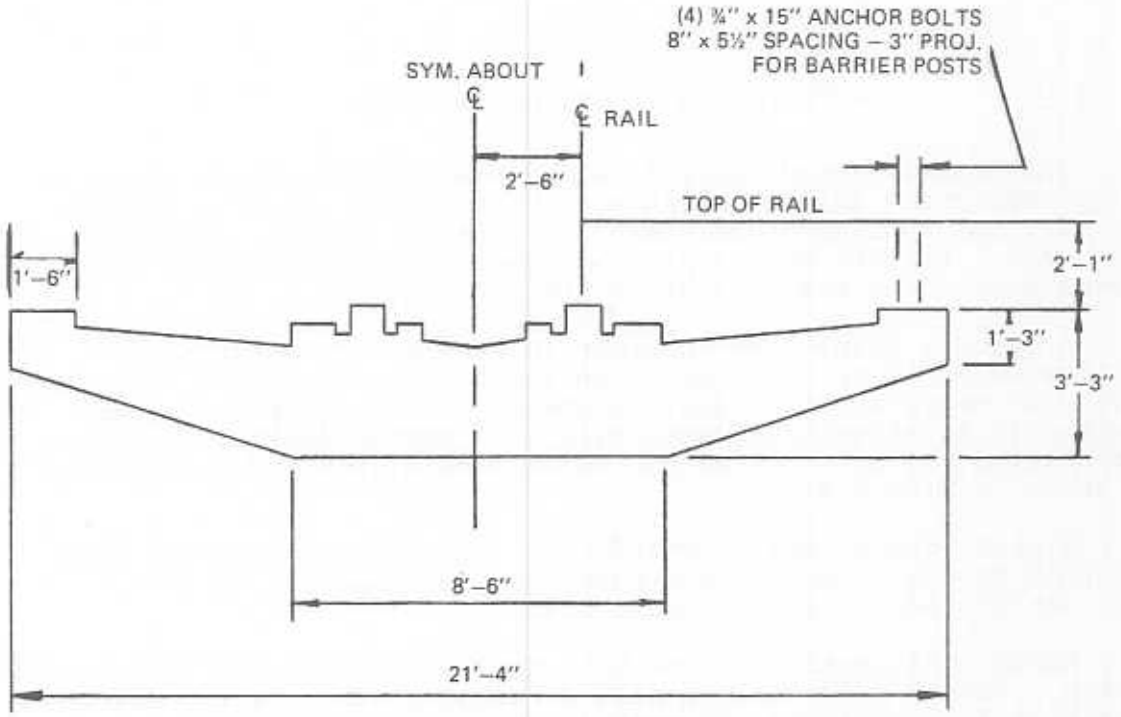


FIGURE A.1 RETARDER/BARRIER FOUNDATION

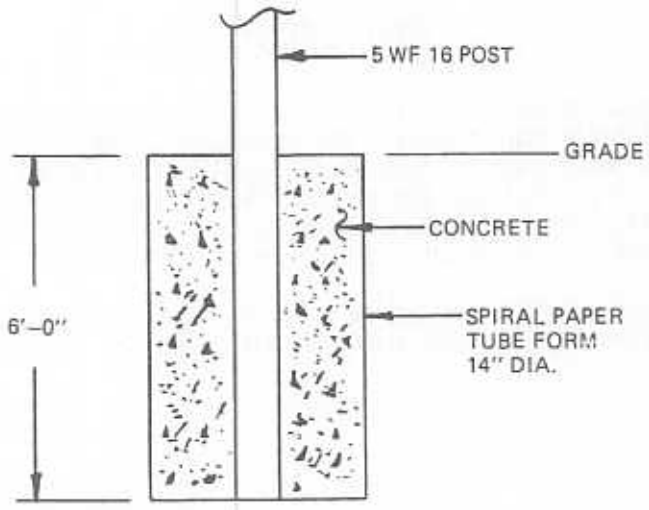


FIGURE A.2 BARRIER EXTENSION POST SETTING DETAIL

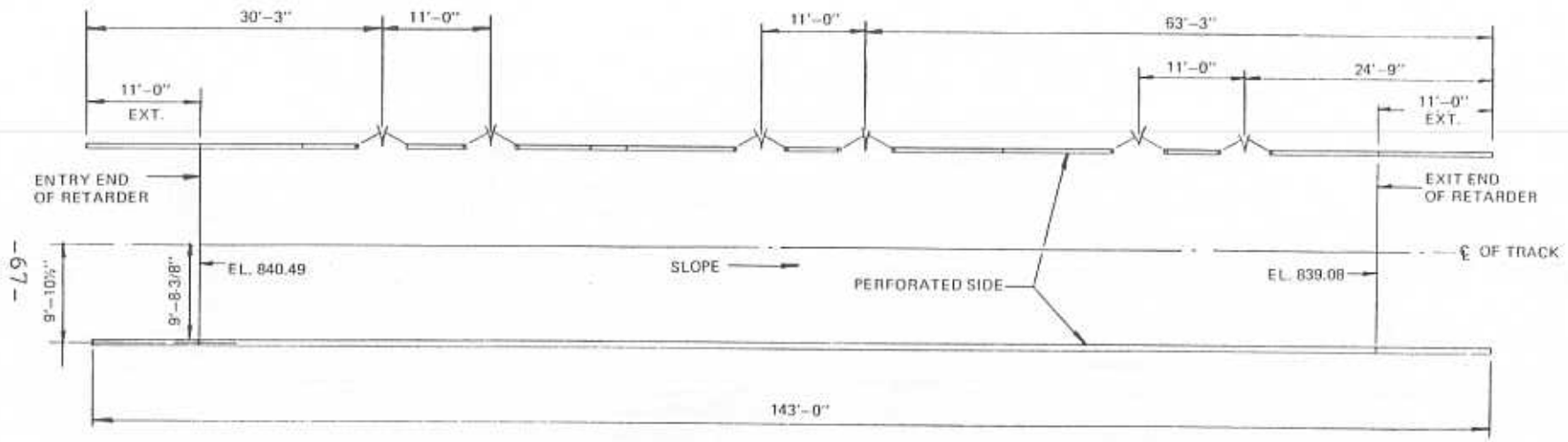
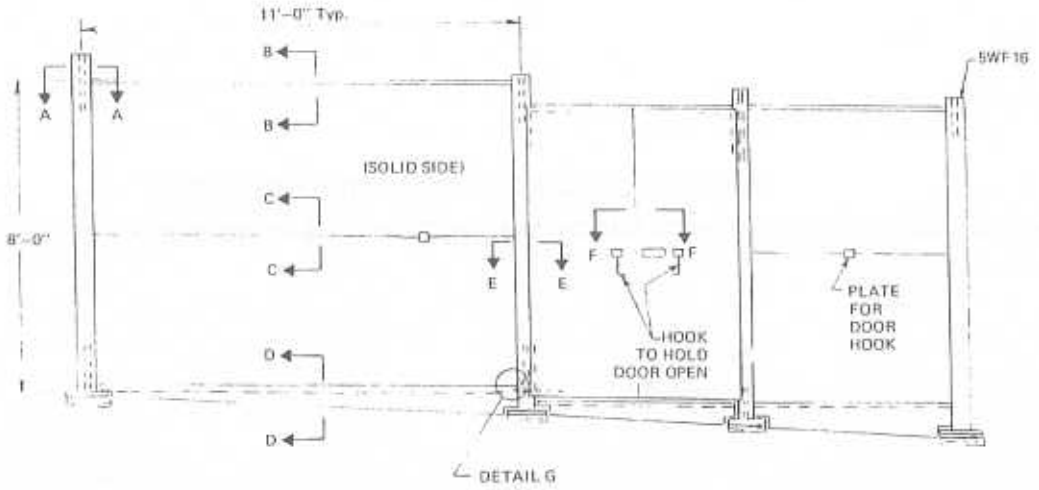
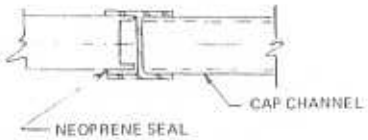
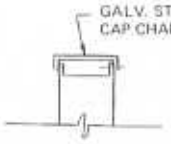


FIGURE A.3 PLAN VIEW OF ACOUSTICAL BARRIER SYSTEM FOR BURLINGTON NORTHERN GROUP RETARDER NO. 3 NORTHTOWN YARD

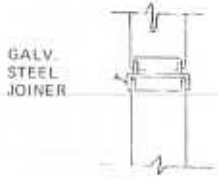




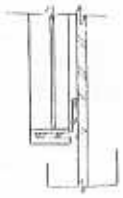
SECTION A–A



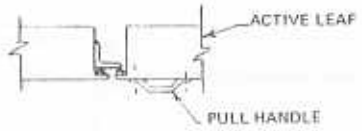
