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Measurements of Railroad Noise-Line Operations, Yard Boundaries, and Retarders

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Applied Acoustics Section
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Final Report

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Abstract

A field investigation of noise emission from railroad operations was conducted. The objectives of the study were the establishment of a data base on the noise levels associated with railroad operations, both line (trains in transit) and yard, and the development of measurement procedures that could be utilized in regulations applicable to the noise from rail carrier equipment and facilities. For trains in transit, measurements were made as a function of horizontal distance from the tracks [five locations at 25, 50, 100, 200 and 400 feet] and as a function of microphone height [three different heights at the 25 and 50 foot microphone locations]. Train passby data are presented as the maximum A-weighted sound level observed during the passby and as Single Event Noise Exposure Levels (both A-weighted and one-third octave band levels). A-weighted sound level measurements were made at the boundary of the railyard, at 0.1 second intervals, for periods of time ranging from 1 to 23 hours over several days. These data are presented as the energy equivalent sound level and the level exceeded ten percent of the time. The directionality of retarder noise was also investigated. Measurements were made of the noise emitted in various directions during retarder operation.

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1. Introduction

The U. S. Environmental Protection Agency (EPA) is charged, under Section 17 of the Noise Control Act of 1972 (Public Law 92-574), with the development of railroad noise emission standards. The law states "After consultation with the Department of Transportation, EPA is required to promulgate regulations for surface (rail) carriers engaged in interstate commerce, including regulations governing noise emission from the operation of equipment and facilities of such carriers."

The lack of data in the public domain on the noise levels associated with railroad operations necessitated the establishment of a substantial data base prior to Federal rule making in this area. Through an inter-agency agreement, EPA requested the assistance of the National Bureau of Standards (NBS) in the establishment of such a data base. These data, in conjunction with data from other sources [1, 2][1/], provide the technical basis for the proposed EPA interstate rail carrier noise emission regulations.

2. Field Test Program

For the purpose of this report, the broad range of noises emitted by railroad operations has been divided into two categories -- line operations (trains in transit) and yard operations.

The movement of locomotives and freight/passenger cars over main line and local branch main line tracks is termed line operations. For trains in transit, there exists two major noise contributors -- the noise from the locomotive, or road power unit, and the wheel/rail interaction noise which defines the car-generated noise levels.

Railroad yard operations, on the other hand, include all operations which are conducted within the confines of the yard property boundaries, including the classification of freight cars and services relating to the performance testing and routine maintenance of cars and locomotives. The classification process -- the uncoupling of cars from incoming trains and recoupling them into outgoing trains bound for various destinations -- is the major yard activity. The various noise sources associated with this operation include: (1) switcher engine noise as incoming cars are pushed up the hump for weighing, classification and destination determination, (2) wheel/rail and retarder noise as the speeds of the free-rolling rail cars which have been pushed over the hump are controlled by retarders -- rails which squeeze against the wheels of the moving cars -- as they are guided to the outgoing train make-up area and (3) the coupling noise as the free-rolling rail cars bump into the other (stationary) cars of the outgoing train.

[1/] Figures in brackets indicate the literature references at the end of this report.

The noise associated with both yard and line operations was investigated during this study with emphasis on the development of measurement procedures and the establishment of a data base appropriate to railroad operations.

2.1. Railroad Line Operations

The noise levels associated with trains in transit are dependent upon the physical characteristics of the train, the operating speed, the condition of the wheels and rails, total weight and length of the train, and the contour of the track bed. Although these variables can be determined, they cannot be controlled in a field study such as this; therefore, it is difficult to correlate the noise levels and frequency spectra of successive train passbys. This section presents a discussion of the field test site and test procedures utilized during the data acquisition phase of the railroad line operation study as well as a presentation of the resultant data.

2.1.1. Field Test Site (Line)

The high speed main line of the Chesapeake and Ohio Railroad, located adjacent to the Montgomery County Fairgrounds in Gaithersburg, Maryland (in close proximity to the National Bureau of Standards) was selected as the field test site for the line operation noise study. The Fairgrounds provided a large grass-covered (mowed) open area free of any large reflecting surfaces. Figure 1 is a contour map of the test site and surrounding area. The roads interspersed throughout the area are dirt with the exception of the one adjacent and parallel to the tracks which is paved. The stands for the baseball field are open style grandstand bleachers. Immediately south of the tracks is a fairly dense growth of weeds and brush about 2 to 3 feet thick and 6-7 feet high. Behind the brush is a large open area that drops in elevation until it reaches Interstate Highway 70-S which is 20 feet below the level of the track bed.

Microphones were located along a line perpendicular to the tracks as indicated in Figure 1. The point of intersection of track and the line of microphones is approximately 520 feet from the nearest point of I-70-S. Along the microphone line, the ground elevation decreases as it recedes from the tracks. The land was surveyed to establish the elevation of the microphone positions relative to the track bed (see Figure 2). For the purpose of this measurement, the track bed is defined as the top of the wooden ties.

At this location, two types of rails exist -- continuous welded rail on the westbound tracks and jointed rail on the eastbound track. Since grade could be an important parameter affecting train noise, the track elevation was surveyed 300 feet on either side of the intersection between the microphone array and the track (see Figure 3). Eastbound trains go up a slight grade as they pass the microphones while westbound trains go down the grade.

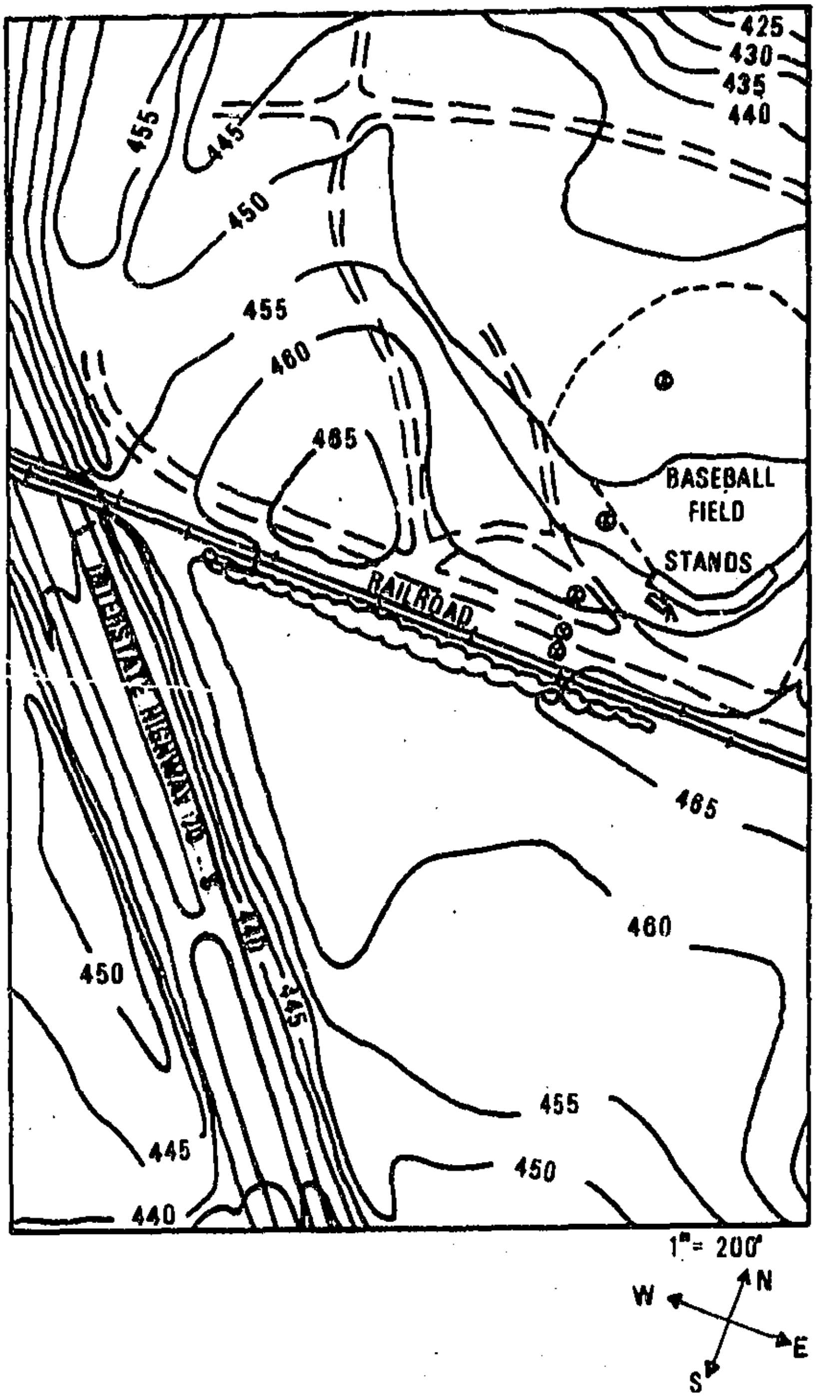


Figure 1. Field test site for trains in transit study showing microphone locations, ⊗, and the location of the mobile instrumentation van, A. Scale 1 in. = 200 ft.

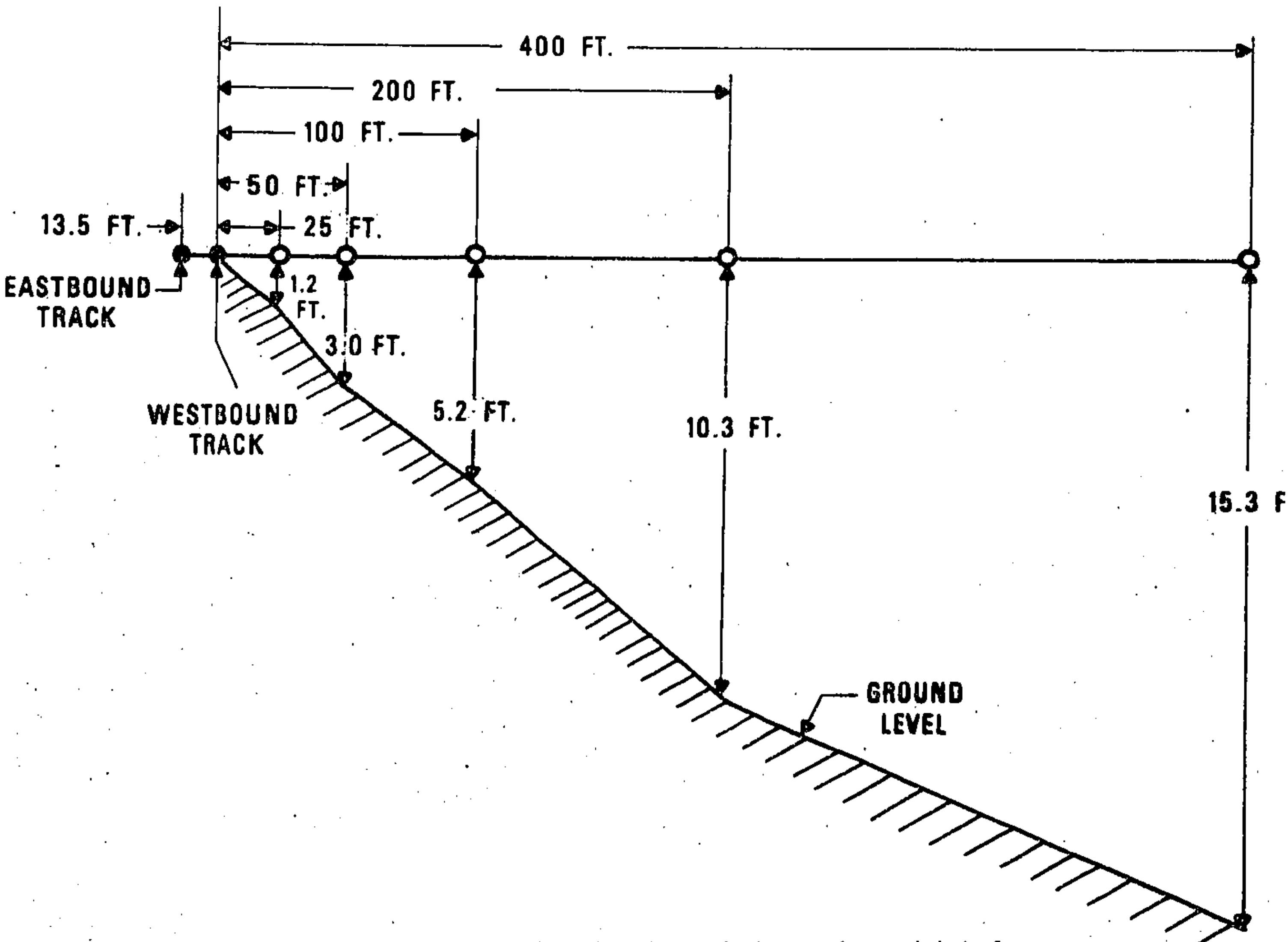


Figure 2. Ground elevations at the microphone locations relative to the track bed of the Chesapeake and Ohio main line at the Gaithersburg test site.

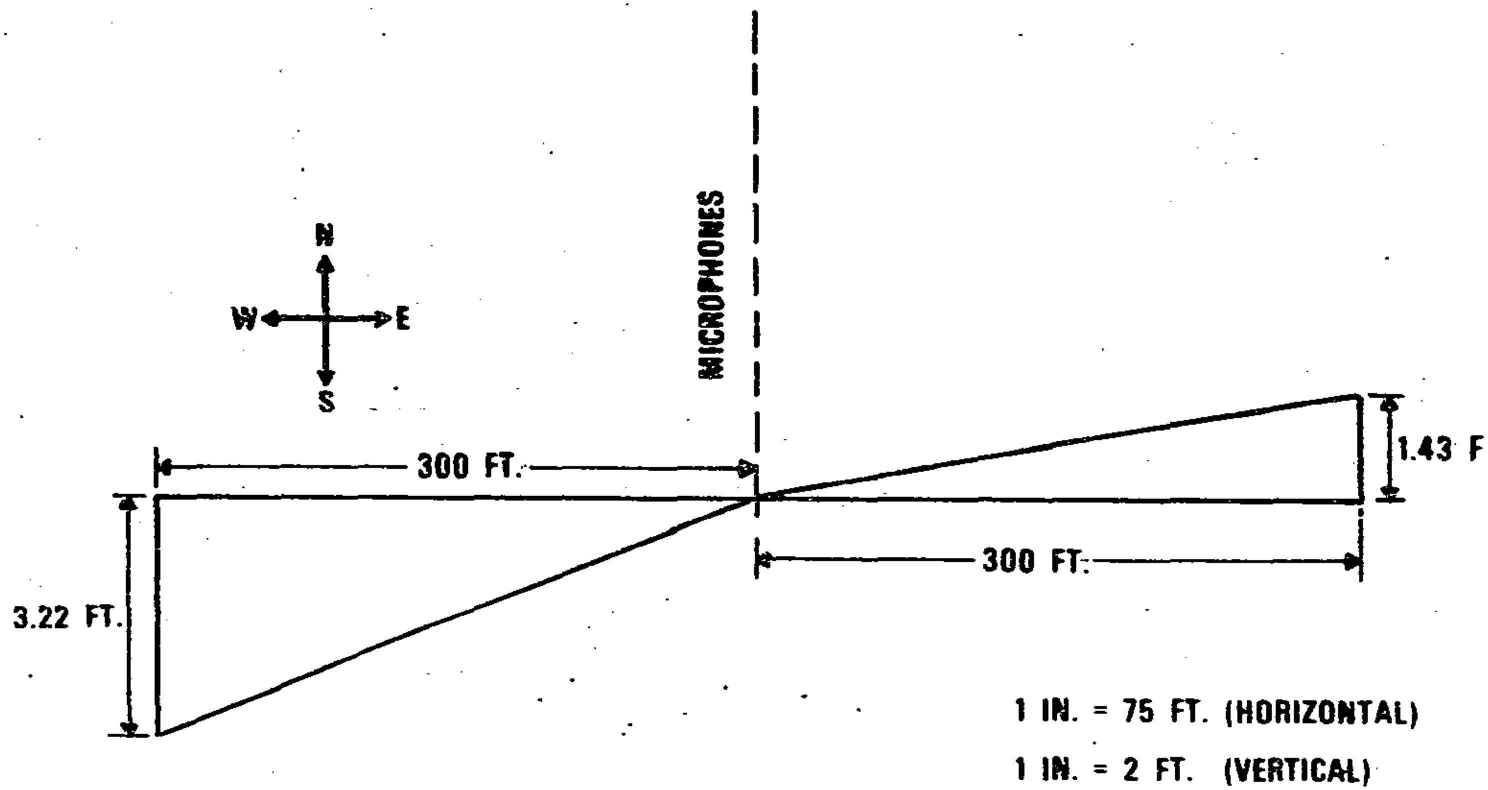


Figure 3. Track elevation 300 feet on either side of the intersection point of the track and the line of microphones.

2.1.2. Test Procedure (Line)

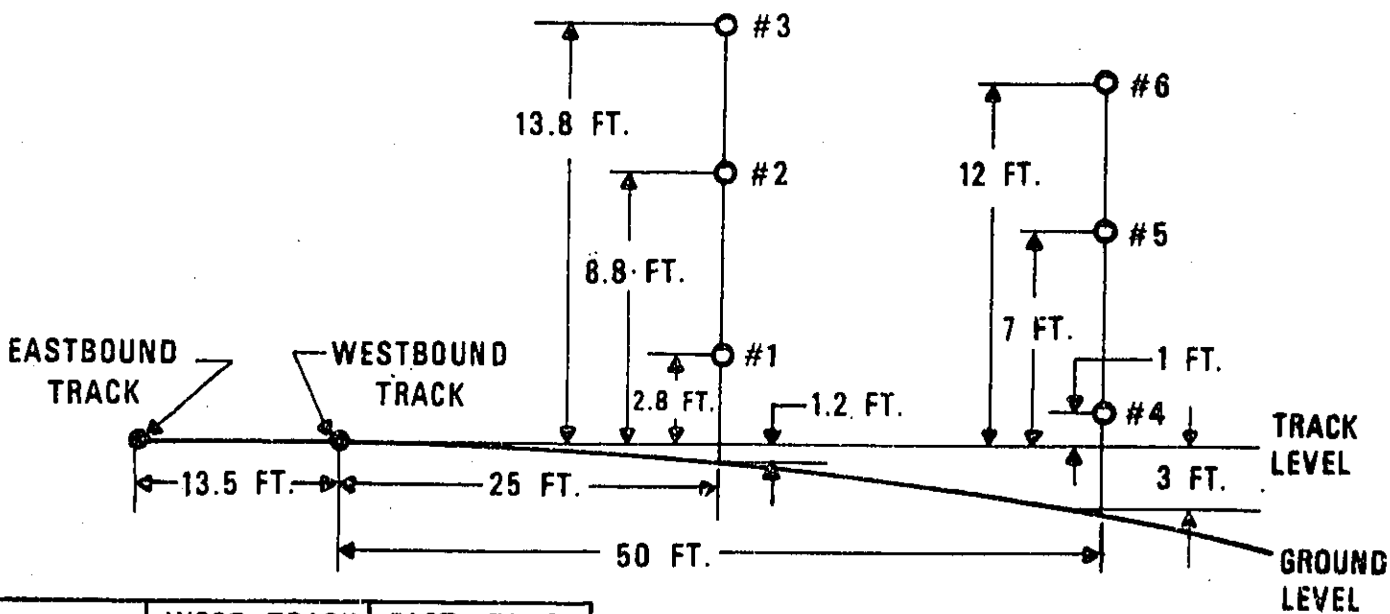
As stated previously, the microphones were located along a line perpendicular to the direction of travel of the trains. For one series of measurements, five microphones, located at distances of 25, 50, 100, 200 and 400 feet as measured from the centerline of the westbound track, formed a horizontal array. Each microphone was mounted on a tripod and positioned at a height of 4 feet above ground level. Since the ground along the microphone line was not level (see Figure 2) the line-of-sight distance between the microphones and the tracks were slightly different from the nominal distances cited above. Table 1 shows the angle and line-of-sight distance for each microphone in the horizontal array with respect to both the eastbound and westbound tracks.

Table 1 Angle (Θ) and line-of-sight distances (d) for each microphone in the horizontal array with respect to the eastbound and westbound tracks. (See Figure 2)

Microphone	West Track		East Track	
	Θ	d,ft	Θ	d,ft
1	6° 23'	25.2	4° 10'	38.6
2	1° 9'	50.0	0° 54'	63.5
3	0° 41'	100.0	0° 36'	113.5
4	1° 48'	200.1	1° 41'	213.6
5	1° 37'	400.2	1° 34'	413.6

A second series of measurements were also conducted utilizing a vertical, rather than a horizontal, microphone array. For these measurements microphones were mounted at heights of 4, 10 and 15 feet above the ground at horizontal distances of 25 and 50 feet as measured from the centerline of the westbound track. Figure 4 illustrates the array and shows the microphone heights with respect to the track bed and ground level. The associated table gives the angle and line-of-sight distance for each microphone with respect to the track bed.

During both series of measurements, the microphones were connected through coaxial cables to the tape recording and monitoring equipment housed in the mobile instrumentation van. The van was located approximately 125 feet from the westbound track and 100 feet to the east of the line along which the microphones were located -- point A in front of the stands in Figure 1. The data from each microphone were recorded on one channel of a seven-channel F.M. tape recorder. The recorder was manually started and stopped upon the approach and subsequent departure of each train. Appendix A contains a detailed discussion of the instrumentation which comprised the data acquisition and analysis system for line operation studies.



MICROPHONE	WEST TRACK		EAST TRACK	
	θ	d, FT.	θ	d, FT.
#1	6°23′	25.2	4°10′	38.6
#2	19°24′	26.5	12°52′	39.5
#3	28°54′	28.6	19°43′	40.9
#4	1°9′	50.0	0°54′	63.5
#5	7°58′	50.5	6°17′	63.9
#6	13°30′	51.4	10°42′	64.6

Figure 4. Layout of vertical microphone array showing angles (θ) and line-of-sight distances (d) for each microphone with respect to the eastbound and westbound tracks.

Statistical information on each train, such as, total number of cars, loaded cars, empty cars, total weight, etc., was provided by the Chesapeake and Ohio Railroad Company (see Tables 2 and 3, Section 2.1.3). Train speed was determined by timing the train with a stop watch as it traversed a marked distance of 450 feet. Depending on the train length, repeated timings were obtained and the average used to compute the speed.

2.1.3. Test Results (Line)

Data were obtained during 23 train passbys. For 12 of the passbys a horizontal microphone array was utilized which consisted of five microphones located at 25, 50, 100, 200 and 400 feet from the centerline of the westbound track. All microphones in the horizontal array were mounted on tripods at a height of 4 feet above the ground. Measurements of the remaining 11 train passbys were made utilizing a vertical microphone array. In this case microphones were located at heights of 4, 10 and 15 feet above the ground at locations of 25 and 50 feet from the centerline of the westbound track. It was felt that the results of this data acquisition program would provide the necessary data base (1) of the noise levels associated with trains in transit and (2) to allow for the selection of appropriate numbers of microphones as well as location and height specifications to ensure adequate characterization of train noise.

In addition to the A-weighted sound level, the Single Event Noise Exposure Level (SENEL) was investigated as a descriptor of train passby noise. SENEL is mathematically defined as:

$$\text{SENEL} = 10 \log_{10} \int_{-\infty}^{\infty} \left[\frac{p(t)}{p_o}\right]^2 \frac{dt}{t_o} = 10 \log_{10} \left[\frac{1}{t_o} \int_{-\infty}^{\infty} 10^{L(t)/10} \, dt\right], \qquad (1)$$

where p is the time-varying, mean-square-sound-pressure at the point of observation, L is the corresponding sound level, p_o is the standard reference pressure (20 micropascals), t_o is the standard reference time (1 second) and t is the time (in seconds). From a practical standpoint, of course, the integration is only carried out over a finite time interval which essentially includes all of the acoustic energy from a given passby.[2] The SENEL value is very dependent on the integration time selected; errors as great as 10 dB can occur if the time is too short. This is especially critical as the microphone distance from the train is increased. Considering the train as a line source, this effect was investigated theoretically and, considering the length and speed of the train and the microphone distance, the integration time was selected for each train passby such that in no case was the error due to the finite integration time greater than 1 dB at any microphone location.

[2] The procedure by which the SENEL integral was evaluated from the analog sound pressures is discussed in Appendix B.

Also, SENEL is easily relatable to the energy equivalent noise level (L_{eq}), which is the level of steady state continuous noise having the same energy as the actual time varying noise. Among the many scales used for noise and its effect, L_{eq} appears to emerge as one of the most important measures of environmental noise effects on man [3].

The data for the 25, 50, 200 and 400 foot microphones of the horizontal microphone array are presented in the following tables and figures. It should be noted that due to instrumentation failure, data were not obtained at the 100 foot microphone location. On several occasions one or more microphones were inoperative during the train passby and therefore, data are not available in these instances either. Table 2 presents information on the characteristics of the 12 trains which were measured. Data such as the train number (identification number of the lead locomotive), the direction of travel, number of locomotives, number of cars and whether the cars were empty or loaded, the total weight and length of the train and the speed of the train, are included. The acoustic data are presented in Figures 5-16. Each figure corresponds to a particular train and is composed of two parts labeled (a) and (b). The one-third octave band Single Event Noise Exposure Level versus frequency data for each microphone position are presented in Figures 5a-16a, while Figures 5b-16b present the A-weighted Single Event Noise Exposure Level and the maximum A-weighted sound level during the train passby plotted versus the perpendicular distance from the center of the track on which the train was running. In the upper right-hand corner of Figures 5b-16b are shown the average attenuation with distance (decibel/doubling of distance) of both the SENEL and L_{MAX}) data.

The one-third octave band SENEL spectral data show that, as expected, train passby noise is characterized by low frequency peaks in the range 40-100 Hz related to the firing frequency of the locomotive engine. The higher frequency portions of the spectra result chiefly from the interation of the wheels with the rails.

Both the spectral and the attenuation-with-distance data point out why complaints triggered by train noise come from people living miles away from the railroad tracks. Even at distances of 400 feet from the passing trains, the low frequency peak is little attenuated from the level measured at 25 feet. The wheel/rail noise, which is typically higher in frequency and is generated by sources closer to the ground, attenuates at an increased rate in comparison to locomotive noise. Because of this, a general tendency exists for the rate of attenuation of A-weighted sound levels to increase with the number of cars in the train, resulting from the greater contribution from wheel/rail noise, as opposed to locomotive noise.

In order to gain some understanding of the variation in the rate of attenuation with distance as a function of frequency, the 50 foot microphone was selected as a reference and the differences between its reading and those of the other microphones were determined -- [L(x) - L(50)][3]. These differences were computed for the octave band SENEL values over the frequency range from 63 to 4000 Hz. The average values for each frequency were plotted against the microphone distances. A straight line was fitted to the average value data using the method of least squares. The average values, the range, and the least squares line are presented in Figures 17 and 18. The data in these figures are separated according to direction of travel -- east or west -- which also corresponds to differences in track type and grade. It should be noted that the least square lines have been displaced and forced to go through 0 dB at 50 feet for westbound trains and at 63 feet for eastbound trains. The average deviations [L(x) - L(50)] are also plotted versus frequency for each microphone location as shown in Figures 19 and 20 for the west and east bound trains, respectively.

As expected, there is a general tendency for an increased rate of absorption at higher frequencies. The data also seem to indicate that destructive interference is occurring in the region of 500 Hz (this phenomena will be discussed in detail later in this section). Since the data include both locomotives and cars -- for which the effective source heights, and hence the expected rate of attenuation, are different -- no quantitative conclusions can readily be drawn.

In order to determine the influence of microphone height as a parameter, a vertical microphone array was utilized to measure the noise from 11 passing trains. As stated earlier, the vertical array consisted of six microphones -- three at heights of 4, 10 and 15 feet above the ground at a distance of 25 feet from the centerline of the westbound track and three at the same heights at a 50 foot distance. The data obtained with the 4 foot high microphone located at 50 feet were found to be erroneous; therefore, the only tie with the horizontal array was the 4 foot high microphone located at 25 feet and this microphone was selected as the reference microphone.

These were 11 train passbys; however, on two occasions east and west bound trains passed the microphone array simultaneously. These are noted on Table 3 which presents data on the characteristics of the trains measured utilizing the vertical microphone array.

Figures 21 and 22 present the differences in the A-weighted Single Event Noise Exposure Level and A-weighted sound levels that existed between the reference microphone and the other microphones [L(x,y) - L(25,4)][4].

[3] L(x) is the noise level measured at the microphone location whose horizontal distance from the source is defined within the parenthesis, i.e., L(50) is the level measured at the 50 foot microphone location.

[4] L(x,y) is the noise level measured at the microphone location whose horizontal distance from the source and height above the ground are defined within the parenthesis, i.e., L(25,10) is the level measured at the 25 foot microphone location for a microphone height of 10 feet.

The horizontal distances shown correspond to data for westbound trains -- the distances for the eastbound trains were 13.5 feet greater.

The chief conclusion to be drawn from these data is that some care is required in attempting to predict levels at one vertical height from measurements at some other height. At a horizontal measurement distance of 50 feet, assuming a 15 foot high locomotive and a 15 foot high microphone, an acoustic signal originating from the roof-top exhaust would travel about 8.5 feet further by undergoing one reflection from the ground than it would travel in going directly from the exhaust to the microphone. A distance of 8.5 feet corresponds to one-half wavelength for sound at a frequency of about 70 Hz. This is in the frequency range where the maximum sound pressure levels due to the locomotive engine firing frequency occur. This observation would suggest that the anomalously low levels at the 15 foot high microphone at a horizontal measurement distance of 50 feet were due to destructive interference between the direct signal and that reflected from the ground.

For measurements using a microphone 4 feet above the ground, assuming a hard reflecting surface, at a distance of 100 feet from a locomotive (distances that have been suggested for regulatory purposes), a 15 foot high source (i.e., locomotive exhaust) would result in destructive interference at about 500, 1500, 2500, 3500,..Hz and constructive interference at about 1000, 2000, 3000, 4000, ...Hz. The first frequency at which destructive interference occurs is well above the frequency range associated with the fundamental firing frequency of the locomotive engine. Thus one would not expect serious measurement errors due to interference phenomena. Similarly, measured sound levels should be reasonably independent of small differences in microphone height, provided the terrain is reasonably flat and level. However, if there were a small valley between the train and the microphone, destructive interference could occur at frequencies near that of acoustical radiation associated with the fundamental firing frequency of the locomotive engine. As an example, assume the ground falls off to about 10 feet below track level at 50 feet away and then rises to be level with the track at 100 feet away. For exhaust noise from a 15 foot high locomotive, destructive interference would occur (for a 4 foot high microphone) at frequencies of about 80, 240, 400, 560,...Hz. Destructive interference would occur near these same frequencies if the ground fell off, for example, to 7 feet below track level at a distance of 50 feet and then rose to about 5 feet above track level at 100 feet.

2.2. Railroad Yard Operations

The noise levels associated with a railroad yard are dependent upon a variety of activities within the yard. The primary noise sources typically are the various retarders, the coupling of cars, and the working and idling locomotives -- both road and switcher. This section presents a discussion of the field test site and test procedures utilized during the data acquisition phase of the railroad yard operation study as well as a presentation of the resultant data.

Table 2. Characteristics of trains on the main line during measurements made utilizing the horizontal microphone array.

Train*	Direction	Locomotives	Empty Cars	Loaded Cars	Speed Ft/sec	Weight Tons	Length Feet
4103	West	3	94	48	62	7380	7020
6607	West	2	0	0	112	300	136
7411	West	5	138	0	33	4890	6964
4054	West	6	0	0	56	900	408
3823	West	2	20	3	30	1016	1390
4036	West	4	0	81	88	6889	4160
4548	West	4	63	13	43	4162	3920
6970	West	2	32	5	51	2100	1912
4031	West	3	0	77	87	5840	3900
3555	East	3	27	59	46	4800	4332
6955	East	2	16	8	49	1535	1288
5983	East	1	2	2	36	500	260

*The numbers refer to the identification numbers of the lead locomotives.

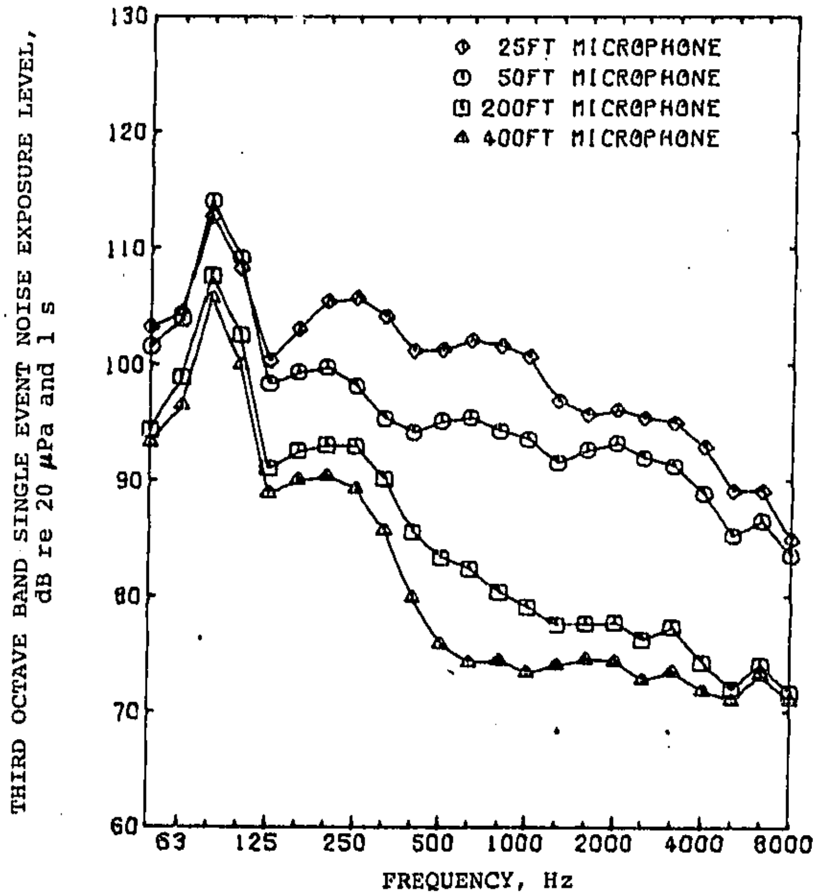


Figure 5a: Single event noise exposure level versus frequency for train no. 4103.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
3	94	48	62	7380	7020

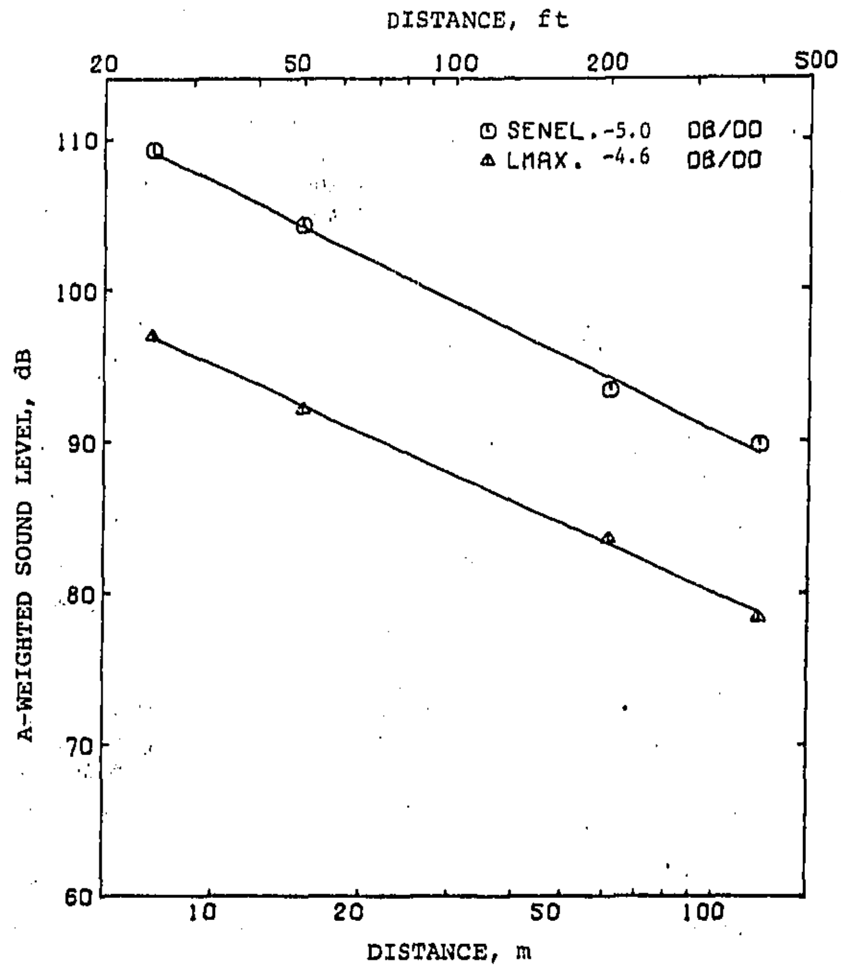


Figure 5b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 4103.

