NO. UMTA-MA-06-0025-78-9

NOISE ASSESSMENT OF THE PORT AUTHORITY TRANSIT CORPORATION LINDENWOLD RAIL TRANSIT LINE

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INTERIM REPORT

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16. Abstract

This report describes the noise climate on and near the Port Authority Transit Corporation (PATCO) Lindenwold High Speed Line. It is one of a series of coordinated assessments sponsored by the Urban Mass Transportation Administration and technically administered through the Transportation Systems Center of the U.S. Department of Transportation. The PATCO urban rail transit line has approximately 14.2 miles of two-way revenue track (of which about four miles are in subway), and 12 stations. Noise level data is given for specific measurements made in cars, in stations, and along the non-subway wayside at appropriate locations. Based on these measurements, in-car average maximum, A-weighted sound levels, L_A(Max), range from 72 to 84 dBA and are estimated to be in the 70 to 79 dBA interval for 95 percent of the PACTO route. Wayside L_A(Max) levels, at 15m (50 ft) from the near track, range from 76 to 84 dBA and are in the 80 to 84 dBA interval for 84 percent of the above ground route mileage. Station L_A(Max) levels are somewhat more dispersed, and are in the 70 to 74 dBA interval for 42 percent of PATCO stations, and in the 80 to 89 dBA interval for 58 percent of the stations.

The rationale for choice of measurement sites and the methodology for arriving at the summary noise distributions from the data are discussed explicitly. Measurement and analysis instrumentation and procedures are also described.

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PREFACE

This report has been prepared under the Urban Rail Noise Abatement Program being sponsored by the Urban Mass Transportation Administration's (UMTA's) Office of Rail and Construction Technology. The Noise Abatement Program is being managed at the Transportation Systems Center for UMTA. The objectives of the Noise Abatement Program are to assess noise produced by urban rail transit operations and to appraise methods and costs for reduction of such noise.

This report is one in a series of six noise assessment reports covering noise due to transit operations on seven rail transit systems in five U.S. cities. Consistent results of the six assessments were achieved through use of standardized noise measurement and data reduction procedures developed at TSC and tested on the Massachusetts Bay Transportation Authority (MBTA) in Boston. The assessment report for the MBTA was published in 1974 (Reference 1).

Physical differences among the transit systems, as well as differences in the technical orientations of the teams, and in funds available to the teams for measurement and analysis, led to some differences in report organization, technical depth and writing style. Therefore, to provide at least introductory consistency among the reports for the reader, the front material, including the introduction of each assessment report, has been edited at TSC. The organization and technical content of each report, however, are basically as originally written by the respective teams and are, together with the accuracy of the measurements, the responsibility of the authors.

This report has been prepared by the Boeing Vertol Company under contract DOT-TSC-850. Authors of the report were R. H. Spencer and E. G. Hinterkeuser. Technical Monitors for the program were Dr. E. G. Apgar and Dr. Robert Lotz. Liaison with the Port Authority Transit Corporation was provided by Mr. David L. Andrus. Dr. Leonard Kurzweil of the Transportation Systems Center directed the final technical editing of the report.

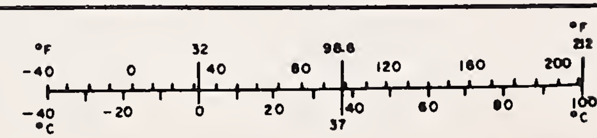
METRIC CONVERSION FACTORS

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



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L_A(Max) - Maximum A-weighted sound pressure level for a given noise event, measured in dBA.

AL_i - Instantaneous A-weighted sound pressure level for sample "i", measured in dBA.

L_{eq} - Equivalent Sound Level - in dBA.

$$L_{eq} = 10 \log \left[\frac{\sum_{i=1}^{n} \text{antilog } (AL_i/10)}{n} \right]$$

n - Number of samples of AL in a specified time period.

L_{dn} - Day-Night Equivalent Sound Level-in dBA.

$$L_{dn} = 10 \log \left[\frac{\sum_{i=1}^{n} 10^{(L_{eq}/10)} W_i \bullet T_i}{24} \right]$$

W_i - Time of day weighting factor

$W_i(0700\text{-}2200) = 1$

$W_i(2200\text{-}0700) = 10$

T_i - Time interval for "i"-th period

L_R - L_A(Max) + 10 log T_5, in dBA

T_5 - Duration between the 5 dBA-down-from-L_A(Max) points measured in seconds

L_X - The A-weighted sound level equaled or exceeded X% of the time-in dBA.

SENEL - Single Event Noise Exposure Level, measured in dBA.

$$\text{SENEL} = 10 \log \left[\sum_{i=1}^{n} \text{antilog } (AL_i/10) \bullet \Delta t \right]$$

Δt - Effective duration of noise event, measured in seconds.

CNEL - Community Noise Equivalent Level-in dB.

$$\text{CNEL} = 10 \log \left[\frac{\sum_{i=1}^{n} W_i \bullet \text{antilog } (\text{SENEL}_n/10)}{86400} \right]$$

W_i' - Time of day weighting factor

W_i' (0700-1900) = 1

W_i' (1900-2200) = $\sqrt{10}$

W_i' (2200-0700) = 10

Hz - Frequency, measured in cycles per second

1. SUMMARY

The Urban Mass Transportation Administration is supporting a program under the technical administration of the Transportation Systems Center to determine the noise climate of the major rapid rail transit systems in the United States and to assess the impact of that noise on patrons, employees, and wayside communities. The results are to be used in determining approaches and associated costs to reach various selected noise abatement levels. The methodology, measurement techniques, and analysis are common for all systems studied so that results can be compared. Noise assessment reports, covering each of the major rapid transit systems, are being issued as a series.

The Port Authority Transit Corporation (PATCO) Lindenwold Line, described in this report, consists of approximately 14.2 miles of two-way revenue track of which 4 are underground, 4.6 are on an embankment, 4.1 at grade, one mile in cut, and one-half mile on concrete viaduct.

The average speed for the entire route (including stops) is 40 mph (64 kph), with normal running speeds of 75 mph (121 kph) southeast of Camden. Fully welded track is used, except on the Benjamin Franklin Bridge and certain sections of underground track in Philadelphia. Stainless steel Budd Company electric cars are in use on the PATCO system, operated as single units and in married pairs. Upholstered seat covers provide some measure of acoustical absorption, and acoustical insulation is used in the car body construction.

Another acoustical feature noted on the PATCO system is the use of thin metal perforated ceiling throughout the six New Jersey stations.

Noise Assessment was of three general types:

1. Community noise
2. Station noise
3. In-Car noise.

Conditions for each type of measurement were standardized as far as possible for supporting later analysis and for ensuring comparability of results with those of other systems. In addition to the acoustic data channels, one channel of a tape track was provided for comments by the measurement observer to assist in the later description or explanation of the noise environment and phenomena.

Noise recordings were made with standardized instrumentation having a flat (unweighted) frequency response characteristic. Field calibration was performed during the data acquisition. In addition, equipment was periodically calibrated using Class 2 NBS standards.

Detailed results are too extensive to show in this summary. However, the following estimates of sound levels (in dBA), were determined for the PATCO Lindenwold Line.

TABLE 1.1. AVERAGE MAXIMUM A-WEIGHTED SOUND LEVEL DISTRIBUTIONS FOR THE PATCO LINDENWOLD LINE.

	MAXIMUM SOUND LEVELS (dBA)					
	70 to 74	75 to 79	80 to 84	85 to 89	90 to 94	95 to 100
Car Interior* (Percent of Route Mileage)	48	47	5	0	0	0
Wayside at 15 m (50 ft) Distance (Percent of Above Ground Route Mileage)	0	7	84	0	9	0
Station Platform (Percent of Stations)	42	0	16	42	0	0

*Average of Single and Double Cars

2. INTRODUCTION

2.1 Program Scope

This report describes the noise climate of the Port Authority Transit Corporation (PATCO). The work is part of a noise assessment study by this contractor which included PATCO, the Southeastern Pennsylvania Transportation Authority (SEPTA), the San Francisco Bay Area Rapid Transit (BART) System, and the Greater Cleveland Regional Transit Authority (RTA), formerly the Cleveland Transit System (CTS). Similar assessments have been undertaken by separate contractors of the Chicago Transit Authority (CTA), the New York City Transit Authority (NYCTA), and the Port Authority Trans-Hudson (PATH). The noise assessments for the BART, RTA, and SEPTA systems, as well as for those systems considered by other contractors, are reported in other documents of this series.

This work was done as part of an Urban Mass Transportation Administration (UMTA) program to assess the noise produced by various U.S. urban rail transit operations and to appraise methods and costs for reduction of such noise. The characterization of the noise climate of each rail transit system, carried out in a uniform manner, provides data to assist in determining UMTA priorities and funding decisions. The noise assessment activity has three elements:

1. Noise climate assessment.
2. Consideration of abatement technique options.
3. Cost estimation for abatement to specified noise levels.

Specifically, this activity allows noise level comparisons (a) of systems, (b) of different types of equipment or track structures on the same system, and (c) before and after noise control actions. It also provides data pertinent to the establishment of possible regulatory action to control noise levels.

The specific purpose of the work reported in this volume was to measure and otherwise describe the noise climate of the PATCO system as well as to describe the measurement and analysis methodology used.

The noise climate and associated information includes descriptions of the various sources and paths of noise, and their relative contribution to the noise climate at the point of measurement.

The PATCO Lindenwold Line was surveyed and classified by vehicle type, station type, roadbed construction type, and type of wayside land use. Representative measurement locations were then defined for each of these categories as well as for other locations with specified singularities (unique noise characteristics). This

.approach, common to all assessments, is based on the noise assessment of the Massachusetts Bay Transportation Authority (MBTA), (Reference 1), which served as a pilot study for these later assessments. Consistency of results were achieved through the use of a standardized noise measurement and data reduction process. This process was successfully validated through "round robin" tests in which the assessment teams made simultaneous measurements of noise from Massachusetts Bay Transportation Authority trains and, without communication between teams, reported the resulting reduced data. The findings of all teams correlated well.

For the purposes of this assessment activity, it is adequate to measure a limited, but statistically sufficient number of vehicles, stations, and community sites, selected to cover the major construction and operating features of the system.

The present data describe the existing system noise climate and permits a first order estimate of abatement techniques and associated costs to satisfy reduced noise level criteria. When a preliminary investigation such as this reveals noise problems, and a decision is made to proceed with their solution, more detailed measurements and analyses must be made. Normally, this would include detailed diagnostic measurements to identify the dominant sources and paths for engineering design of site-specific noise control treatments.

2.2 Reader's Guide to Report

The general measurement methodology, including sampling strategy for measurement site selections, site conditions, microphone positions, and measurement procedures for community, station, and in-car noise assessments are presented in Section 3. Details of the instrumentation and data analysis procedures are given in Section 4. Section 5 includes an overview of the PATCO system (Section 5.1) followed by a detailed description of the measurement results. The principal findings are summarized in Section 6.

3. GENERAL MEASUREMENT METHODOLOGY

3.1 Community Noise

Sampling Strategy - The purpose of this survey was to determine noise levels in the wayside community caused by train operations as well as other community background noise. Measurements of noise in the community have been categorized as shown in Table 3.1 by source, path and receiver. In each case, the variable which affects either the physical noise during generation, propagation, or reception, or the response of the listener to that noise, have been itemized.

For each transit line in this study, the type of railcar used was typical of the system as was the rail type and quality. However, a wide variation in roadbed type, background noise, conditioning of residents to noise, and land usage was noted.

Except for areas where wheel screech, rail joint noise or other singularities prevailed, the sites were selected from operational characteristics of the transit systems. Thus, locations were chosen at the wayside where the trains were operating near normal full speed as well as decelerating and accelerating near stations.

Noise measurements considering all the variables shown in Table 3.1 would be not only costly and time-consuming, but also unnecessary to adequately describe the community noise. Site selection was based on the following parameters:

Type of Roadbed Support

(1) Aerial Structure
(2) At-grade
(3) Underground
(4) Other sites with singularities

Building Construction Type

(1) Residential
(2) Commercial

The measuring microphone or sound level meter for all types of transit structures was 1.6m (5.25 ft) above the ground. This was also the case near aerial structure. Previous measurement on BART* indicated that for the type of structure present on that system, no significant difference existed between noise levels at 1.5m (5 ft) above grade and 9.1m (29.9 ft) above grade, 15m (50 ft) from the near track centerline.