SECTION B–B



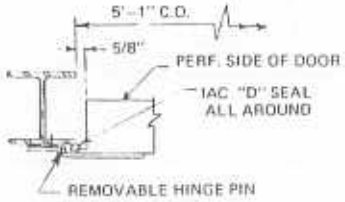
SECTION C–C



DETAIL G



SECTION F–F



SECTION E–E

SECTION D–D

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FIGURE A.4 ACOUSTICAL BARRIER CONSTRUCTION DETAILS FOR BURLINGTON NORTHERN RETARDERS – NORTHTOWN YARD

TABLE A.1 ABSORPTION COEFFICIENTS OF FACINGS USED IN RETARDER BARRIER STUDY

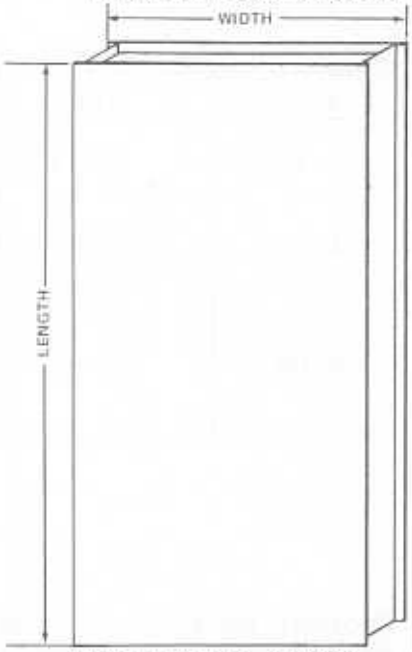
Test Sample	Frequency, Hertz 1000	2000	4000
Normal Panel	0.72	0.72	0.63
Panel covered with 2" Fiberglas	1.13	1.14	1.07
Panel covered with 1/8" thick Tempered Masonite	0.07	0.05	0.05