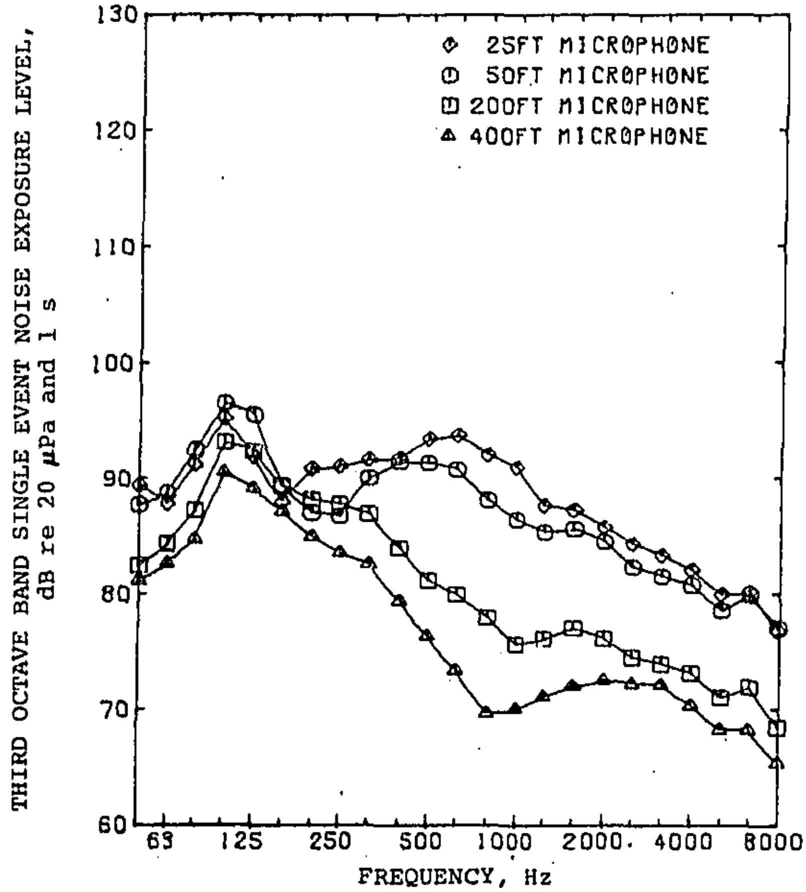


Figure 6a. Single event noise exposure level versus frequency for train no. 6607.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
2	0	0	112	300	136

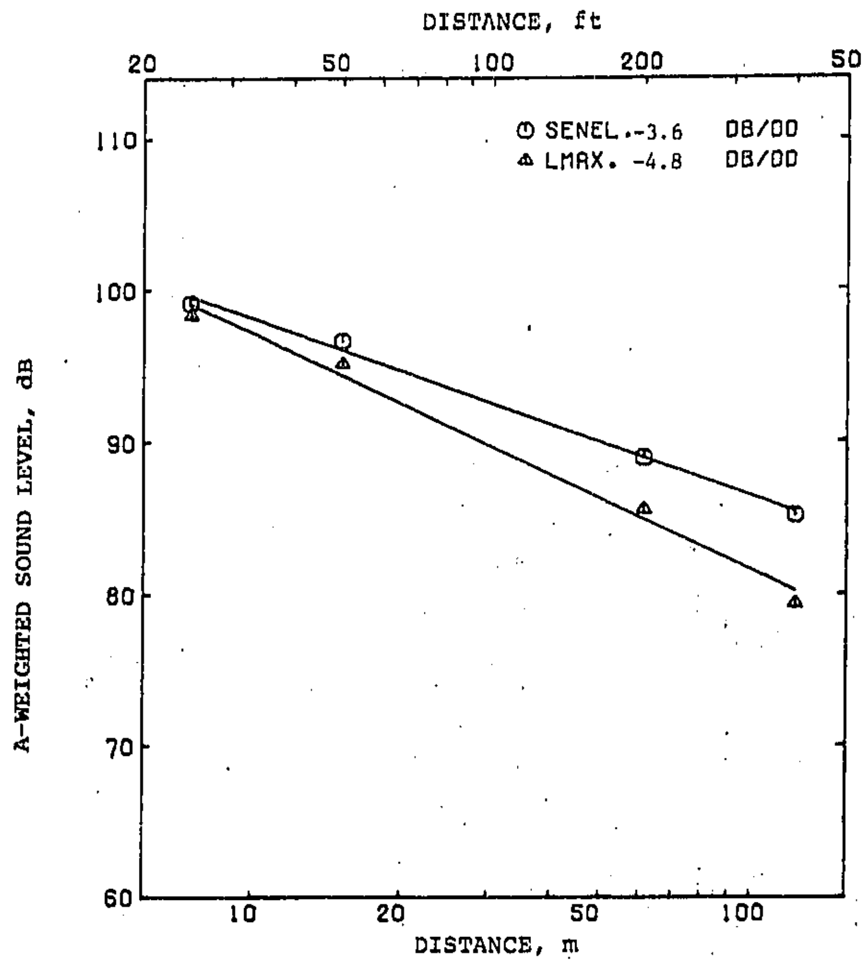


Figure 6b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 6607.

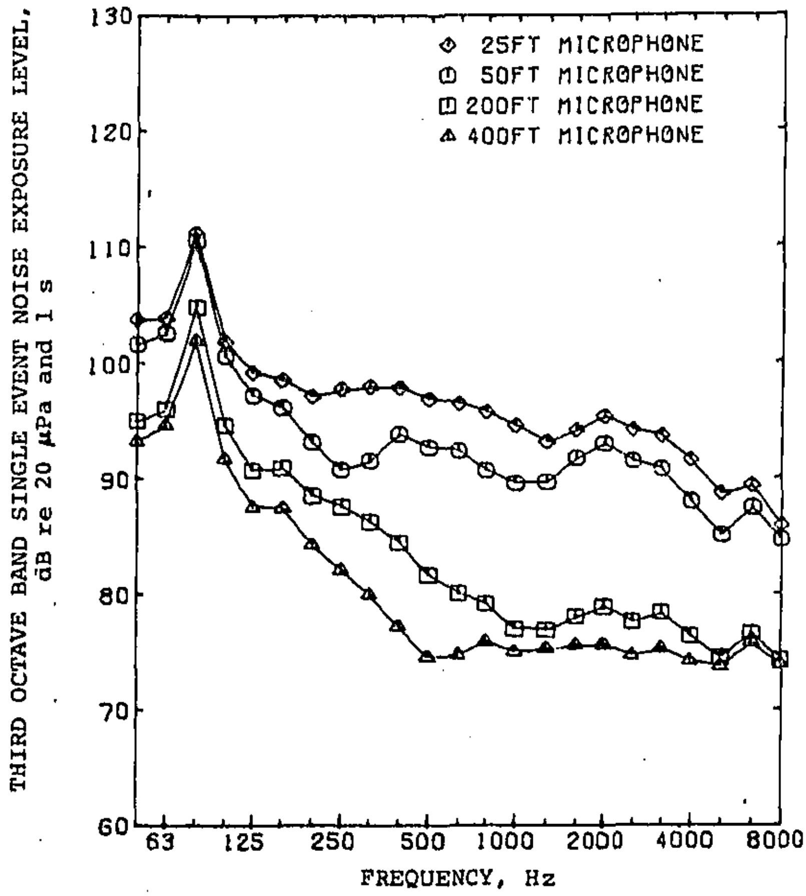


Figure 7a. Single event noise exposure level versus frequency for train no. 7411.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
5	138	0	33	4890	6964

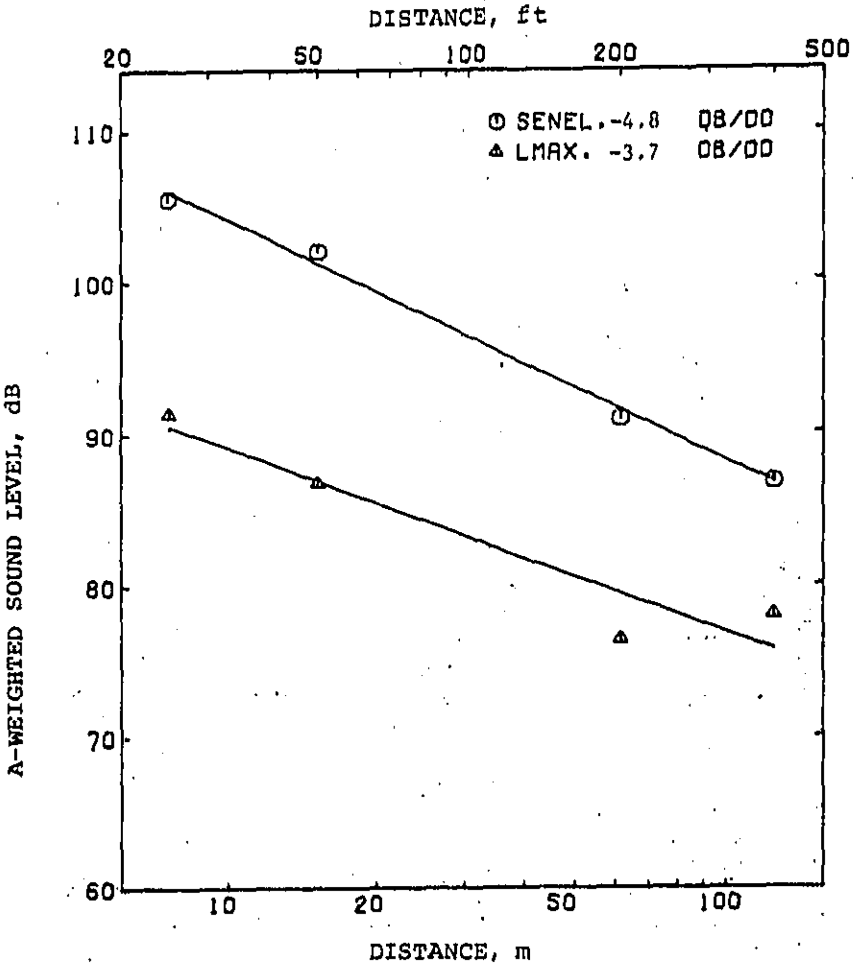


Figure 7b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 7411.

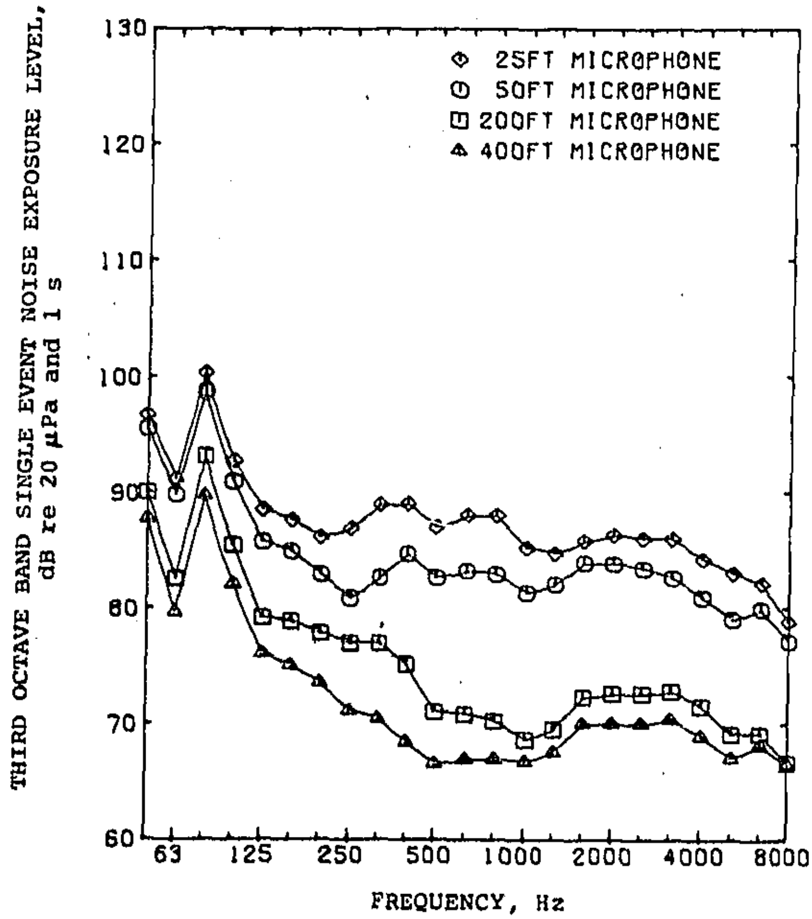


Figure 8a. Single event noise exposure level versus frequency for train no. 4054.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
6	0	0	56	900	408

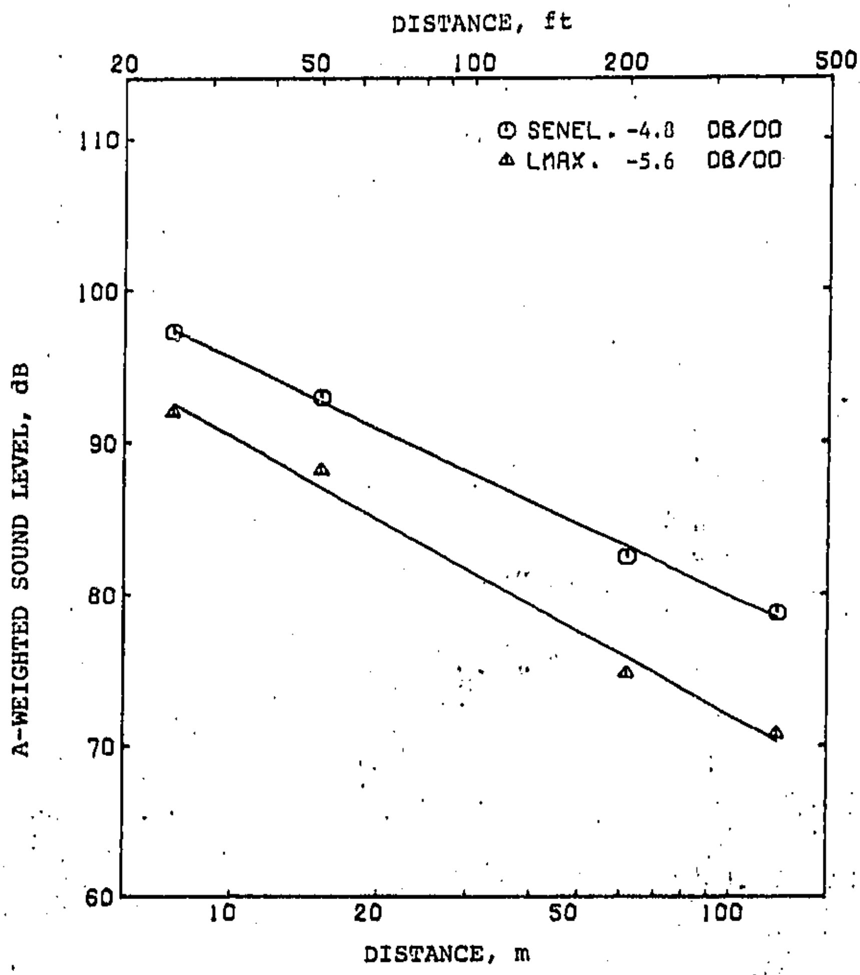


Figure 8b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 4054.

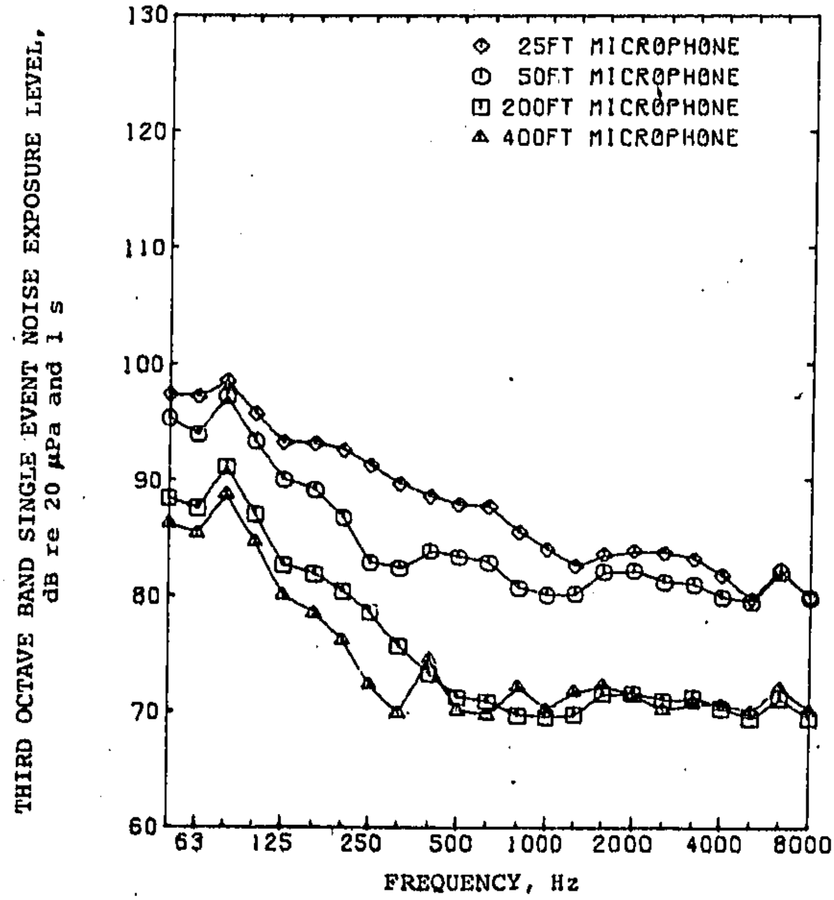


Figure 9a. Single event noise exposure level versus frequency for train no. 3823.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
2	20	3	30	1016	1390

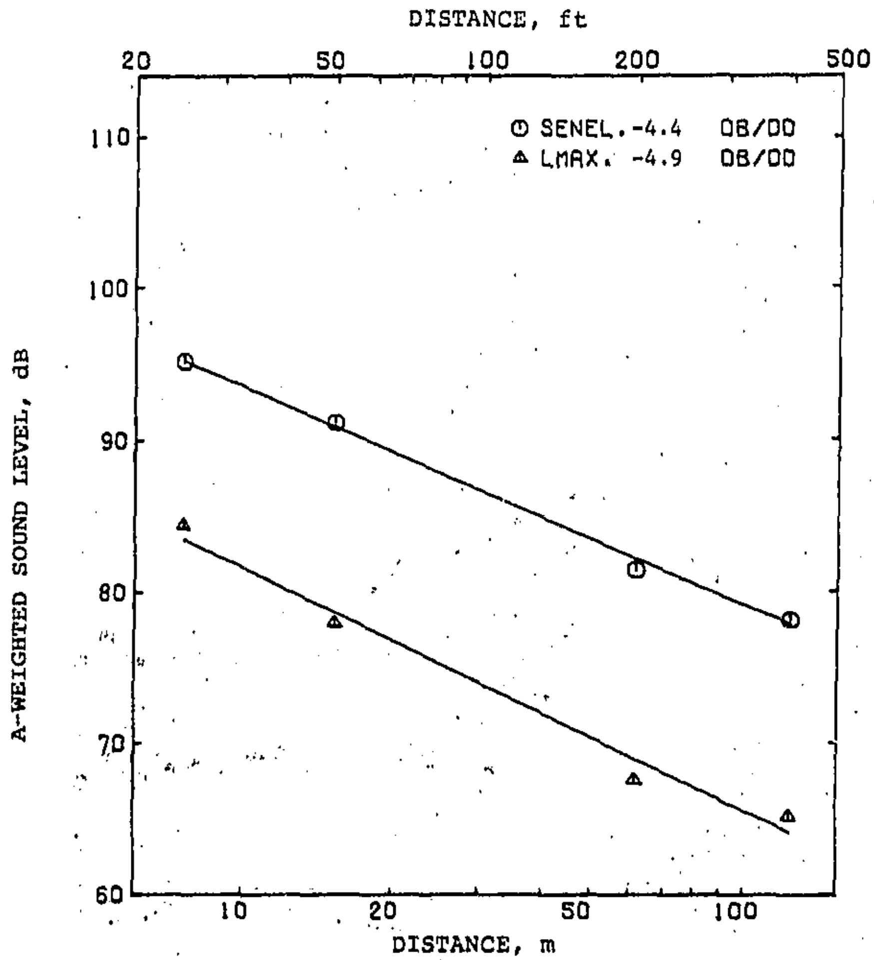


Figure 9b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 3823.

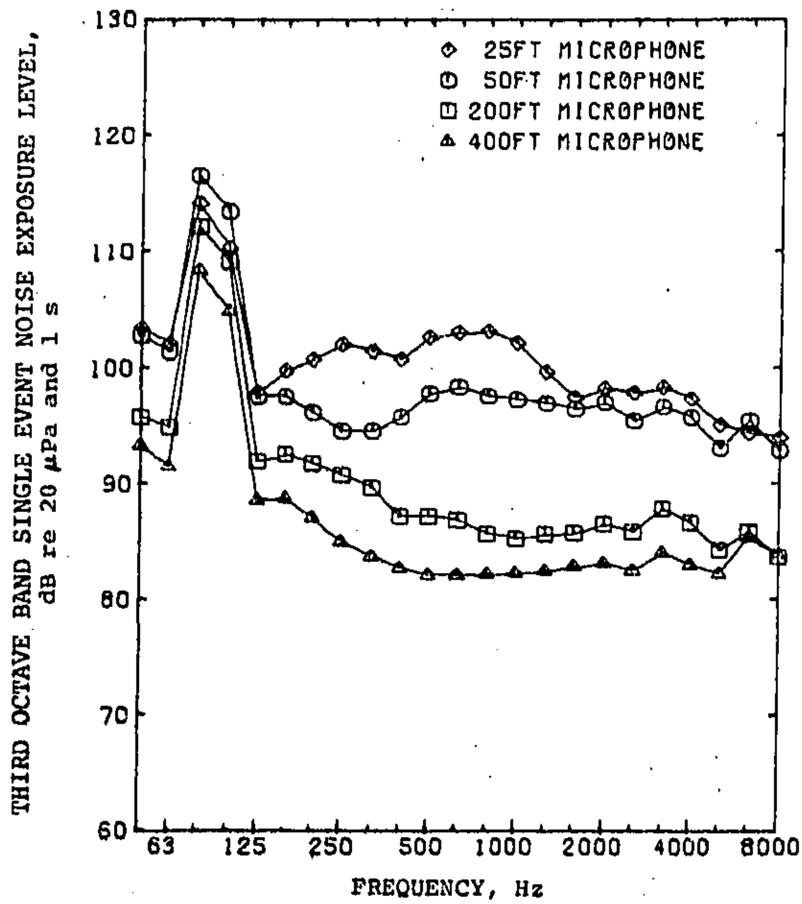


Figure 10a. Single event noise exposure level versus frequency for train no. 4036.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
4	0	81	88	6889	4160

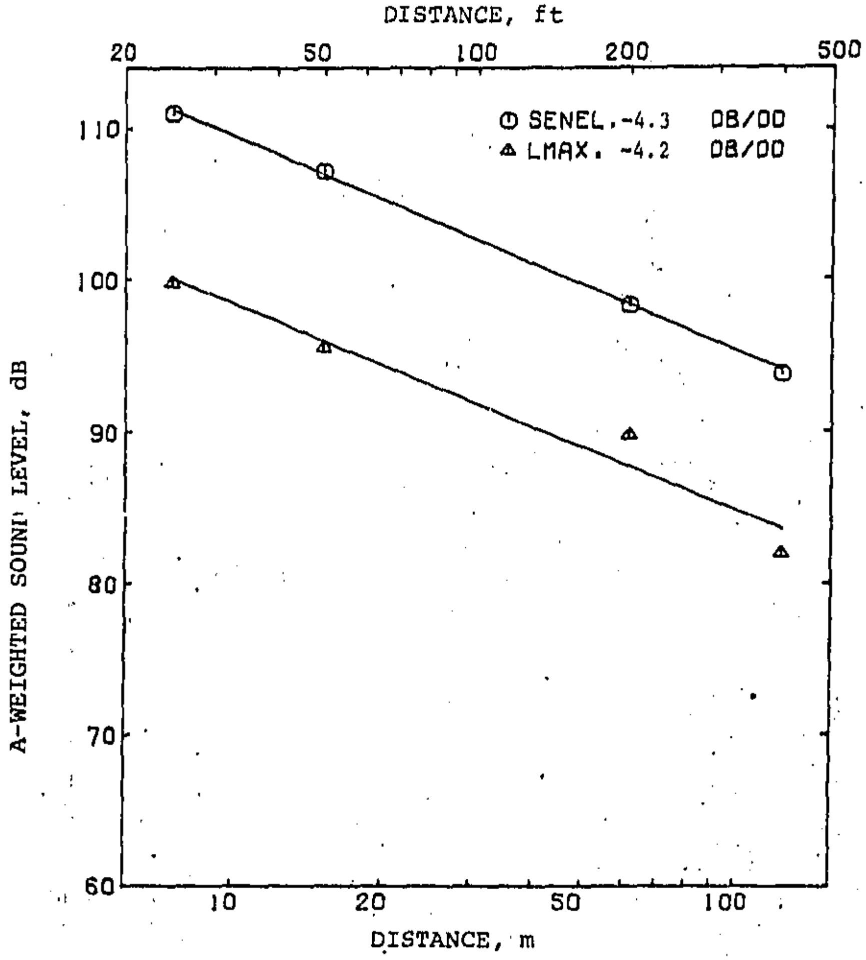


Figure 10b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 4036.

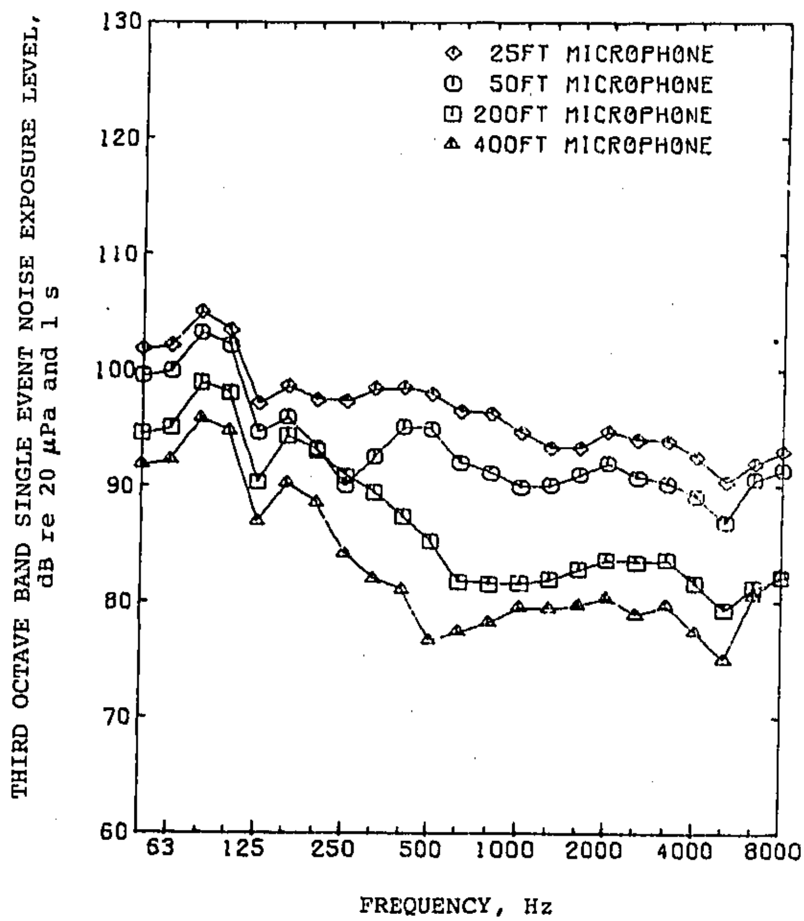


Figure 11a. Single event noise exposure level versus frequency for train no. 4548.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
4	63	13	43	4162	3920

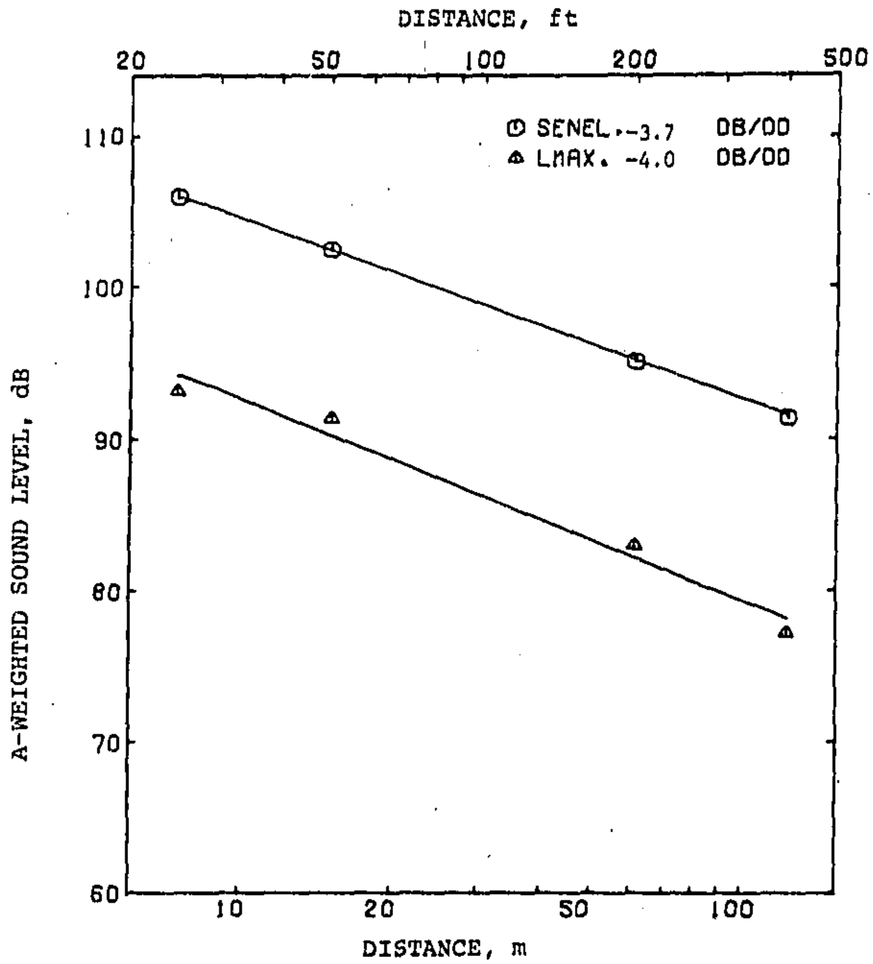


Figure 11b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 4548.

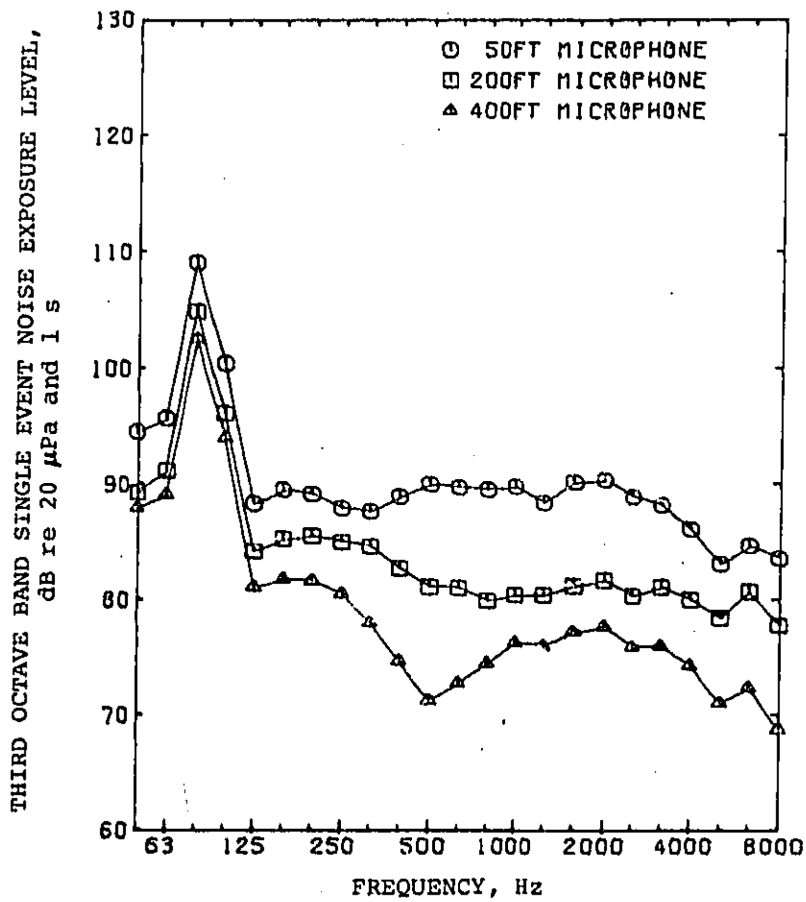


Figure 12a. Single event noise exposure level versus frequency for train no. 6970.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
2	32	5	51	2100	1912

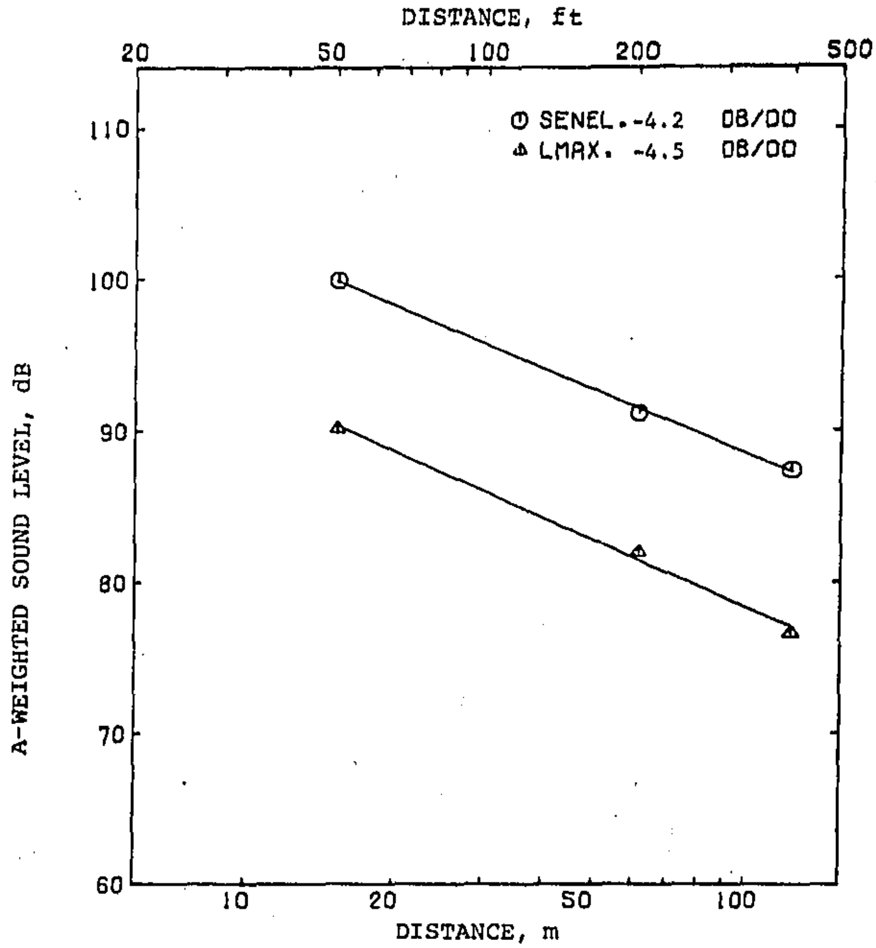


Figure 12b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 6970.