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* S.L. Wolfe, H.J. Saurenman, P.Y.N Lee, "Noise Assessment of the Bay Area Rapid Transit System," UMTA-MA-06-0025-78-10, October 1978.

TABLE 3.1. COMMUNITY NOISE SURVEY STRATEGY
Sound Source Parameters Car Type, No. Cars, Wheel Quality, Truck Type Rail Type Jointed, Welded, Surface Roughness, Type of Fastener Track Construction Tangent, Curve
Sound Path Parameters Roadbed Type Open-cut (Concrete, Grassy), At-grade, Elevated Structure (Steel, Concrete), Underground Terrain Attenuation Housing Density, Terrain Type
Sound Receiver Parameters Background Noise Time of Day (Waking/Sleeping) Conditioning of Residents to Noise Land Use Residential, Commercial

Conditions at Measurement Site - The measurement site was chosen such that no obstacles were in the vicinity of the microphone to disturb the sound field. Meteorological conditions such as temperature and wind were noted and no measurements were made in winds above 7m/sec (23 ft/sec). Microphones were located no closer than 2m (6.6 ft) from any reflecting surface (other than the ground). Photographs of each measurement site were taken.

Microphone Positions - The basic distance for measurement of noise for all wayside measurements was 15m (50 ft) with alternate distances of 7.5m, 30m, 60m (25, 100 and 200 ft respectively) selected where the 15m distance was not achievable.

The microphone and windscreens were oriented vertically at a distance of 1.6m (5.25 ft) above local ground level for all measurements.

Measurement Procedure - Measurement procedures and practices as defined in International Standard ISO-3095-1975(E) in draft form at the time of the noise measurements, "Acoustics - Measurement of Noise Emitted by Railsound Vehicles," were used as a guide for the measurement program. A calibration tone was recorded on each tape track just prior to and immediately following the measurement program to insure that a valid sample of data had been obtained. A sound level meter also was employed frequently as a verification measurement system. Recorder gain settings were selected to provide optimum dynamic range coverage.

For each train passby, additional information such as vehicle identification number and wheel condition, or specific noise sources whether or not they were related to the transit train, was recorded. In general, 30-minute recordings were made at each microphone location four times during a normal day and included measurements during daytime off-peak service (10 a.m. to 2 p.m.), rush hour (4 p.m. to 6 p.m.), evening (7 p.m. to 10 p.m.), and night (11 p.m. to 4 a.m.) to obtain sufficient information to calculate day-night levels, L_{dn}.

It was also necessary to establish the number of train passbys required to be included in the data sample such that future reductions of system noise of 5 dBA or more could be detected and whether the reductions would be significant for a 95% confidence level. The methodology describing this investigation is presented in detail in Appendix A. In this appendix it has been shown that a sample size of 4 trains is adequate to detect a reduction in system noise level. Based on daytime headways of 6-7½ minutes between trains for each of the systems surveyed, a 30 minute recording interval was then selected for a sample. This was then standardized for each time period throughout the day. It was generally observed that during this period, six trains in each direction passed by the microphone location.

No attempt was made to operate the propulsion system with the car on jacks (spin test) to determine the contribution of motor and gearbox noise. This should be performed in any future study where noise reduction of an existing car is contemplated. Although a complete diagnostic study of the data was not performed, sufficient information was obtained to identify sources which contribute to the car signature in the community.

3.2 Station Noise

Sampling Strategy - Station platform noise measurements were intended to assess the noise environment to which the transit system patrons are exposed while entering and leaving trains at a station platform or while waiting for trains, and to determine the exposure of employees in ticket booths due to train passage. Measurements of noise in transit stations were categorized by station platform layout (i.e., center platform, side platform) and roadbed category (i.e., elevated, at-grade, underground, freeway median).

Conditions at Measurement Site - The microphone locations were chosen so that no permanent obstacles were present near the microphone. The platform locations selected were open visually and acoustically to all tracks at that station so that noise of all trains had some direct-incident waves arriving at the microphone. Except for rush-hour measurement periods, shielding at mid-platform locations by patrons was minimal. Meteorological conditions such as temperature and wind were noted and no measurements were made in winds above 7m/sec (23 ft/sec). Photographs of each measurement site were taken.

Microphone Positions - The noise measurement locations were 1.6m (5.25 ft) above the platform level in the middle of a stopped train and at the end of a stopped train at a distance of 2m (6.6 ft) or one-half the platform width, whichever was smaller, from the platform edge. The microphone was oriented vertically with a wind-screen attached.

Measurement Procedure - Procedures for measurement of noise levels on station platforms generally follow those outlined for community noise recordings. The 30 minute sampling time provided sufficient passings of trains to achieve statistical confidence levels as described in Appendix A.

3.3 Vehicle Interior Noise

Sampling Strategy - Measurements of noise within the transit vehicle were made to document the acoustic environment which patrons and operating personnel experience under typical service conditions. Continuous recordings were made in the second car of a multicar train during round trips. Microphone locations were selected to be representative of the locations of patrons and car operators; that is, a mid-car seated ear level position and an operator's ear level position within the cab area.

Cars selected for measurement were chosen as being typical examples of a specific car model to be surveyed. Cars with wheel flats were avoided when smoothed wheels were normally observed in operation.

Conditions at Measurement Site - Data were taken during non-rush hour conditions so that the area within 1m (3.3 ft) of the microphone was free of riders. This also improved the chances for obtaining data which was clear of conversation and other non-vehicle noise. No effort was made to correct for these sources. The car chosen for recording was free from unusual noise sources. General vehicle conditions and unusual conditions such as slowing for maintenance or construction personnel were noted.

Microphone Positions - The microphone was oriented vertically at the ear level of a seated passenger at a mid-car position 1.2m (4 ft) above the floor. In addition to a mid-car microphone position, noise data was recorded at the train operator's location and over a truck. To standardize with other program measurements, a windscreen was placed over the microphone. Variations in noise throughout the car both longitudinally and vertically were investigated using a sound level meter.

Measured or estimated speeds were reported on the tape at least once between adjacent stations. Each car in the train surveyed was identified by car number, and unusual conditions of any nature in the car were similarly reported.

Measurement Procedure - The procedure for recording vehicle interior noise levels was to calibrate the on-board microphones prior to data recording. Data records were then initiated at a station stop with doors open, and continuous records were taken over the travelled route. An auxiliary channel was used to voice-annotate the data with incidentals such as travel time, station stop, estimated speed, and track identification. At the end of the trip, with car doors open, the data recorder was stopped and the microphone recalibrated.

4. INSTRUMENTATION AND DATA ANALYSIS

4.1 Instrumentation

Data Requirements - The noise of the transit system was recorded on magnetic tape using a flat, or unweighted, frequency response characteristic. Flat response is important in order to avoid peak clipping and harmonic distortion of the recorded noise data. The monitoring meter of the tape recorder was set to fast/quasi-peak to avoid overload, such as might occur during wheel/rail impact noise at joints and crossovers.

Noise data has been summarized in tabular and graphic format in a standard manner so that comparisons may be made among measurements for each test condition or among different transit systems.

Data Acquisition System - The prime data acquisition systems (illustrated in Figures 4.1 and 4.2) consisted of Bruel and Kjaer one-half inch and one-inch microphone cartridges and cathode followers, either battery-powered or driven from a power supply integral to the magnetic tape recorders. These microphones, in addition to their normal protection grids, were fitted with wind-screens for both interior and exterior noise measurements. These were spherical, open cell foam covers.

The output of the microphones was tape recorded in the direct mode (amplitude modulation) on portable Kudelski tape recorders, either Nagra Model III for single-channel, or Nagra IV SJ for dual-channel data acquisition. The tape recorder was battery-operated and run at a tape speed covering the frequency range of interest.

To supplement laboratory calibrations, field equipment checks were made using Bruel and Kjaer Sound Level Calibrators for single frequency, single level calibrations. This was done prior to the start and after the completion of any measurements recorded on each tape reel with occasional in-between calibrations if the measurements extended over a period of hours on any one tape reel.

The data recorded on magnetic tape was also checked for fidelity by the simultaneous use of headsets on the output of the tape recorders while data was in the process of being recorded. Where this was not feasible (for example, when the acoustic environment was too high to aurally separate the headphone signal from the surrounding environment) the built-in loudspeakr of the tape