NOTE:

Absorption coefficients for the "normal panel" are less than those for a "Regular Noishield Panel" (see page 70) because of the use of an impervious film, in this case 1.25-mil polyethylene, for protection of the absorptive fill material. IAC has alternative film-protected designs which will provide absorption coefficients of 0.9 to 0.97 at the frequencies tabulated above.

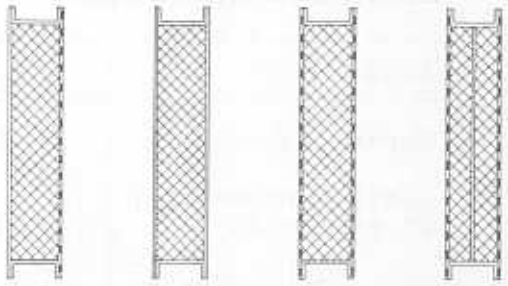
MODULINE®
STANDARD PANELS

TYPICAL PANEL CONFIGURATION



PANEL THICKNESS – 4 INCHES

CROSS SECTIONS OF 4 STANDARD CONSTRUCTIONS OF MODULINE PANELS



All constructions available in *Noishield*® design. **Regular** and **Hard** panels also available in *Noise-Lock*® design.

APPLICATION AND CONSTRUCTION DATA

REGULAR–Solid surface is 16 gauge cold rolled steel. Perforated surface is 22 gauge galvanized steel. Design weight: *Noishield*, 8 lb/sq ft, *Noise-Lock*, 10.5 lb/sq ft; "U" factor: 0.07.
USE: Partitions, offices, cubicles, rooms, enclosures, sound barriers and acoustic/thermal plenums.

HARD–Both surfaces are solid 16 gauge cold rolled steel. Design weight: *Noishield* 9.5 lb/sq ft; *Noise-Lock* 14.5 lb/sq ft; "U" factor: 0.07.
USE: Partitions, special purpose rooms, enclosures, sound barriers and thermal plenums; reverberant rooms (Special *Noise-Lock only*).

SPLITTER–Both surfaces are 22 gauge perforated galvanized steel. Design weight: 6.5 lb/sq ft; "U" factor: 0.06.
USE: Partitions, divider walls, baffles and silencers. Wherever two highly sound absorbent surfaces are required. When high transmission loss is also required, use **Septum** panels.

SEPTUM–Both surfaces are 22 gauge perforated galvanized steel, with internal solid septum sheet. Design weight: 9 lb/sq ft; "U" factor: 0.07; NRC: 0.85.
USE: Same as for **Splitter** panels and acoustic/thermal plenums.

DIMENSIONS – STANDARD PANELS

W x L in.	W x L in.	W x L in.
16 x 60	36 x 60	48 x 60
16 x 72	36 x 72	48 x 72
16 x 78	36 x 78	48 x 78
16 x 84	36 x 84	48 x 84
16 x 96	36 x 96	48 x 96
16 x 120	36 x 120	48 x 120
16 x 144	36 x 144	48 x 144
–	36 x 168*	48 x 168*

*These panels are furnished in full widths, do not deduct for clearances. Intermediate sizes of panels are available, ranging from 6 in. to 144 in. in either dimension. These are used as fillers with standard panels, and to complete the structure under special conditions. Length can also vary from 144 in. to 168 in. providing width remains a full 36 in. or 48 in. width. Refer to Moduline Design Guidelines Data Sheet MDS 1040, for further information. Maximum panel size 48 in. W x 168 in. L.

NOTES

All dimensions are nominal • Acoustic fill is inert, mildew-resistant, vermin-proof • Materials used are durable, non-combustible • Welded and riveted internally reinforced construction • Perforated material has 3/32 in. diameter holes on 3/16 in. staggered centers • Standard finish: One coat grey prime paint • Galvanized available at extra cost - 18 gauge solid, 22 gauge perforated

TRANSMISSION LOSS, dB

OCTAVE BAND CENTER FREQUENCIES, Hz	63	125	250	500	1000	2000	4000	8000
Noishield	26	23	30	42	51	59	58	>58
Noise-Lock	30	28	34	40	48	56	62	>62

SOUND ABSORPTION*

OCTAVE BAND CENTER FREQUENCIES, Hz	125	250	500	1000	2000	4000	8000	NRC
Absorption Coefficients	0.89	1.20	1.16	1.09	1.01	1.03	0.93	(1.10) 0.95

*Data applies only to **Regular** *Noishield* panels.

SEE MDS 1120, FOR SUPER NOISE-LOCK PANELS

MODULINE® SPECIFICATIONS

GENERAL INTRODUCTION

This specification describes the physical and functional requirements for an acoustic structure to be constructed of IAC *Moduline*™ panels and components, as manufactured by Industrial Acoustics Company, Inc., 1160 Commerce Avenue, Bronx, New York 10462.