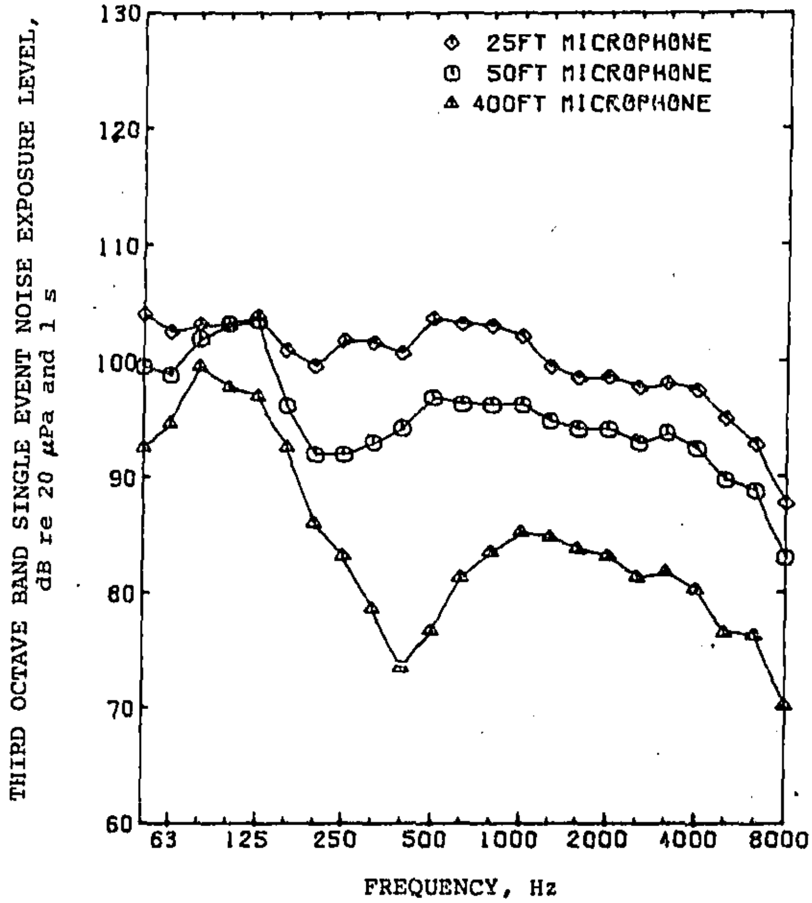


Figure 13a. Single event noise exposure level versus frequency for train no. 4031.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
3	0	77	87	5840	3900

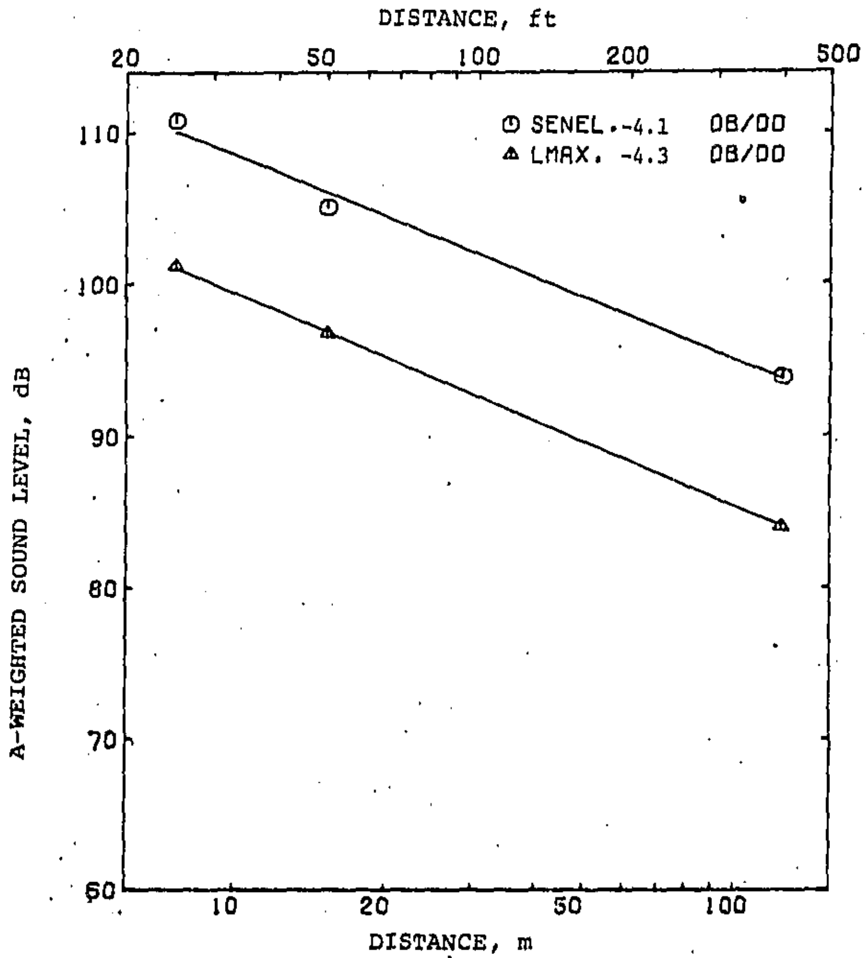


Figure 13b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 4031.

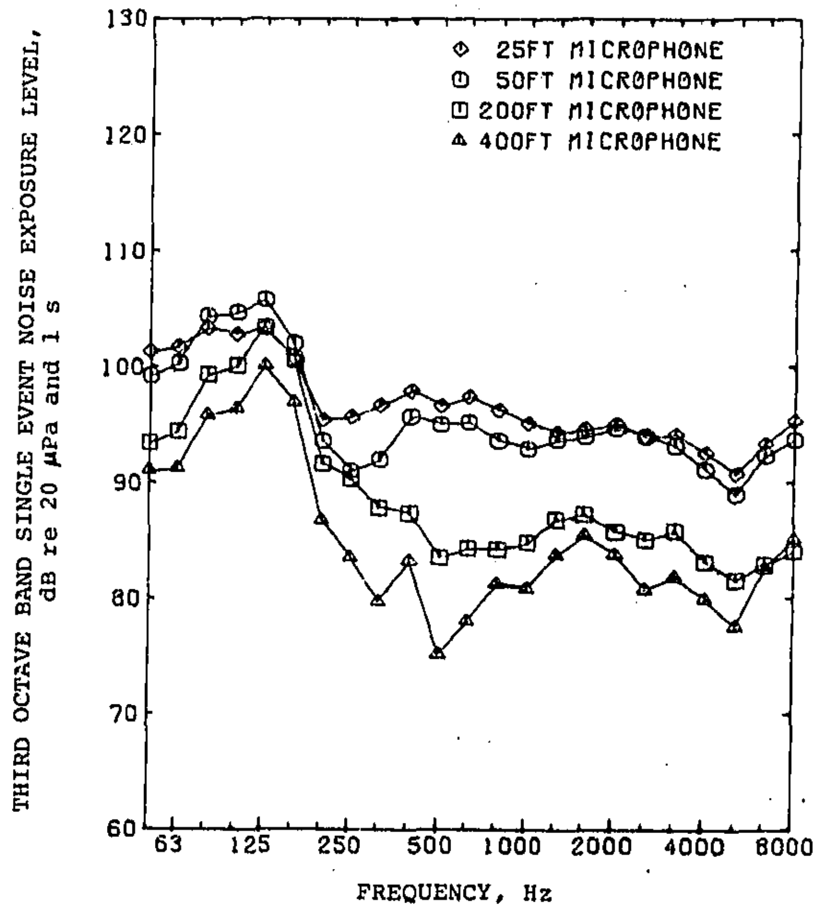


Figure 14a. Single event noise exposure level versus frequency for train no. 3555.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
3	27	59	46	4800	4332

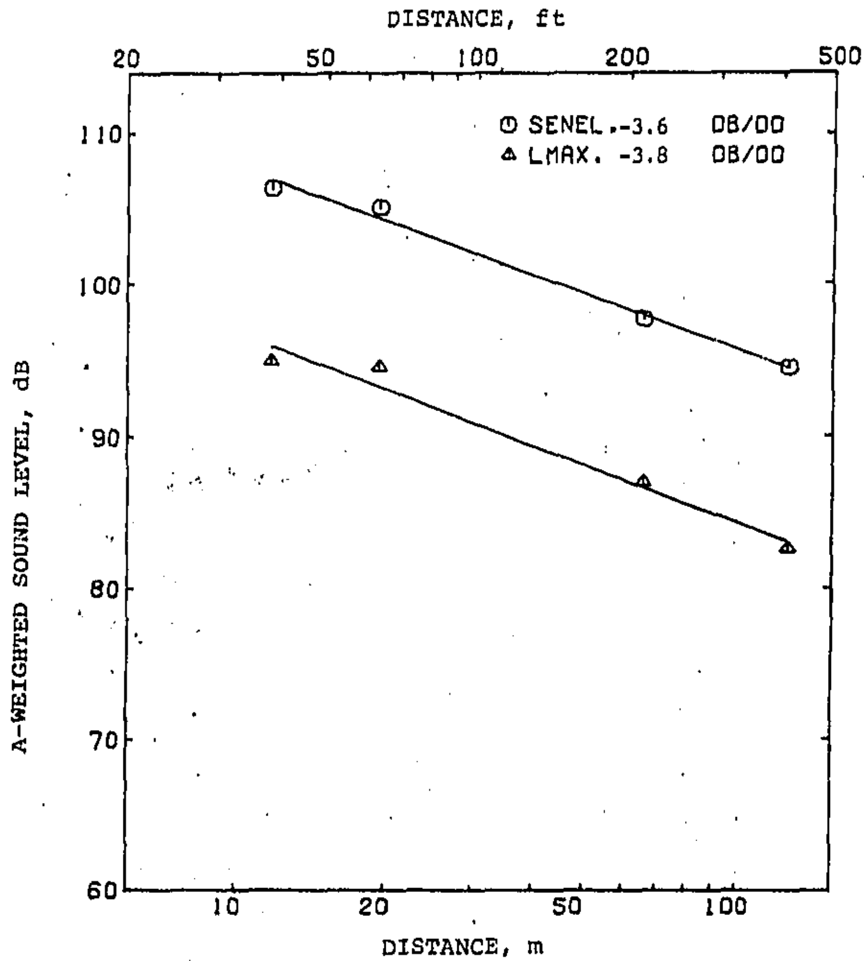


Figure 14b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 3555.

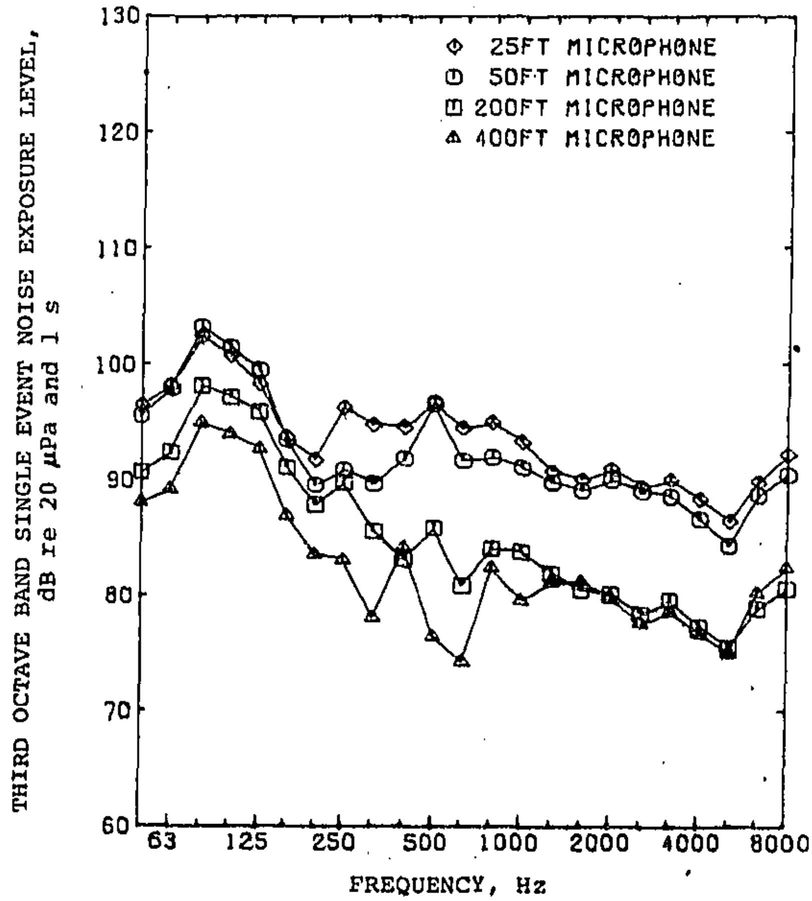


Figure 15a. Single event noise exposure level versus frequency for train no. 6955.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
2	16	8	49	1535	1288

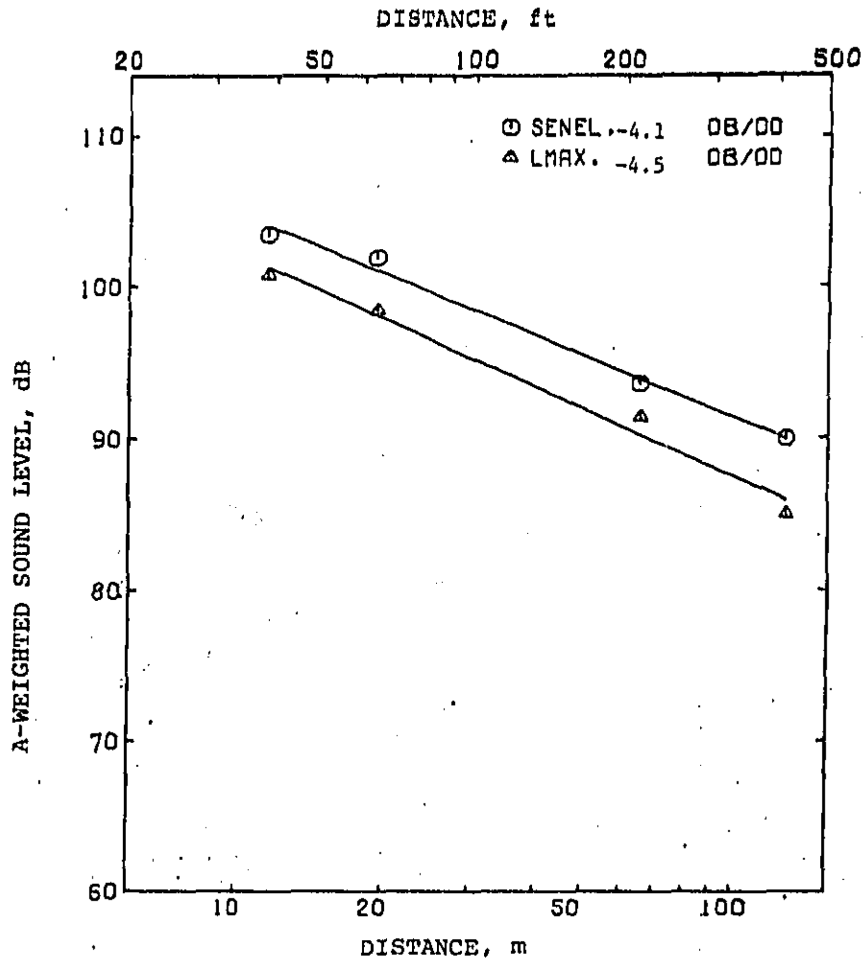


Figure 15b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 6955.

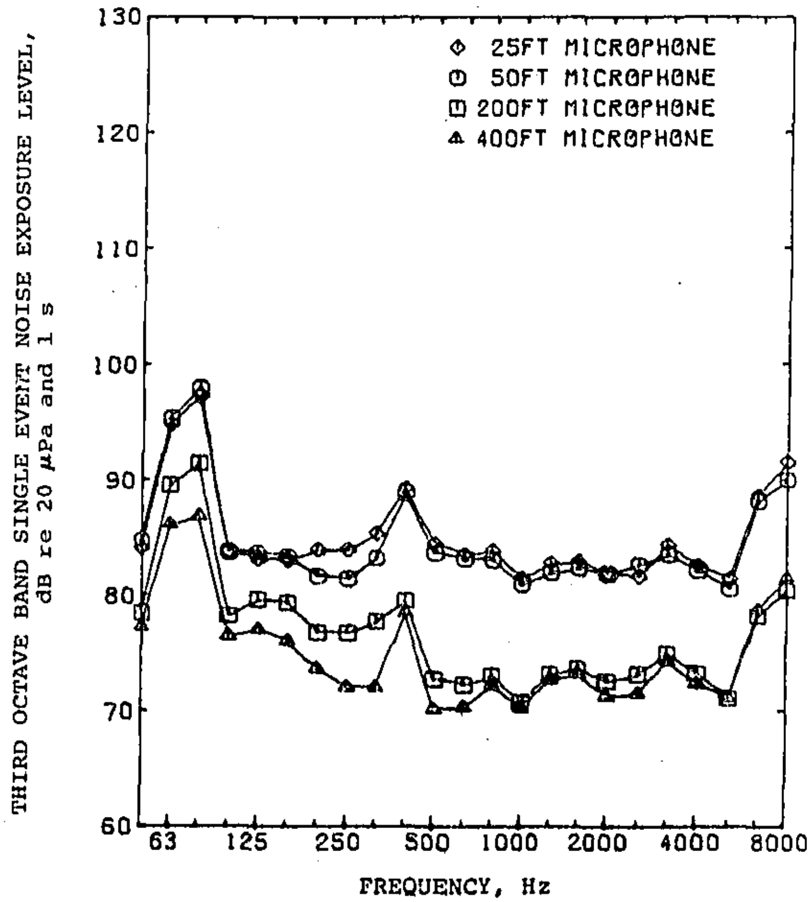


Figure 16a. Single event noise exposure level versus frequency for train no. 5983.

LOCOMOTIVES	EMPTY CARS	LOADED CARS	SPEED (FT/SEC)	WEIGHT (TONS)	LENGTH (FEET)
1	2	2	36	500	260

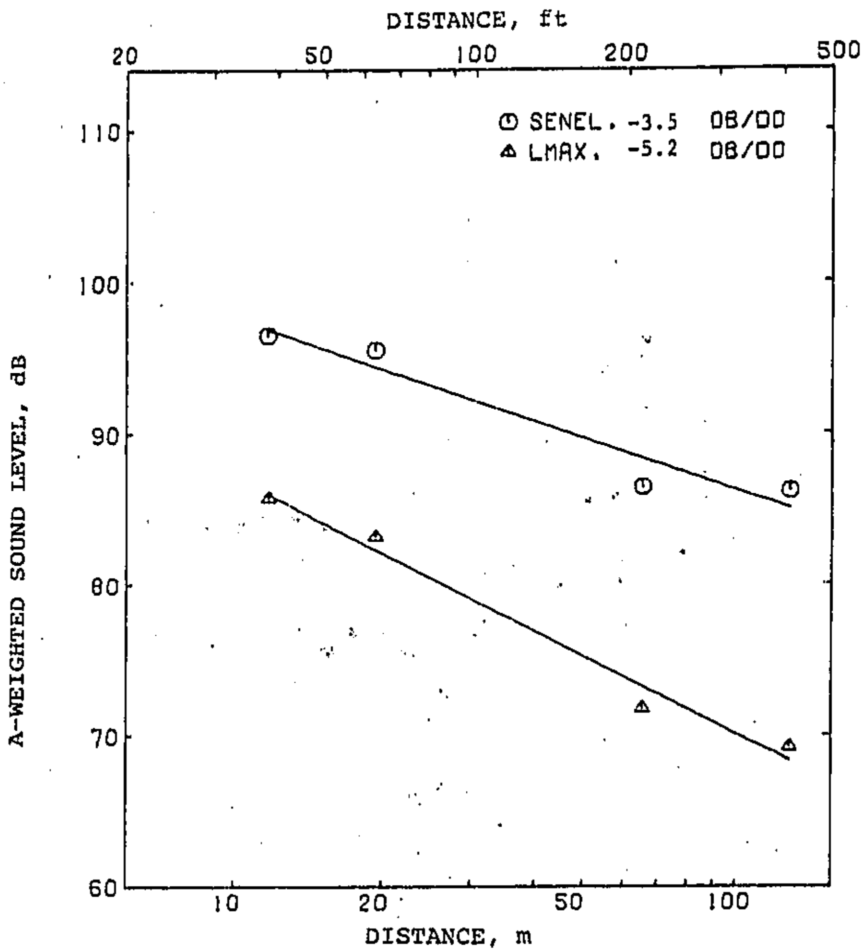


Figure 16b. Maximum A-weighted sound level (in dB re 20 μPa) and A-weighted SENEL (in dB re 20 μPa and 1 second) versus distance for train no. 5983.

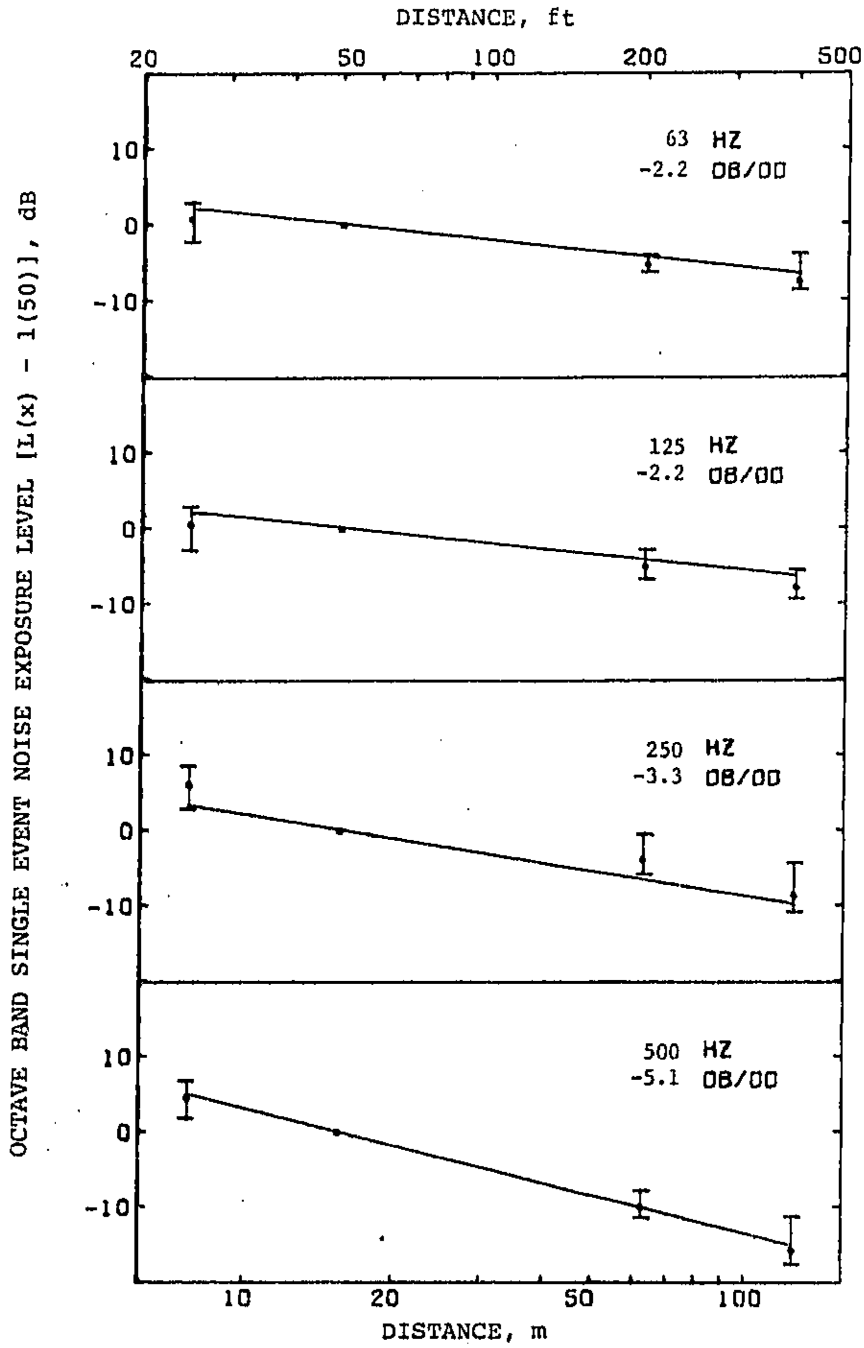


Figure 17a. Octave Band SENEL [L(x) - L(50)] versus distance for west bound trains.

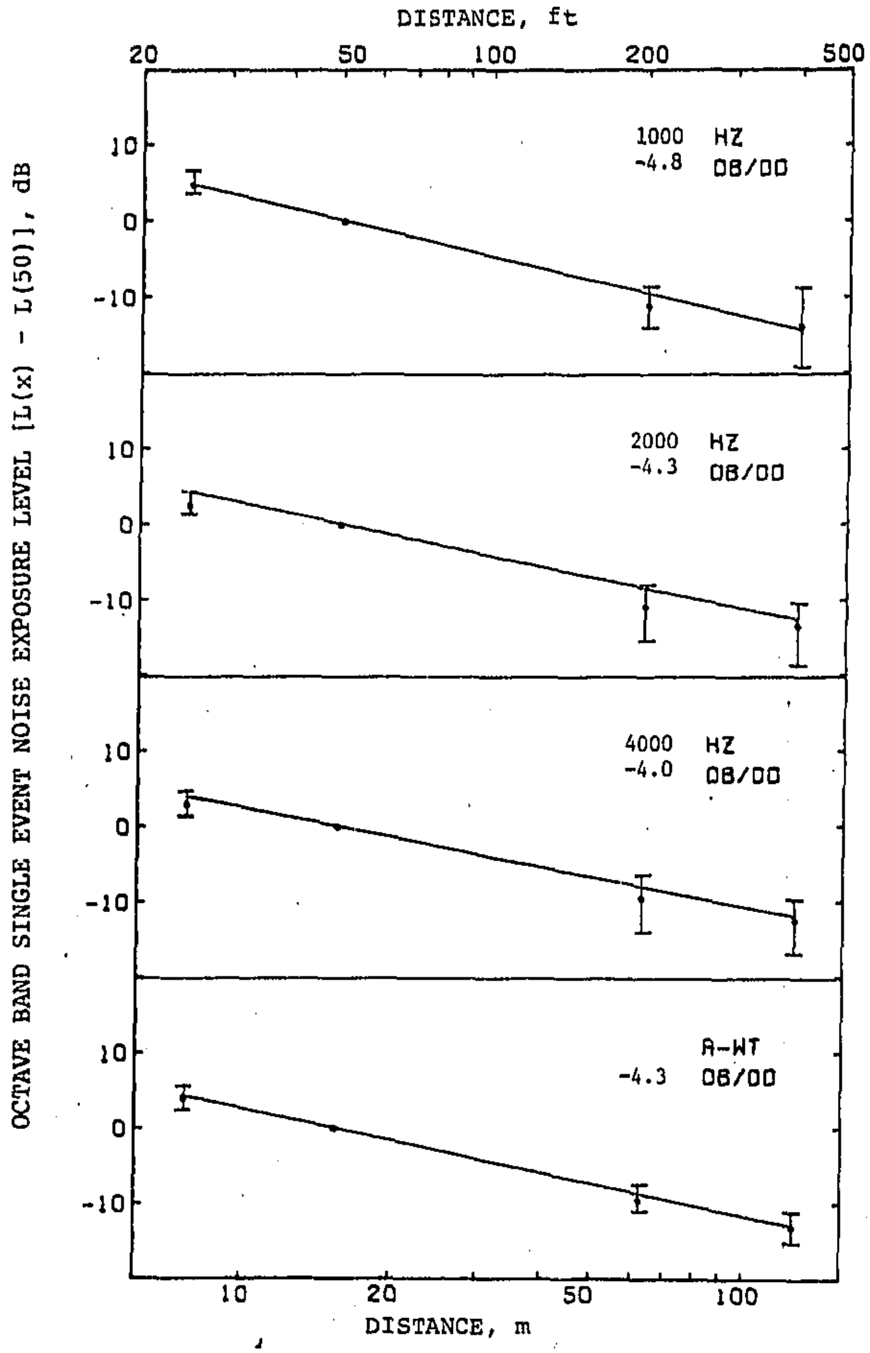


Figure 17b. Octave band SENEL [L(x) - L(50)] versus distance for west bound trains.

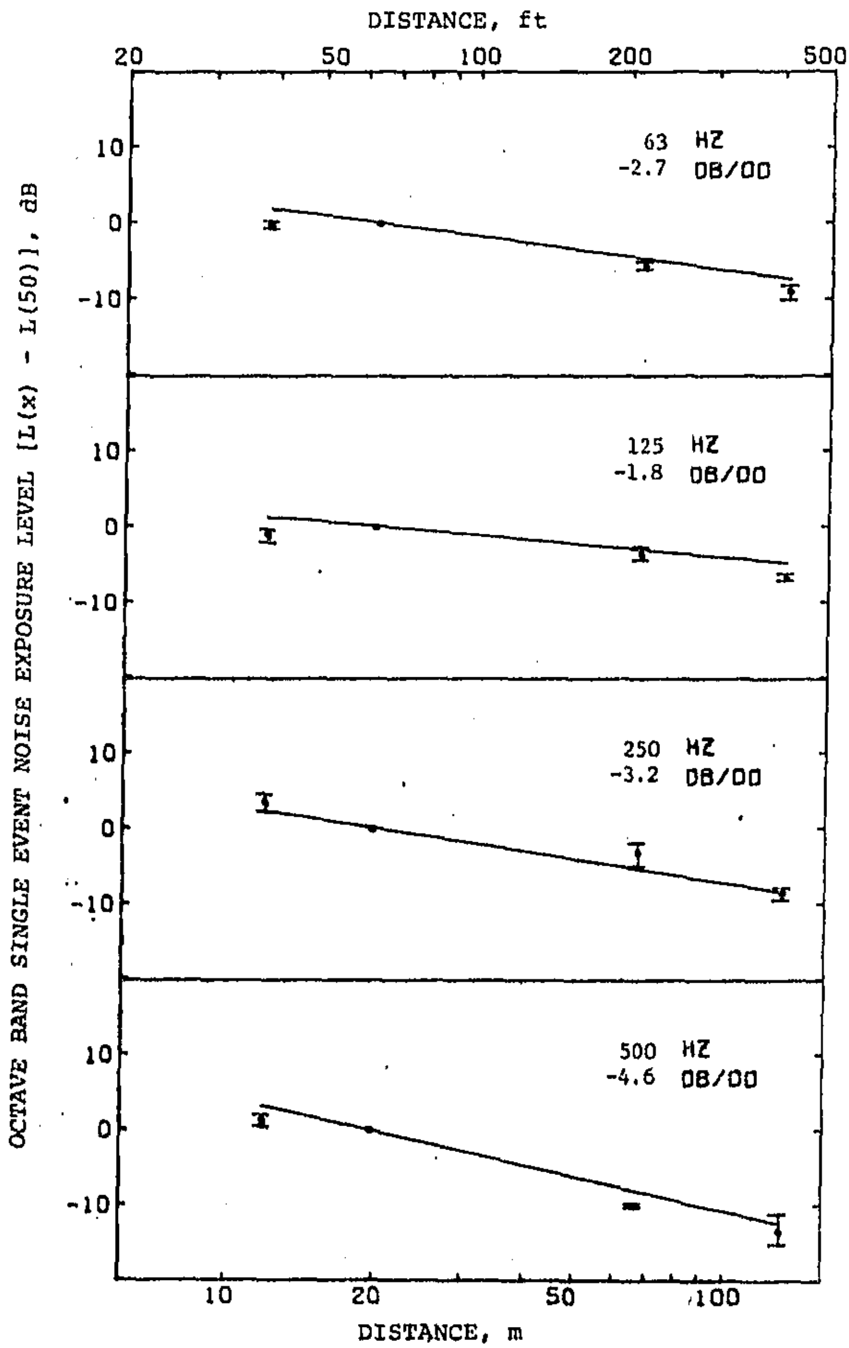


Figure 16a. Octave band SENEL [L(x) - L(50)] versus distance for east bound trains.

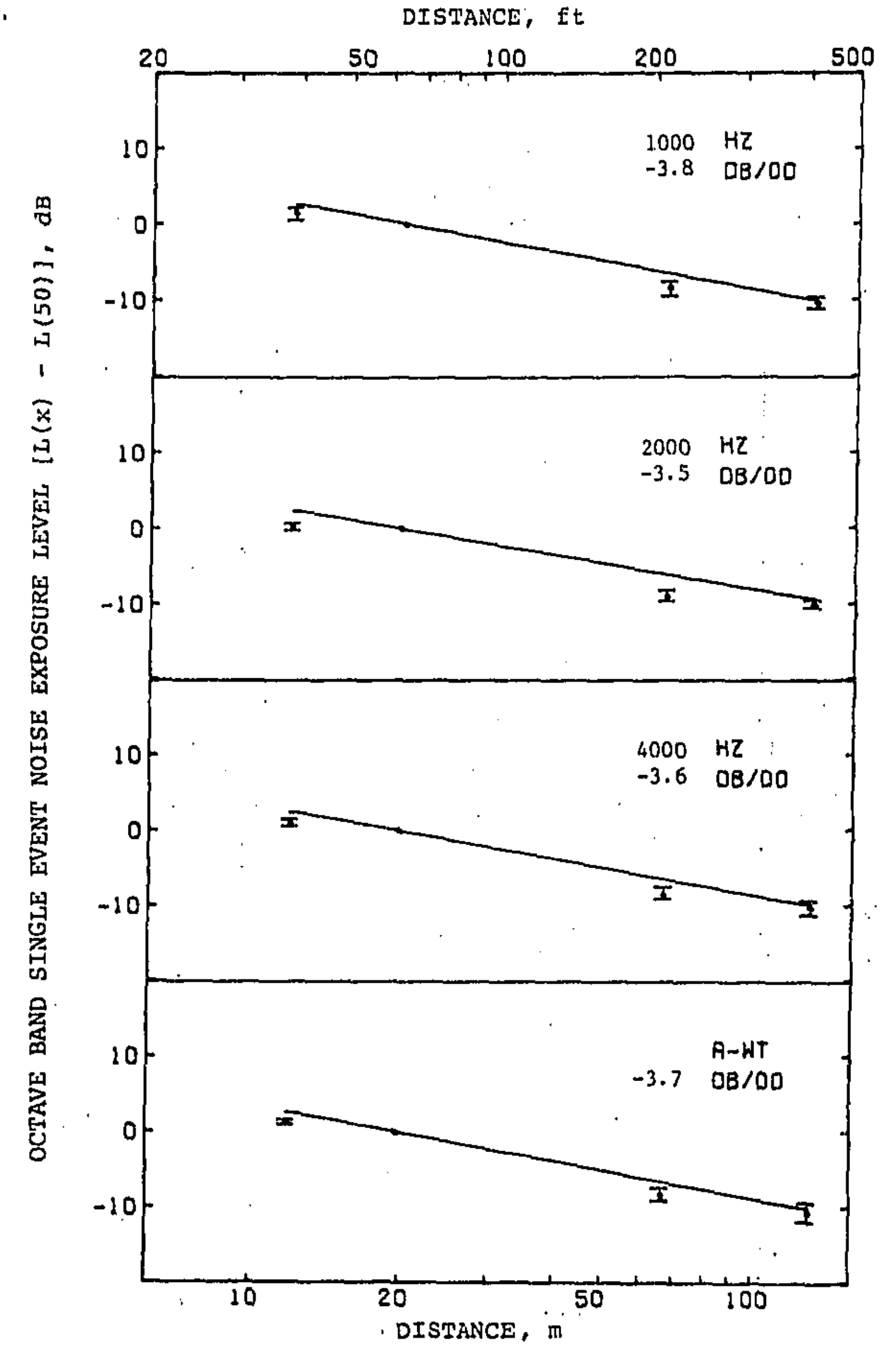


Figure 18b. Octave band SENEL [L(x) - L(50)] versus distance for east bound trains.