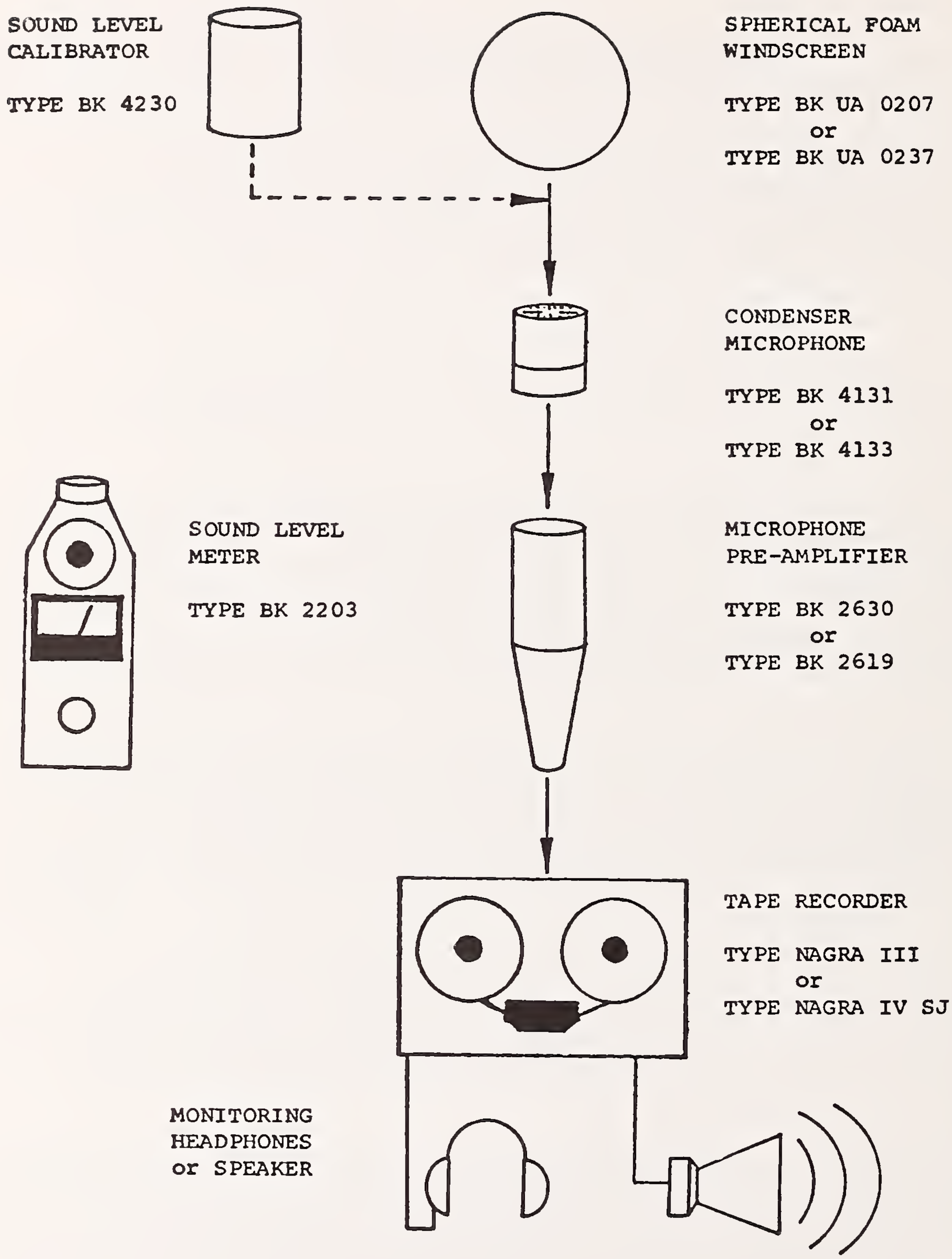


FIGURE 4.1. TYPICAL DATA ACQUISITION SYSTEM

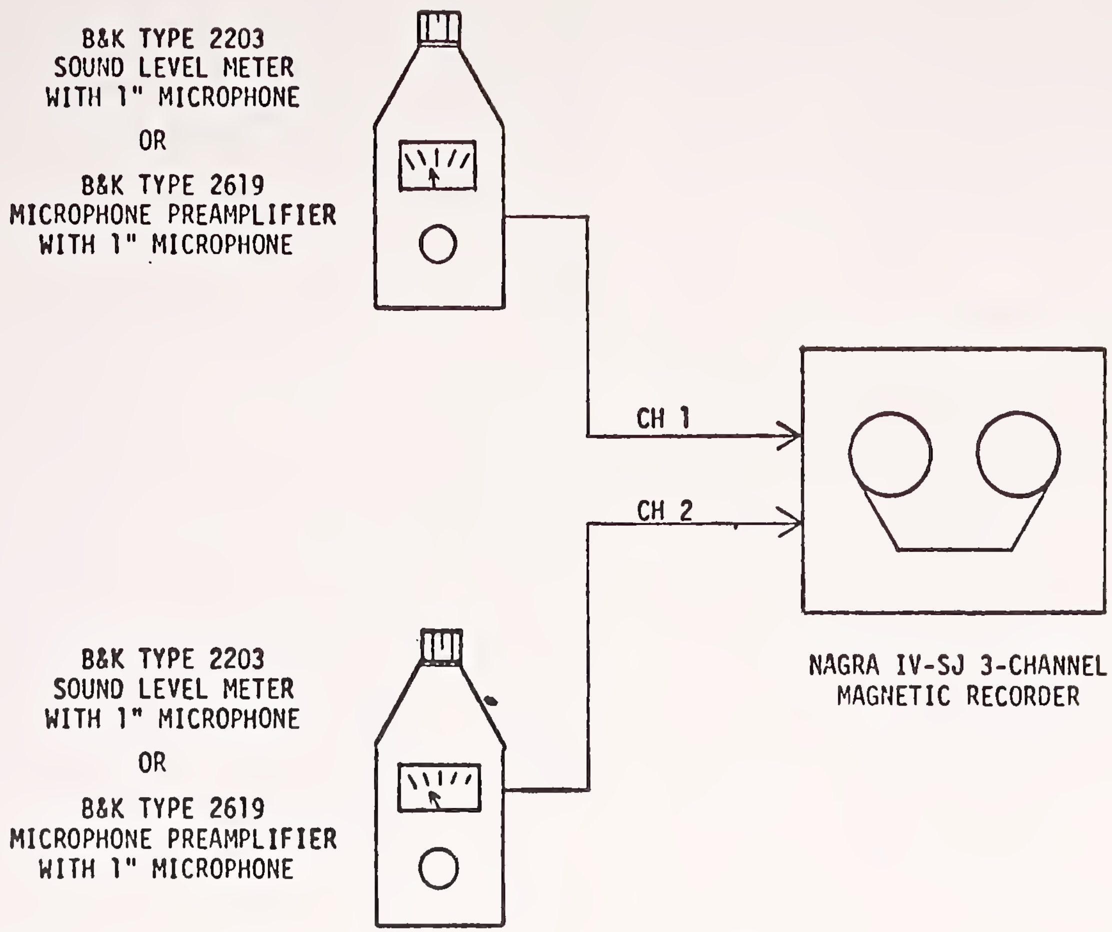


FIGURE 4.2. BLOCK DIAGRAM OF NOISE MEASUREMENT INSTRUMENTATION

recorder was used in a less noisy setting to verify the correctness and fidelity of the noise data, immediately after acquiring the data.

Tape recorder gain settings were optimized for maximum signal-to-noise ratio or dynamic range with the aid of a Bruel and Kjaer sound level meter Type 2203. This is a general purpose sound level meter with characteristics as specified by ANSI Standard S1.4-1971.

Equipment Calibrations - In addition to the field calibrations performed during the acquisition of the data, microphones, calibrators, tape recorders and analysis equipment were periodically laboratory calibrated using reference instruments and signal generators of the Class 2 type which are traceable to the National Bureau of Standards. In this data analysis, compensation has been included for the effects of using a foam windscreen and a microphone protection grid, corrections for random sound wave incidence for in-car and station platform noise data, and right-angle (90-degree) incidence for community noise data. The individual corrections for tape recorder frequency response and incidence angle relative to the microphone were summed as a function of frequency. These corrections were then applied to the analysis in terms of a weighting network with the same characteristic as the correction curve.

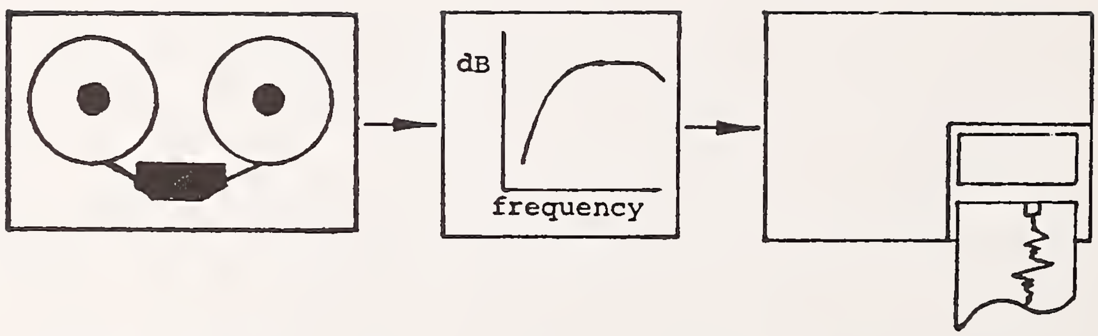
4.2 Data Analysis

Graphic Level Recorder Calibration - Since the data contained in this report will be compared with the acoustical environment of numerous other transit systems, it is important that the levels reported are correct on an absolute basis. It is also important because at some future time this data will form a baseline against which changes in system noise will be measured when improvements have been incorporated. An effort has therefore been made to ensure that the basic noise level data, reported in terms of sound level dBA, is reproducible. The average maximum levels of acoustic events are therefore desired from graphic level recorder traces simulating the "Slow" response of a sound level meter meeting ANSI S1.4-1971 Type 1 accuracy. Equivalence of graphic level recorder response to such a sound level meter accuracy was initially ensured by using the techniques described in a paper by Webster and Farinacci (Reference 2). Subsequently, an alternate and less time-consuming instrument calibration method was adopted when laboratory comparisons indicated that ordinary train and other environmental noises were accurately reproduced. This simpler method consisted of setting the potentiometer range control knob of the graphic level recorder to 40 dB, and the lower limiting frequency knob to 20 Hz. The writing speed knob was then adjusted to give a square corner trace to a 1000 Hz, 400 millivolt step input with the graphic level recorder baseline sensitivity adjusted to give a trace deflection at the 30 dB line on the 50 dB range paper. This test was then repeated at the 40 dB line. The final writing speed knob setting was chosen as the middle writing speed of those settings which met the square corner criterion. Transient noises also were correctly represented with errors not exceeding 2 to 3 dBA.

Individual Event Analysis - Typical acoustical events have been illustrated in a dBA time history format with calibrated amplitude and time axes on a strip-chart. These are annotated to illustrate special, as well as expected, acoustic events such as wheel squeal, door closings, etc.

Figure 4.3 illustrates the basic data reduction equipment in schematic form. Specifically, the typical events illustrated on the strip chart recordings are:

- Community Noise: Passby as a function of distance from track



TAPE RECORDER
PLAYBACK

TYPE NAGRA III
or
TYPE NAGRA IV SJ

dB(A)
WEIGHTING
NETWORK

TYPE BK 2112
or
TYPE GR 1921

GRAPHIC LEVEL
RECORDER

TYPE BK 2305

FIGURE 4.3. DATA ANALYSIS EQUIPMENT SCHEMATIC
FOR INDIVIDUAL EVENT ANALYSIS

- Station Noise: Passby, Train Arrival, Train Departure, Train Stopped
- In-Car Noise: Acceleration, Steady Speed, Deceleration, Special Noises

A-weighted time histories of the above types of noise events are used to determine both the Average Maximum Level L_A(Max) and the duration (T) in seconds of the noise event measured 5 dBA below the L_A(Max). The duration is then used to calculate L_R:

$$L_R = L_A(\text{Max}) + 10 \log T_5 \quad \text{dBA}$$

where:

L_A(Max) = maximum A-weighted sound level for a given noise event

T_5 = duration in seconds of the 5 dB-down points from L_A(Max)

L_R is, in effect, an approximation to SENEL, the Single Event Noise Exposure Level used in computing the Community Noise Equivalent Level (CNEL). L_R was suggested by Schultz (Reference 3) and has been applied to urban rail transit vehicle noise as a measure of the total sound energy contained in a discrete noise event as measured at a standard receiver location. L_R has been applied to data measured as part of this program on station platforms and at community wayside locations. Figure 4.4 illustrates this method of determining L_R and also indicates the smoothed curve faired through fluctuating data.

Special noises noted may be specific to a particular site, illustrations of train squeal, pure tones from equipment, tunnel section, wheel impact at rail joints, turnouts and crossovers, car banging due to hunting, flange rubbing, etc. The equipment illustrated in Figure 4.5 was utilized for the documentation of singular spectral characteristics with either fixed bandwidth or fixed percentage bandwidth frequency analyzers.

Grouped Data Analysis - In order to assess the statistical significance and the level of confidence which can be expected from the results of this measurement program, a detailed statistical analysis was performed of the noise data encountered at one of

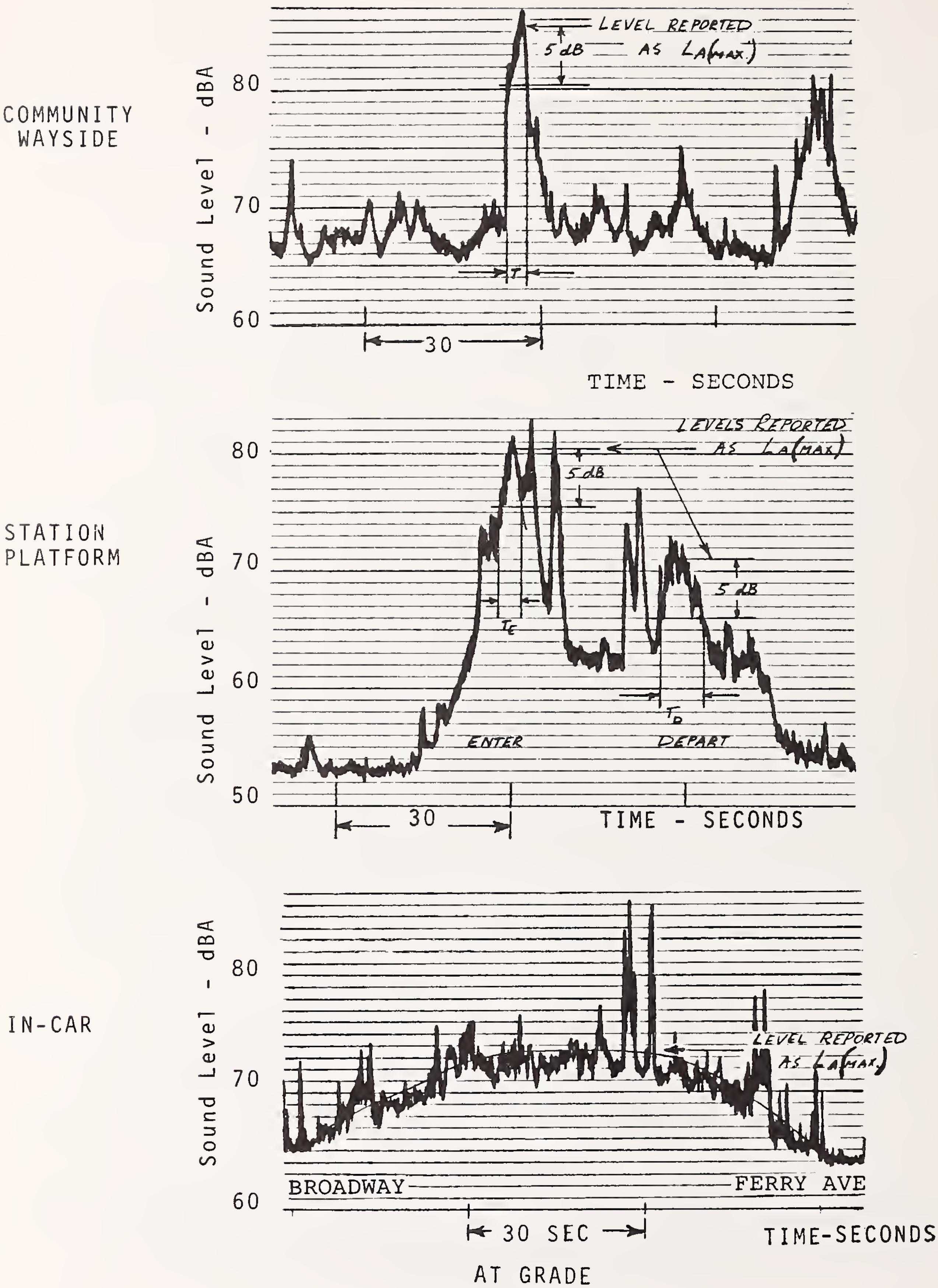
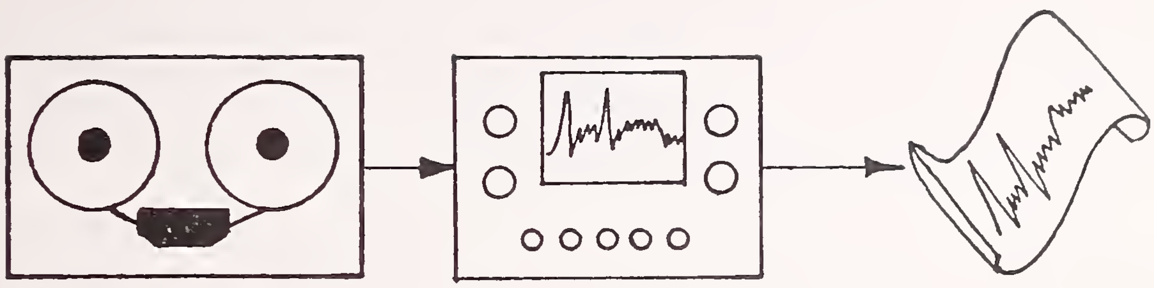