MATERIALS AND CONSTRUCTION

1. Perforated panel sheets shall be 22 gauge galvanized steel with 3/32 in. diameter openings spaced on 3/16 in. staggered centers.
2. Solid panel sheets shall be 16 gauge cold rolled steel.
3. Sound retarding and absorbing fills shall be incombustible, inert mildew-resistant and vermin-proof.
4. Internal panel reinforcement shall be a minimum of 18 gauge cold rolled steel and spaced so that span does not exceed 2 ft-0 in.
5. Perimeter and internal reinforcement and panel face and back sheets shall be welded and riveted to form a rugged metal-sheathed acoustical panel.
6. Spot welds shall be not more than 2 in. apart.
7. Prior to attaching the face sheet the panel shall be damped and filled with sound retardant and absorbing elements. The fill shall be slightly larger and thicker than the inside dimensions of the panel. No voids will be tolerated.
8. The face sheet shall be welded and riveted to the panel assembly to acoustically compress and hold in place the fill materials. Panel assembly shall hold the fill materials in place under severe conditions of vibration encountered in shipping, installation and in the operation of completed structure.

PANEL TYPES

Panels of the construction specified shall be furnished as shown on the drawings and panel schedule.

1. IAC *Noise-Lock*™ Panel — For critical applications and low frequency attenuation. This heavy duty panel type shall have special fill consisting of visco-elastic damping compound, high density attenuator and sound absorbing fill assembled in multiple layer sandwich construction.
2. IAC *Noishield*™ Panel — For all but the most critical of applications and when high sound absorption is a main requirement. This general purpose panel shall contain a semi anechoic absorbing and damping element.

PANEL CONSTRUCTIONS

1. **REGULAR** — 16 gauge solid back sheet and 22 gauge perforated face sheet. Design weight: *Noise Lock* — 10.5 lb per sq ft; *Noishield* — 8.0 lb per sq ft.
2. **HARD** — 16 gauge solid back and face sheets. Design weight: *Noise Lock* — 14.5 lb per sq ft; *Noishield* — 9.5 lb per sq ft.
3. **SEPTUM** — 22 gauge perforated back and face sheets with 16 gauge solid center septum. Design weight: *Noishield* — 9.0 lb per sq ft.
4. **SPLITTER** — 22 gauge perforated back and face sheets. Design weight: *Noishield* — 6.5 lb per sq ft.

DOOR PANELS

SINGLE LEAF DOORS

1. Materials

a. Door leaf shall be 2-1/2 in. thick, fabricated from 16 gauge steel and filled with sound absorbing and damping elements.

b. Frame shall be fabricated from 16 gauge steel.

c. Assembly and adjustment of single leaf door, frame, acoustic seals and hinges shall take place at factory and entire unit shipped to job ready to install and operate.

d. Acoustic Seals — Side and head of door and frame shall receive two (2) sets of self-aligning magnetic-compression seals. Door to be held in closed position by magnetic force of perimeter seals. Acoustic labyrinth shall be created when door is in closed position. Bottom of door leaf shall contain continuous gravity-activated seal which shall compress against floor as door is closed. Raised sills and threshold drop seals will not be permitted.

e. Hardware

1. *Hinges*—two (2) IAC cam-lift butt-type hinges finished in US 26-D satin chrome shall be supplied with each door leaf.

2. *Latches* shall not be required to hold the door closed or to achieve acoustic seal.

3. *Pull handles*, inside and outside, shall be supplied and installed at the factory.

DOUBLE LEAF DOORS

1. Door and frame construction shall be the same as for the single leaf doors.
2. Double leaf door assemblies to be shipped with door leaves removed from the door frames for ease of handling.
3. Inactive leaf of the double leaf door shall be held at the top by chain bolt and at the bottom by cane-bolt.
4. Double leaf door assemblies to be shipped in two or more pieces as required by job conditions and motor carrier limitations.

WINDOW PANELS

Windows shall be furnished in panels of the type and construction specified and shown on the drawings and the panel schedule.

1. Windows shall consist of two layers of 1/4 in. safety glass separated by an air space and sealed in acoustically tight rubber seals.
2. Air space shall contain a desiccant material to prevent misting.

FLOOR PANELS AND VIBRATION ISOLATORS

Floor panels shall be furnished in accordance with the drawings and panel schedule.

1. Floor panels, damped and filled with sound retarding and absorbing fill, shall consist of 11 gauge hot rolled steel wearing surface, 16 gauge cold rolled steel back sheet, structurally reinforced and welded to form rugged assembly. Design weight: 20 lb per sq ft.
2. Floor panel assembly shall rest on properly loaded vibration isolator rails providing a natural frequency of less than 7 cps.

APPENDIX B: DATA ACQUISITION AND REDUCTION

B.1 Introduction

Through the cooperative efforts of the Department of Transportation Systems Center (TSC), the Burlington Northern Railroad (BN) and Industrial Acoustics Company (IAC), a noise measurement program was conducted by TSC at the BN Northtown Freight Yard in Fridley, during the period May 29, 1975 to June 27, 1975.