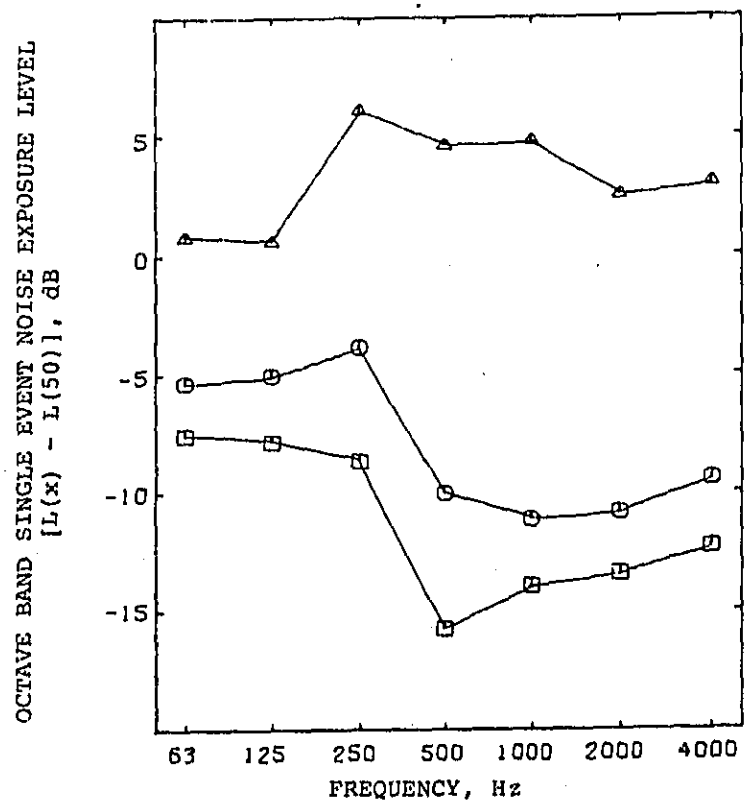
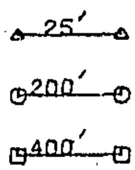


Figure 19. Octave band SENEL [L(x) - L(50)] versus frequency for west bound trains.



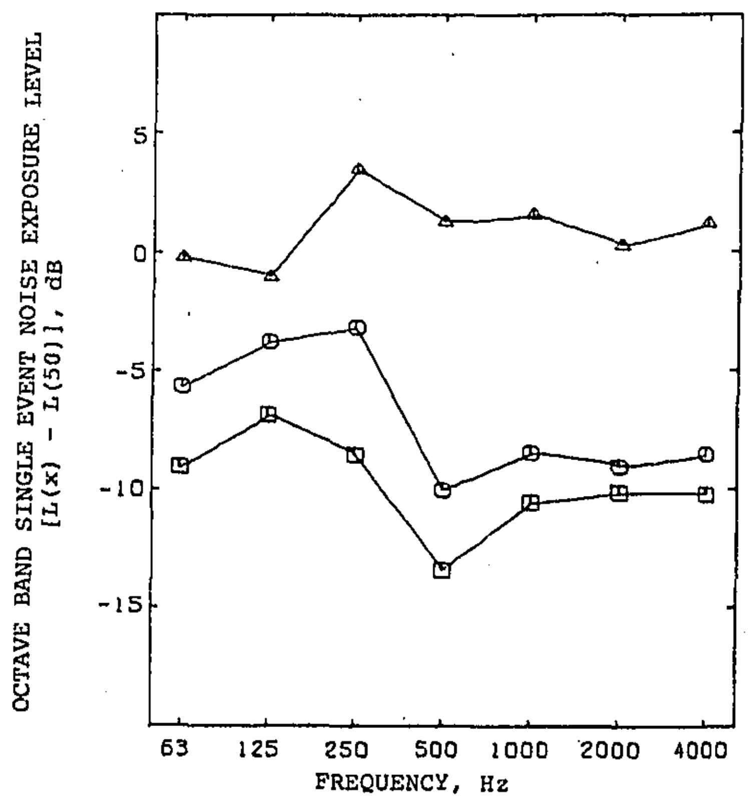


Figure 20. Octave band SENEL [L(x) - L(50)] versus frequency for east bound trains.

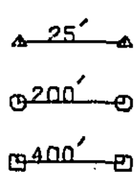


Table 3. Characteristics of trains on the main line during measurements made utilizing the vertical microphone array.

Train*	Direction	Locomotives	Empty Cars	Loaded Cars	Speed Ft/sec	Weight Tons	Length Feet
3692	West	4	74	46	39	6682	6032
6964	West	2	0	0	44	300	136
6493	East	1	2	2	30	500	260
4100	East	2	313	0	41	4230	6424
4157**	East	3	0	118	44	7730	5868
4108**	West	3	0	68	52	4730	3468
6955**	East	2	4	29	33	2900	1720
6964**	West	2	0	0	44	300	136
9910***	East	4	0	0	87	236	349
1456***	East	1	3	0	107	239	349
9911***	East	4	0	0	88	236	349

*The numbers refer to the identification numbers of the lead locomotives.
**Simultaneous Passby
***Commuter Trains

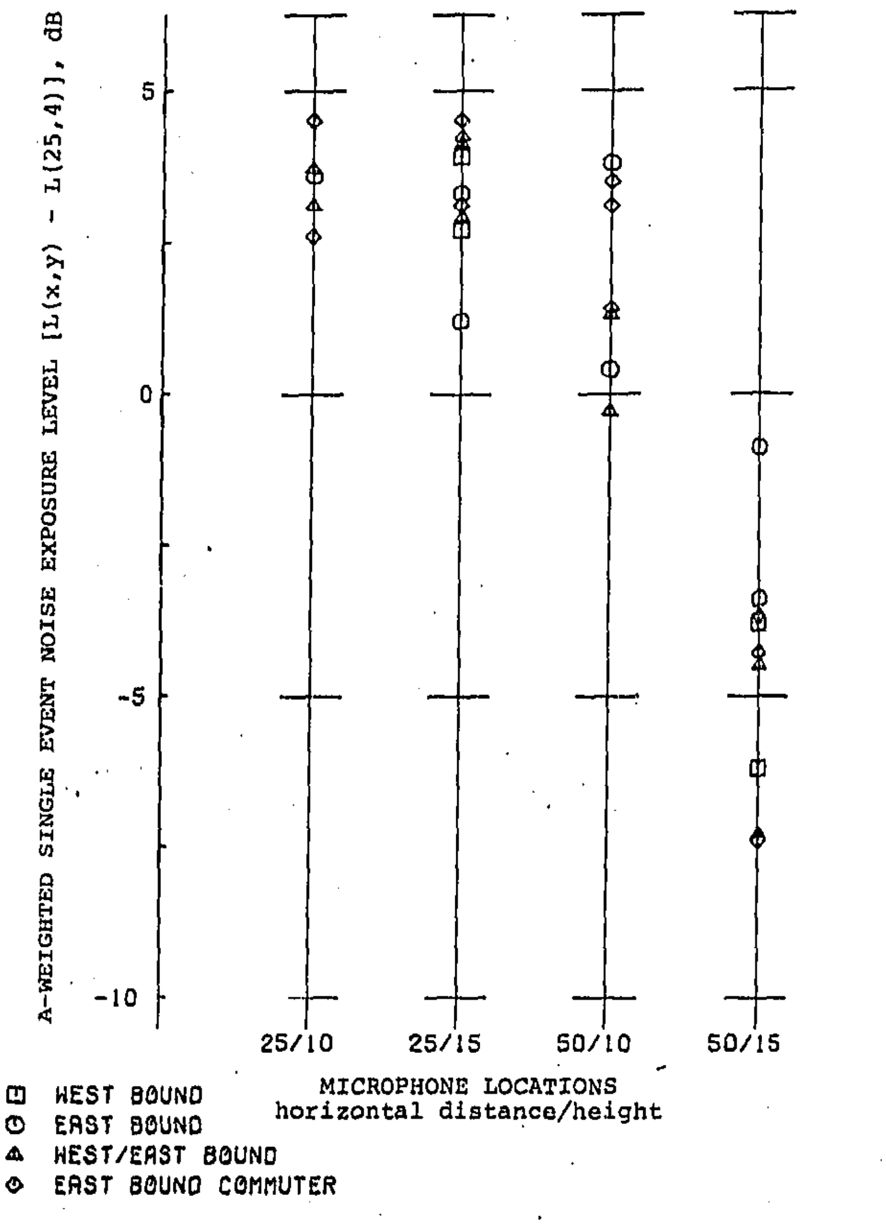


Figure 21. A-weighted SENEL [L(x,y) - L(25,4)] for various microphone locations.

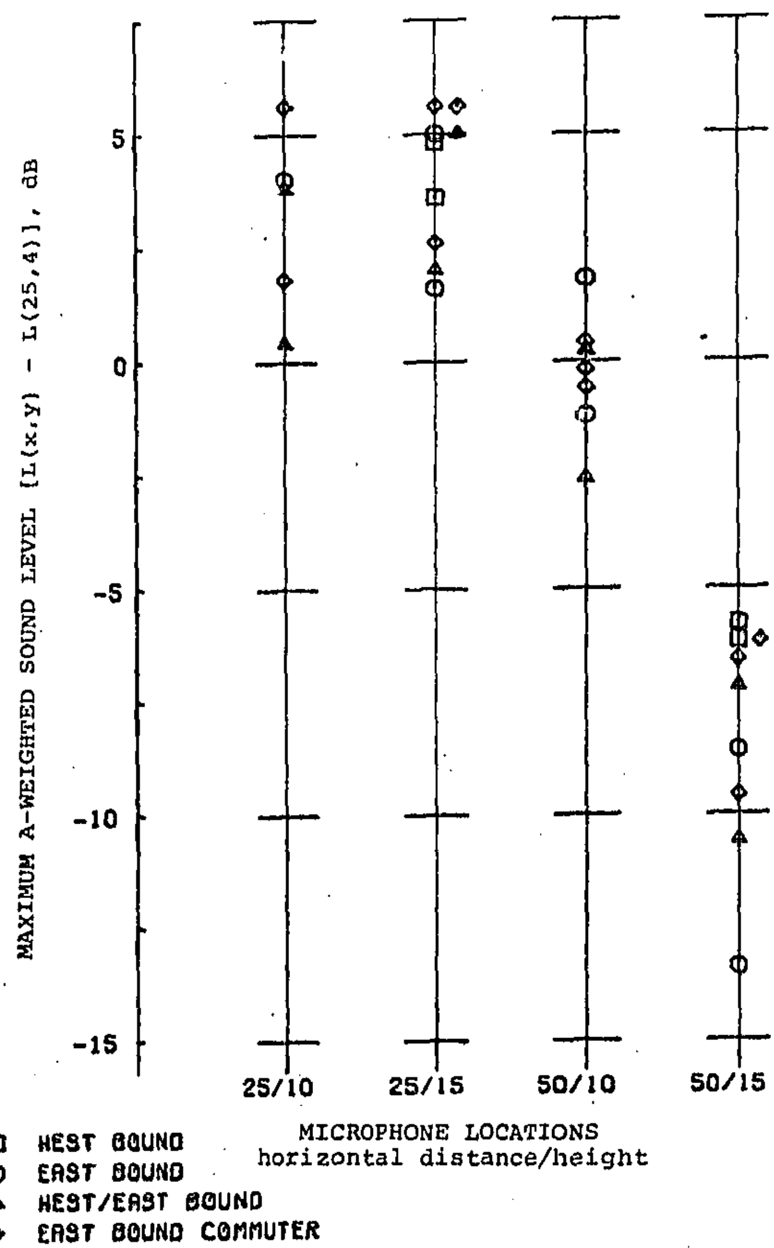


Figure 22. Maximum A-weighted sound level [L(x,y) - L(25,4)] for various microphone locations.

2.2.1. Field Test Site (Yard)

Rail yard measurements were made at the Norfolk and Western Railroad Terminal located in Roanoke, Virginia. The Roanoke terminal is the eastern hub of the Norfolk and Western Railway system and as such is operated on a 24-hour, 7 days per week basis. The following statistics are presented to provide an indication of the size and activity of the facility:

- There is an average of 4500 cars handled daily through the terminal, with peak loads near 6500 cars. An average of over 85 trains arrive and depart Roanoke on a daily basis.
- Approximately 2100 cars each day are classified over the dual hump (master retarders).
- The classification yard contains 55 classification tracks with a capacity of approximately 1950 cars.
- The receiving yard contains 20 tracks with a capacity of approximately 2000 cars.
- The hump computer controls 2 master, 2 intermediate, and 9 group retarders, and 65 switches.
- The terminal contains 228 miles of track.

A reduced reproduction of a detailed map of the Roanoke Yards is shown in Figure 23. Superimposed on the map are the microphone positions at the yard perimeter (locations A1, A2, B1 and B2) and within the yard (location C) which were utilized for rail yard measurements.

2.2.2. Test Procedure (Yard)

Measurements were made at four locations (designated A1, A2, B1 and B2) along the boundary of the Roanoke train yard and at one location (designated C) within the yard.

Microphone positions A1 and A2 were selected because of their proximity to the intermediate and group retarders and the car coupling area respectively. Figure 24 shows an overview of this area with microphone number A1 in the foreground. The two microphones at location A were mounted on tripods at a height of 5 feet above the ground. They were located at the edge of an embankment which was approximately 50 to 60 feet above the level of the track bed of the nearest track. The line-of-sight distances from the microphones to the edge of the nearest track were 65 and 81 feet for locations A1 and A2 respectively.

At microphone positions B1 and B2 (see Figure 25) the microphones were also mounted 5 feet above the ground at the edge of an embankment. At this

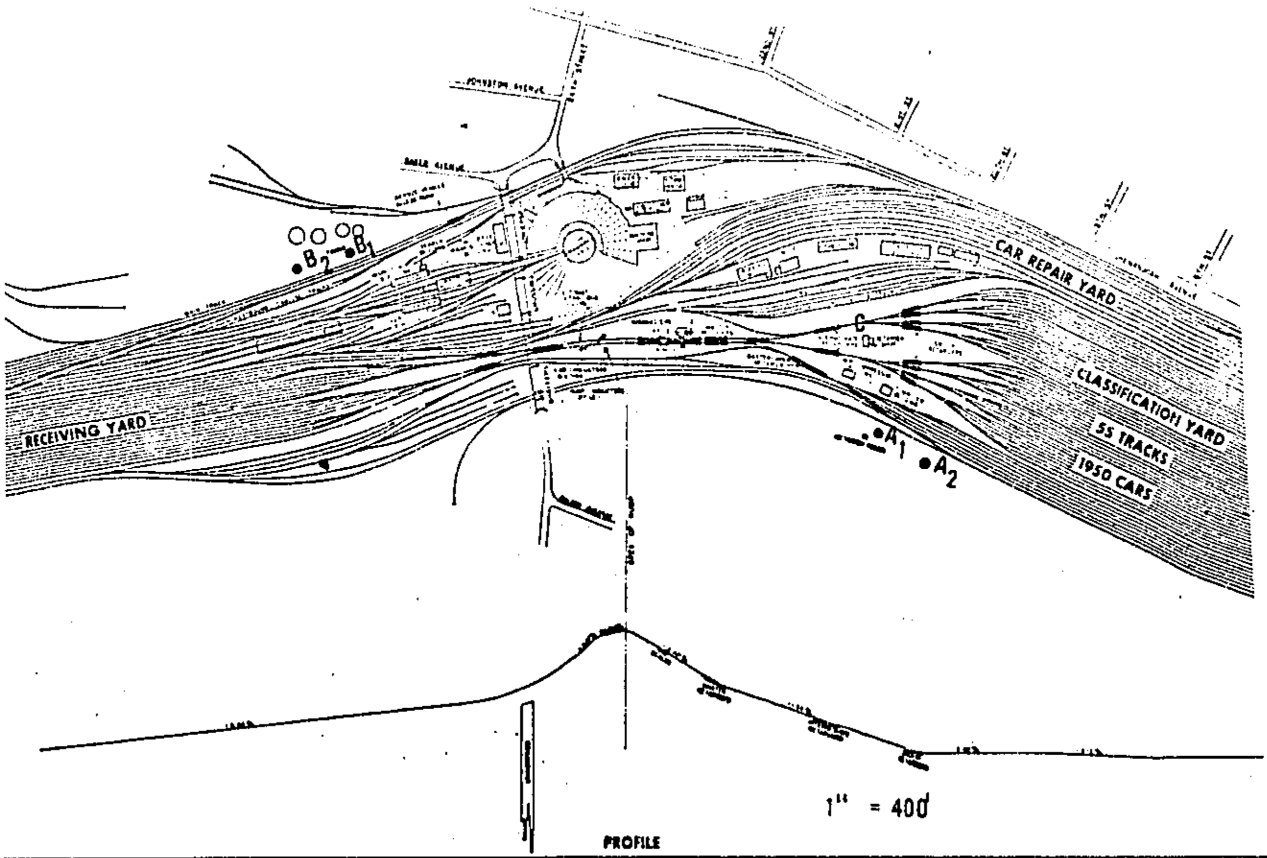


Figure 23. Layout of the Norfolk and Western Railroad Terminal, Roanoke, Virginia, showing microphone locations, designated A1, A2, B1, B2, and C, for rail yard noise measurements.

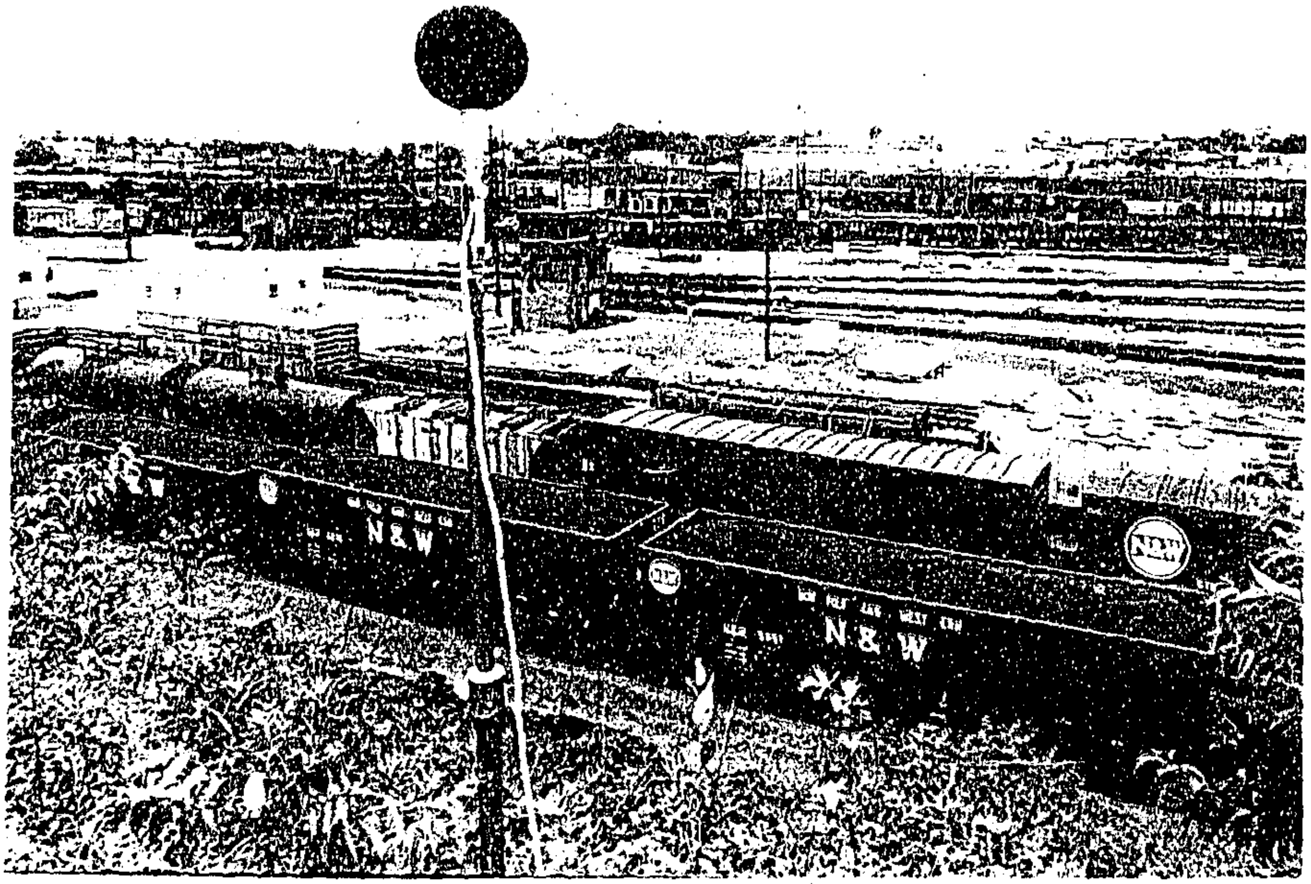


Figure 24. Overview of the retarder and car coupling areas of the Roanoke train yard showing microphone position A1.

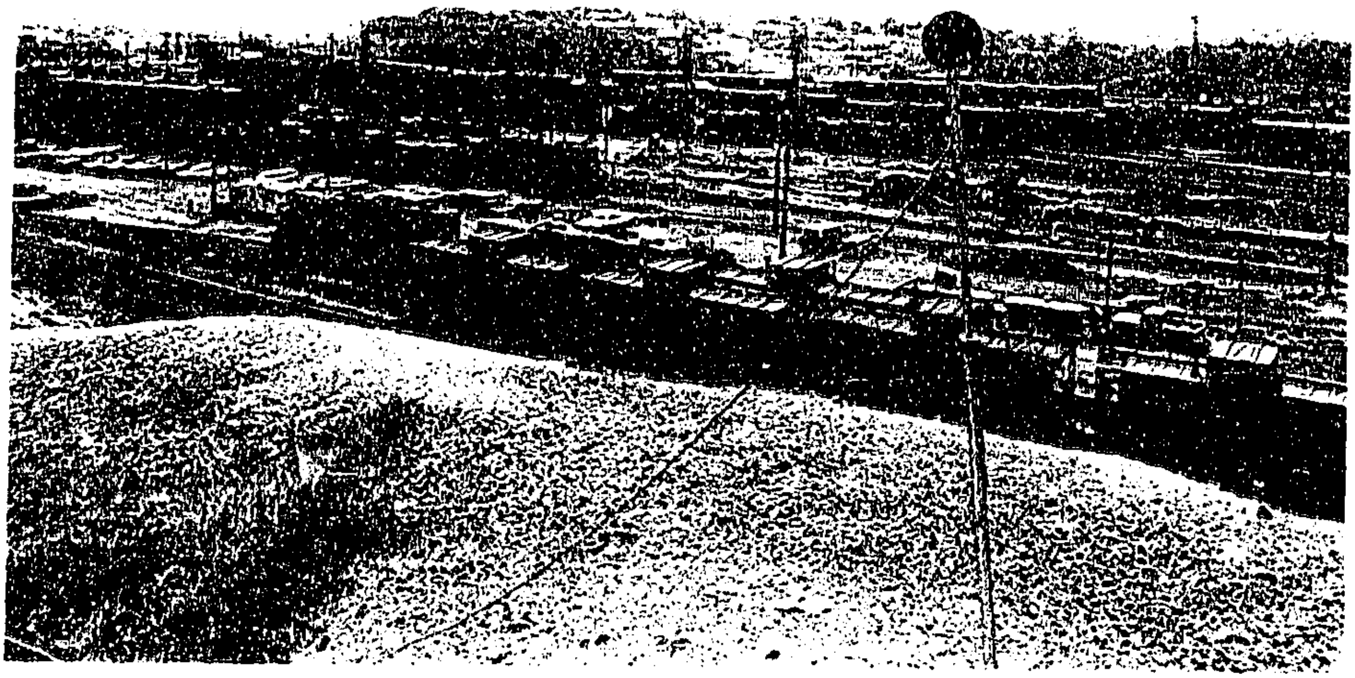


Figure 25. Overview of the engine idling area of the Roanoke train yard showing the location of microphone position B1.

location the embankment was 35 to 45 feet above the level of the nearest track. The noise levels measured at this location were dominated by the noise from stationary (idling) and moving locomotives.

In order to gain a better understanding of the noise levels and the directionality patterns of the noise associated with retarders, measurements were also made within the yard interior. This location is designated location C. Figure 26 shows the eight microphone positions utilized. Retarder number 1 was selected as the primary source to be studied; therefore, all positions selected are in relation to this retarder. The noise from retarder number 2 was also measured and dimensions relative to this retarder are also given. Microphone position 1 was established on a line perpendicular to retarder number 1 and 50 foot from the centerline (both longituinal and lateral) of this retarder. Microphone heights of 5, 10 and 15 feet above the ground were utilized at microphone position number 1. A line was then drawn through microphone position number 1 parallel to the long axis of retarder number 1. Microphone positions 2 and 3 were located along this line at an angle of 30° and 45° respectively, in relation to the line from microphone number 1 perpendicular to retarder number 1. At these two positions, microphone heights of 5 and 15 feet were used. A final position, number 4, was located at an angle of 75° but as close to retarder number 1 as possible rather than along the line of microphone positions 1, 2 and 3. At location 4 a single microphone height of 5 feet was utilized. Since various locations and heights were utilized, it was determined that one way to keep track of the positions would be to designate each with an angle and a height which would uniquely define each measurement position. For example, the microphone at the five foot height at position 1 was designated (0°, 5 ft.).

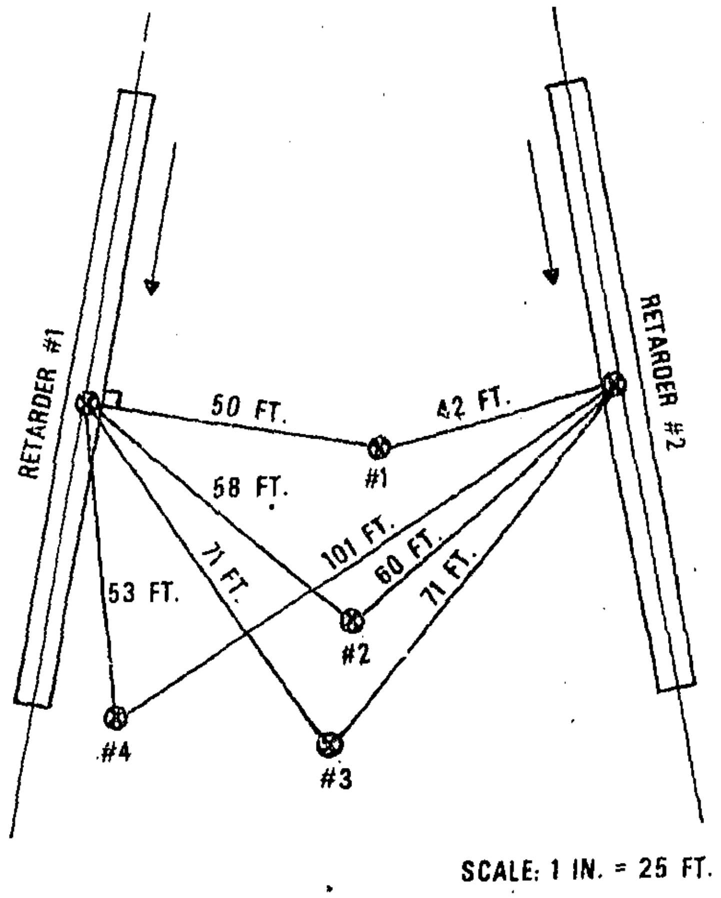
For each measurement two microphones were utilized. One of the microphones was always at the reference position -- location 0°, 5 ft. -- while the other microphone was successively placed at the other seven test positions as indicated in the table of Figure 26. Figures 27 and 28 show the reference microphone (0°, 5 feet) and a test microphone (0°, 10 feet) from two different perspectives showing the area in and around the retarder locations.

2.2.3. Test Results (Yard)

A-weighted sound level measurements were made at the boundary of the rail yard at 0.1 second intervals utilizing a mini-computer-based digital data acquisition system (described in Appendix C). Data were taken for periods of time ranging from 1 to 23 hours over a 7 day period.

Data at positions A1 and A2 were taken from 1200 hours of the 145th day of 1973 until 1000 hours of the 150th day of 1973. At positions B1 and B2, data were taken from 1100 hours of the 150th day of 1973 until 1000 hours of the 151st day. The data resulting from these measurements are presented in this section in the form of the A-weighted sound levels exceeded ten percent of the time (L_{10}) and the energy equivalent A-weighted sound levels (L_{eq}), both plotted as functions of time.

MICROPHONE LOCATIONS



LOCATION	θ	HEIGHT, FT.
#1	0°	5, 10, 15
#2	30°	5, 15
#3	45°	5, 15
#4	75°	5

Figure 26. Measurement location C. Microphone locations near retarders. θ is defined as the angle between lines drawn from microphone number 1 and any other microphone through the intersection of the longitudinal center-line of retarder number 1 with the perpendicular line drawn from microphone number 1 to retarder number 1.

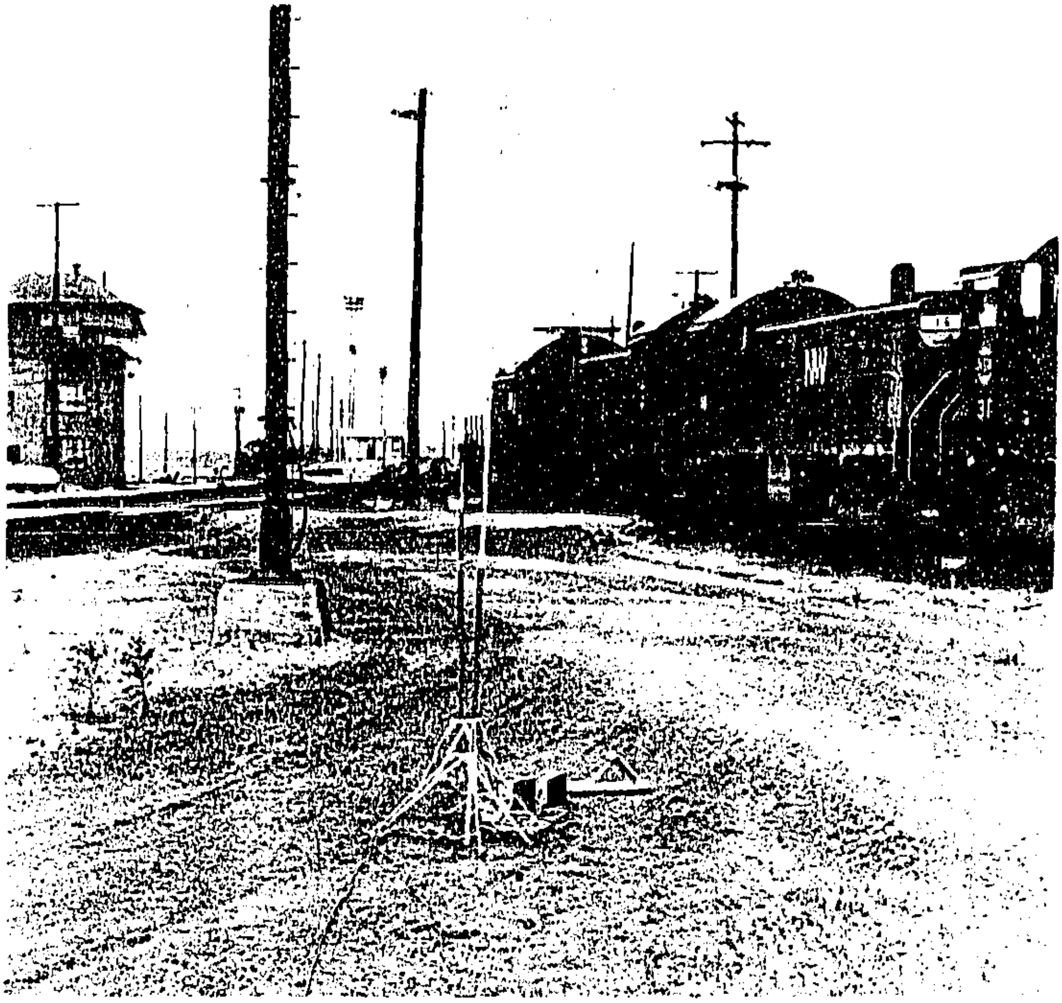


Figure 27. Measurement position C. Retarder number 1 is to the left, retarder number 2 is to the right with the master retarder and hump in the background. The two microphones in this photograph are the reference microphone (θ = 0°, height = 5 feet) and one of the seven test microphones (θ = 0°, height = 10 feet).

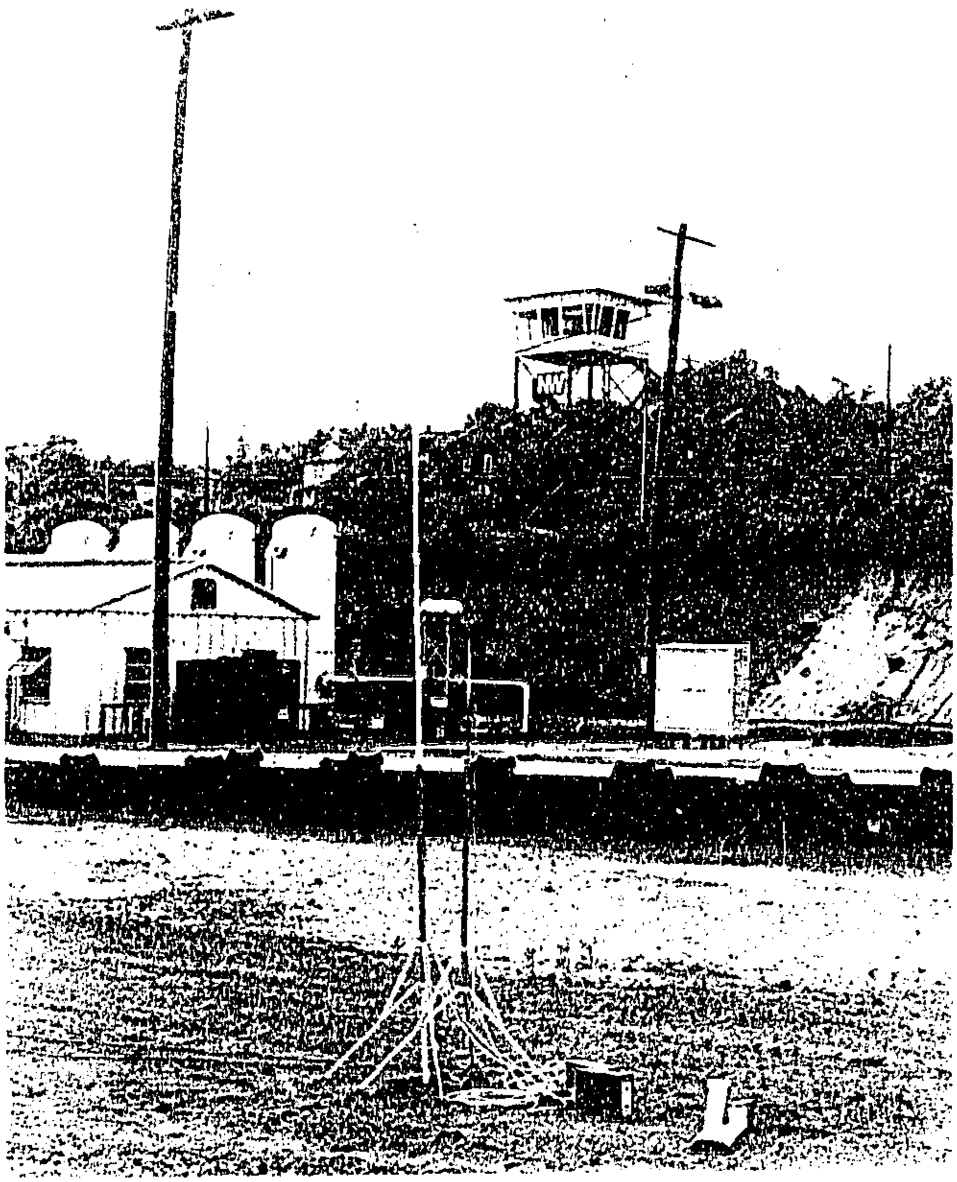


Figure 28. Measurement position C. View of retarder number 1. The two microphones in this photograph are the reference microphone ($\theta = 0°$, height = 5 feet) and one of the seven test microphones ($\theta = 0°$, height = 10 feet).