FIGURE 4.4. METHOD OF DETERMINING L_A(Max) AND T_5



TAPE RECORDER
PLAYBACK

TYPE NAGRA III
or
TYPE NAGRA IV SJ

SPECTRUM
ANALYZER

TYPE GR 1921

CHART RECORDER

GRAPHIC LEVEL

FIGURE 4.5. SPECTRAL ANALYSIS EQUIPMENT SCHEMATIC FOR SITE SPECIFIC NOISE SINGULARITIES

Philadelphia's subway station platforms. This analysis (detailed in Appendix A) established that in order for a future 5 dBA reduction in train noise level to be significant statistically with a 95-percent confidence level and detectable considering normal data scatter, a sample of from four to six train passbys was necessary. This criterion was generally met at all measuring locations and times of day with the exception of nighttime when reduced transit system activity did not permit a sufficient data sample. Based on the assumption that the noise of transit systems other than Philadelphia's have similar statistical properties, the statistical analysis further showed that a standard deviation of less than 2.2 dBA at a particular site indicates a sufficiently small data scatter permitting the detection of a 5 dBA reduction with 95-percent confidence.

The validity of the foregoing conclusions have been further demonstrated by comparing the average L_A(Max) platform noise levels for two SEPTA Broad Street Subway stations. In each case, the specific sites compared were for the two meter microphone positions adjacent to the local southbound tracks. Four-car trains were recorded during the daytime period at the Walnut-Locust and the Spring Garden Stations with the following results:

TRAIN OPERATING CONDITION	L_A(Max) ~ dBA	
	WALNUT-LOCUST	SPRING GARDEN
ARRIVING, NEAR TRACK	94	92
DEPARTING, NEAR TRACK	86*	92
ARRIVING, FAR TRACK	90	89
DEPARTING, FAR TRACK	88	90
AVERAGE MAXIMUM LEVEL	90	91

* low speed

With one exception, the corresponding noise events are within 2 dBA of each other. The exception is for noise levels of departing trains, operating on the near track at Walnut-Locust which differ by 6 dBA from the corresponding condition at Spring Garden. This reduction in level at Walnut-Locust can be attributed to slower train speeds since immediately south of Walnut-Locust the system changes from a four-track system to a two-track system.

Since both Walnut-Locust and Spring Garden are four-track, two center platform stations with the same architectural features at platform level, the close agreement among the measured noise levels confirms the validity of the detailed statistical analyses at the beginning of the measurement program. This analysis demonstrated the justification for sampling only one station of each type on the system.

The measurement summary tables included for each measurement site reported therefore list the standard deviation for L_A(Max) and L_R for each noise sample recorded. In addition, the cumulative amplitude distributions have been tabulated for L_{99}, L_{90}, L_{50}, L_{10}, and L_1. The equivalent sound level, L_{eq}, and the Day-Night Level, L_{dn} (for wayside sites), are also presented for each measurement site documented.

The Equivalent Sound Level, L_{eq}, provides a single number measure of the time varying noise, not only of the transit vehicles, but all noise at a specific site. It has been calculated separately for each time period when noise was sampled. It also is used for calculating the Day-Night Levels. L_{eq} has been determined from the following expression:

$$L_{eq} = 10 \text{ Log } \frac{\sum_{i=1}^{n} \text{antilog } \frac{AL_i}{10}}{n}$$

where:

AL_i is the instantaneous A-level for sample i

n is the number of samples of AL in a specified time period

For the analysis, n was chosen based on a sampling rate of r = 10/second, where n = rT and T is the sample time. Thus, for a 30-minute sample:

$$n = 10 \times 30 \times 60$$

$$n = 18000$$

The Day-Night Equivalent Sound Level (L_{dn}), like the Equivalent Sound Level (L_{eq}), was developed as a single number measure of community noise exposure, but unlike L_{eq}, L_{dn} adds corrections to nighttime noise to account for increased annoyance during the night hours. It has been included in this study to assess the total community noise and has significance in that the transit system is a contributor to the total noise environment. In some instances, reduction of transit system noise would have to be accompanied by reductions in numerous other community noise sources to arrive at any substantial reduction in L_{dn}. The expression used for calculating L_{dn} is:

$$L_{dn} = 10 \log \left[\frac{\sum_{i=1}^{n} 10^{L_{eq}/10} \cdot W_i \cdot T_i}{24} \right]$$

where:

L_{eq} is determined as noted above for four time periods throughout the day

W_i is the weighting factor for nighttime annoyance

W_i (7 a.m. - 10 p.m.) = 1

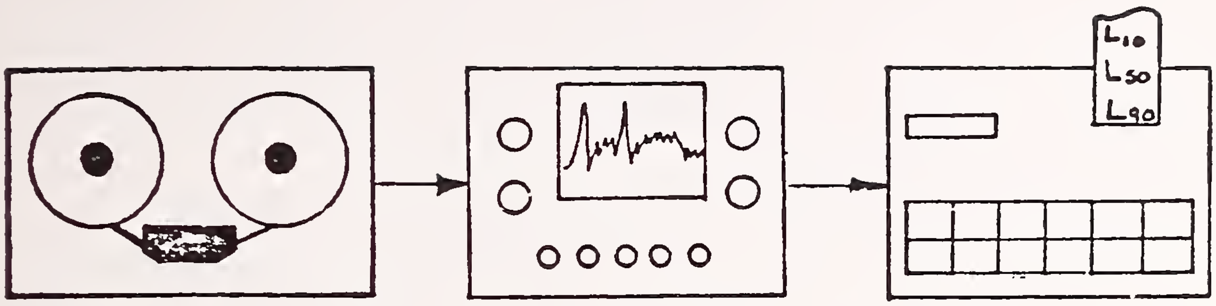
W_i (10 p.m. - 7 a.m.) = 10

T_i is the time interval for i^{th} period

n is the number of weighted-L_{eq} periods throughout the day

Input for calculating L_{dn} for stations and communities is presented in a later section of this report.

Statistical Analysis - Characteristic noise profiles were also prepared in terms of cumulative sound level amplitude distribution plots and tabular summaries so that L_x statistics can be used to derive additional transit system noise attributes. Figure 4.6 illustrates the analysis equipment used to derive statistical and other environmental noise parameters such as L_{eq} and L_{dn}.



TAPE RECORDER
PLAYBACK

TYPE NAGRA III
or
TYPE NAGRA IV SJ

SPECTRUM
ANALYZER

TYPE GR 1921

NOISE PROPERTIES
COMPUTER
(L_{10}, L_{50}, L_{90}, L_{eq})

TYPE TEK 31

OR

TYPE BL 2112

TYPE IBM 1800

FIGURE 4.6. SYSTEM NOISE LEVEL AVERAGES AND CHARACTERISTICS - ANALYSIS EQUIPMENT

5. NOISE ASSESSMENT DATA

5.1 Description of Transit System

Routes and Service - The Delaware River Port Authority's Port Authority Transit Corporation Lindenwold High Speed Line has a route structure as shown in Figure 5.1 and operates rapid service between Philadelphia and Lindenwold, New Jersey. The line is 14.2 miles (22.9 km) long and has 12 stations. It went into operation in January 1969 between Camden and Lindenwold, with service extended to Philadelphia one month later on a section of track formerly used by the SEPTA bridge cars. The entire distance is covered in less than 23 minutes, for an average speed (including 10 intermediate stops) of 40 mph (64 kph). West of Camden, speeds are held to 40 mph (64 kph) maximum in the four miles (6.4 km) of subway which has several sharp curves requiring 30, 20 and 15 mph limits (48, 32, 24 kph). Southeast of Camden, on the new section of track, normal running speed is 75 mph (121 kph).

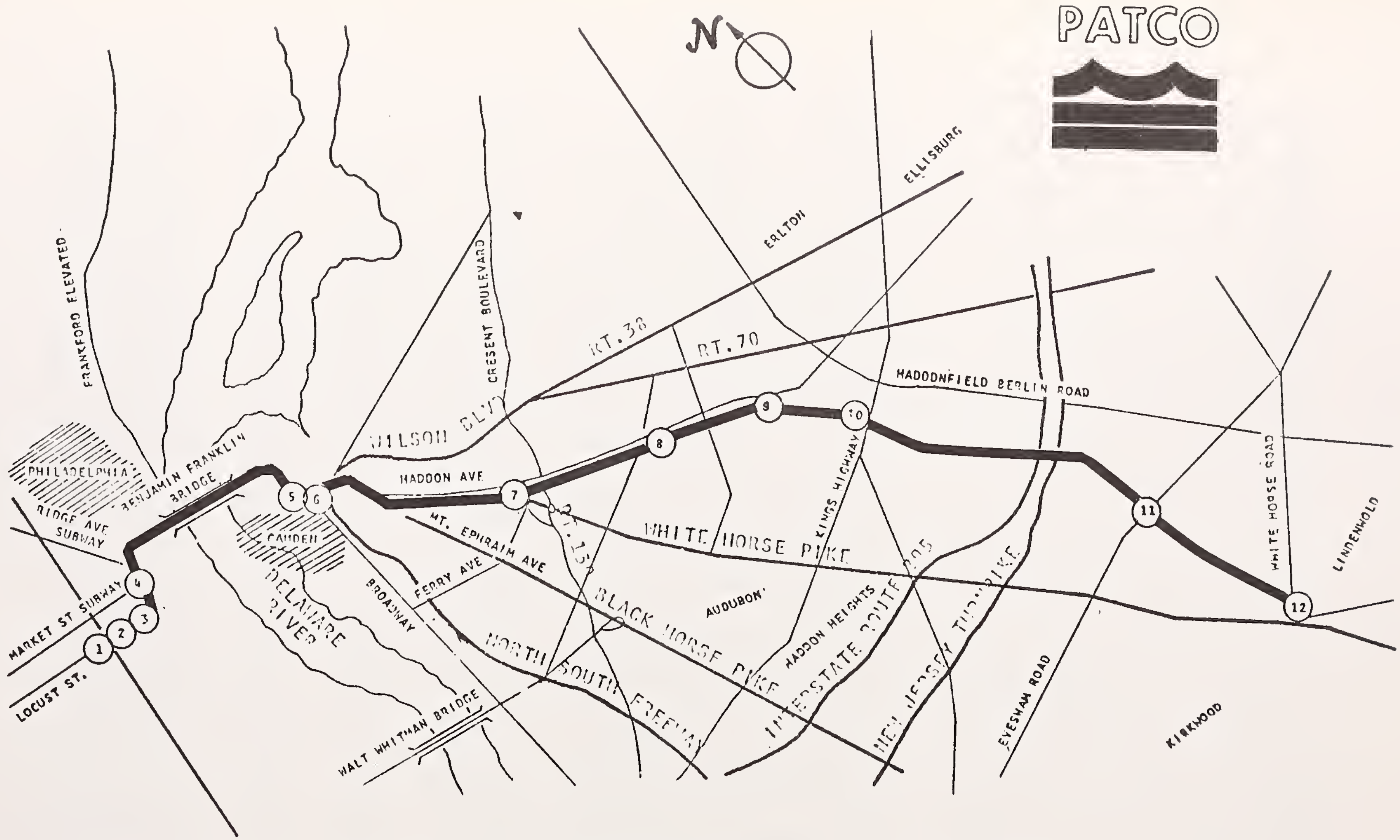
Roadbed - Fully welded track is used, except in the subway between 8th and Race Streets (near the Ridge Avenue connection) and 16th Street in Philadelphia, and on the Benjamin Franklin Bridge and its approaches where the rail is jointed. The roadbed in these latter sections consists of short wood ties set in concrete, with every fifth tie a long tie, Figure 5.2(a). East of the Broadway station in Camden, the roadbed is new with continuously welded rail seated on double-shouldered tie-plates, and anchored using compression clips (Figure 5.2(b)). Ten miles of roadbed in New Jersey is above ground, with 45 percent on an embankment, 5 percent on concrete viaduct, (Figure 5.2(c)), 40 percent at grade, and about 10 percent in a cut. The remaining section, some of which is in Camden and about 2.5 miles (4 km) on the Pennsylvania side, is underground.