Measurements were made in and around Group Retarder No. 3 to assess the performance of a variable geometry acoustic barrier built around the retarder. Fourteen barrier configurations were tested including the original barrier designed and constructed to BN/IAC specifications and the no barrier situation.

For this program the TSC Mobile Noise Laboratory, a fully equipped noise measurement and analysis laboratory, was used on site for on-line data reduction and analysis. This provided the opportunity to modify measurement techniques or repeat measurements as required. The laboratory was positioned approximately midway between the master retarder and Group Retarder No. 3.

B.2 Measurement System Deployment

Fifteen microphone systems were deployed as shown in Figure 3.1. Table 3.1 lists the microphone height relative to the ground and to the top of the near rail at the center of Retarder No. 3.

Figure B.1 depicts the noise data collection system deployed and identifies the instrumentation used and their interconnections. Random incidence microphones were used on all systems.

Records of car speed, car identification and weather data were obtained and correlated with acoustical data as noted in Section 3 of this report.

B.3 On-Line Analysis and Recording System

Figure B.2 depicts the On-Line Analysis and Recording System used in the TSC Mobile Noise Laboratory. On-line analysis was accomplished using the General Radio (GR) 1921 Real Time Analysis System made up of a GR 1925 Multifilter and GR 1926 Multichannel RMS Detector.