The energy equivalent noise level, L_{eq}, for a stated period of time is the level of a constant, or steady state, noise which has an amount of acoustic energy equivalent to that contained in the measured time-varying noise. L_{eq} is mathematically defined as:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T}\int_0^T \left(\frac{p}{p_o}\right)^2 dt\right] = 10 \log_{10}\left[\frac{1}{T}\int_0^T 10^{L(t)/10} dt\right], \quad (2)$$

where p is the time-varying, mean-square sound pressure at the point of observation, L is the corresponding sound level, p_o is the standard reference pressure (20 micropascals) and T is the period of integration. [5]

The A-weighted L_{10} sound levels at locations A1 and A2 are presented in Figures 29a-34a for days 145 - 150. The hourly equivalent A-weighted sound levels, i.e., L_{eq} for each hour, for locations A1 and A2 for days 145 - 150 are presented in the complementary Figures 29b - 34b. Similar data for measurement locations B1 and B2 are presented in Figures 35a - 36b. The data points on these plots represent the cumulative noise level during the preceding hour; that is, the data point at 1200 hours represents the noise which occurred between 1100 and 1200 hours. The lack of data at certain hours on these plots is due either to inclement weather or electrical power failures or power fluctuations which affected the data acquisition system at the field test site.

To provide some indication of the correlation between specific activity within the yard and the L_{10} and L_{eq} sound levels measured at the boundary of the railyard, retarder activity from 1600 hours on day 149 until 0900 hours on day 150 has been summarized in Table 4. Since measurement locations A1 and A2 along the railyard boundary were in the vicinity of the active retarders, the operations can easily be compared with the corresponding values of L_{10} and L_{eq} A-weighted sound levels for these days as shown in Figures 33a, 33b, 34a and 34b.

The data contained on plots 29a - 36b are compressed into two summary plots (Figures 37 and 38) which show the L_{10} and L_{eq} A-weighted sound levels for the total time period (days 145-151). Note that the data prior to 1100 hours of day 150 was for location A while data after this time was for location B.

It is important at this time, on the basis of these data, to examine the relationship between L_{10} and L_{eq} and evaluate the appropriateness of the two measures as descriptors of the noise emanating from railroad yards. Figures 39 and 40 show plots of L_{10} versus L_{eq} at microphone positions A1

[5] The procedure by which the L_{eq} integral was evaluated from the digital data is discussed in Appendix B.

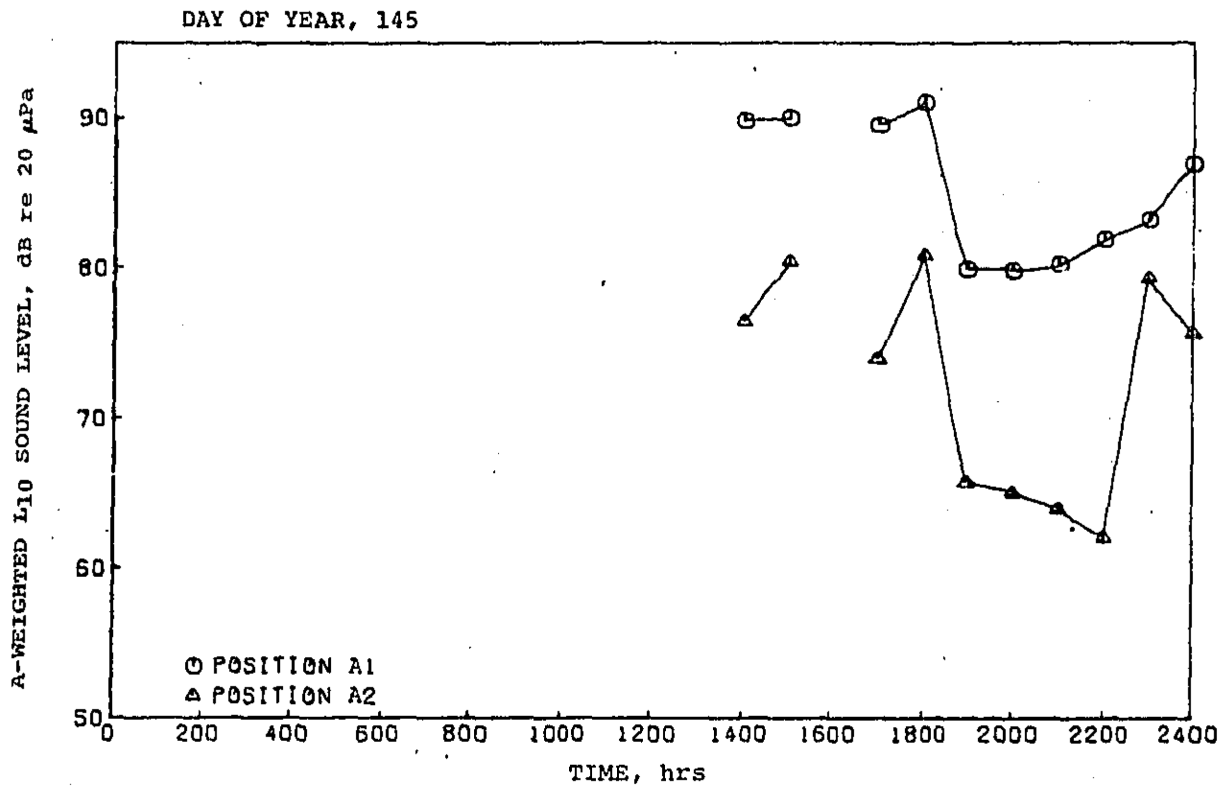


Figure 29a. A-weighted L_{10} sound level versus time.

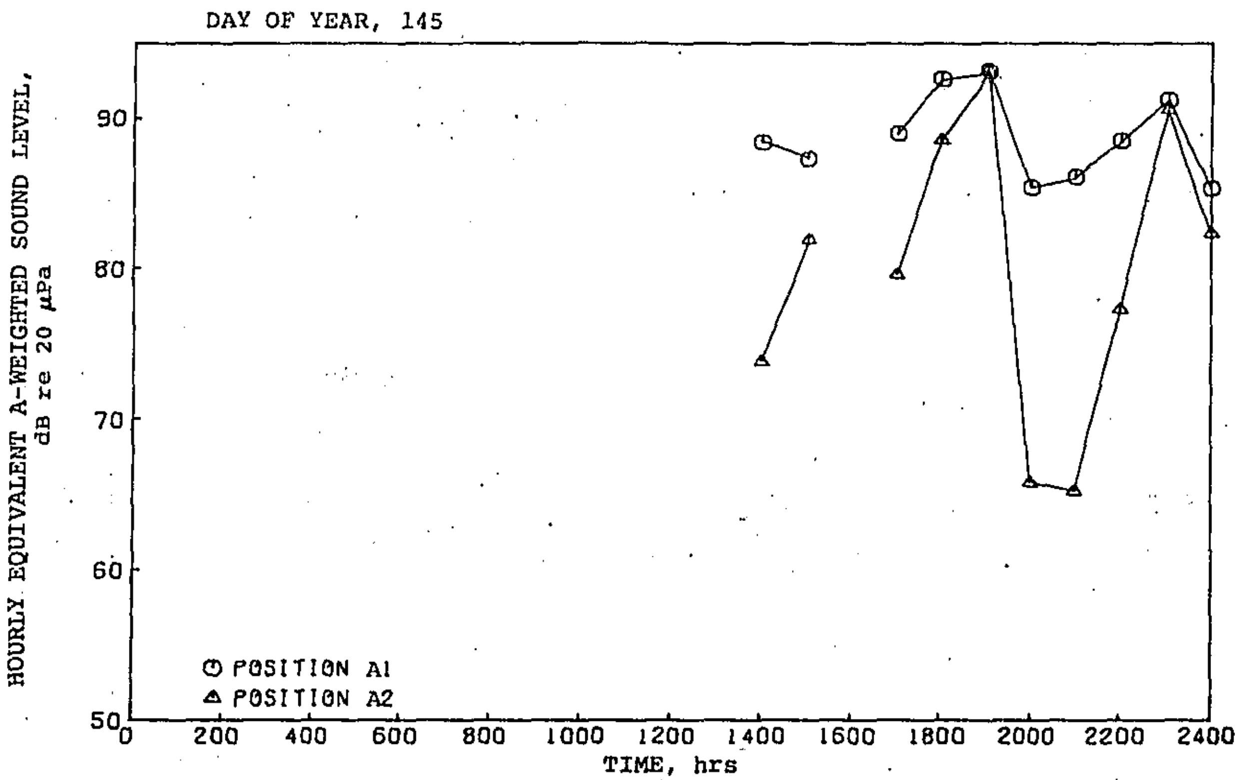


Figure 29b. Hourly equivalent A-weighted sound level versus time.

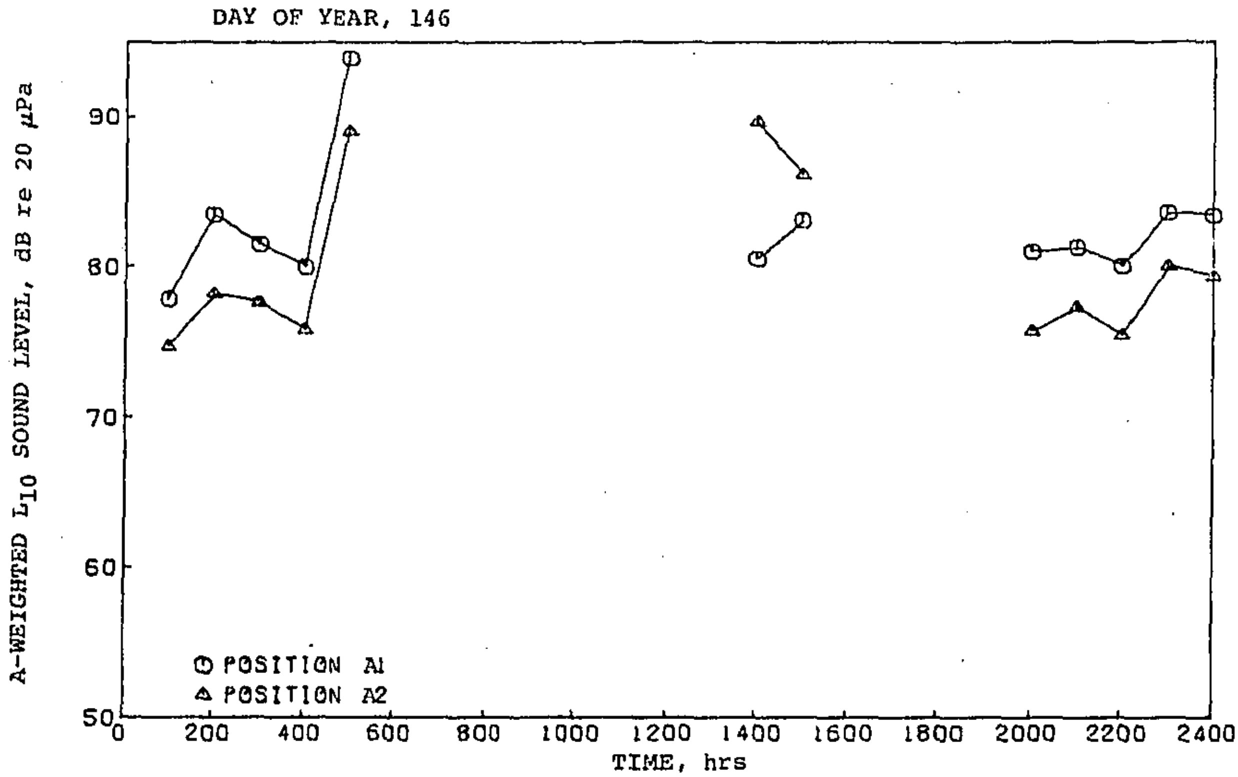


Figure 30a. A-weighted L_{10} sound level versus time.

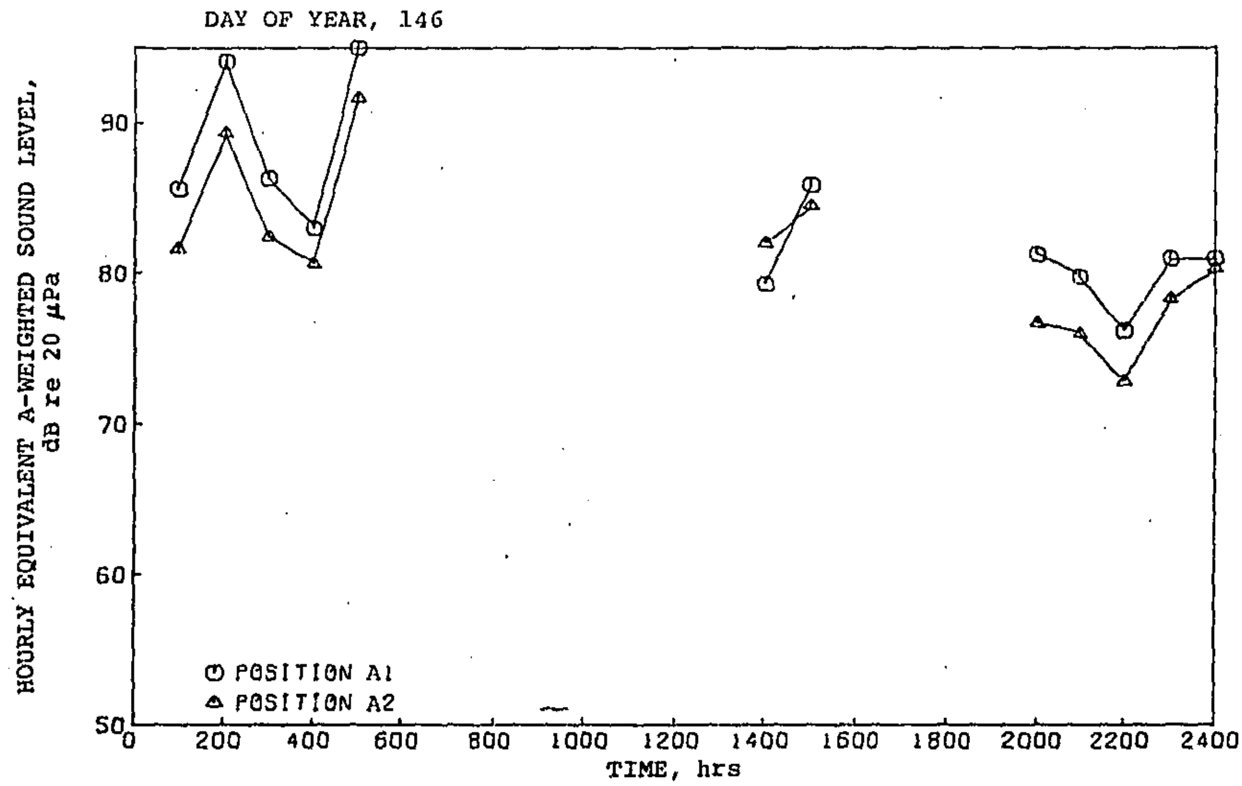


Figure 30b. Hourly equivalent A-weighted sound level versus time.

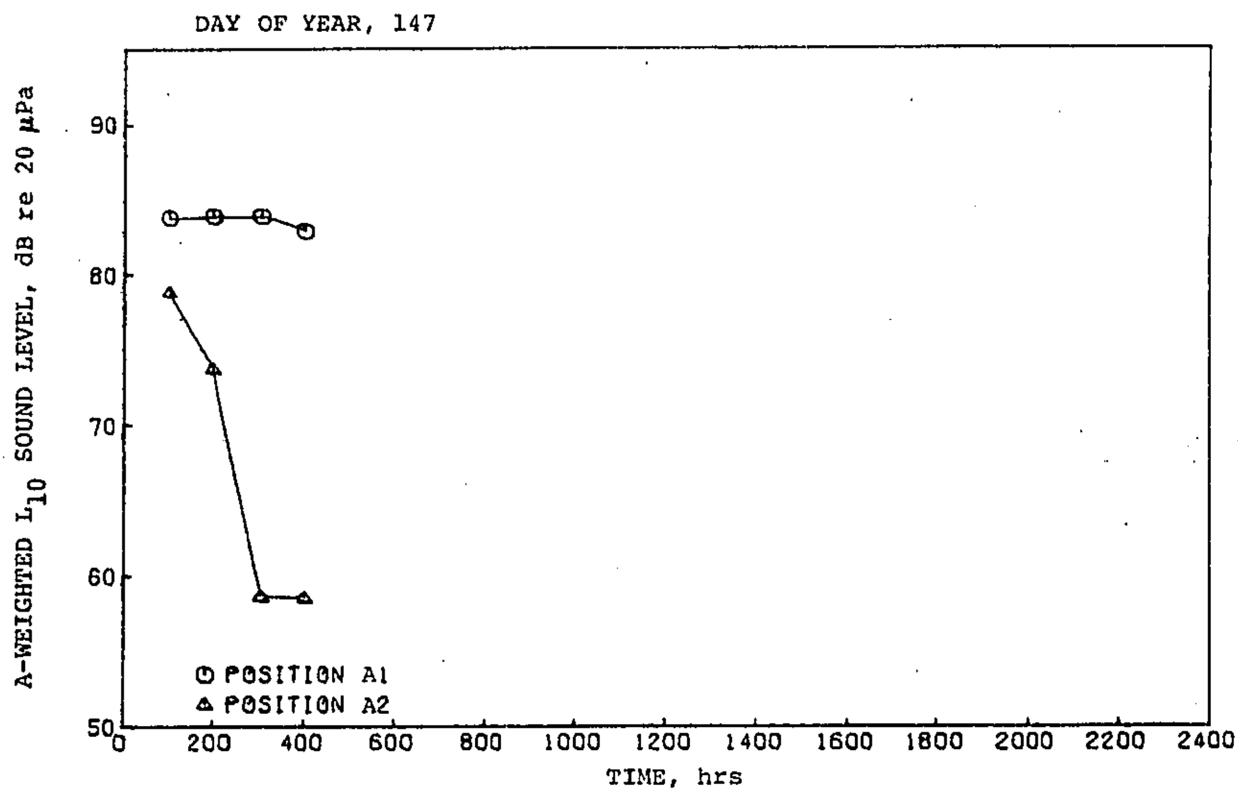


Figure 31a. A-weighted L_{10} sound level versus time.

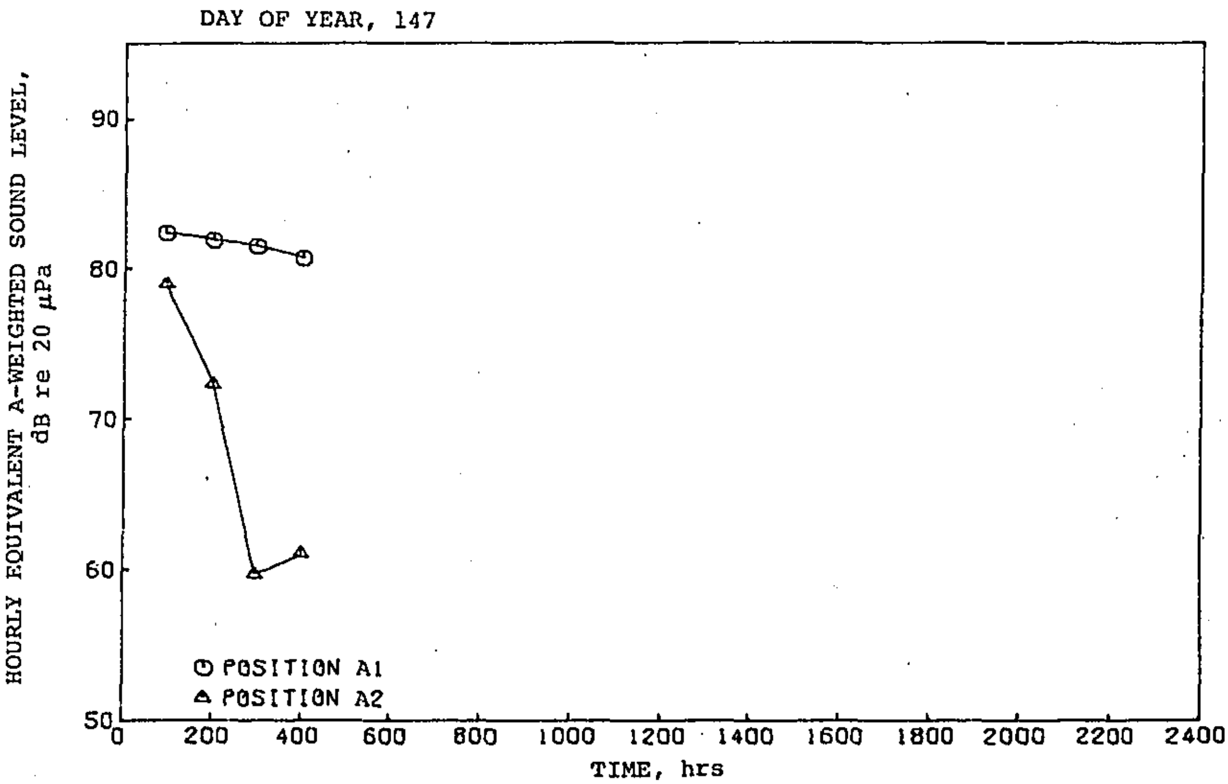


Figure 31b. Hourly equivalent A-weighted sound level versus time.

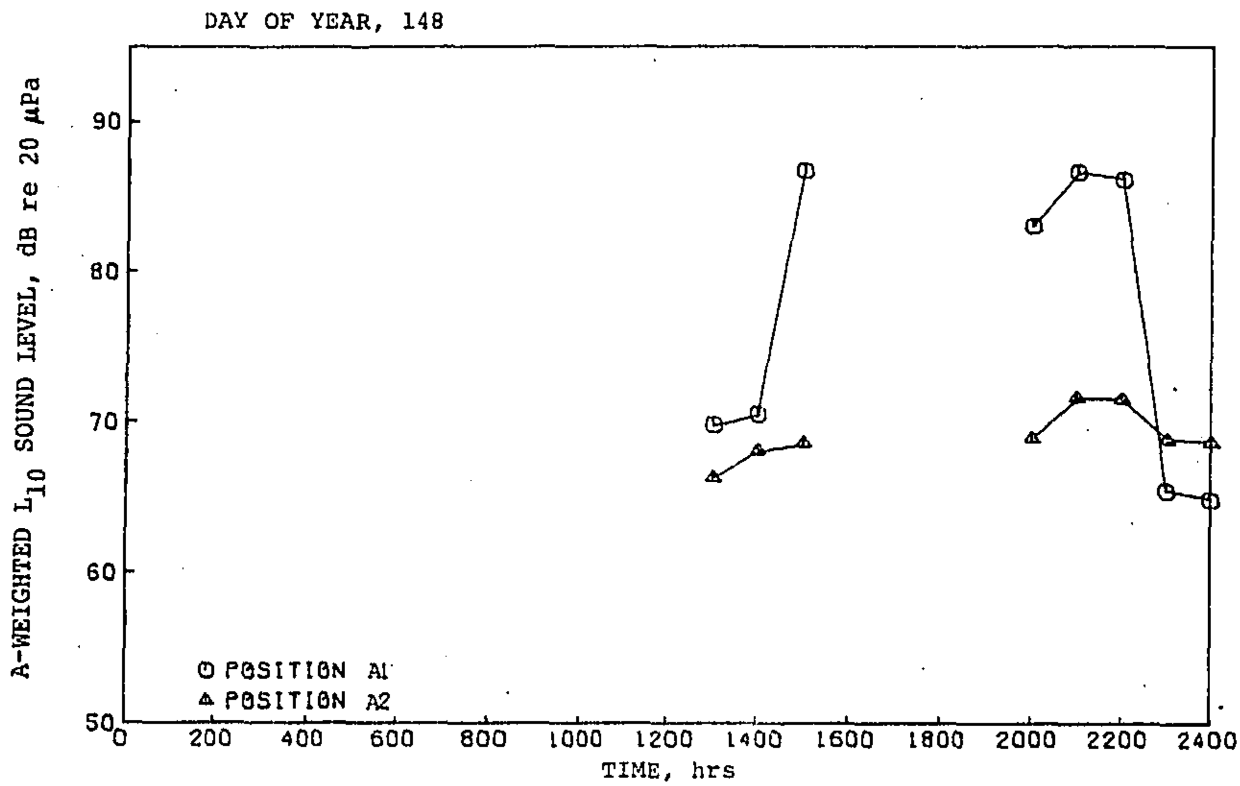


Figure 32a. A-weighted L_{10} sound level versus time.

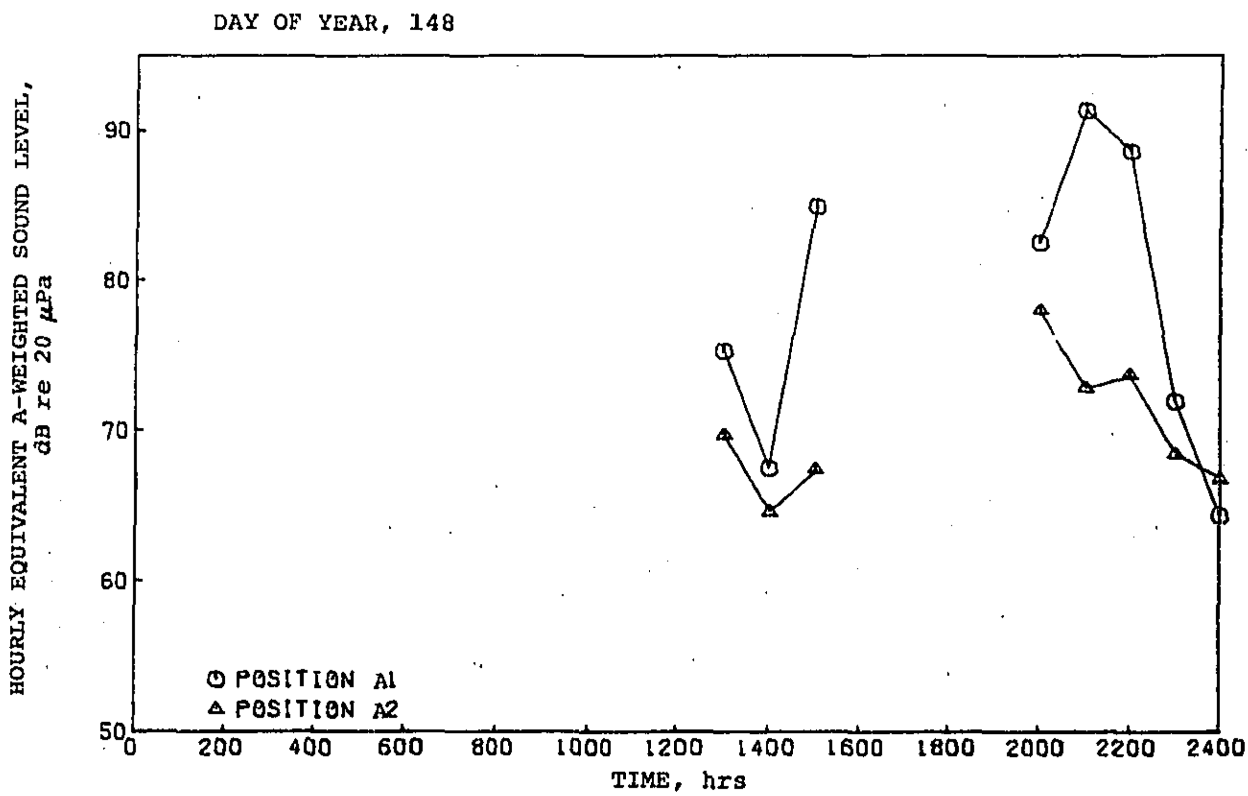


Figure 32b. Hourly equivalent A-weighted sound level versus time.

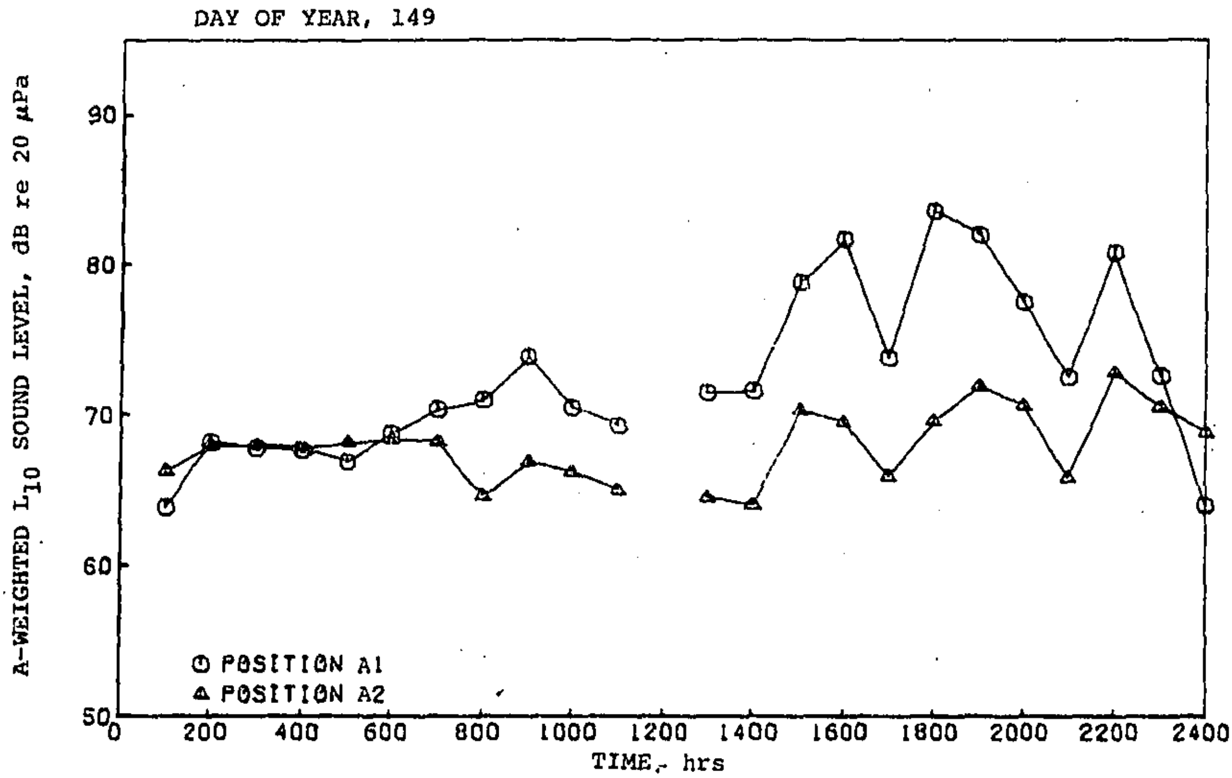


Figure 33a. A-weighted L_{10} sound level versus time.

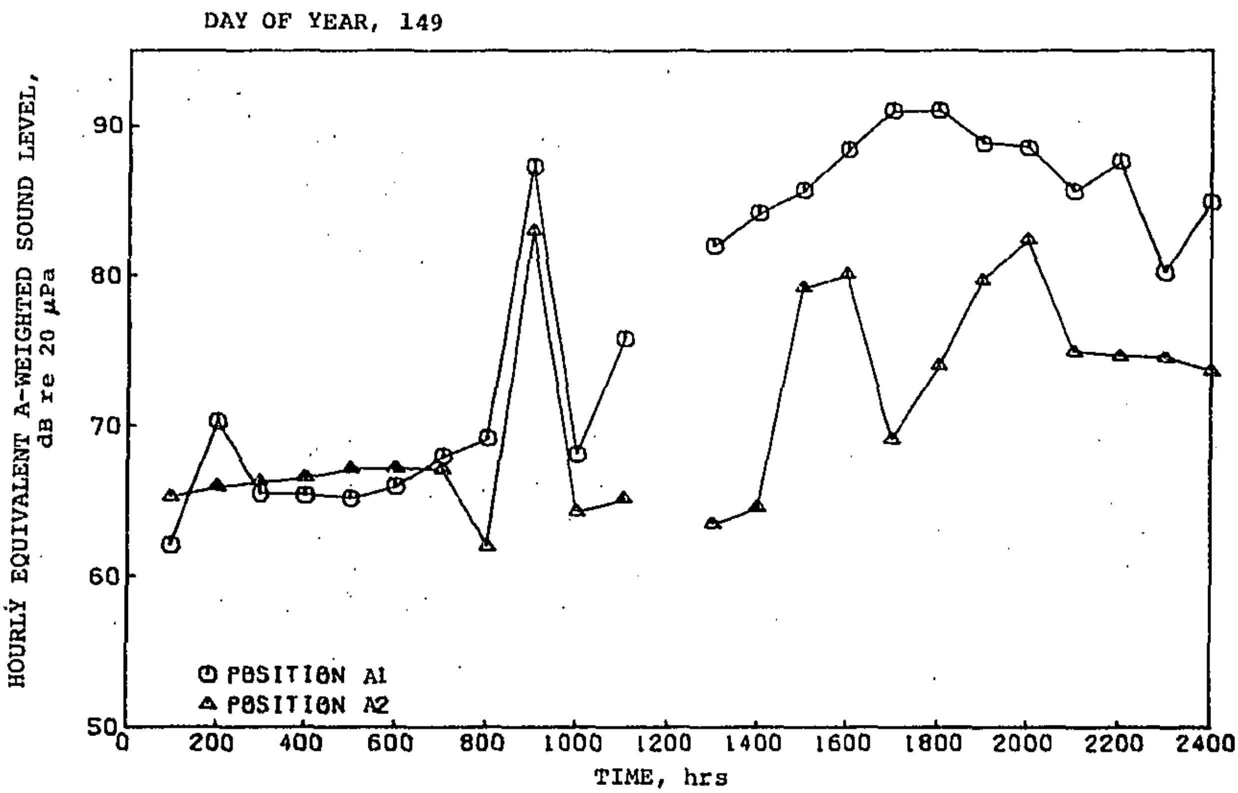


Figure 33b. Hourly equivalent A-weighted sound level versus time.

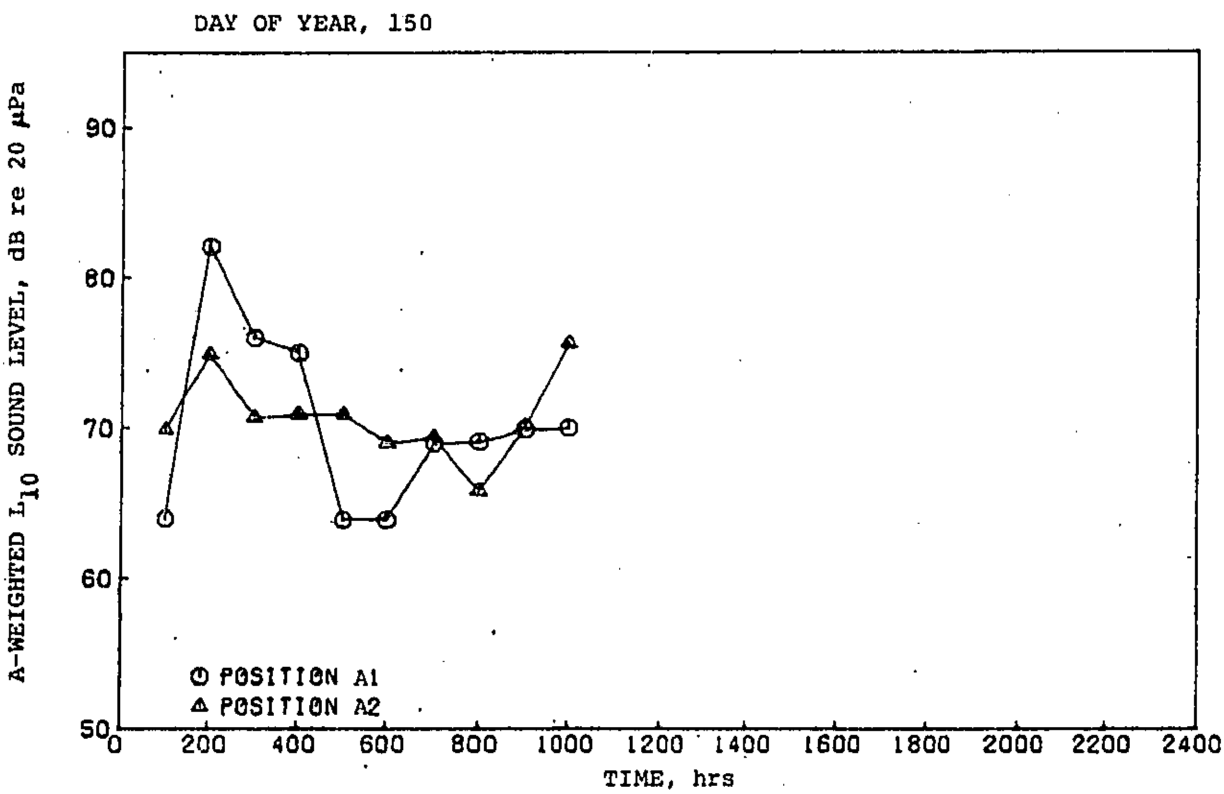


Figure 34a. A-weighted L_{10} sound level versus time.