Near Lindenwold there is a short section of roadbed which runs at-grade, parallel to the Pennsylvania-Reading Seashore Line (PRSL). The Lindenwold station itself is on elevated embankment, with the PRSL track at-grade parallel to it.

Two stations on the system, Westmont and Collingswood, are located on concrete viaducts. At the Collingswood Station, residential dwellings are within 75 ft of the roadbed.

Wheel squeal was noted at the Lindenwold yardloop, and at six underground locations in both Philadelphia and Camden. Impact noise occurs at insulated track joints.

Rail Vehicles - PATCO uses 75 Budd Company electric cars with a third rail shoe collecting power for the stainless steel cars which, according to type, are in two weight classes: double cars and single cars. Detailed construction features are outlined in Table 5.1. There are 25 single-unit double-end cars seating 72, and 50 cars arranged as 25 married pairs, each car seating 80.



(1) 15th-16th and LOCUST STS. PHILA	(5) CITY HALL, CAMDEN	(9) WESTMONT
(2) 12th-13th and LOCUST STS. PHILA.	(6) BROADWAY, CAMDEN	(10) HADDONFIELD
(3) 9th -10th and LOCUST STS. PHILA.	(7) FERRY AVENUE, CAMDEN	(11) ASHLAND
(4) 8th- and MARKET STS PHILA.	(8) COLLINGSWOOD	(12) LINDENWOLD

FIGURE 5-1. PATCO LINDENWOLD RAPID TRANSIT SYSTEM SCHEMATIC

(A)

UNDERGROUND

(B)

ON GRADE

(C)

CONCRETE VIADUCT

FIGURE 5·2 PATCO ROADBED

TABLE 5.1
PATCO TRANSIT CAR SPECIFICATIONS

MANUFACTURER -	The Budd Company
DESIGNER -	Louis T. Klauder & Assoc.
LENGTH OVER COUPLERS -	67' 6"
MAXIMUM WIDTH -	10' 0"
HEIGHT, RAIL TO TOP -	12' 4"
LENGTH, TRUCK CENTERS -	47' 6"
TRUCK WHEEL BASE -	7' 6"
LIGHT WEIGHT -	78,000 Lb. (singles)
SEAT ARRANGEMENT -	2-2 fixed transverse seats
PASSENGERS, SEATED -	80 each in married pairs; 72 in singles
CONSTRUCTION -	Integrated body, no center sill. Stainless steel frame and siding.
BUFF STRENGTH -	200,000 lb.
BRAKING -	Dynamic plus electropneumatic tread type.
BRAKE UNITS -	Composition shoes
BRAKE RATE -	Service from 75 to 60 mph - 2.5 mphps increasing to 3.0 mphps at 50 mph continuing 3.0 to stop.
EMERGENCY -	3.2 mphps at 50 mph with electro-pneumatic only.
SUSPENSION -	Entirely air springs with automatic leveling, load weighing to maintain acceleration level.
WHEEL SIZE -	28"
NO. OF MOTORS	4 GE 1255A3 (140 HP)
HORSEPOWER PER CAR -	500
SPEED -	85 mph maximum programmed for maximum of 75 mph.
INITIAL ACCELERATION -	3.0 mphps. Average acceleration to 36.5 mph is 2.75 mphps.
POWER -	680V. DC
CURRENT COLLECTION -	Guarded overrunning third rail.
DOORS PER SIDE -	Two double on all cars plus one single near cab on single cars. Doors interlocked with traction motors for safety.
FEATURES -	Fully automatic train operation with cab signaling; M-G and battery for all auxiliary power; wheel slip-slide protection; tinted glass windows; 10-ton air conditioning; train phone, PA system.

Operation of the cars is under automatic control (ATO) and the most frequent headway intervals are two minutes. These intervals lengthen to 7-1/2 to 10 minutes during non-rush hour periods and on weekends, and to one hour during 1:30 to 5:30 a.m. "owl" hours. Service is continuous, 24 hours a day, 365 days a year.

The car interiors are fully climate controlled and employ transverse, high-backed suburban seating. The seats provide some measure of acoustical absorption by their upholstered covers. The floor construction is plymetal with thermal/acoustical insulation on the underside covered with stainless steel sheets. The walls and ceiling also contain acoustical/thermal insulation to increase the car body transmission loss.

Stations - The PATCO system has 12 stations with an average station spacing of 1.29 miles (2.08 km). Distances between the stations are shown in the following table:

Table 5.2. Distances Between Rapid Transit Stations

	Miles	km
Lindenwold to Ashland	1.79	2.88
Ashland to Haddonfield	3.19	5.13
Haddonfield to Westmont	0.87	1.40
Westmont to Collingswood	1.05	1.69
Collingswood to Ferry Avenue	1.61	2.59
Ferry Avenue to Broadway	2.16	3.48
Broadway to City Hall	0.25	0.40
City Hall to 8th-Market	2.28	3.67
8th-Market to 9-10/Locust	0.43	0.69
9-10 Locust to 12-13/Locust	0.29	0.47
12-13/Locust to 15-16 Locust	0.28	0.45
TOTAL	14.2	22.85

All of the stations are of the center platform type on short concrete pillars. Ferry Avenue Station in Camden is somewhat unique in that its platform is split by a tail track for local trains. Figure 5.3 illustrates the track diagram for the remainder of the system.

An acoustical feature noted on the PATCO line is the use of thin metal perforated ceiling throughout its six New Jersey stations.

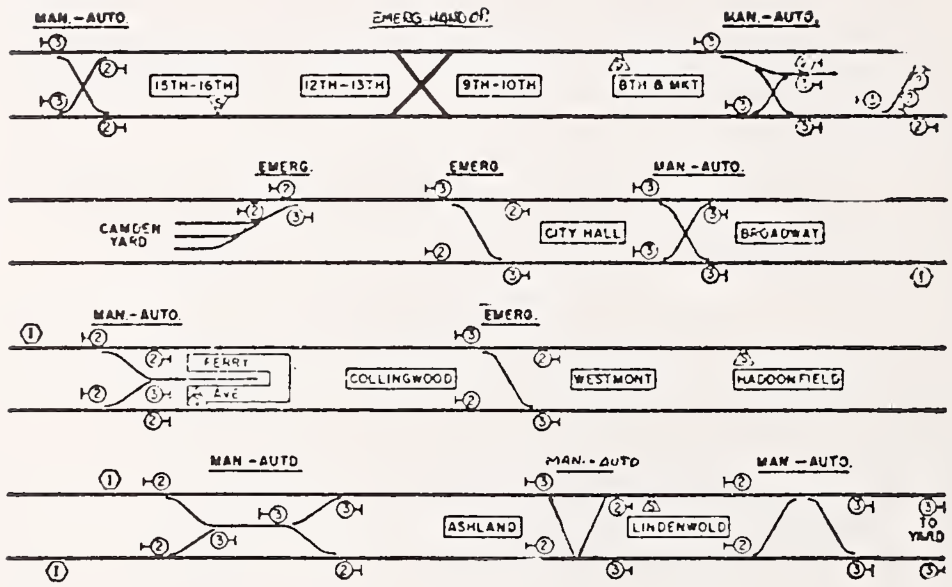


FIGURE 5·3. SYSTEM TRACK DIAGRAM

5.2 Noise Assessment Data

The environmental noise data of the transit system has been grouped for each measurement location with site descriptions and data on the noise survey results. After a general review of the test sites, whether they be community, station or car, and their relationship to the overall transit system geography, specific details are furnished for each site, including the following:

a. A short description of the important features of the measurement site.

b. A description of the noise climate identifying the major sources of noise at the location.

c. Photograph of site including both microphones and tracks.

d. Sketch of site showing location of both microphones and tracks.

e. A summary table of the statistical measures of each noise sample (L_1, L_{10}, L_{50}, L_{90} and L_{99}, L_{eq}), along with the average maximum levels of the train passbys on the near and far tracks. Also given in the table are the average level of L_R for the passbys on the near and far tracks.

f. Statistical distribution curves for all 30 minute samples at each site.

g. A sample strip chart trace including near and far track train passbys at the microphone closest to the track.

Table 5.3 is presented to describe the content of information in each summary table. An explanation of each column follows:

Column

(1) The measurement period in 24 hours during which the noise sample was taken.

(2) Distance of the microphone from the centerline of the nearest track.

(3) Length of data sample, in minutes.

TABLE 5.3. EXPLANATION FOR MEASUREMENT RESULT SUMMARY TABLES PRESENTED AT EACH SITE.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)					(11)
TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR	L_{99}	L_{90}	L_{50}	L_{10}	L_1	

Notes: a - Track
b - Number of Trains - (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

(12) L_{dn} =

Column

(4) Type of train operation during sample, i.e. Passby for community noise and Arrival or Departure for station noise.

(5) Identification for the data presented.

N = Number of trains in sample - cars per train (4-2 indicates four 2-car trains)

dBA = Averaged A-weighted sound levels, L_A(Max) for number of trains noted (See Fig. 4-4)

S = Standard deviation of L_A(Max) or L_R listed immediately above it.

$$S = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N-1}}$$

where x_i = individual L_A(Max) or L_R

$\bar{x}$ = Mean value of L_A(Max) or L_R

(6) L_A(Max) data for trains operating on near tracks.

(7) L_A(Max) data for trains operating on far tracks.

(8) L_R data for trains operating on near tracks.

(9) L_R data for trains operating on far tracks.

(10) Summary of cumulative amplitude distribution for data sample, dBA.

(11) Equivalent Sound Level for sample of duration noted in Column (3) (See Section 4-2)

(12) Day-Night Equivalent Sound Level for A-weighted noise level integrated over 24 hour period. Weightings are applied to the noise levels measured during the four time periods during the day. (See Section 4-2 and Table 6.1.)

5.2.1 Wayside Community

Community noise surveys on the PATCO line were conducted at five locations: one in Camden, two at Collingswood, one near the Haddonfield Station, and one in Westmont (See Figure 5.4).

The Benjamin Franklin Bridge portal site in Camden has high level vehicular traffic ambient noise and is, in addition, subject to transit car wheel squeal and noise from sounding the transit car warning horn upon entering the tunnel. Noise levels resulting from wheel squeal are not noticeable at any other community location along the system, with the exception of occasional squeal emitted at the Lindenwold shop area as trains come on and off line, out of and into the yard area.

Collingswood is a residential community located close to the system right-of-way. It has a quiet surburban noise characteristic and surveys were made near sections of track located on elevated embankment as well as concrete viaduct.

In Westmont, the train passes within 82 ft (23m) of a high rise apartment building. Train operation and track geometry is similar to the Collingswood concrete viaduct site.

Haddonfield is the site of the fifth community noise survey. The track is located in a cut which channels and significantly changes the directivity of train noise in the surrounding community.

KEY

A CAMDEN, BENJ. FRANKLIN BRIDGE PORTAL
B COLLINGSWOOD, CONCRETE VIADUCT.
C COLLINGSWOOD, ELEVATED ENBANKMENT
D WESTMONT, CONCRETE VIADUCT
E HADDONFIELD, IN CUT

FIGURE 5·4 · COMMUNITY NOISE SURVEY LOCATIONS

BENJ. FRANKLIN BRIDGE WAYSIDE

SITE DESCRIPTION (see Figure 5.5)

The transit system operates across the Benjamin Franklin Bridge and exits the subway on the New Jersey side of the bridge at a portal which is located directly under the road surface on the bridge ramp. The track then is located outboard of the road surface on the bridge proper. On entering the tunnel, eastbound, the tracks curve sharply to the south under 5th Street, Camden. At the measurement site, the track is layed on ballast and wood ties. Fourth Streeet passes under the bridge approach and also has an exit onto Pearl Street. The Camden campus of Rutgers University is situated immediately south of the bridge plaza. Data was taken at 12m rather than the normal 15m distance since the latter site was in a traffic lane on Pearl Street.