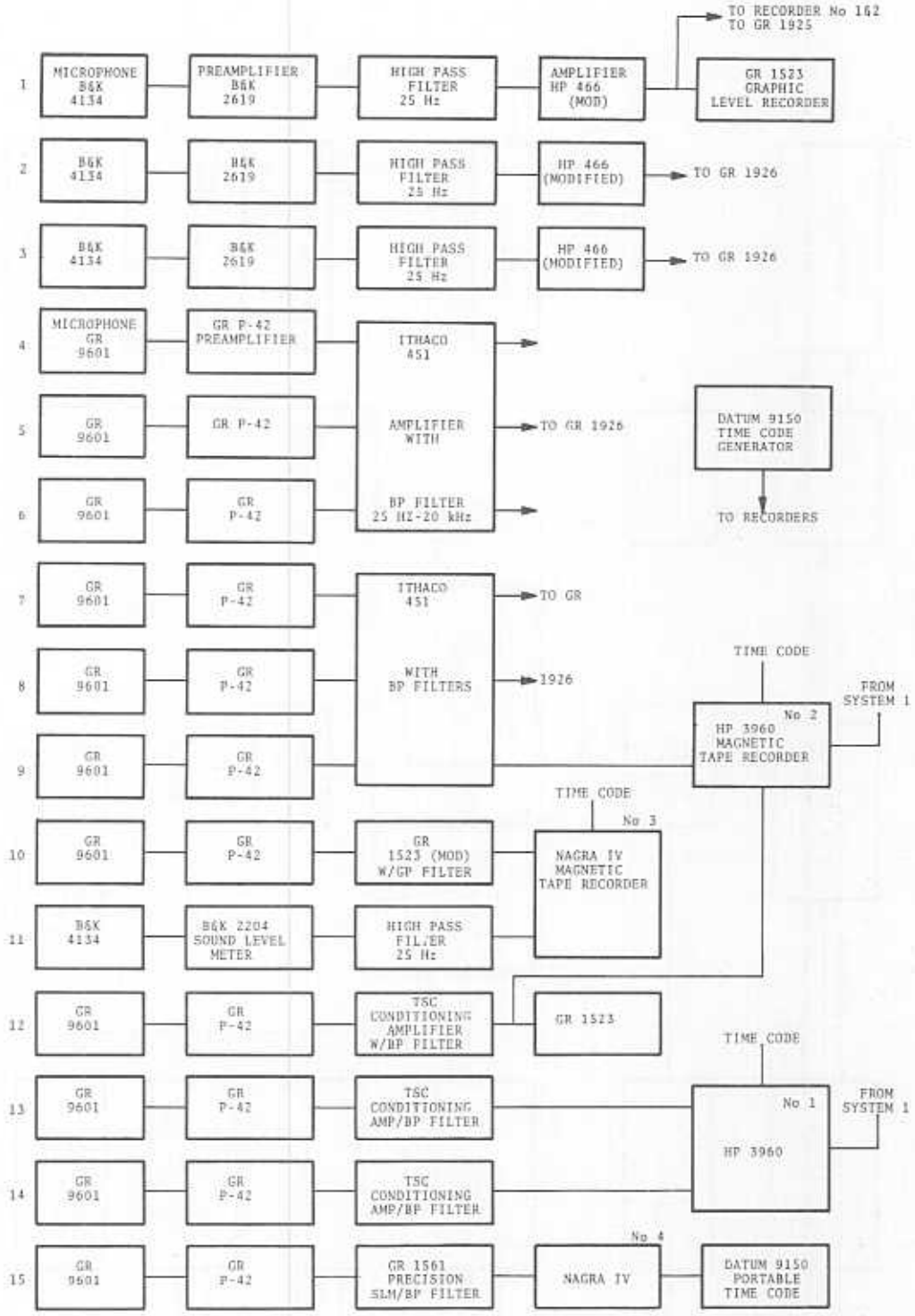


FIGURE B.1 DATA COLLECTION SYSTEMS

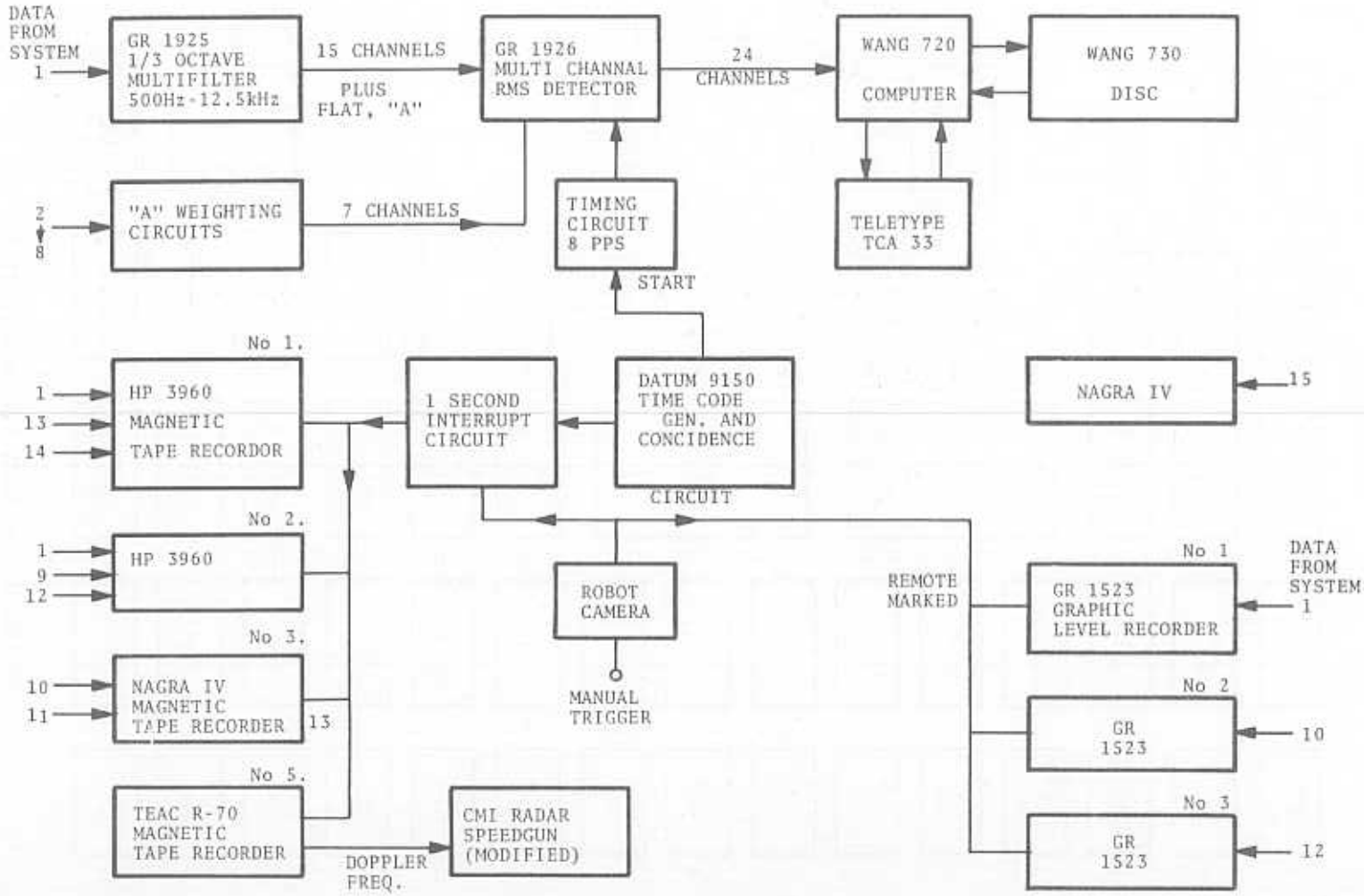


FIGURE B.2 ON-LINE ANALYSIS AND RECORDING SYSTEM

The GR 1921 system was modified to accept data simultaneously from microphone systems 1 through 8. Data from microphone 1 were fed to the GR 1925 which contained 15 parallel 1/3 octave filter channels from 500 Hertz to 12.5 Kilohertz including an unfiltered channel, "Flat", and a standard A-weighted channel. The outputs of these 17 channels were fed to the GR 1926. The outputs of microphones 2 through 8 were fed to the GR 1926 but through standard "A" weighting networks and matching circuitry. The 1/3 octave filters and "A" weighting networks conform to International Electrotechnical Commission specification IEC-225, 1966 and the American National Standards Institute specification for type 1 Sound Level Meters, ANSI-S1.4, 1971 respectively.

The GR 1926 detector was programmed to compute simultaneously the root-mean-square (rms) sound level in decibels for each of the above 24 channels over a 1/8-second measurement period and to convert the levels to digital numbers. The digital numbers for each 1/8-second measurement period were fed to the Wang 720 computer which was programmed to sort and store the digitized data in the Wang 730 Disc system. The start of each measurement period was controlled by a timing circuit which, once started from the time code generator coincidence circuit, provided 8 triggers per second to the GR 1926.