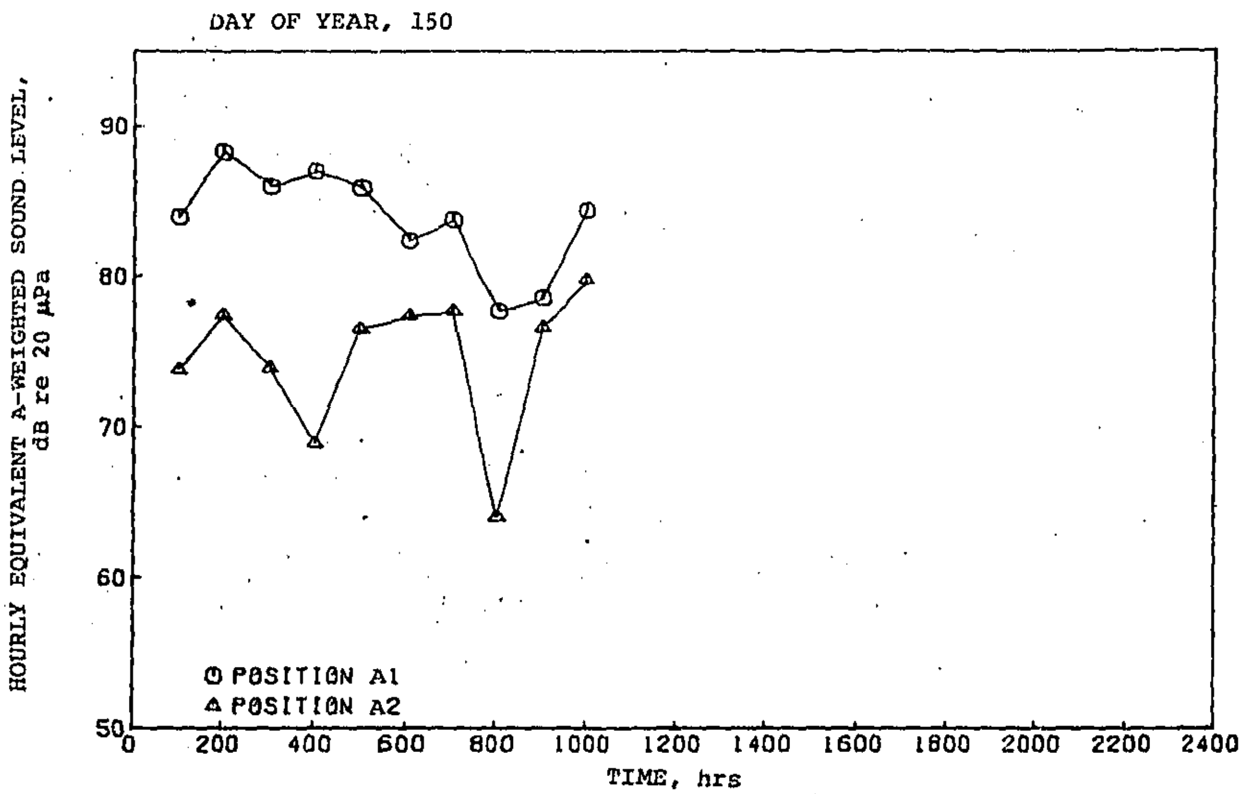


Figure 34b. Hourly equivalent A-weighted sound level versus time.

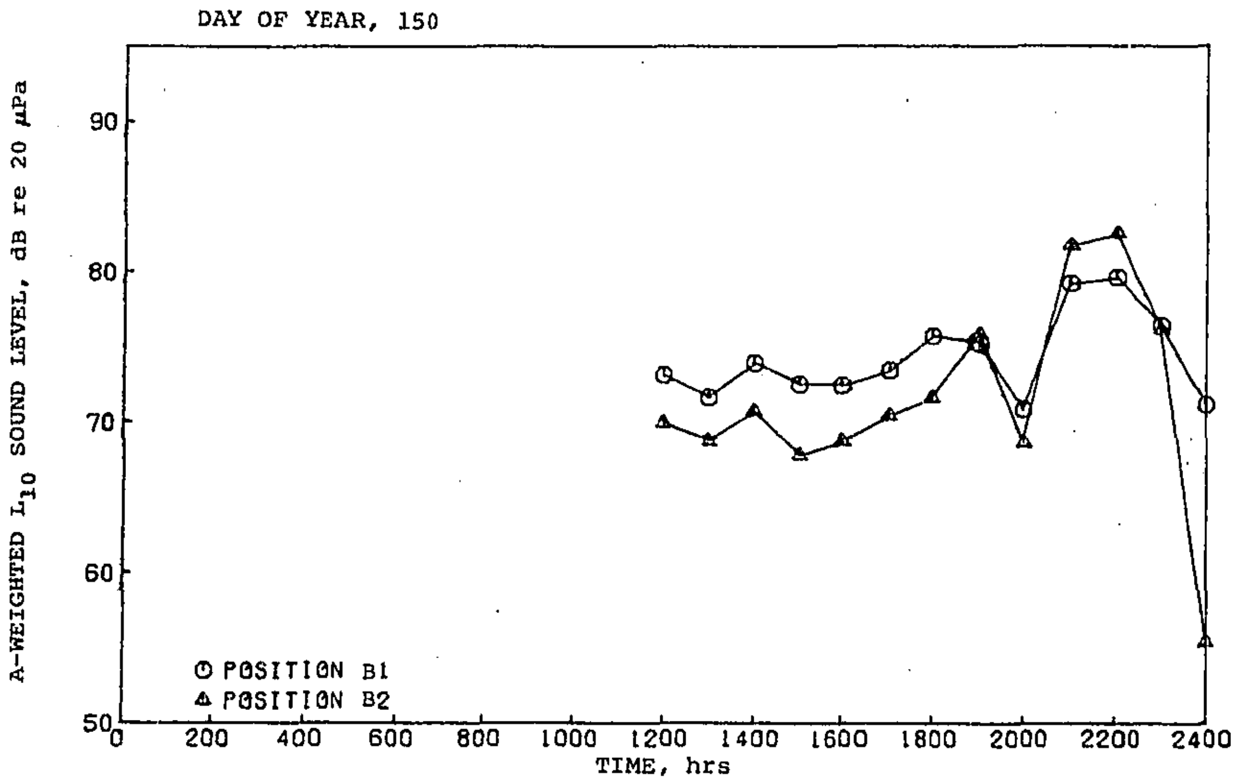


Figure 35a. A-weighted L_{10} sound level versus time.

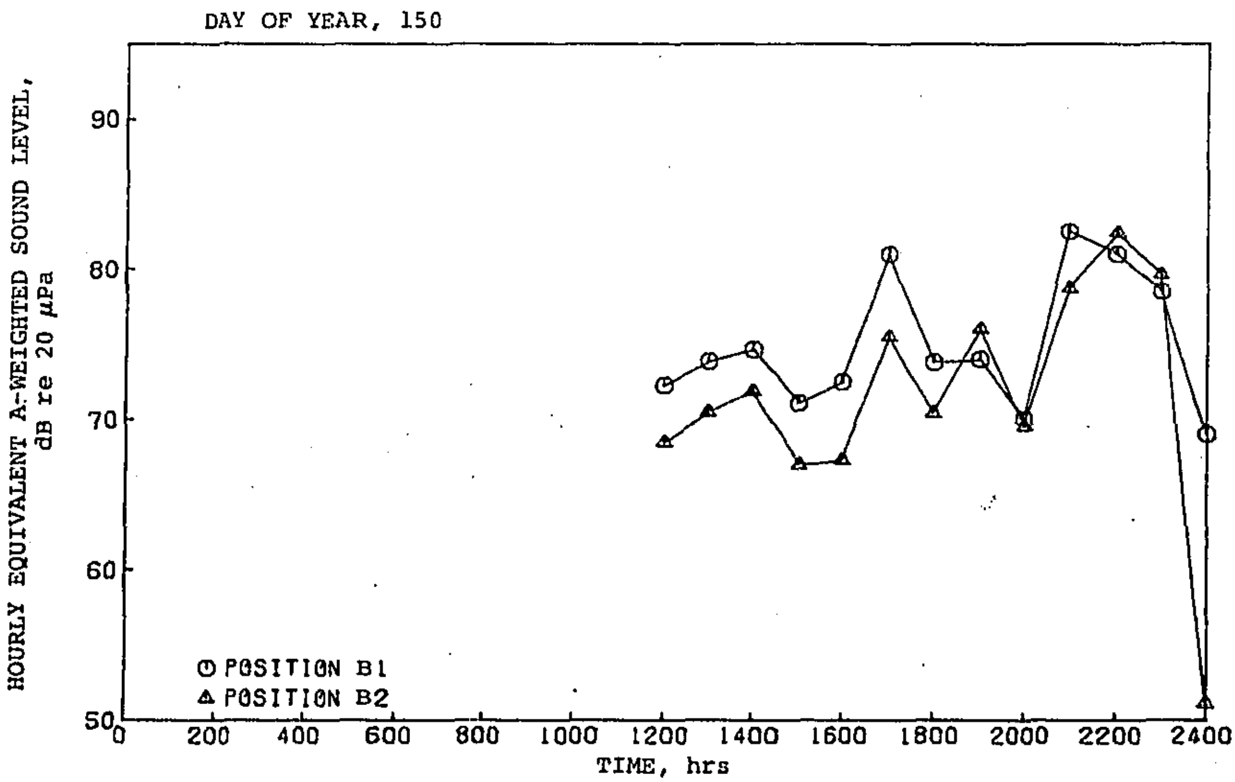


Figure 35b. Hourly equivalent A-weighted sound level versus time.

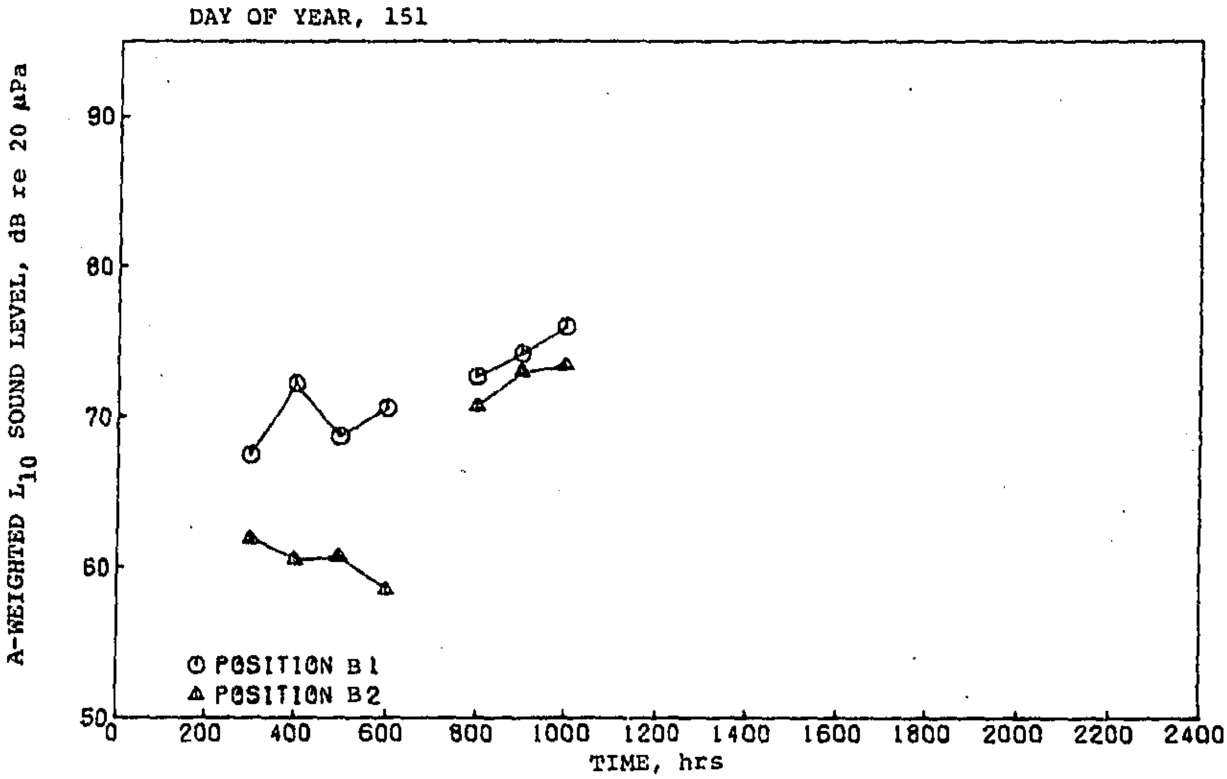


Figure 36a. A-weighted L_{10} sound level versus time.

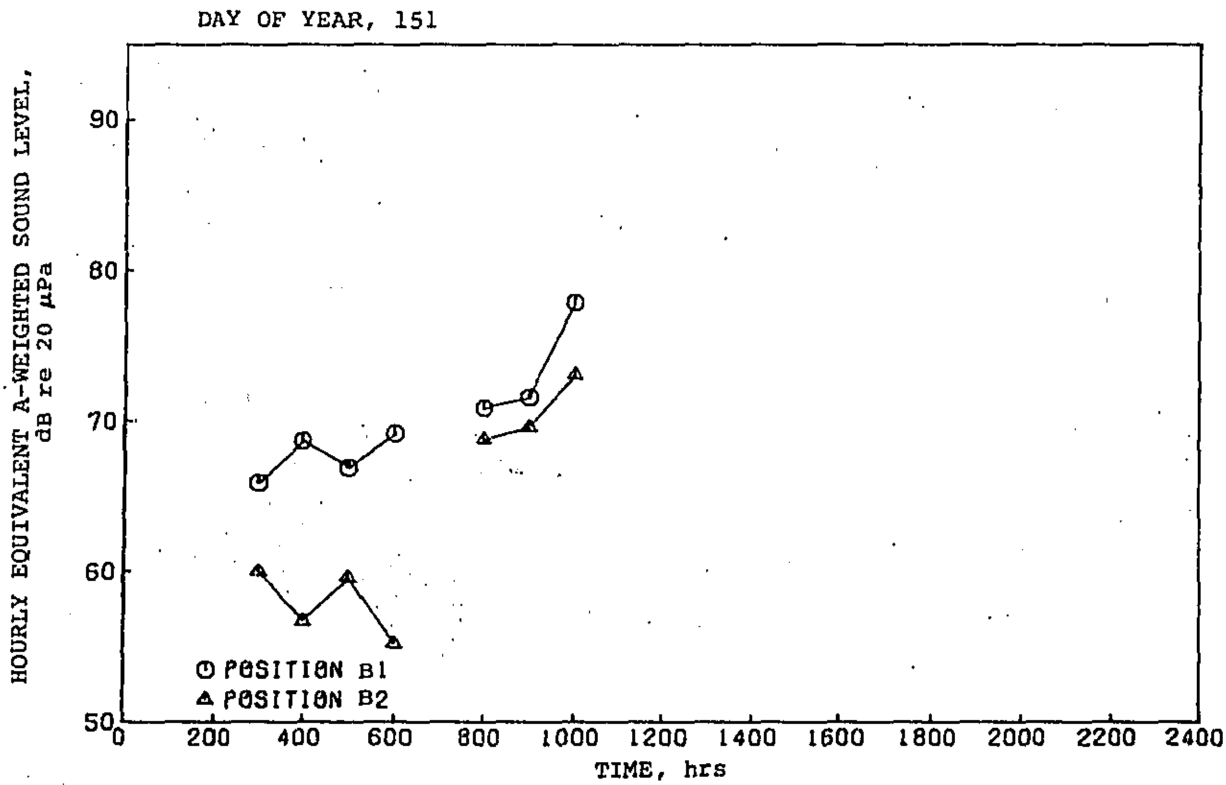


Figure 36b. Hourly equivalent A-weighted sound level versus time.

Table 4. Summary of retarder activity from 1600 hours on day 149 until 0900 hours on day 150.

Day	Retarder Start	Operations Finish	Empty Cars	Loaded Cars
149	1616	1650	90	0
	1705	1736	35	35
	1756	1808	31	51
	1840	1841	*	*
	1936	1954	19	24
	2019	2045	33	31
	2100	2127	14	23
	2131	2139	9	9
	2223	2300	27	25
	2323	2331	2	18
150	0010	0050	36	19
	0100	0122	3	50
	0148	0207	20	22
	0214	0233	38	21
	0310	0321	9	25
	0333	0413	101	0
	0406	0423	25	8
	0436	0454	49	0
	0545	0607	23	60
	0627	0635	0	18
	0816	0829	9	21
	0835	0913	41	51

*Unknown

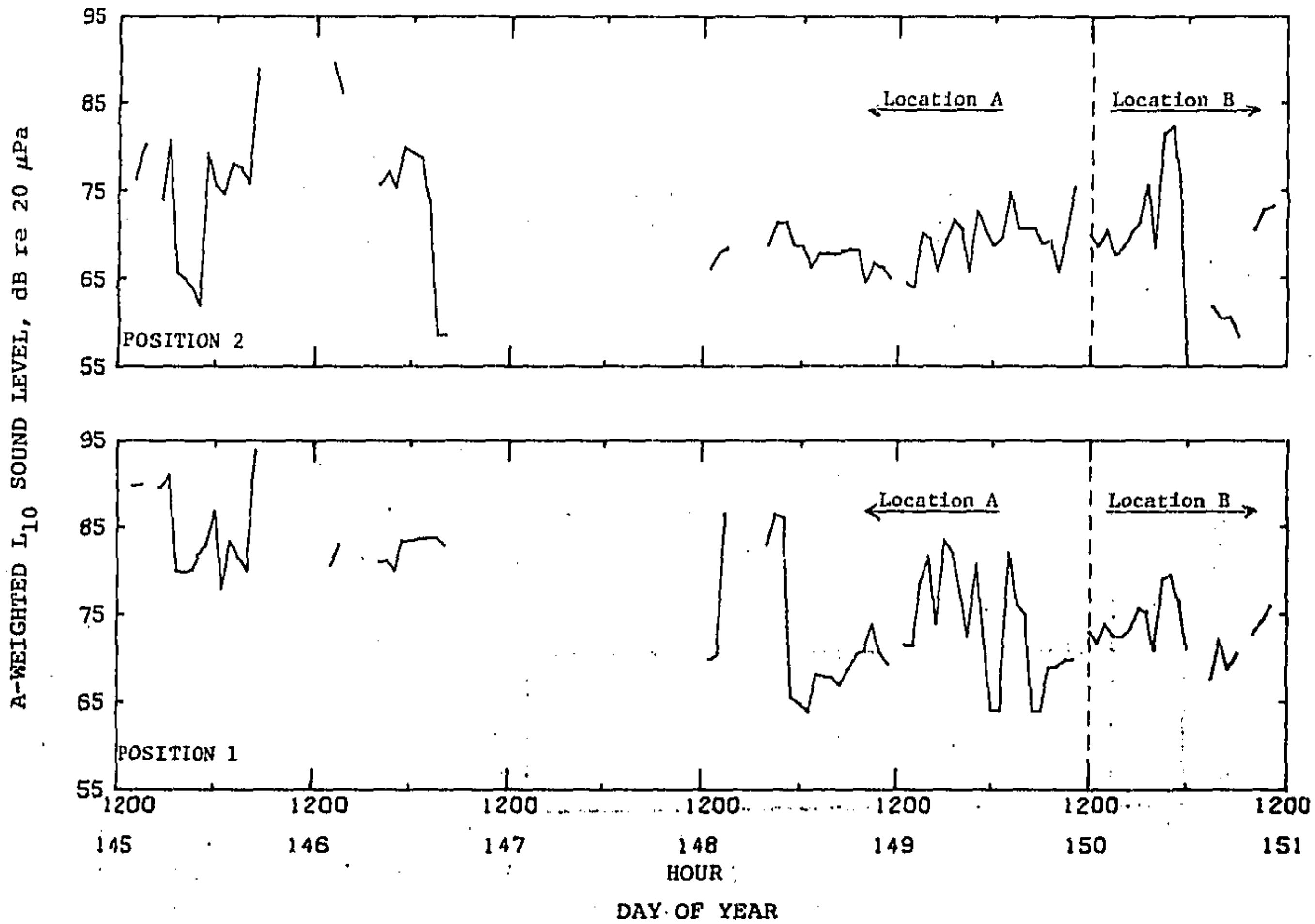


Figure 37. A-weighted L_{10} sound level versus time.

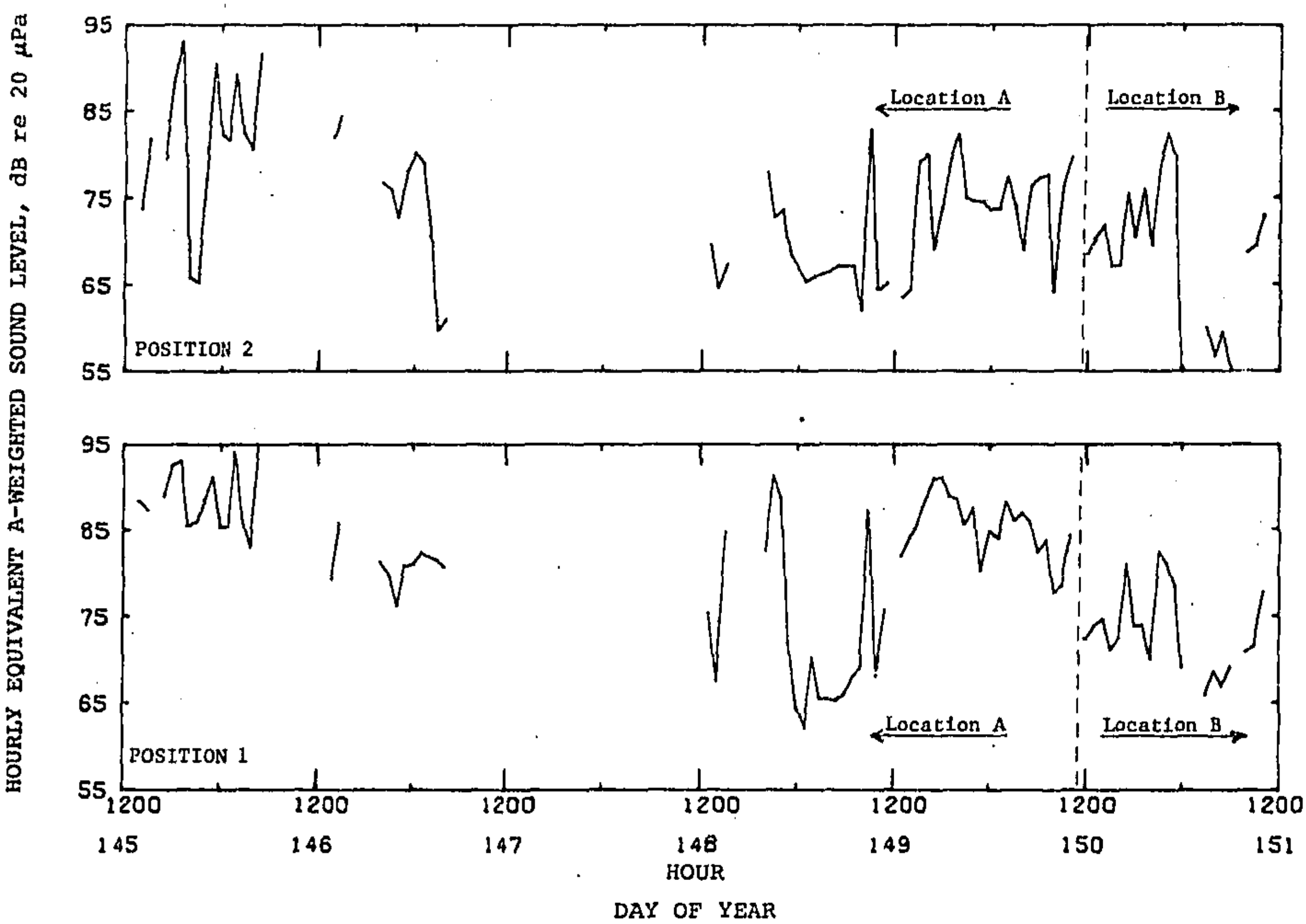


Figure 38. Hourly equivalent A-weighted sound level versus time.

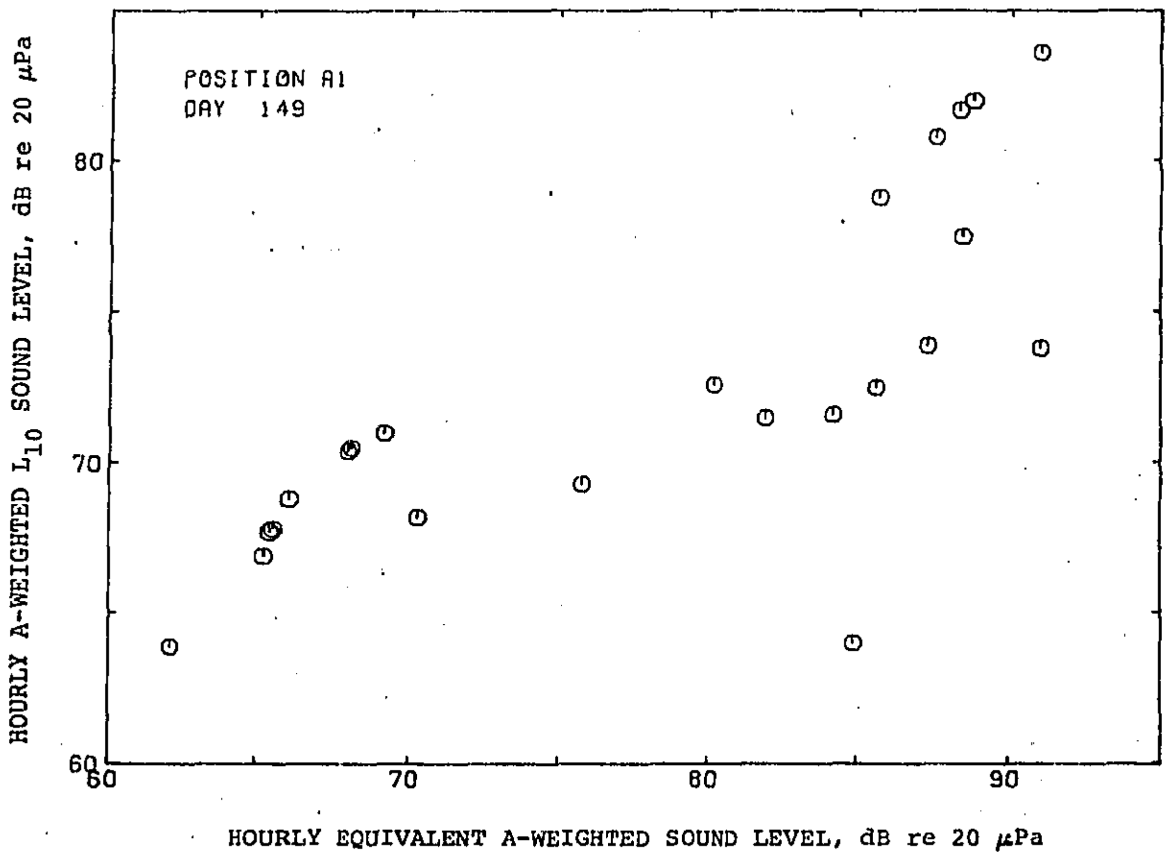


Figure 39. Interrelationship between hourly L_{10} and L_{eq}.

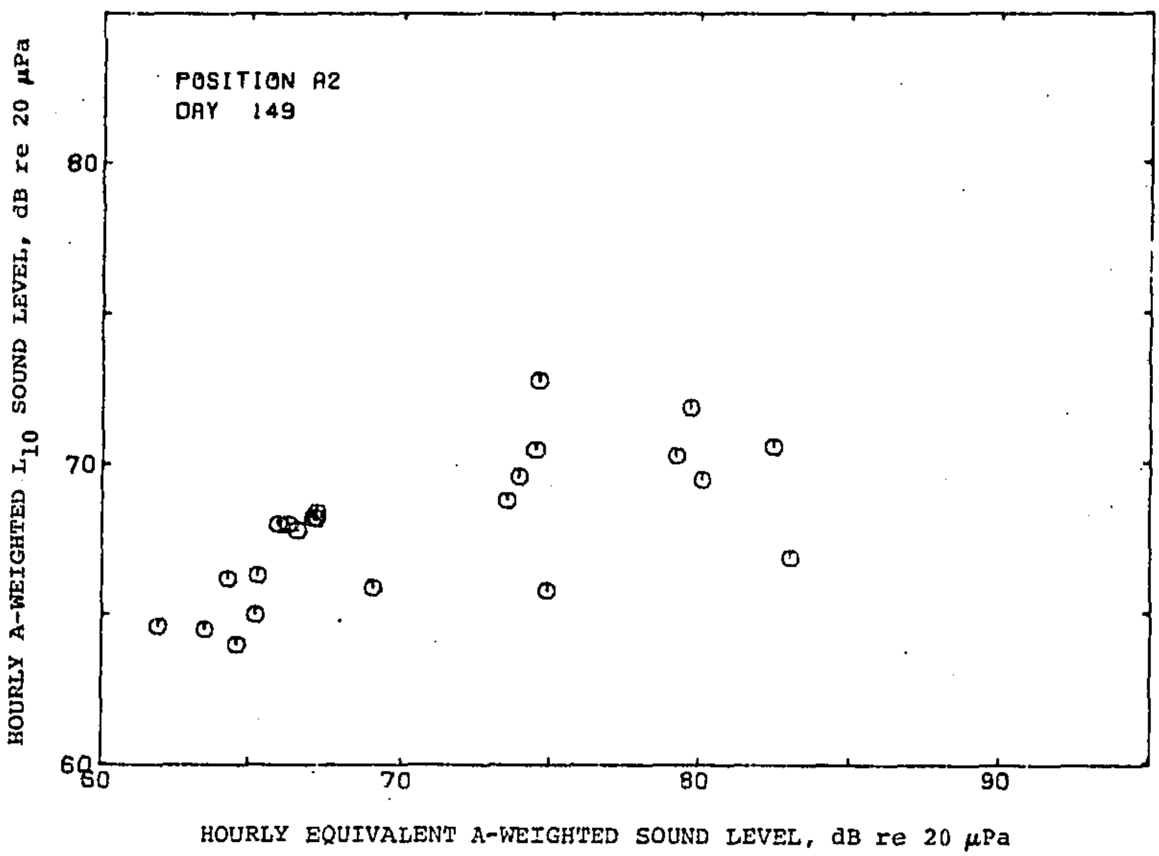


Figure 40. Interrelationship between hourly L_{10} and L_{eq}.

and A2 respectively for measurements made on day 149. As can easily be seen, the correlation between the two descriptors is not very good in this case. The probable reason for the large differences -- as much as 20 dB -- between L_{10} and L_{eq} is the fact that short duration, high level noises which do not occur more than 10 percent of the time have a significant influence on the value of L_{eq} but absolutely no influence on the value of L_{10}. A review of the raw data confirmed this to be the case for railyard measurements taken during this study. For those hours where the differences between L_{10} and L_{eq} were the largest, the raw data showed that high level noises occurred for nearly 10 percent of the time and therefore, the L_{eq} value tended to be much higher than the L_{10} value (which was not influenced at all by the high level noises since they did not occur more than 10 percent of the time during the hour of interest). What these data show is that the nature of the activities within a railyard are such that L_{10} is a poor descriptor of the noise in this case. Similar data have been reported [4] for L_{10} and L_{eq} data at sites near airports. Differences between the two descriptors were as much as 20 dB over a major portion of the day at a residential site under the landing path of Los Angeles International Airport while for a suburban residential site, comparable L_{10} and L_{eq} values were reported over a 24 hour day (typical differences on the order of a few decibels or less). L_{10} is a relatively simple descriptor but it should be utilized with caution, especially in situations where high level sounds occur for short periods of time.

However, L_{eq} is not without problems either. It has been previously reported [1], in the case of railroad yard boundary measurements that: "In general, the 10 minute sample times utilized for this survey [Wyle survey] were of insufficient duration for accurate measurement of the yard activities, indicating that due to the random nature of most yard operations, 24 hour continuous recordings would most likely be required."

In order to investigate this problem further, the data for the time period from 0041 hours to 0240 hours of day 150 were selected for investigation as to the variation one could expect in the values of L_{eq} as a result of the integration time selected. The results (for measurement positions A1 and A2) are presented in Figures 41 - 45 for integration times of 1, 3, 10, 30 and 60 minutes. Since the A-weighted sound levels were digitally recorded every 0.1 second, this corresponds to 600, 1800, 6000, 18,000 and 36,000 samples, respectively. The values of L_{eq} plotted in these figures correspond to the beginning point of the integration time; that is, in Figure 42 the data plotted at 40 minutes represents the L_{eq} value for the period extending from the beginning of the 40th minute to the beginning of the 43rd minute. Since only a two-hour data sample was used, there are no L_{eq} values plotted over the last period of integration of the two-hour period.

On the basis of these data, it would appear that regulation of rail yard noise emission levels, in terms of L_{eq}, would require, at a minimum, continuous monitoring for each of several representative hours in a given day. Con-

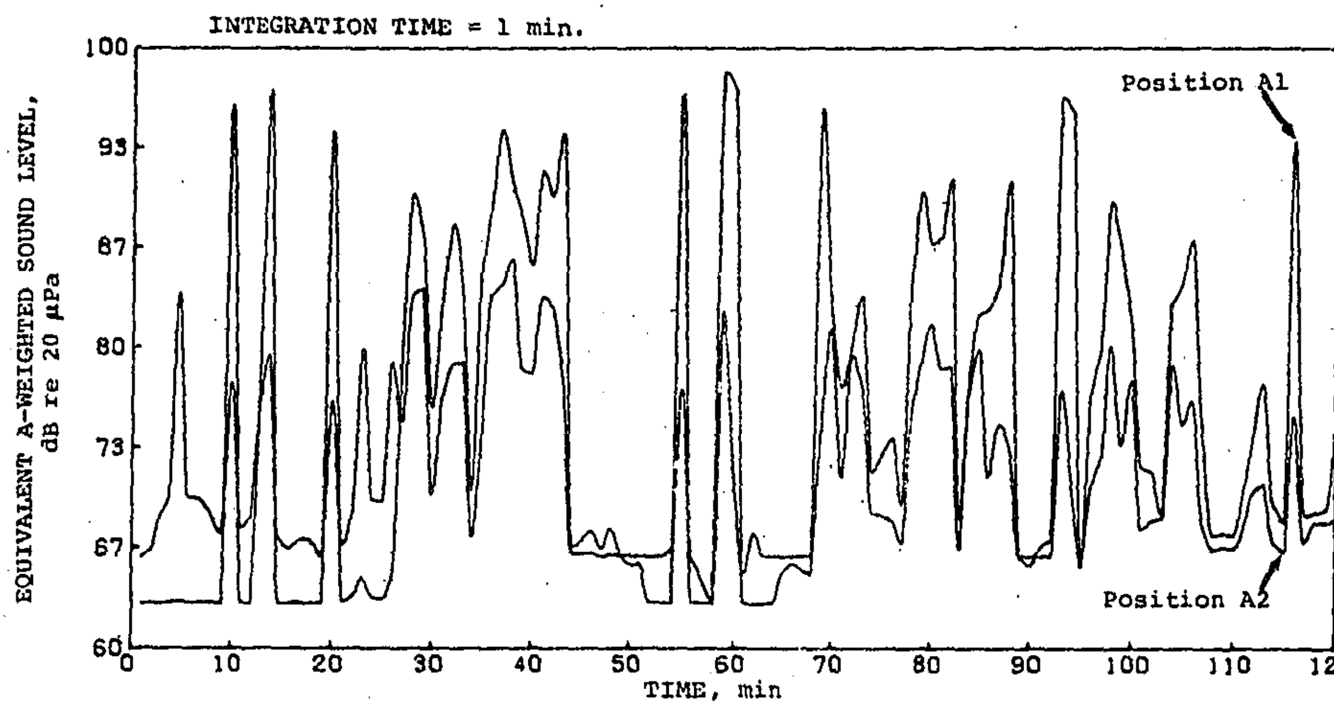


Figure 41. Equivalent A-weighted sound level versus time.