NOISE CLIMATE (see Table 5.4, Figures 5.6 - 5.14)

A predominant source of noise at this site is the vehicle traffic on the Benjamin Franklin bridge. During change of classes at the university, the activity associated with this, including parking of cars, is audible. Normal city sounds, such as sirens, are also heard from time-to-time. Westbound trains occasionally emit wheel squeal near the tunnel portal, but this is often eliminated by greasing the rail in this area. Eastbound trains are heard as they pass by, but are sometimes masked by truck noise on the bridge.

12M MIC POSITION

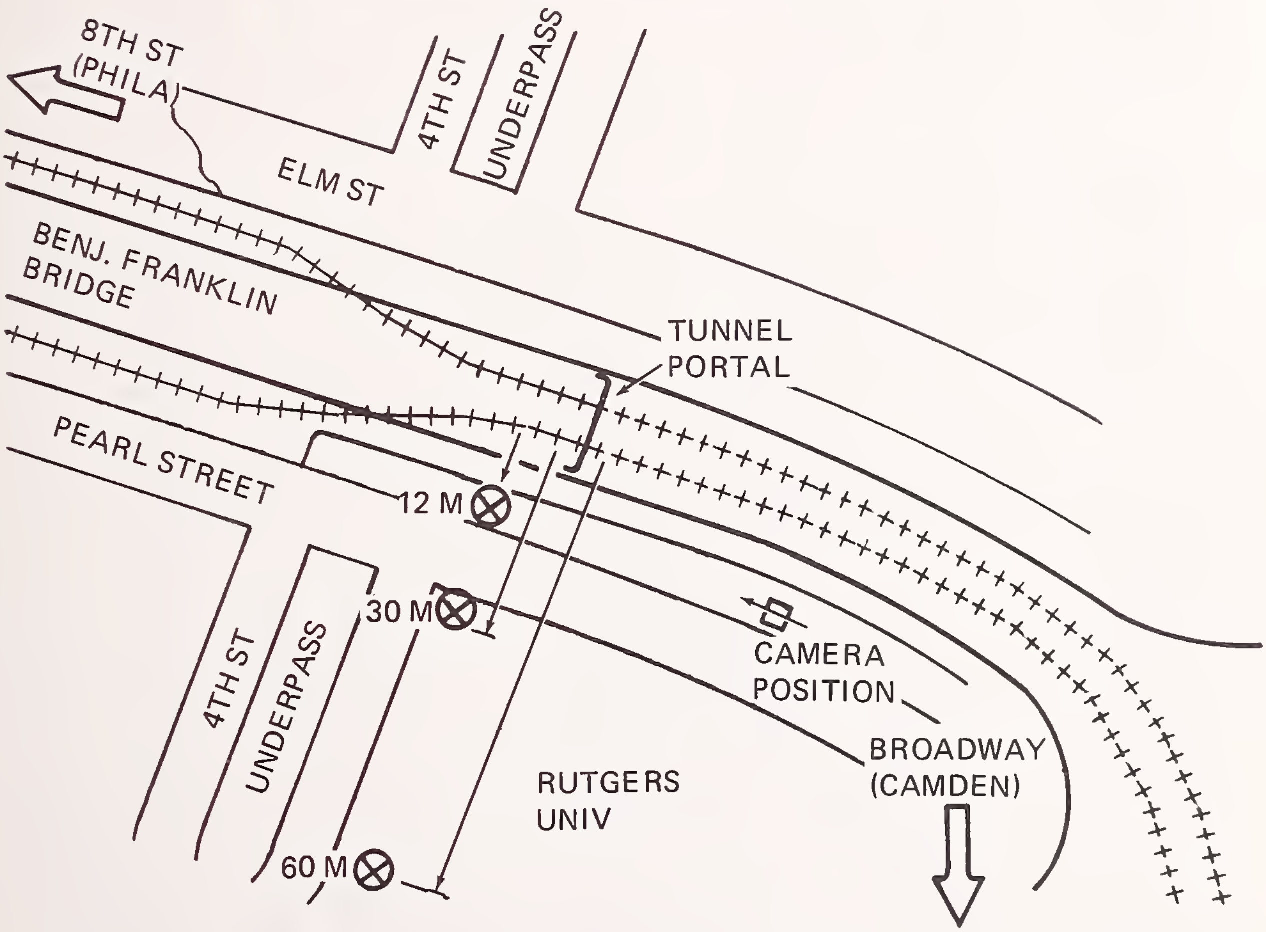


FIGURE 5.5. WAYSIDE MEASUREMENT SITE, BENJ. FRANKLIN BRIDGE PORTAL, CAMDEN, N.J. - NEAR RUTGERS UNIV. CAMPUS

TABLE 5.4 . SUMMARY OF MEASUREMENT RESULTS, 30-MINUTE SAMPLE COMMUNITY NOISE, PATCO-BEN FRANKLIN BRIDGE (SOUTH SIDE)

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR						
					a) EAST	WEST	EAST	WEST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	12m	30 min.	Pass-by	b) N	4-2	4-2	4-2	4-2	64	66	69	72	81	72
				dBA	82	78	88	86						
				c) S	8.52	1.31	6.79	0.81						
				N	1-4	-	1-4	-						
				dBA	79.5	-	88.0							
				S	-	-	-	-						
Rush	12m	30 min.	Pass-by	dBA					65	66	69	73	81	72
Evening	12m	30 min.	Pass-by	dBA					60	62	65	69	80	69
Night	12m	14 min.	Pass-by	dBA					56	58	61	65	76	67
Day	30m	15 min	Pass-by	dBA					74	76	78	82	88	80
Day	60m	15 min	Pass-by	dBA					73	74	77	80	84	78
Evening	60m	15 min	Pass-by	dBA					58	60	63	69	74	66
Evening	120m		Pass-by	dBA					61	62	63	67	72	

Notes: a - Track
b - Number of Trains -(e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

L_{dn} = 76

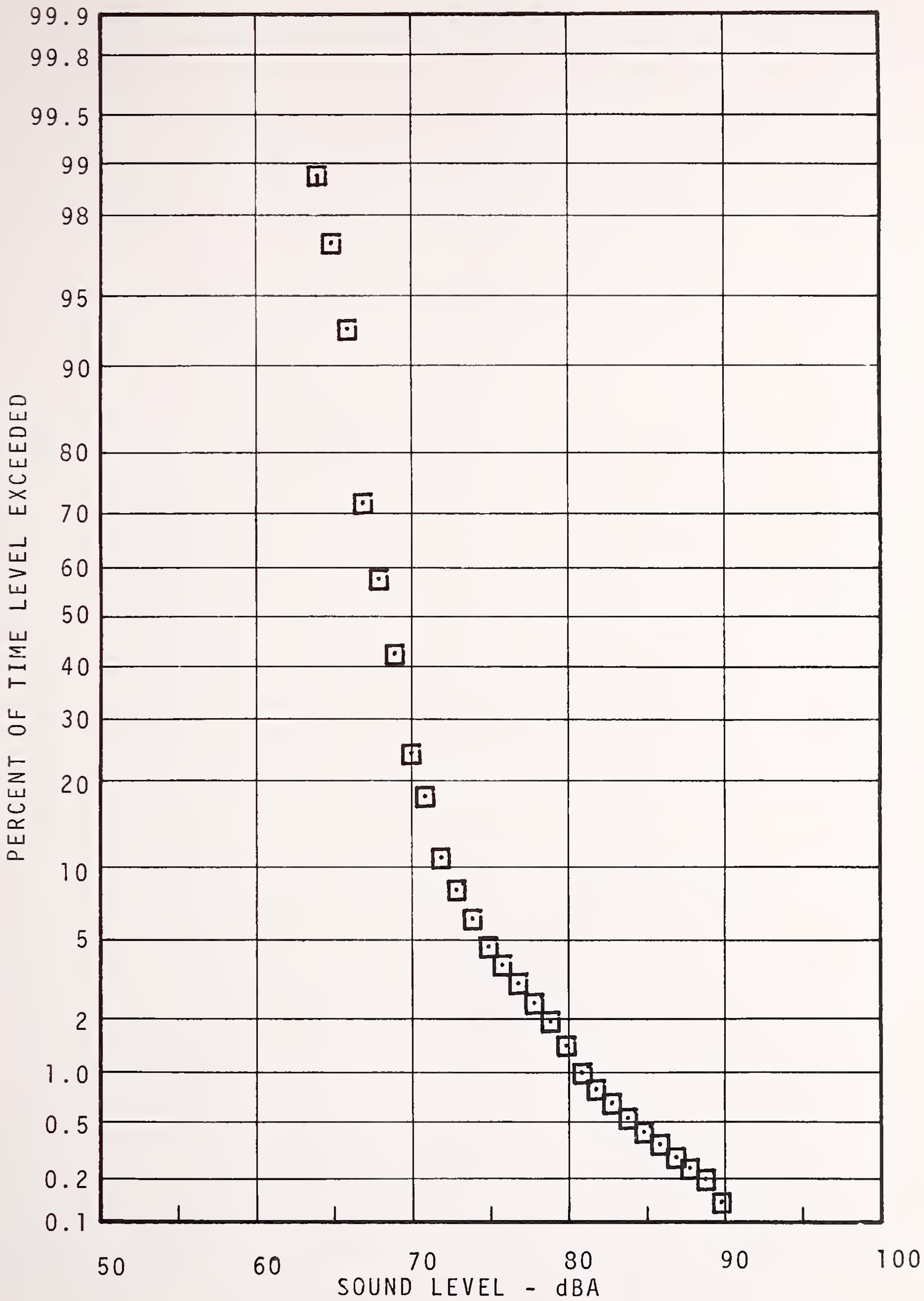


FIGURE 5.6. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 12M DAYTIME.

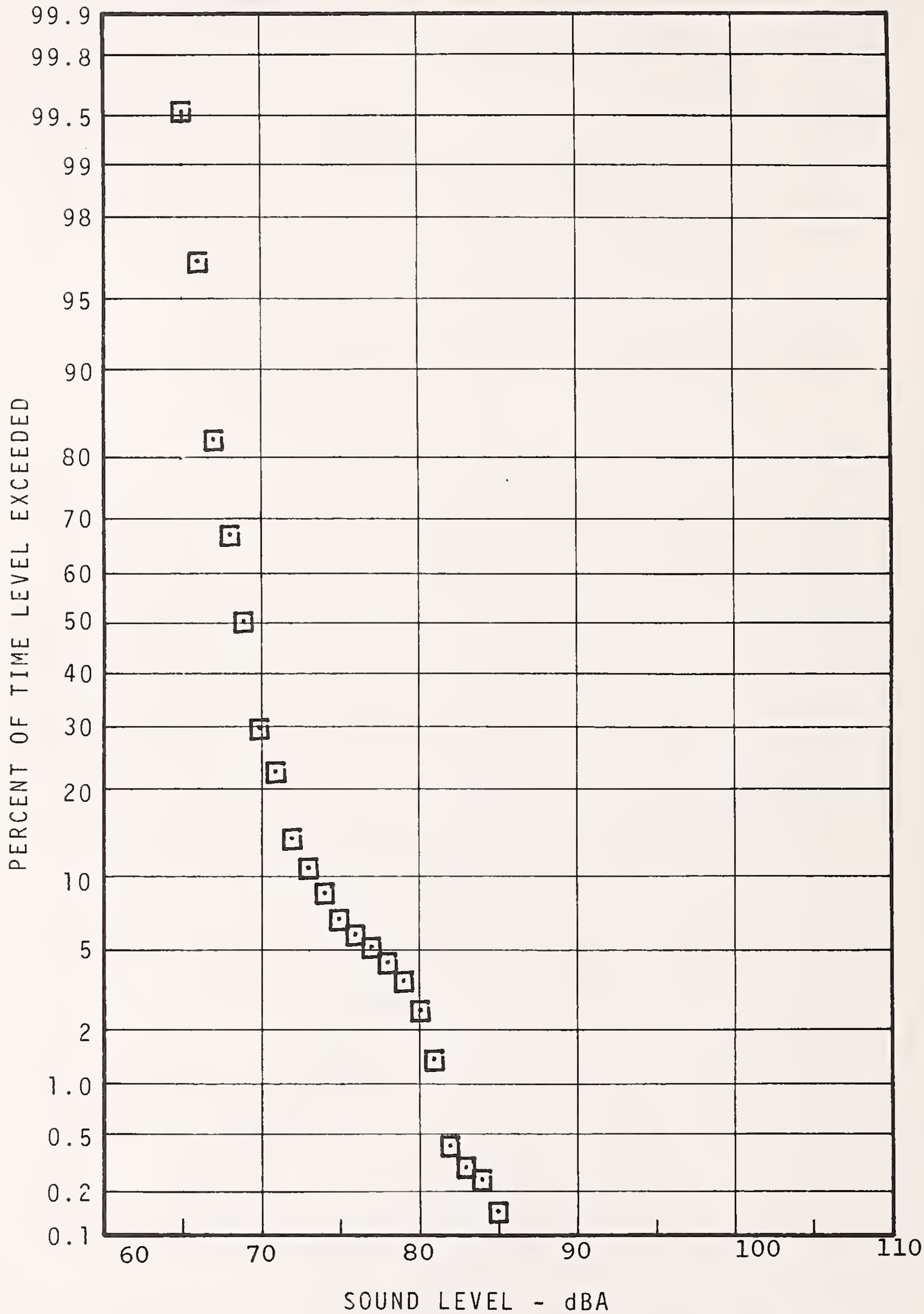


FIGURE 5.7. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 12M - RUSH HOUR.