At the end of a measurement run the Wang 720 was programmed to output the stored data from the 730 disc to the teletypewriter in a variety of forms. The dynamic range of the measuring and analysis system was 60 dB.

In addition to the above on-line analysis, data from the remaining 7 microphone systems, and also from microphone 1, were recorded on four magnetic instrumentation tape recorders for future analysis. The tape recorders were operated in the direct mode and capable of essentially flat recordings from 30 Hertz to 15 Kilohertz. The dynamic range of the recording system was 55 dB. A time code signal from the Datum 9150 time code generator was recorded simultaneously on all tape recorders for synchronization between recorders and with the data analyzed on-line. The trigger pulse from the robot camera was fed to an "interrupt" circuit to interrupt the time code for a period of one second at the instant a photograph was taken (test car 50 feet from start of retarder) thus placing on tape a mark relative to car position.

Data from microphone system 1, 10 and 12 were also fed to three GR 1523 Graphic Level Recorders and graphic level history recordings made for on-line identification of extraneous sound sources and to insure overall system performance. Note that the CM1 Radar was modified to provide an analog representation of speed (doppler frequency) which was recorded on the Teac R-70 magnetic tape recorder along with the time code signal for synchronization to the recorded noise data. The measurement and analysis systems conform to the Society of Automotive Engineer's Standard SAE J184.

System calibration on site was performed prior to and after each measurement series with three GR 1562A calibrators. These calibrators provide a signal of 1000 Hertz at a level of 114 dB re 20 micro Pascal. The signal is generated by a solid-state oscillator driving a small magnetic loudspeaker. The three calibrators were compared to one another on microphone system no. 1 prior to each use to insure their relative levels were stable and to provide correction factors between systems, if applicable. To avoid confusion and control systematic errors, the calibrators were numbered and were always used on the same microphone system each time a calibration was performed. A passive microphone simulator was substituted for the microphone to determine the minimum discernible sound pressure level (noise floor) of the system.

The calibration signals, where appropriate, were recorded on magnetic tape as reference levels or were used to adjust the GR 1926 Detector and GR 1523 Graphic Level Recorders. GR 1926 readings during calibration were tabulated on a data sheet for comparison of before and after calibrations to detect any system instability. Noise floor data were also recorded or tabulated as appropriate.

B.4 Off-Tape Analysis System

Figure B.3 depicts the Off-Tape Analysis System used. Analysis was accomplished using the GR 1921 Real Time Analysis System made up of two GR 1925 Multifilters and a GR 1926 Multichannel RMS Detector. Three channels of recorded data were reproduced and simultaneously fed into GR 1925 Nos. 1 and 2 and into a standard A-weighted network. The output of GR 1925 no. 1 which contained 15 channels of 1/3-octave band data from 500 Hertz to 12.5 Kilohertz plus a flat and A-weighted channel were fed to the GR 1926. The output of GR 1925 no. 2 which contained 5 channels of octave band data from 500 Hertz to 8 Kilohertz plus an A-weighted channel was also fed through the A-weighting network to the 1926 detector.