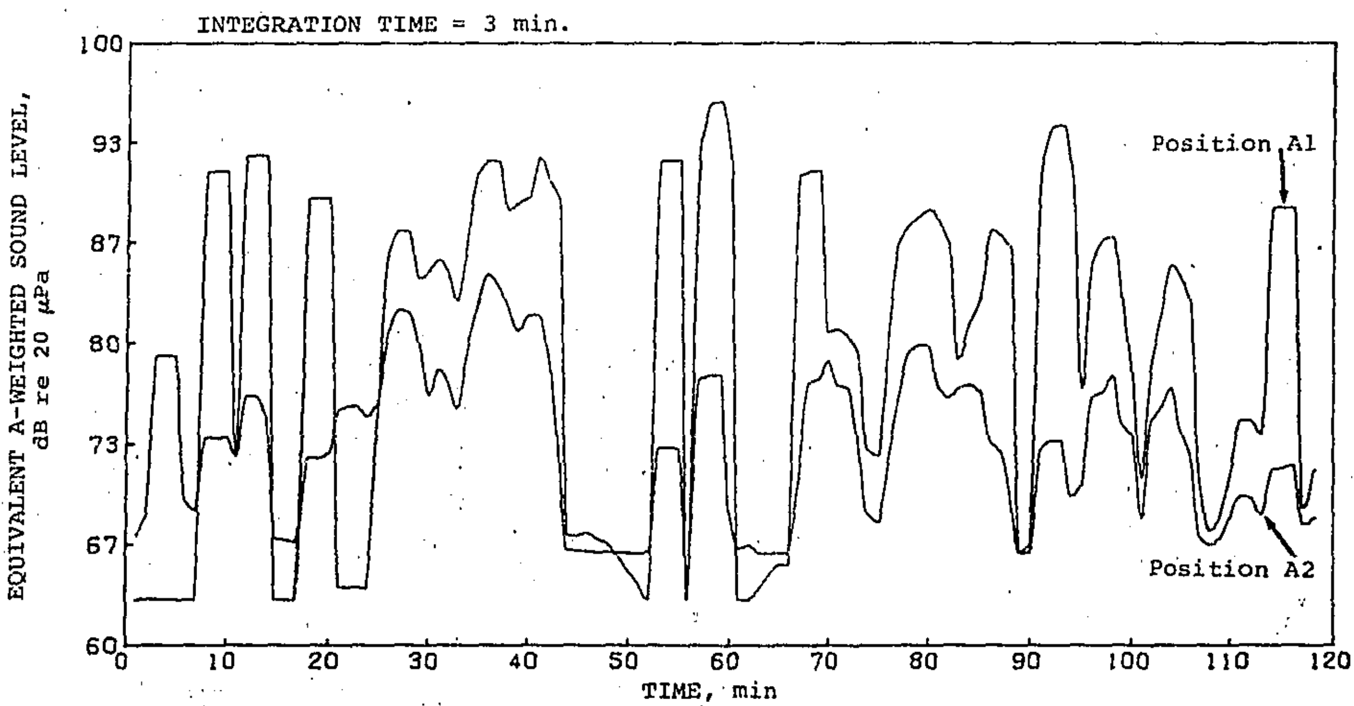


Figure 42. Equivalent A-weighted sound level versus time.

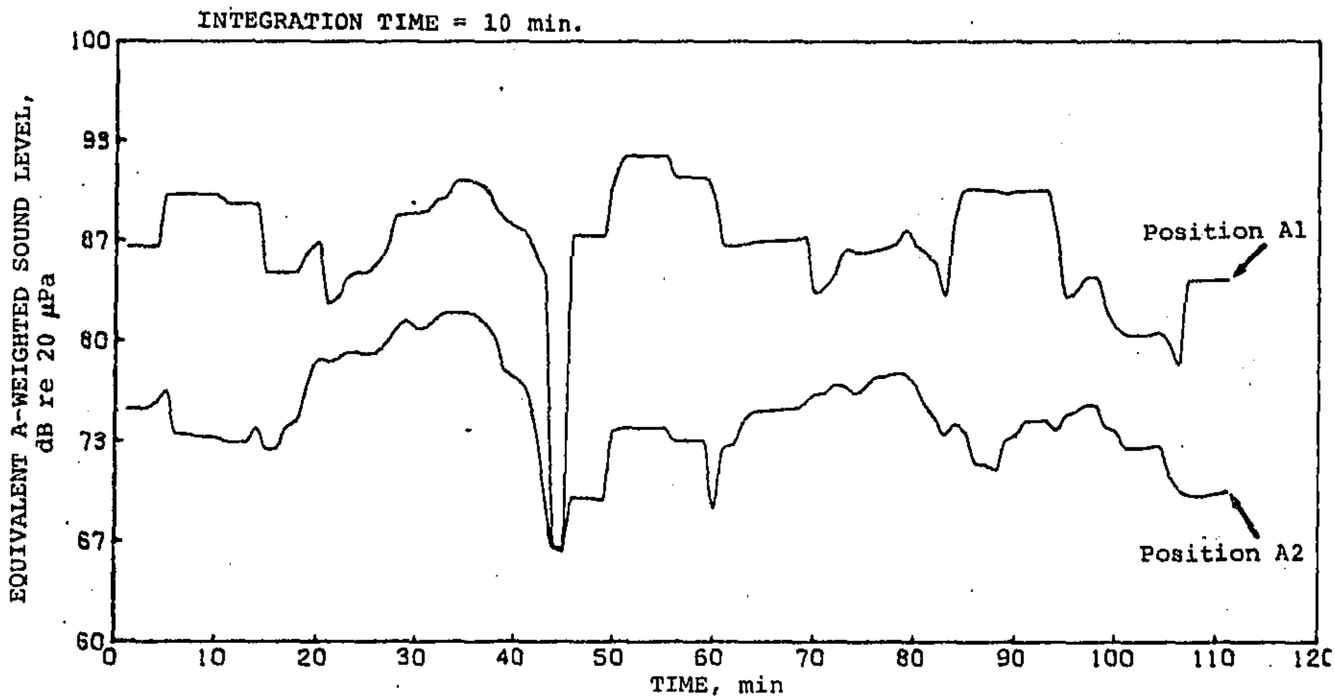


Figure 43. Equivalent A-weighted sound level versus time.

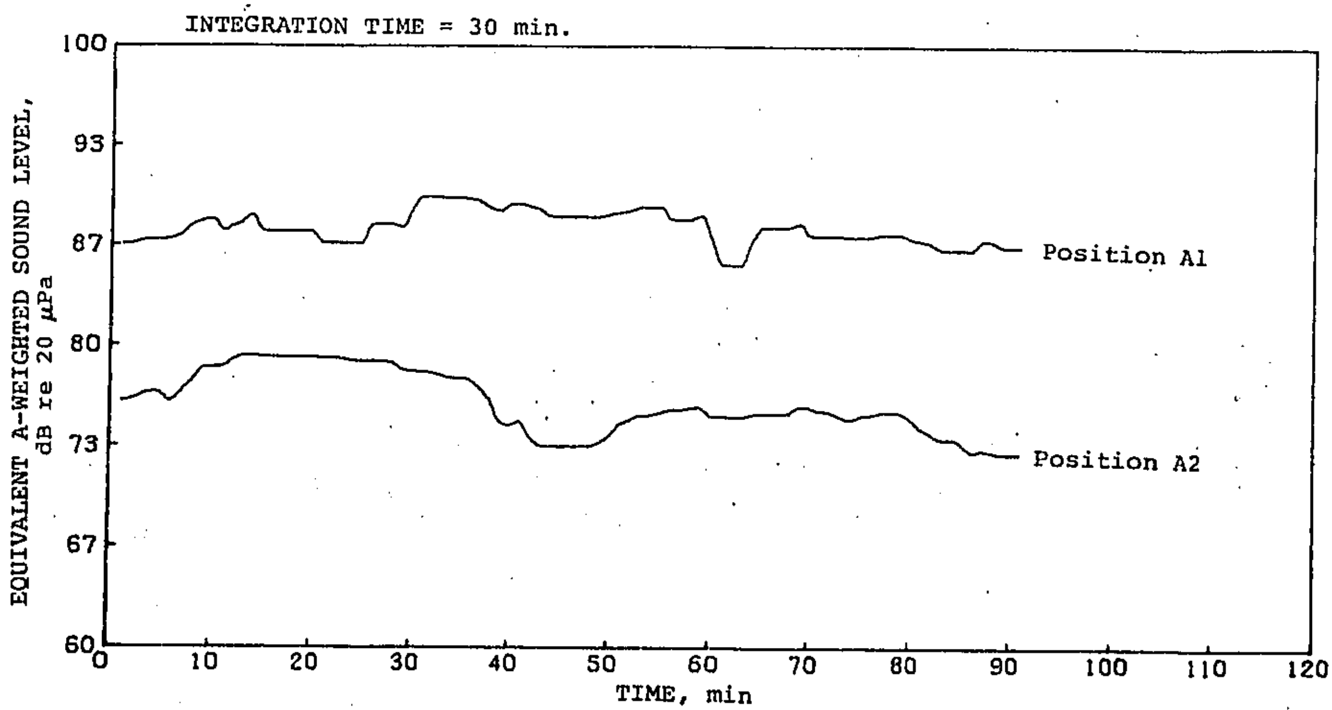


Figure 44. Equivalent A-weighted sound level versus time.

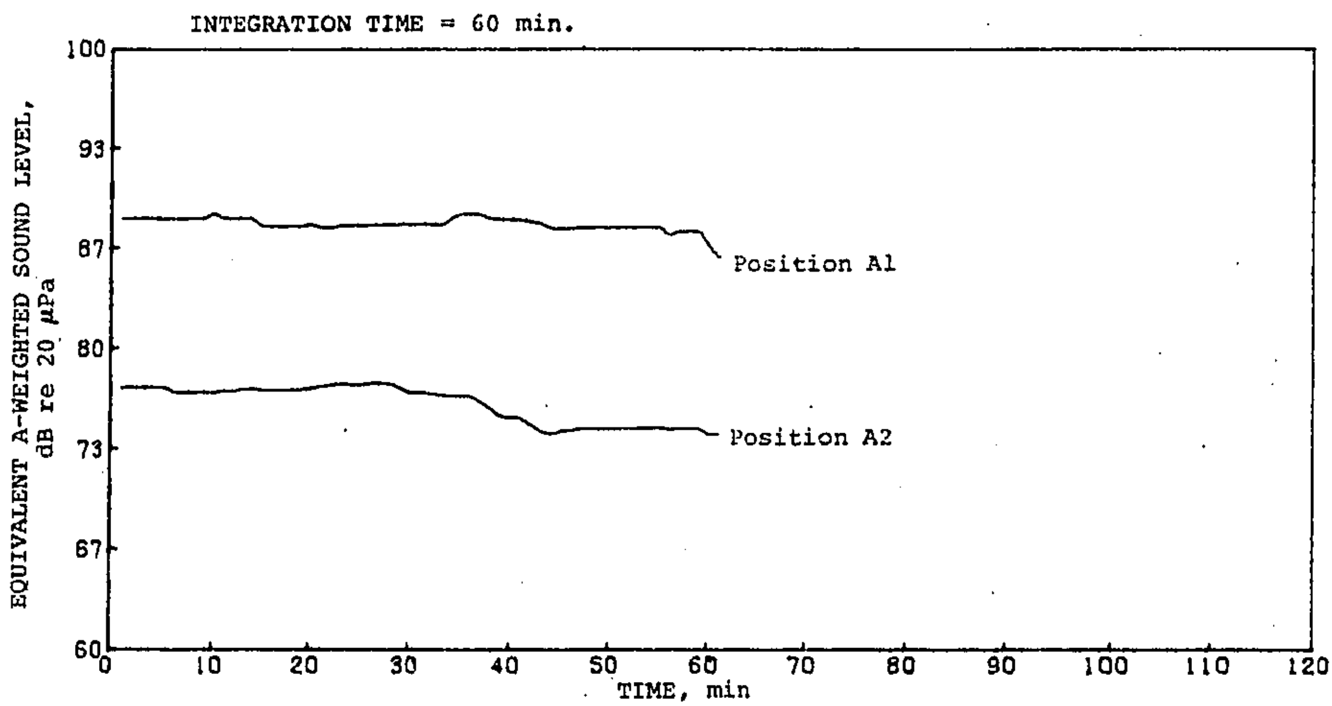


Figure 45. Equivalent A-weighted sound level versus time.

tinuous monitoring for 24 hours on representative days would, of course, yield more reliable results. On the other hand, if it is desired to relate variations in L_{eq} with specific variations in yard activity, integration times in the range of 1 to 10 minutes would be preferred.

As discussed previously in Section 2.2.2., measurements were also made within the rail yard near the active retarders to investigate the characteristic retarder noise levels and directionality -- both in the horizontal and vertical planes. A reference microphone was utilized in conjunction with seven different test microphones. Each test microphone was located at a different height/angle combination in relation to the location of the reference microphone (see Figure 26 for microphone locations with respect to retarders 1 and 2).

Data were obtained for 58 passes through retarder number 1 and 37 passes through retarder number 2. The data for each train car passing through the retarders are presented in the form of (1) the differences in the A-weighted sound level between the test and the reference microphones and (2) the maximum A-weighted sound levels at the reference microphone. For selected passes through retarder number 1, one-third octave band spectral analysis was also performed and the data are presented here.

The differences between the maximum A-weighted sound levels at the test [L(θ,x)][6/] and reference [(L(0, 5)] microphones are presented graphically in Figures 46 and 47. In addition, the data are tabulated in Tables 5 and 6. The level differences are coupled with an identification of the type of rail car passing through the retarder at the time of the measurement. No information was obtained as to whether the numbers and types of cars sampled during this study were representative of the long-term operational statistics for this particular rail yard. An indepth study of retarder squeal (which was not the intent of this study) would of necessity have to investigate such facts as car age, condition and type of wheels, car weight, environmental conditions, speed, etc.

In summary, the average sound level differences between the test and reference microphone locations as well as the standard deviations are presented in Table 7. Note that in the case of position (75,5) the data are shown for retarder number 1 and number 2 seperately rather than combined. The data were plotted in this manner since this location is much closer to retarder number 1 than it is to retarder number 2. At all other measurement locations, the microphone is approximately equidistant from the two retarders.

[6/] L(θ,x) is the noise level measured at the microphone location whose height above the ground and angular location with respect to the perpendicular line drawn from microphone number 1 (see Figure 26) to the longitudinal centerline of retarder number 1 are defined within the parenthesis, i.e., L(0,5) is the level measured at an angle, θ, of 0° and a microphone height, x, of 5 feet.

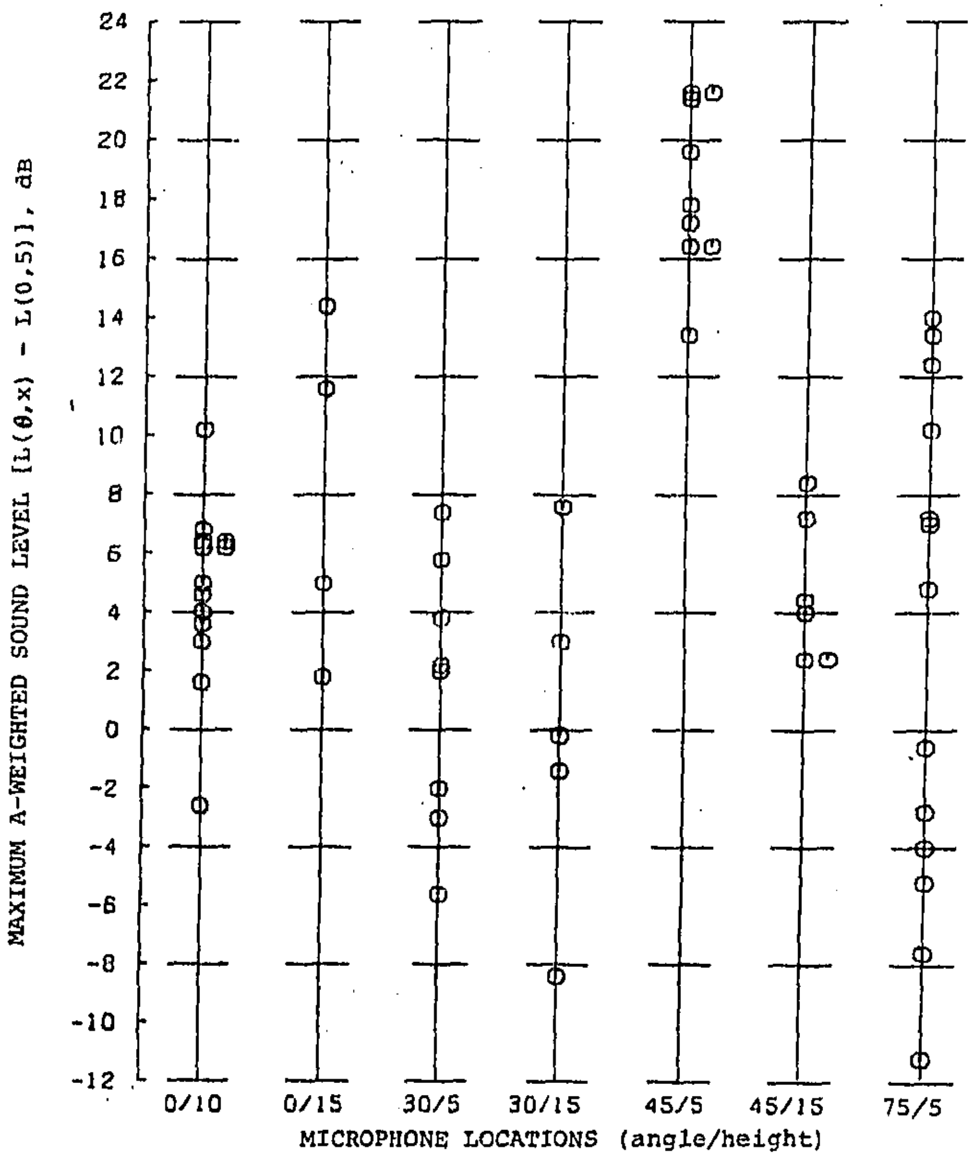


Figure 46. Maximum A-weighted sound level [L(θ,x) - L(0,5)] for various microphone locations, retarder no. 1.

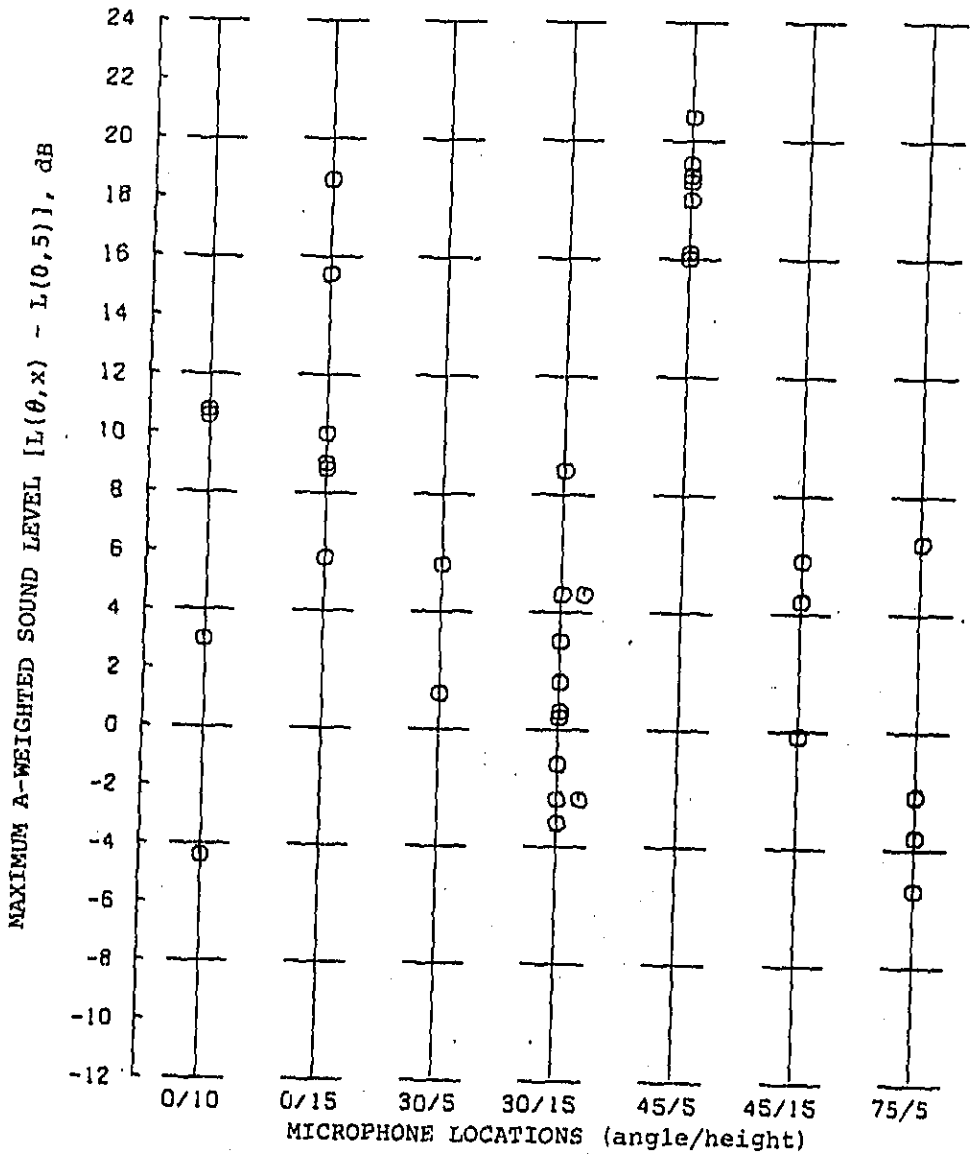


Figure 47. Maximum A-weighted sound level $[L(\theta,x) - L(0,5)]$ for various microphone locations, retarder no. 2.

Table 5. The difference in maximum A-weighted sound level [L(0,x) - L(0,5)] between the test and reference microphones for 58 passes through retarder number 1.

TYPE CAR	0°,10 Ft	TYPE CAR	0°,15 Ft	TYPE CAR	30°,5 Ft	TYPE CAR	30°,15 Ft
Box	4.0	Large Tank	14.4	Box	2.0	Flat(2)	-8.4
Box(2)	6.4	Box	11.6	Box	-3.0	Box	7.6
Coal	3.6	Box	5.0	Box	2.2	Box(2)	-1.4
Box	4.6	Gondola	1.8	Box & Tank	-2.0	Box	3.0
Box	6.4			Box	3.8	Box	-0.2
Box	6.8			Box	7.4		
Box	-2.6			Box	5.8		
Box	1.6			Tank	-5.6		
Box	10.2						
Large Flat	6.2						
Box(2)	5.0						
Box	3.0						
Box(2)	6.2						

TYPE CAR	45°,5 Ft	TYPE CAR	45°,15 Ft	TYPE CAR	75°,5 Ft
Box(2)	21.6	Box	4.4	Box(2)	7.2
Flat	16.4	Tank	2.4	Box	-7.6
Box(2)	17.2	Cement	8.4	Box	-4.0
Box(2)	21.4	Box(2)	2.4	Box	-0.6
Box(2)	21.6	Box(2)	4.0	Box	-5.2
Box	17.8	Box	7.2	Box	-11.2
Flat & Tank	19.6			Box	4.8
Gondola(2)	16.4			Box	10.2
Gondola(2)	13.4			Gondola	14.0
				Box	-2.8
				Large Flat	13.4
				Coal(2)	12.4
				Tank(2)	7.0

Table 6. The difference in maximum A-weighted sound level [L(θ,x) -L(0,5)] between the test and reference microphones for 37 passes through retarder number 2.

TYPE CAR	0°,10 Ft	TYPE CAR	0°,15 Ft	TYPE CAR	30°,5 Ft
Box(2)	3.0	Box	10.0	Cement	5.6
Gondola(2)	10.6	Coal(2)	15.4	Box	1.2
Box	-4.4	Gondola	9.0		
Tank(2)	10.8	Box(2)	8.8		
		Box(2)	5.8		
		Box	18.6		

TYPE CAR	30°,15 Ft	TYPE CAR	45°,5 Ft	TYPE CAR	45°,15 Ft
Box	0.6	Box(2)	18.0	Flat	4.4
Box	-3.2	Box	18.8	Grain	5.8
Box	4.6	Box	20.8	Box	-0.2
Box	0.4	Box & Cement	16.2		
Tank	-1.2	Box	16.0		
Automobile	4.6	Box(2)	19.2		
Automobile	-2.4	Gondola	18.6		
Box	-2.4				
Box	3.0				
Box(2)	8.8				
Gondola	1.6				

TYPE CAR	75°,5 Ft
Box	-3.6
Grain	-2.2
Box	-5.4
Box	6.4

Table 7. Summary of the average differences in A-weighted sound level between the test and reference microphones and the corresponding standard deviations.

Retarder	Microphone			L(θ,x) - L(0,5)	
	Position	Angle	Height	Average	Std. Dev.
#1 & #2	#1	0°	10 ft.	+4.8 dB	4.1 dB
#1 & #2	#1	0	15	+10.0	5.1
#1 & #2	#2	30	5	+1.7	4.2
#1 & #2	#2	30	15	+0.9	4.3
#1 & #2	#3	45	5	+18.3	2.4
#1 & #2	#3	45	15	+4.3	2.6
#1	#4	75	5	+2.9	8.6
#2	#4	75	5	-1.2	5.2

It can easily be seen that the noise radiation characteristic of retarders exhibit strong directionality in both the horizontal and vertical planes. Much more detailed mapping of the sound field would be needed to adequately characterize the directions of minimum and maximum radiation.

The maximum A-weighted sound levels for the reference microphone were tabulated for all passes through the retarders. The tabulated data were grouped into 5 dB steps for the range of 100 to 140 dB. Since only those cases where the maximum exceeded an A-weighted sound level of 100 dB are presented, these data should not be construed as being indicative of the average noise levels associated with retarder operations. The tabulation was performed individually for each retarder. These data are presented in Figures 48 and 49 for retarders number 1 and 2 respectively.

To provide an indication of the spectral content of "retarder squeal" a limited amount of one-third octave band analysis was performed. One event was randomly selected from the group of events that comprised each 5 dB step for passes through retarder number 1. These events are labeled A through G. The one-third octave band sound pressure levels versus frequency measured at the reference microphone at the time corresponding to the occurrence of the maximum A-weighted sound level are presented in Figures 50a and 50b for each of the randomly selected events. The absence of data at certain frequencies indicate that the sound pressure levels were not above the base line of the analysis equipment. It should be noted that on curves A and G there is a single datum point at 63 Hz.

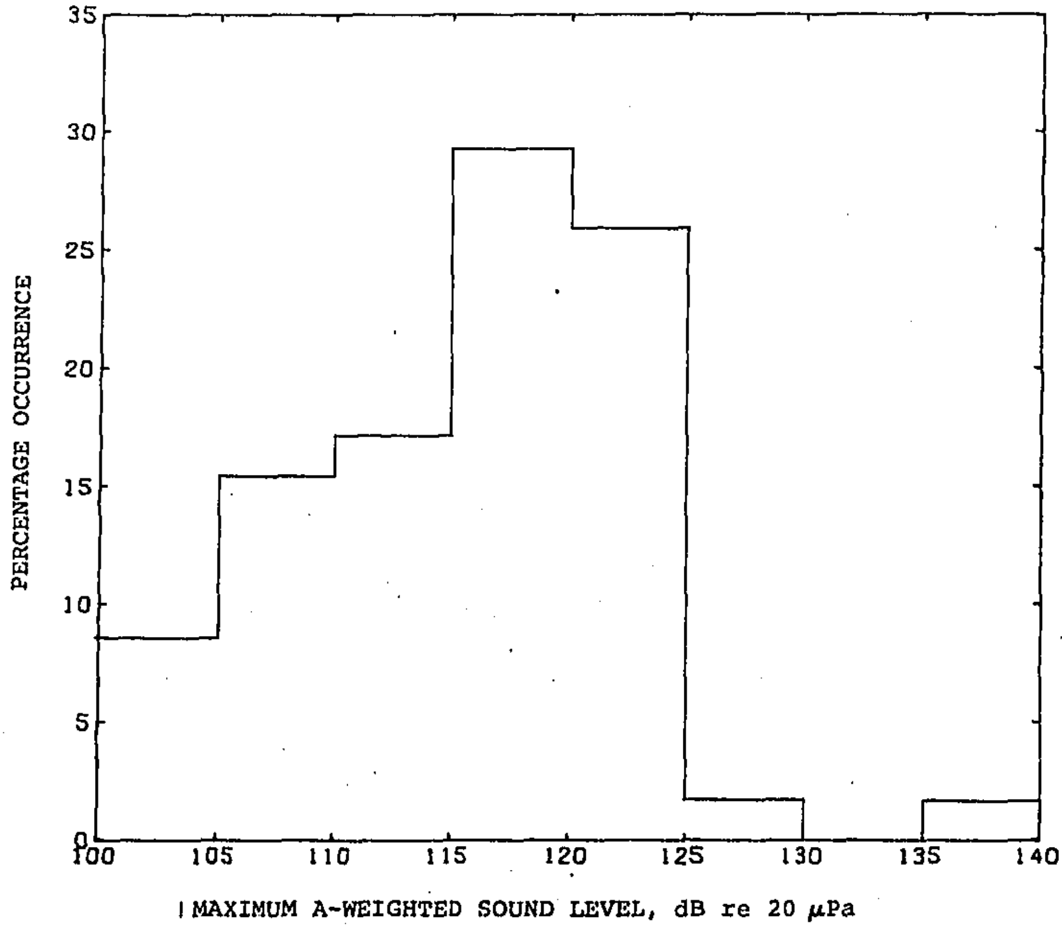


Figure 48. Percent of occurrence for maximum A-weighted sound levels above 100 dB measured at the reference microphone for passes through retarder number 1.

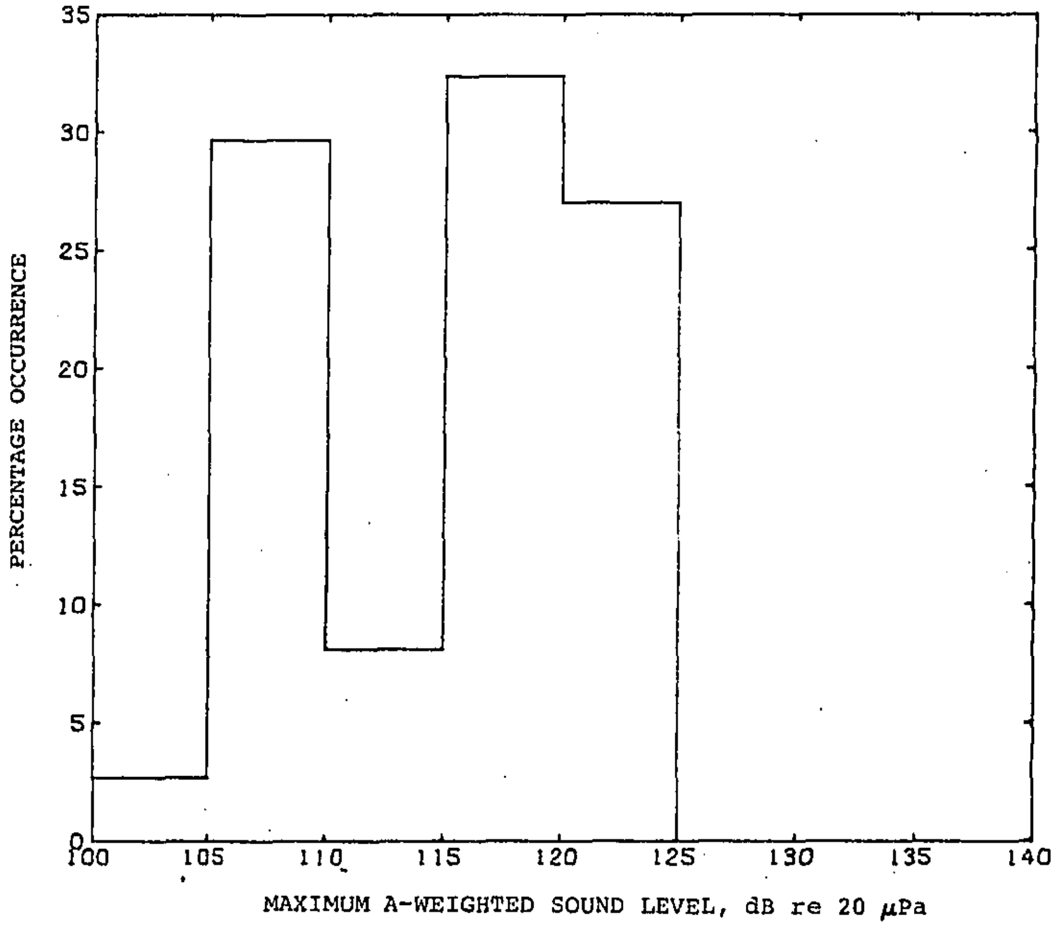


Figure 49. Percent of occurrence for maximum A-weighted sound levels above 100 dB measured at the reference microphone for passes through retarder number 2.