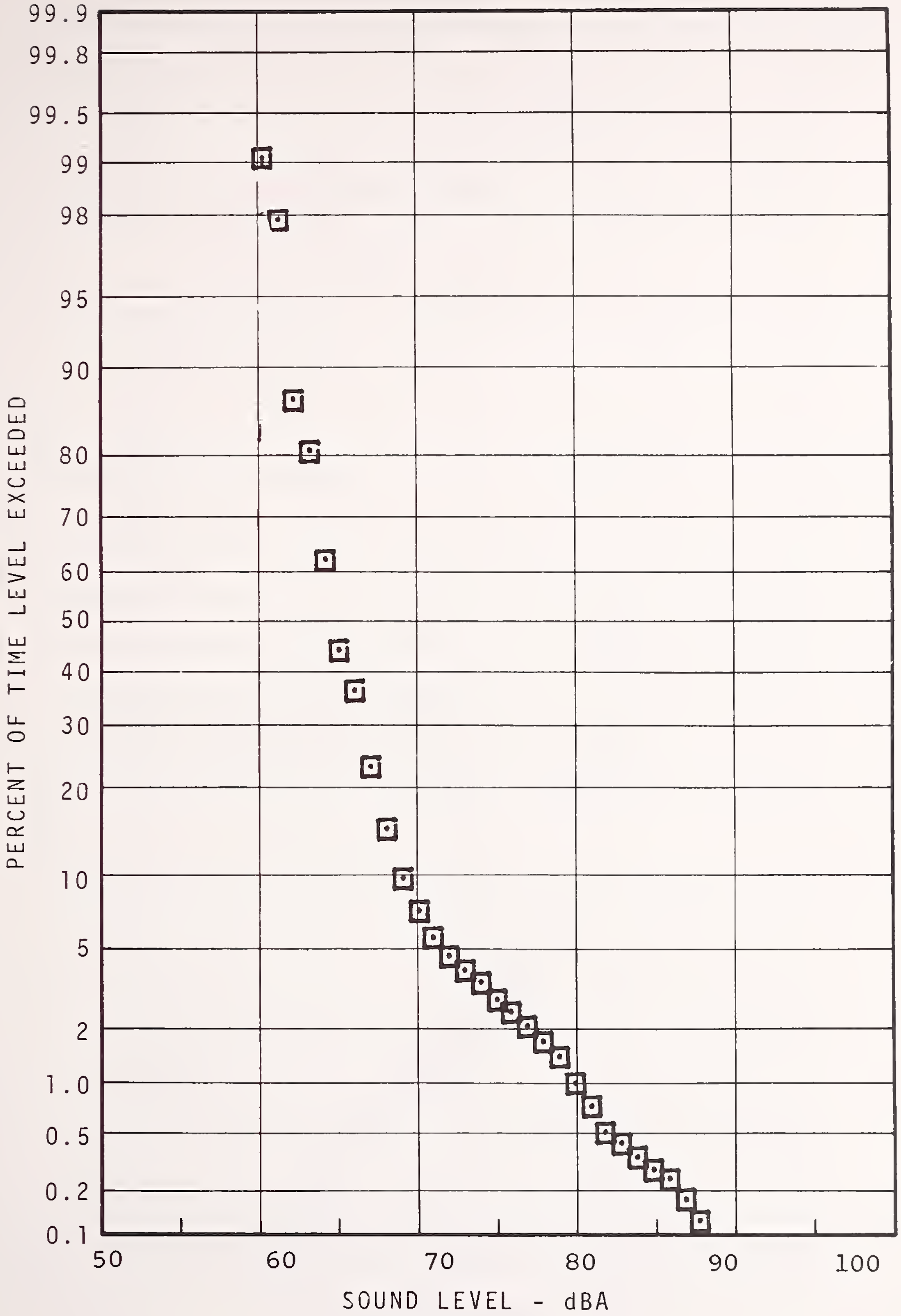


FIGURE 5.8. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 12M - EVENING.

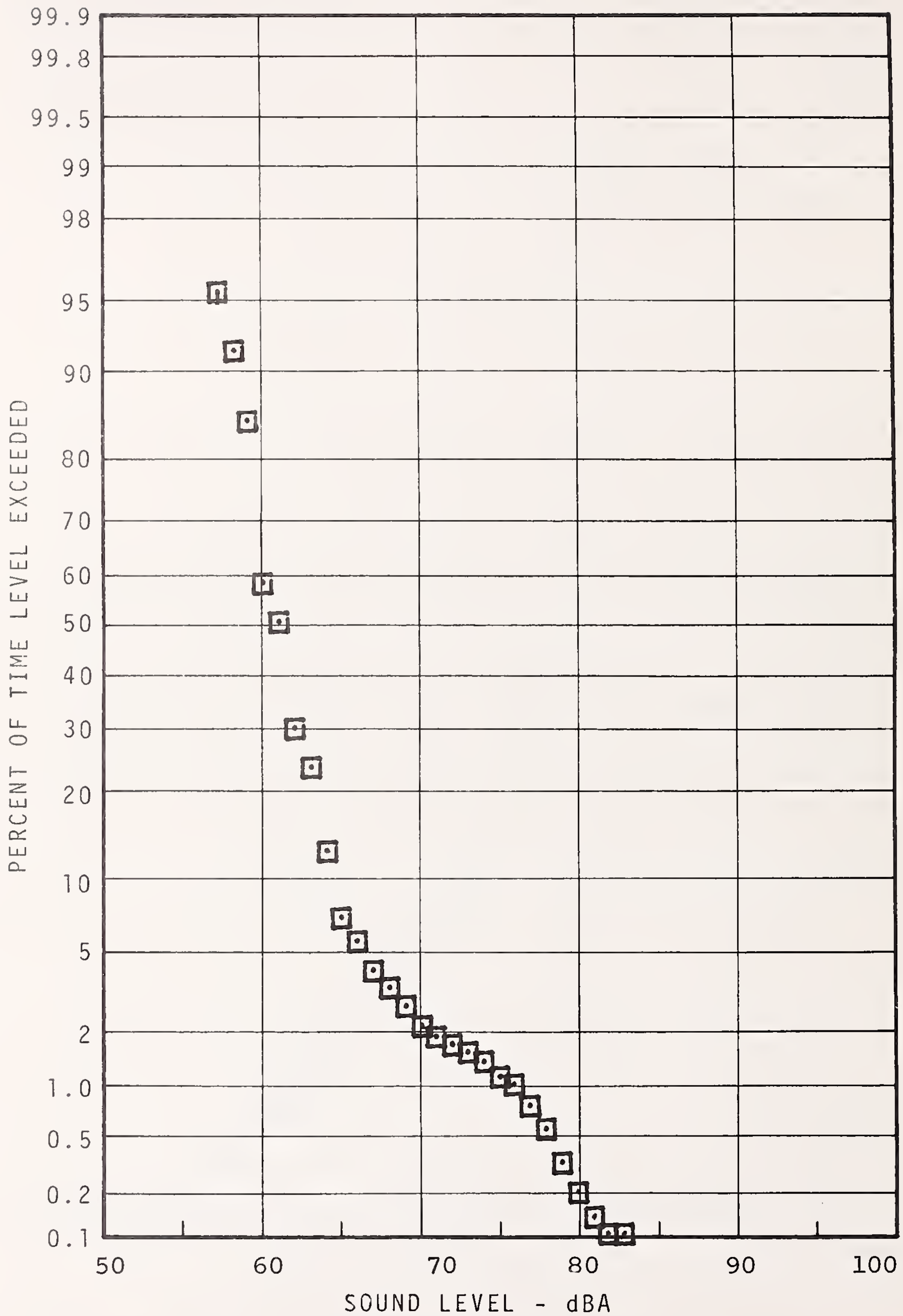


FIGURE 5.9. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 12M - NIGHT.

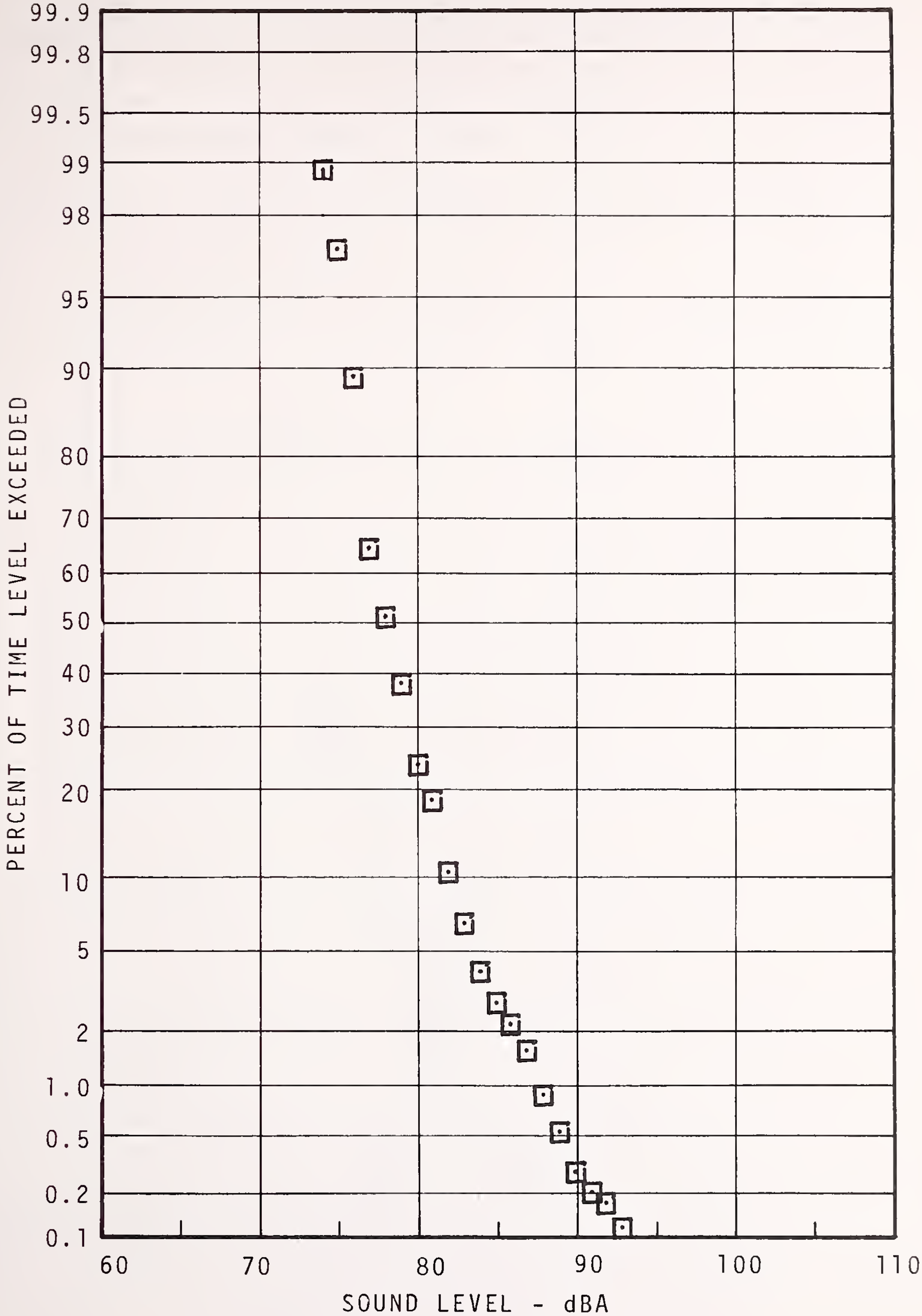


FIGURE 5.10. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 30M - DAYTIME.