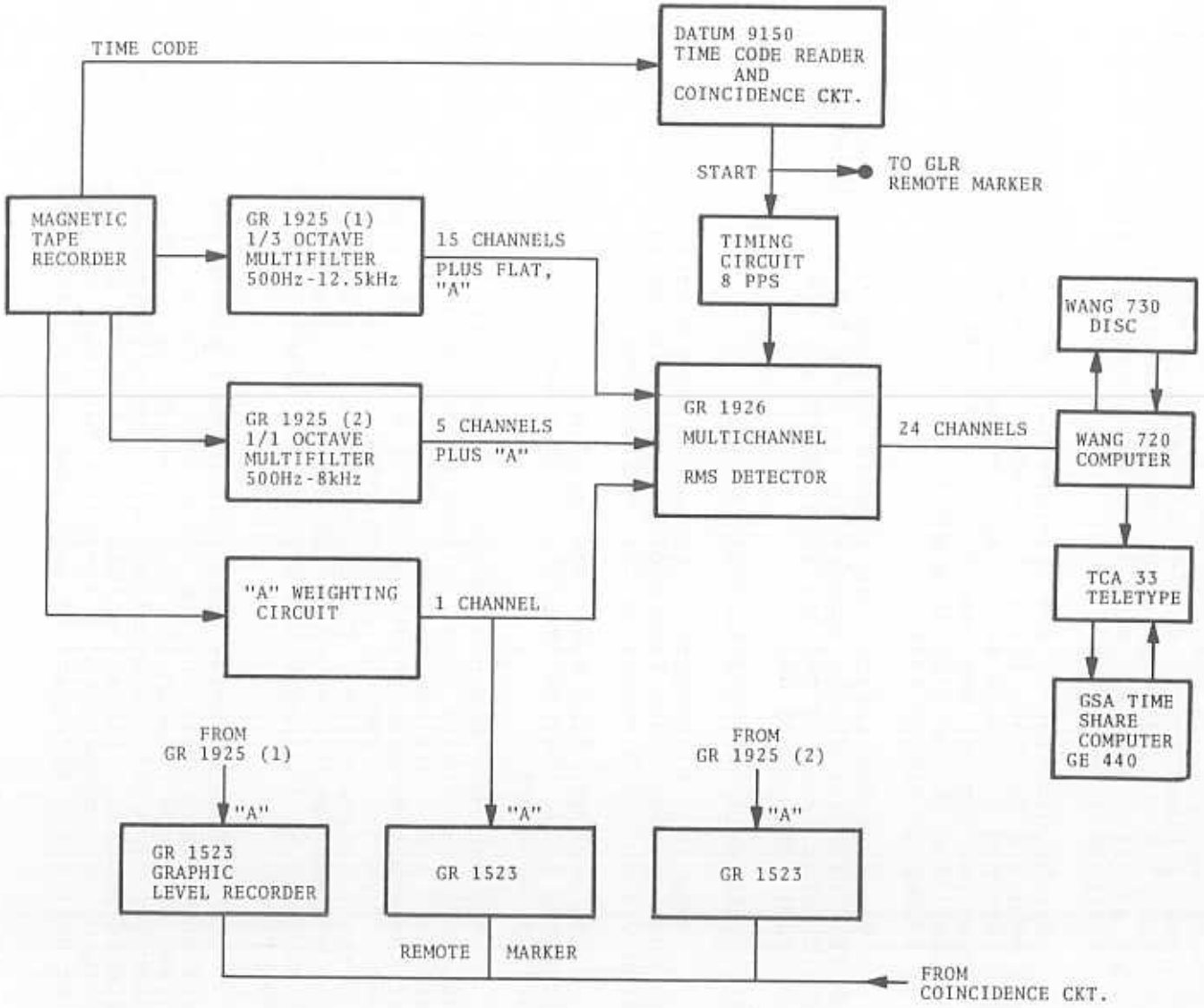


FIGURE B.3 OFF-TAPE ANALYSIS SYSTEM

As in the on-line system the GR 1926 detector was programmed to compute simultaneously the rms sound level in decibels for each of the above 24 channels over a 1/8-second measurement period and covert these levels to digital numbers. The digital numbers for each 1/8-second measurement period were fed to the 720 computer and stored in the Wang 730 disc system in a similar manner as in the on-line system.

Synchronization of the off-tape data with the on-line data was achieved by controlling the exact start of the measurements. The recorded time code signal and the Datum 9150 Time Code Reader Coincidence Circuit was used to start the timing circuit at the precise time the on-line data was started and provide 8 triggers per second to the GR 1926.

The recorded calibration signals were used to adjust the GR 1926 detector to the appropriate reading for each channel. The dynamic range of the analysis system was limited by the tape recorder range of 55 dB.

B.5 Data Collected and Analysis Summary

Data from microphones 1 through 8 were exactly synchronized to one another. Data from microphones 9 through 14 were synchronized within $\pm$ 1/4 second to the on-line data.

To conserve disc space and to eliminate a majority of extraneous noise sources the data on disc were compressed in the following manner:

The computer was programmed to examine the stored A-weighted data of a particular event in time as obtained from microphone system 1 and digitized on line. The digital envelope or history of the event between points on the skirts of the event, which were 30 dB down from the maximum level stored, was printed out on the teletypewriter. The digital levels were compared with the graphic level history of the event, produced on line from microphone 1, to insure the correct and complete event was described.

Once satisfactorily described in this manner the computer was programmed utilizing the exact timing of the above digitized envelope between the 30-dB down points to store in a new disc location all synchronized data from all microphone systems stored on disc. Repeating this for all events results in a new file on disc composed of a series of "windows" of data encompassing only the time period of each event. Thus, the information

between events was eliminated from the data along with a majority of extraneous noise sources. The original on-line data for microphones 1 - 8 remain intact, preserved on disc.

Using the new compressed file it was then possible to program the computer to manipulate the data more efficiently in a number of ways to examine the effect of the barrier configuration on the measured noise around the retarder. Data from microphone system 15 were not compressed in this fashion since synchronization of this data was impossible at that distance from the retarder. Statistical data for the complete time of each run are provided for microphone 15.

A punched paper tape of the teletypewriter data output was made for inputting data from the computer system in the mobile noise van into the larger time shared computer system for additional manipulation as required.

APPENDIX C: REPORT OF NEW TECHNOLOGY

After a diligent review of the work performed under this contract on Railroad Retarder Noise Reduction, we have determined that, to date, no innovations, improvements or inventions have been made.

We have discovered, as a result of the work performed, that currently available schemes for prediction of acoustical performance of a barrier do not yield accurate predictions for railroad retarder applications. These schemes assume a source shielded by a single barrier with no adequate means of considering barrier absorptivity and with no other absorptive or reflective boundaries present. Departure from this rather idealized situation in a retarder application leads to predicted performance somewhat better than is actually obtained with an absorptive barrier and far better than is actually obtained with a reflective barrier. Probable reasons for this are discussed and recommendations for further study have been made, in this report.

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