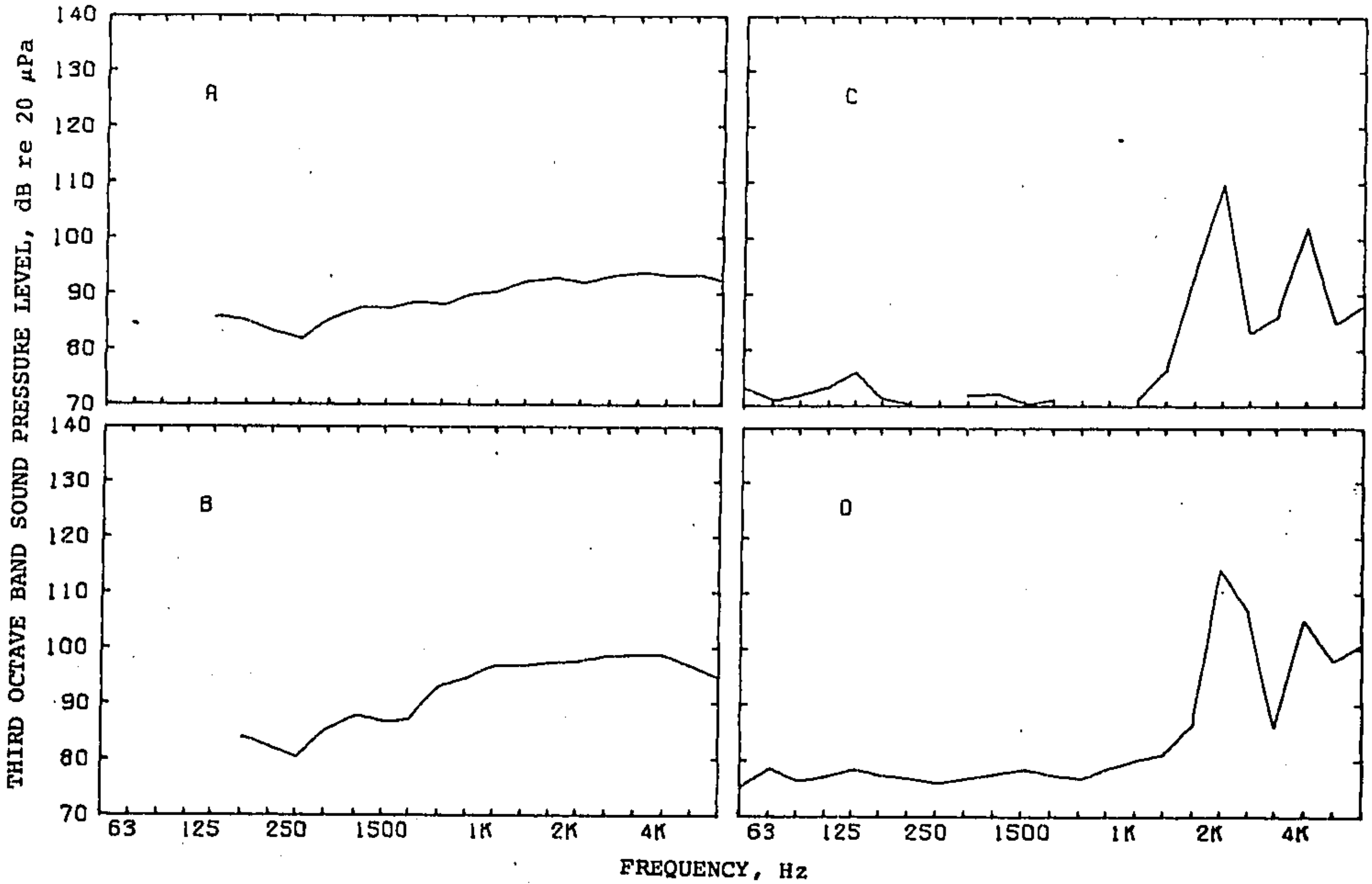
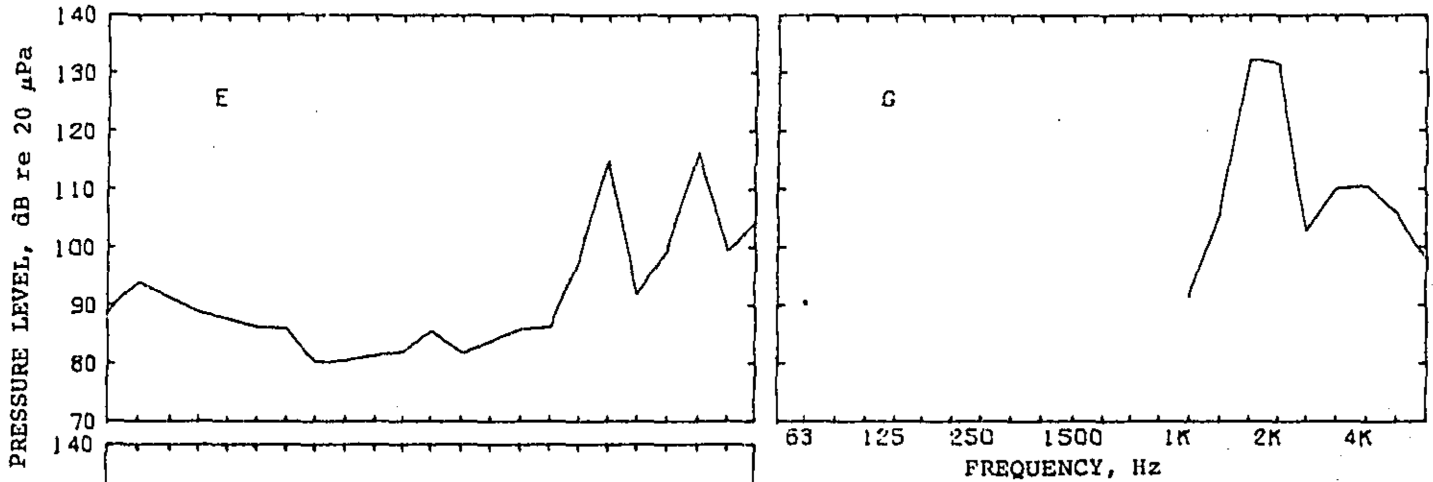
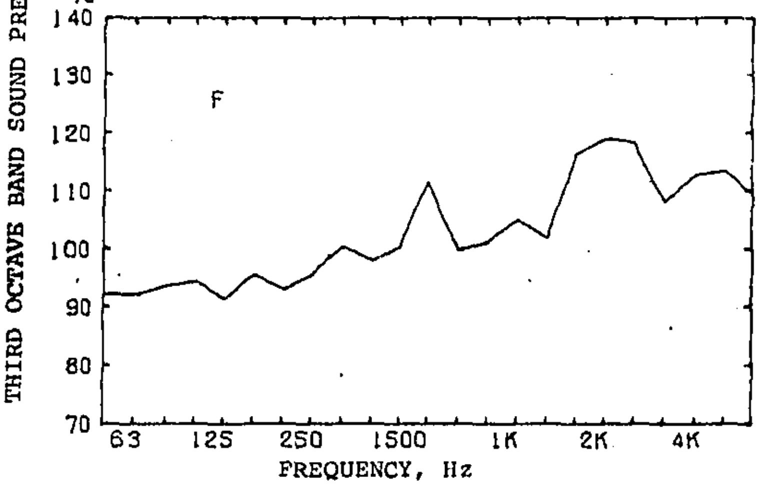


Figure 50a. Third octave band sound pressure level versus frequency at the time corresponding to the occurrence of the maximum A-weighted sound level measured at the reference microphone for passes through retarder number 1.





CURVE	A-WT, DB	A-WT RANGE, DB	PERCENT OCCURRENCE
A	103.0	100-105	8.6
B	108.8	105-110	15.5
C	112.6	110-115	17.2
D	117.2	115-120	29.3
E	120.4	120-125	25.9
F	125.2	125-130	1.7
G	136.6	135-140	1.7

Figure 50b. Third octave band sound pressure level versus frequency at the time corresponding to the occurrence of the maximum A-weighted sound level measured at the reference microphone for passes through retarder number 1.

3. Conclusions

Based on the data obtained during the conduct of this test program, the following conclusions can be drawn:

- The Single Event Noise Exposure Level (SENEL) value is very dependent on the integration time selected; errors as great as 10 dB can occur if the time is too short. This is especially critical as the microphone distance from the train is increased.

- A general tendency exists for the rate of attenuation to increase with the number of cars in the train, reflecting a greater contribution from wheel/rail noise (high frequency) as opposed to locomotive noise (low frequency).

- If the terrain between the train and the measurement location is not reasonably flat and level, destructive interference can occur at frequencies near that of the acoustical radiation associated with the fundamental firing frequency of the locomotive engine.

- Caution should be exercised if attempts are made to predict the noise levels for trains in transit at locations other than the ones at which measurements were actually taken. This is especially critical for changes in vertical height.

- The nature of activities within a railyard are such that L_{10} is a poor descriptor of the noise at the boundary of a railroad yard.

- Regulation of railyard noise emission levels, in terms of L_{eq}, would require, at a minimum, continuous monitoring for each of several representative hours in a given day. Continuous monitoring for 24 hours would be preferable.

- The noise radiated from active retarders is highly directional in both the horizontal and vertical planes, and any attempts to regulate retarder noise should consider this directionality.

4. Acknowledgement

Appreciation is expressed to officials of the American Association of Railroads, officials and personnel of the Norfolk and Western Railroad, and officials and personnel of the Chesapeake and Ohio Railroad, for their assistance in this measurement program.

The authors also express appreciation to the following members of the Applied Acoustics Section: John S. Forrer, Charles O. Shoemaker and Richard B. Gold for the development of the data acquisition and analysis system and Daniel M. Corley and Ronald L. Fisher for the associated software.

5. References

[1] Swing, J. W. and Pies, D. B., Assessment of noise environments around railroad operations, Report WCR 73-5 (Wyle Laboratories, El Segundo, California, July 1973).

[2] Rickley, E. J., Quinn, R. W. and Sussan, N. R., Noise level measurements of railroads: freight yards and wayside, Report DOT-TSC-OST-73-46 (Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts, May 1974).

[3] Public health and welfare criteria for noise, Report 550/9-73-002 (U. S. Environmental Protection Agency, Washington, D. C., July 27, 1973). Available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402

[4] Bishop, D. E. and Simpson, M. A., Noise levels inside and outside various urban environments, Sound and Vibration 8 (5), 51-54 (May 1974)

[5] American National Standard Specification for Sound Level Meters, S1.4-1971 (American National Standards Institute, New York, New York, April 1971).

6. Appendix A. Data Acquisition and Analysis System for Line Operations

Figure A-1 identifies the components of the data acquisition system utilized for the measurement of noise from trains in transit. To describe the workings of the system, the following example is cited with the contribution of each component discussed.

Consider a train passing an array of microphones. As the train moves forward, it causes pressure fluctuations which travel as waves and activate each microphone's diaphragm into vibration. These vibrations are transduced into an AC voltage which can be recorded for analysis at a later time. The microphone itself was a three-part subsystem comprised of a one inch condenser microphone cartridge, protecting grid and a microphone preamplifier. Battery-powered microphone power supplies were utilized to provide the necessary polarization voltage to the microphones. It was not practical to locate the tape recorder next to the microphone array, since one wanted to minimize undesired reflection effects; therefore, long cables carried the signal from the microphone to the recording facility housed in a mobile instrumentation van. Once the signal reached the tape recorder there existed a need for signal conditioning prior to actual recording. A specially designed electronic system provided the necessary amplification/attenuation capability and in addition, through a series of panel lights, provided an indication as to whether or not a tape channel had become saturated (i.e., the signal had exceeded the dynamic range of the recorder) and thus the data were not acceptable. The signal from each microphone was then recorded on one track of the seven-channel F. M. tape recorder. Windscreens were placed over the microphones at all times.

A single point calibration utilizing a pistonphone which produced a 124 dB sound pressure level (re 20 micropascals) at a frequency of 250 Hz was used for system calibration in the field.

Once the data had been recorded, the analog tapes were returned to the National Bureau of Standards for reduction and analysis. Figure A-2 identifies the equipment which was utilized for analysis purposes. Each tape was played back a channel at a time through the real-time analyzer. An interface was necessary to ensure compatibility between the real-time analyzer and the mini-computer. The time constant for the one-third octave filters was 0.2 second above 2 kHz and below 2 kHz the time constant increased with decreasing frequency to 20 seconds at 20 Hz. The time constant for the A-weighting network was 240 milliseconds which corresponds to the requirement for "RMS Fast" specified in American National Standard S1.4-1971 [5]. Once all data had been analyzed in one-third octave bands, the computer stored the data and dumped it onto digital magnetic tape formatted to be acceptable to the large NBS computer which was utilized for further analysis and graphical plot generation.

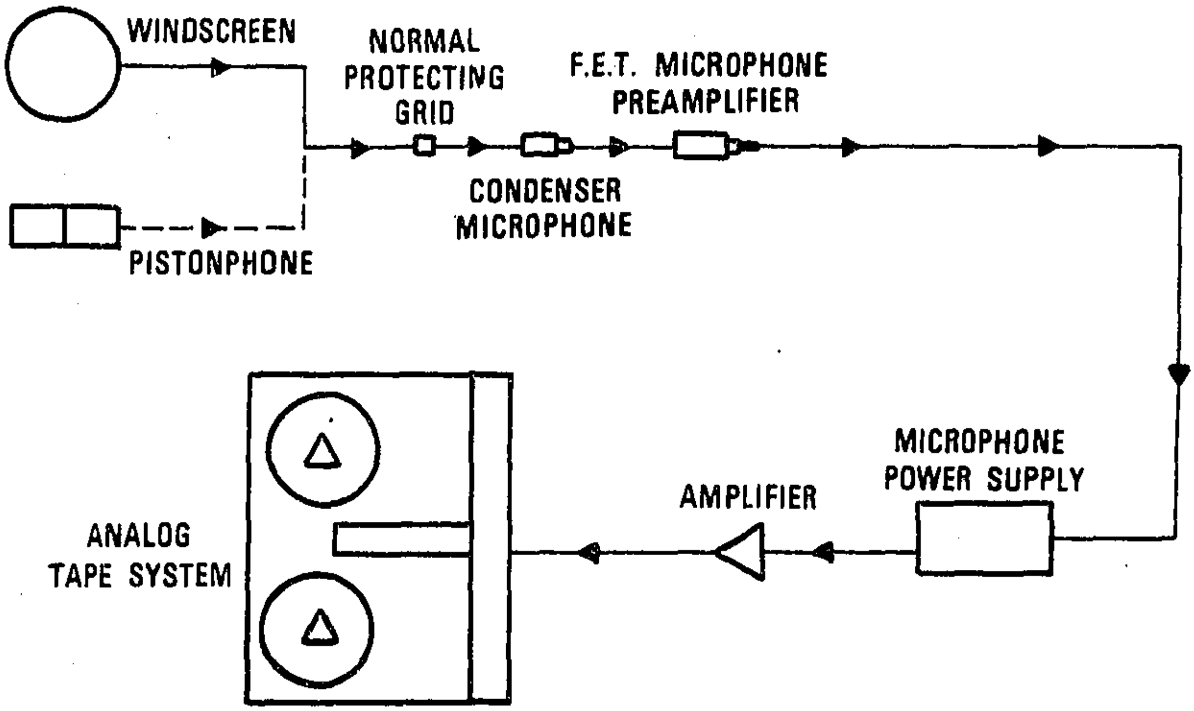


Figure A-1. Data acquisition and recording system for noise on main line.

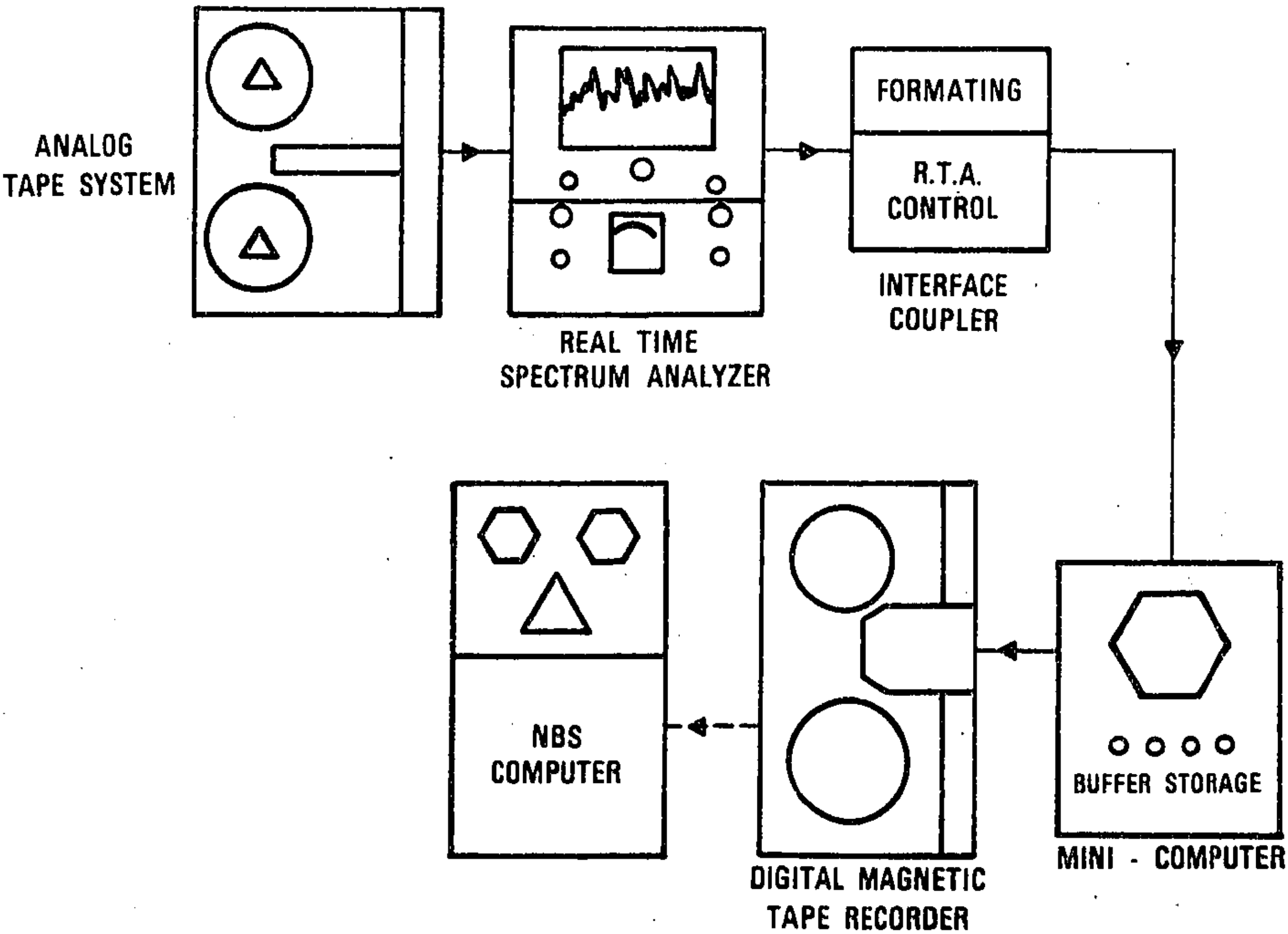


Figure A-2. Data reduction and analysis system for noise on main line.

7. Appendix B. Procedures for Calculation of L_{eq} and SENEL

The equivalent sound level (L_{eq}) is the average, on an energy basis, noise level (usually the A-weighted level) integrated over some specified amount of time. The purpose of L_{eq} is to provide a single number measure of the time-varying noise for a predetermined time period. Equivalent, in this case, means that the numerical value of the fluctuating sound is equivalent in level to a steady state sound with the same amount of total energy. L_{eq} is defined as:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p}{p_o}\right)^2 dt \right] = 10 \log_{10} \left[\frac{1}{T} \int_0^T 10^{L(t)/10} \, dt \right] , \quad \text{(B-1)}$$

where p is the time-varying, mean-square sound pressure at the point of observation, L is the corresponding sound level, p_o is the standard reference pressure (20 micropascals) and T is the period of integration.

A specialized mini-computer-based digital data acquisition system (described in Appendix C) was utilized for measurements of A-weighted sound levels for rail yard boundary measurements. Data were sampled at 0.1 second intervals. For discrete sampling of the A-weighted sound level for a specified time period, equation B-1 becomes:

$$L_{eq} = 10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} 10^{L_i/10} , \quad \text{(B-2)}$$

where L is the instantaneous A-weighted sound level for the ith sample and n is the number of samples of L in a specified time period.

The Single Event Noise Exposure Level (SENEL) provides a measure which quantifies the effect of duration and magnitude for a single event. In this case, SENEL is a measure of the individual train passby which time integrates the level accumulated during this event with reference to a duration of one second. SENEL is defined as:

$$\text{SENEL} = 10 \log_{10} \int_{-\infty}^{\infty} \left[\frac{p(t)}{p_o}\right]^2 \frac{dt}{t_o} = 10 \log_{10} \left[\frac{1}{t_o} \int_{-\infty}^{\infty} 10^{L(t)/10} \, dt \right] , \quad \text{(B-3)}$$

where p is the time-varying, mean-square sound pressure at the point of observation, L is the corresponding sound level, p_o is the standard reference pressure (20 micropascals) and t_o is the standard reference time (1 second).

An analog data acquisition system (described in Appendix A) was utilized for rail line noise measurements. As the train passed the microphone array, voltages corresponding to the sound pressures at each of the measurement locations were recorded on magnetic tape in analog form. During analysis, each analog tape was played back a channel at a time through a one-third octave band real-time-analyzer interfaced to a mini-computer. One-third octave band sound pressure levels and A-weighted sound levels were digitized and stored on magnetic tape. The analog data were sampled at 0.3 second intervals. For temporal sampling of the data, equation B-3 becomes:

$$\text{SENEL} = 10 \log_{10} \frac{1}{t_o} \sum_{i=1}^{n} 10^{L_i/10} \Delta t, \qquad \text{(B-4)}$$

where L is the instantaneous A-weighted sound level or one-third octave sound pressure level for the ith sample, Δt is the time interval between samples, t_o is the standard reference time (1 second) and n is the number of samples included in the time interval which essentially includes all of the acoustic energy from a given passby. That is, from a practical standpoint, the noise samples must be taken during the time the signal is within a given number of decibels down from the maximum value. As was pointed out in Section 2.1.3., the SENEL value is very dependent on the integration time selected. For this study, the integration time for each passby was selected to ensure that the error due to the finite integration time was no greater than 1 dB at any microphone position.

8. Appendix C. Data Acquisition and Analysis System for Rail Yard Boundary Measurements

To facilitate data acquisition in the field, a specialized mini-computer based digital data acquisition system was designed and fabricated by NBS. This system was utilized for measurements of A-weighted sound levels near the rail yard property line.

The analog portion of the system consisted of a condenser microphone, a battery-powered microphone power supply, an amplifier, an A-weighting network, a true r.m.s. detector log converter and a sample and hold amplifier (see Figure C-1). The dynamic range of the amplifier was 80 dB. The r.m.s. detector had a time constant corresponding to r.m.s. fast response for a type-I sound level meter as specified in American National Standard S1.4-1971[5]. The sample-and-hold circuitry was under computer control and maintained the time coherency between the two channels utilized for data acquisition. A third channel was used for calibration and synchronization.

The digital portion of the system consisted of a three-channel multiplexer, an eight-bit analog-to-digital converter (ADC), an asychronous first in-first out memory (FIFO), a time-of- day clock (the data and time of day are recorded automatically) and a power fail safe unit to ensure that no data were lost in the event of a power failure. The system was self-correcting in time of day and channel synchronization when power failed and was designed so that no data were lost while the computer was writing data on the digital tape or writing the analyzed data on an output device. Additionally, a read-only-memory (ROM) was used for the timing of the various functions of the digital section.

The data were sampled and held ten times per second. The aperture time of the sample and hold circuitry was 20 nanoseconds with a hold drift rate of one millivolt per second. One millisecond after the data were sampled, the reference channel was multiplexed to the ADC. The two data channels were digitized using a ten bit ADC. The output of the ADC was connected to a first in-first out asynchronous external memory so that data could be written on magnetic tape without losing new input data.

Initial calibration and check-out of the system in the field was performed using a program which interrogated the multiplex interface and printed the internal reference value and the values for channels one and two on the teletype writer. Additionally a Fortran program was used to scan the data tapes and print selected values as a check on the quality of the data while still in the field. A pistonphone which produced a 124 dB sound pressure level (re 20 micropascals) at a frequency of 250 Hz was also used for single point calibration. The digital tapes were returned to the National Bureau of Standards for reduction and analysis. Figure C-2 identifies the instrumentation which was utilized for analysis purposes.

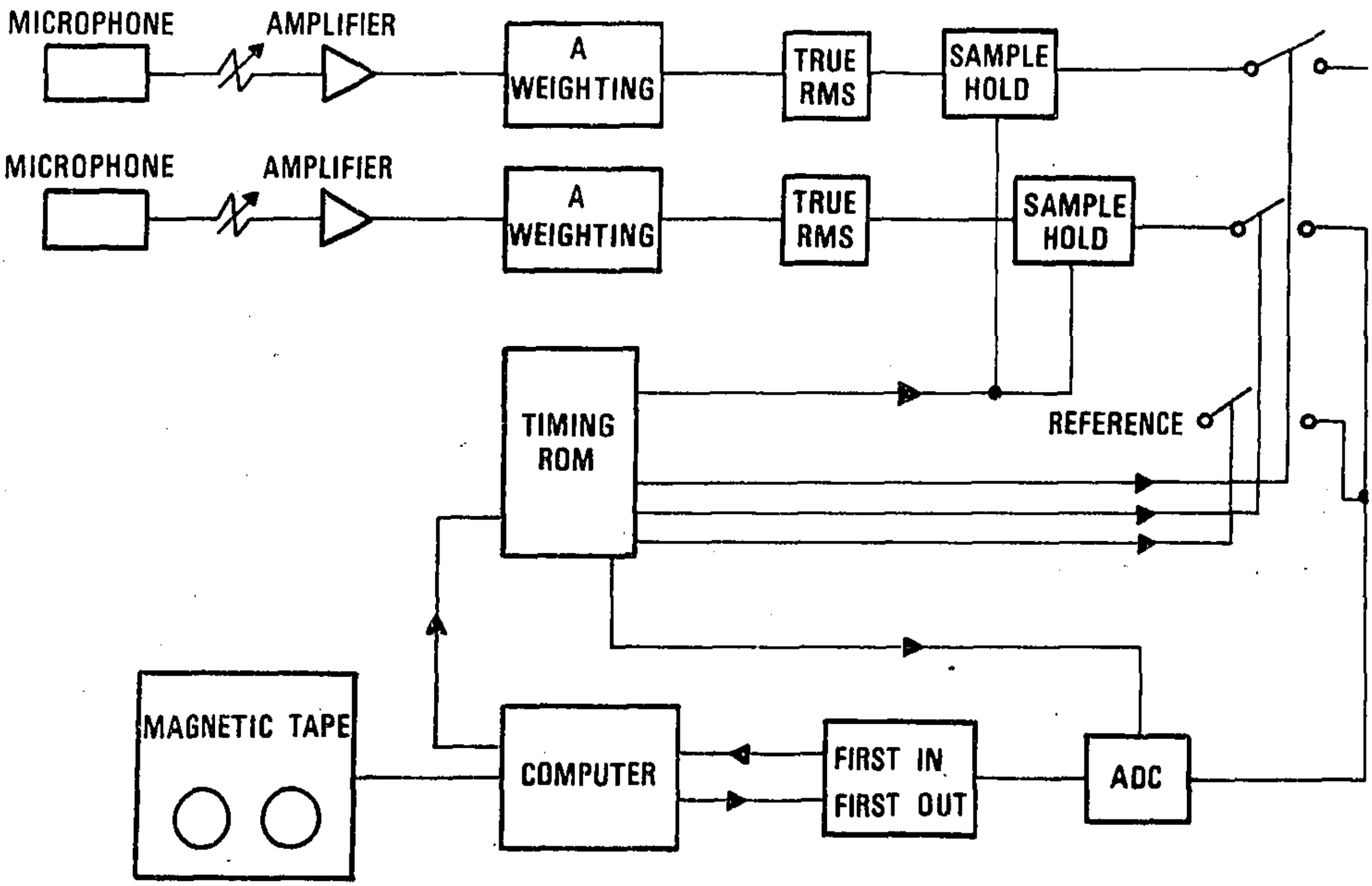


Figure C-1. Data acquisition system for yard noise.

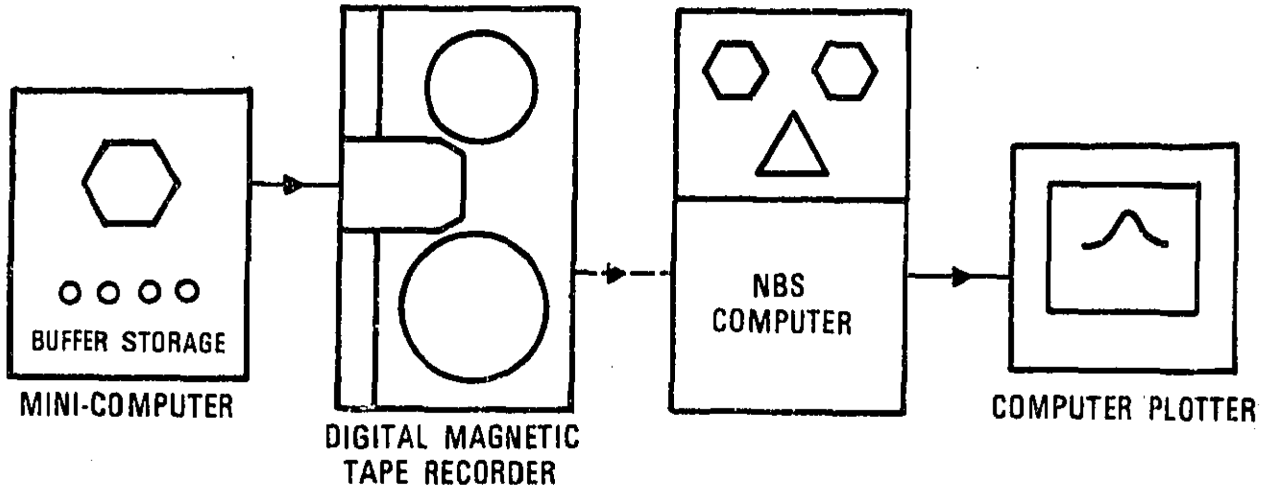


Figure C-2. Data reduction and analysis system for yard noise.

9. Appendix D. Data Acquisition and Analysis System for Retarder Noise Measurements

The data from the reference and test position microphones were recorded on separate channels of a two-channel, direct record tape recorder. The data acquisition system is shown in Figure D-1. A single point calibration utilizing a pistonphone which produced a 124 dB sound pressure level (re 20 micropascals) at a frequency of 250 Hz was used for system calibration in the field.

Once the data had been recorded, the analog tapes were returned to the National Bureau of Standards for reduction and analysis. Figure D-2 identifies the instrumentation which was utilized for reduction and analysis purposes. The time constant for the one-third octave filters was 0.2 second above 2 kHz and below 2 kHz the time constant increased with decreasing frequency to 20 seconds at 20 Hz. The time constant for the A-weighting network was 240 milliseconds which corresponds to the requirement for "RMS Fast" as specified in American National Standard S1.4-1971[5].

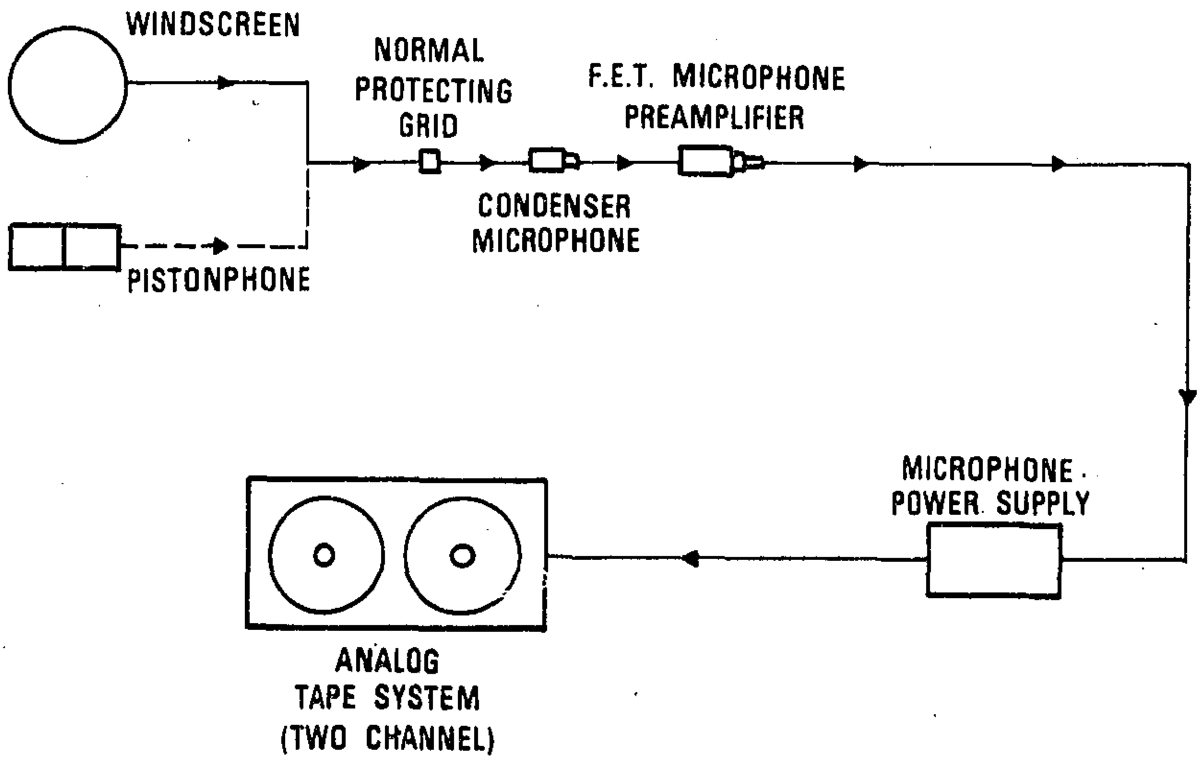


Figure D-1. Data acquisition and recording system for retarder noise.

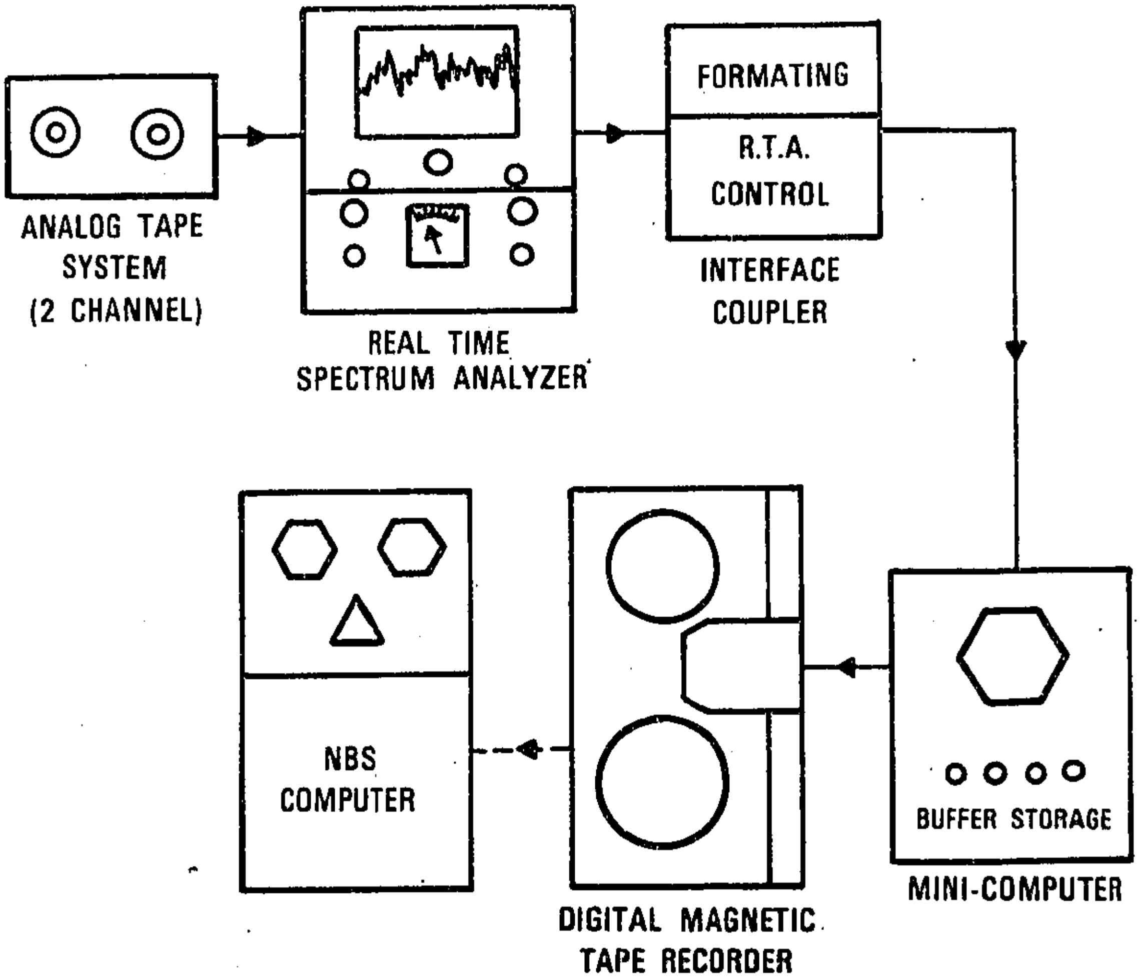


Figure D-2. Data reduction and analysis system for retarder noise.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A field investigation of noise emission from railroad operations was conducted. The objectives of the study were the establishment of a data base on the noise levels associated with railroad operations, both line (trains in transit) and yard, and the development of measurement procedures that could be utilized in regulations applicable to the noise from rail carrier equipment and facilities. For trains in transit, measurements were made as a function of horizontal distance from the tracks [five locations at 25, 50, 100, 200 and 400 feet] and as a function of microphone height [three different heights at the 25 and 50 foot microphone locations]. Train passby data are presented as the maximum A-weighted sound level observed during the passby and as Single Event Noise Exposure Levels (both A-weighted and one-third octave band levels). A-weighted sound level measurements were made at the boundary of the railyard, at 0.1 second intervals, for periods of time ranging from 1 to 23 hours over several days. These data are presented as the energy equivalent sound level and the level exceeded ten percent of the time. The directionality of retarder noise was also investigated. Measurements were made of the noise emitted in various directions during retarder operation.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)

Acoustics; noise measurement; noise (sound); railroad yard; trains

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