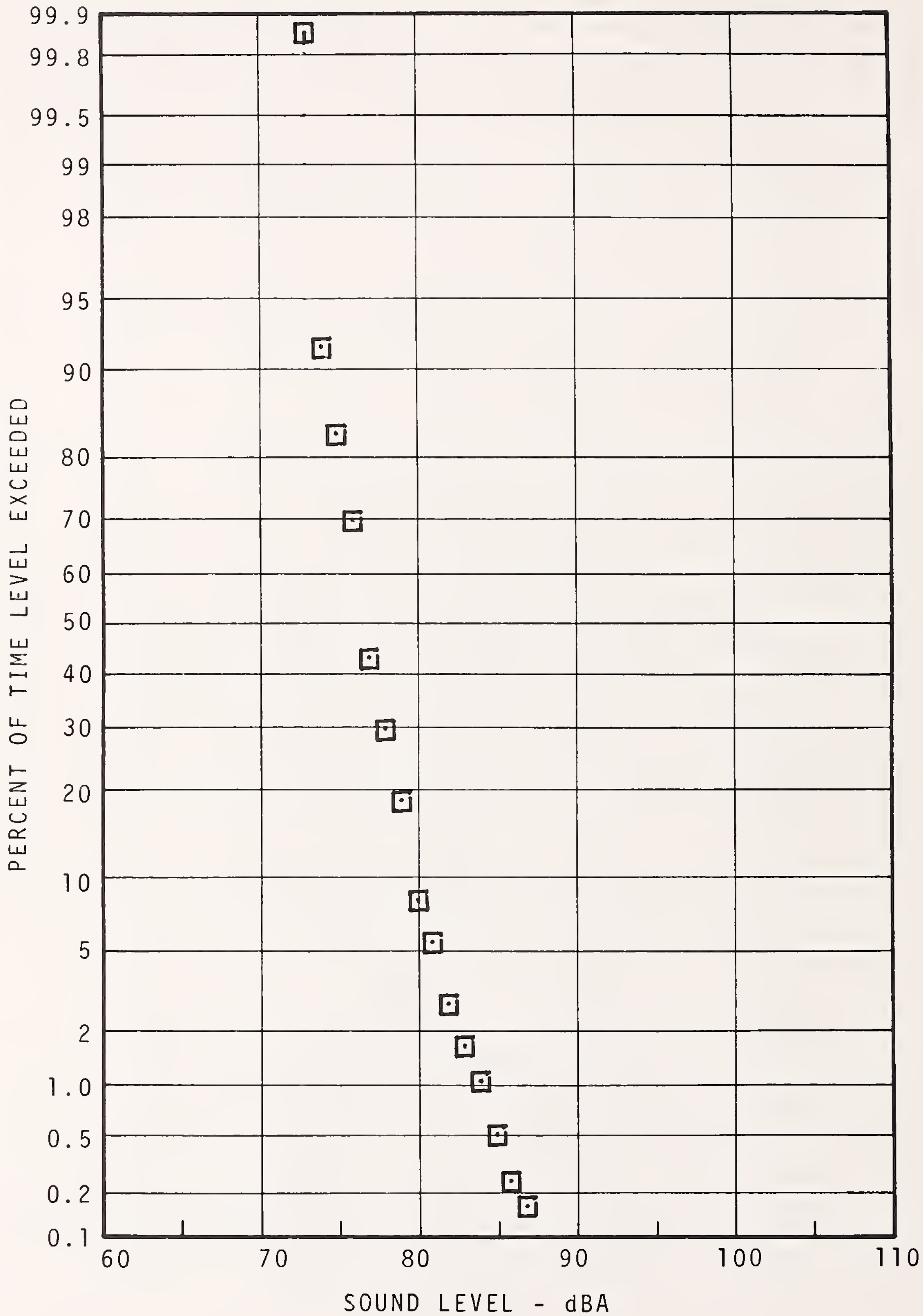


FIGURE 5.11. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 60M - DAYTIME.

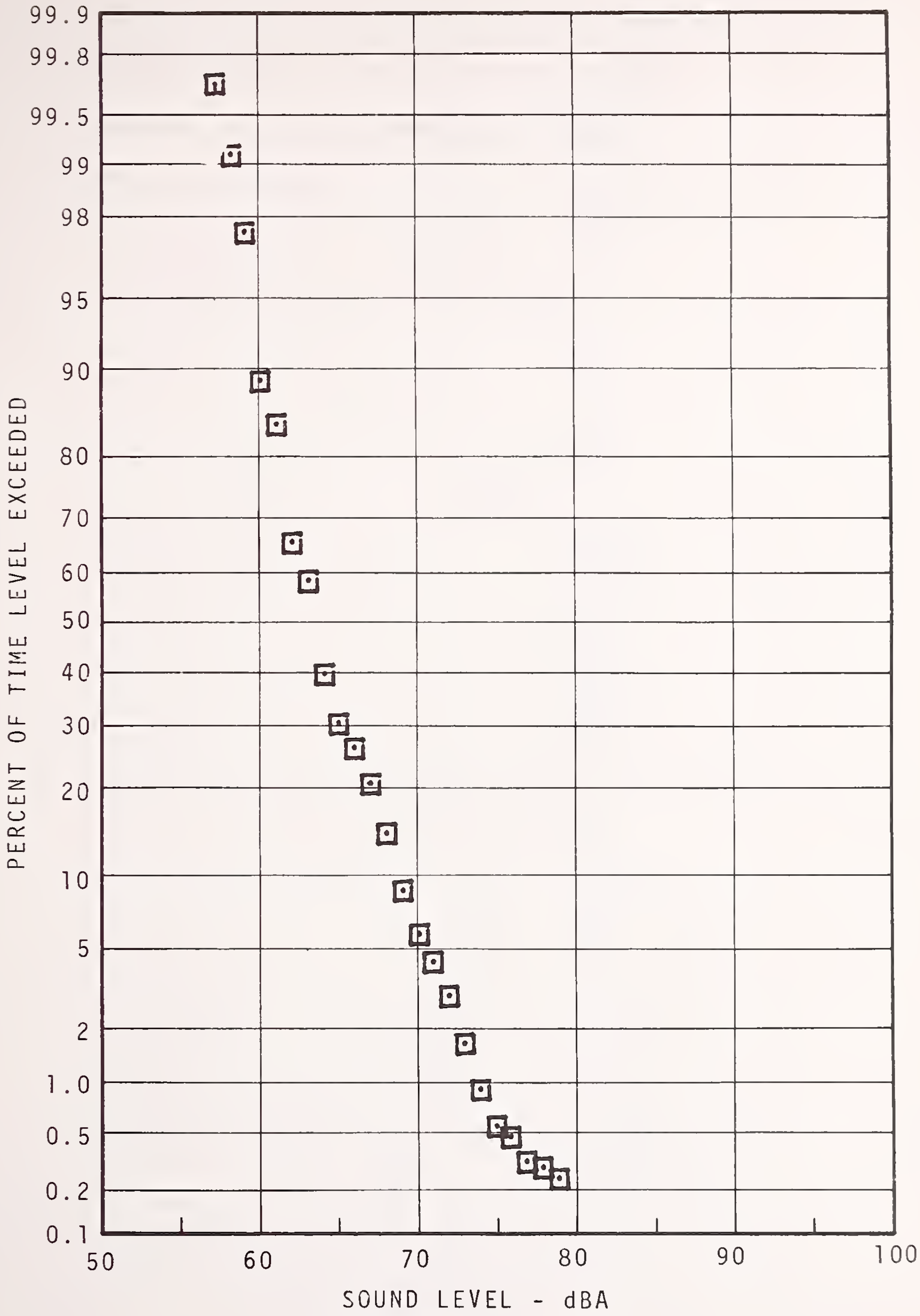


FIGURE 5.12. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 60M - EVENING.

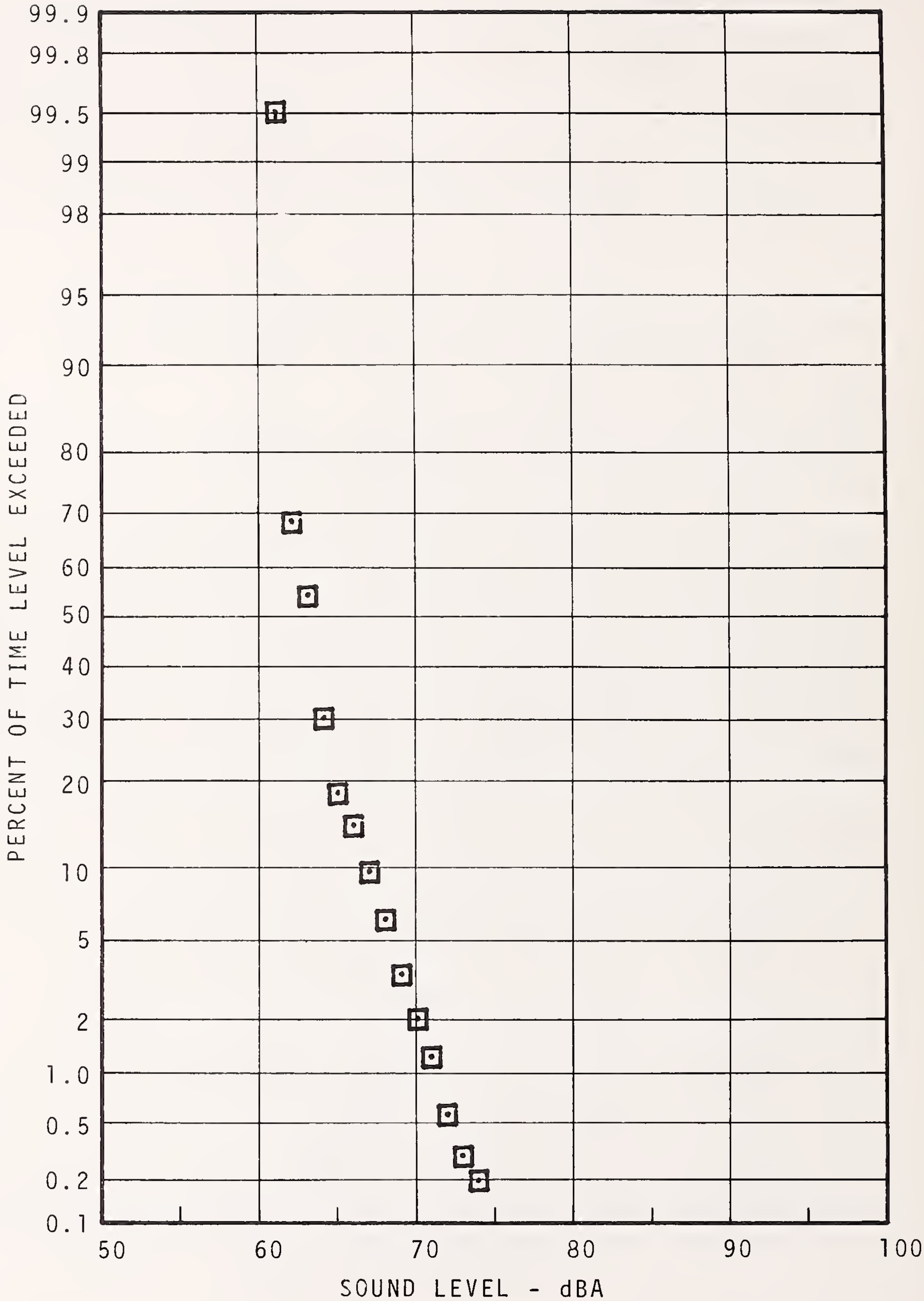


FIGURE 5.13. BEN FRANKLIN BRIDGE (SOUTH SIDE) COMMUNITY STATISTICAL DISTRIBUTION - 120M - EVENING

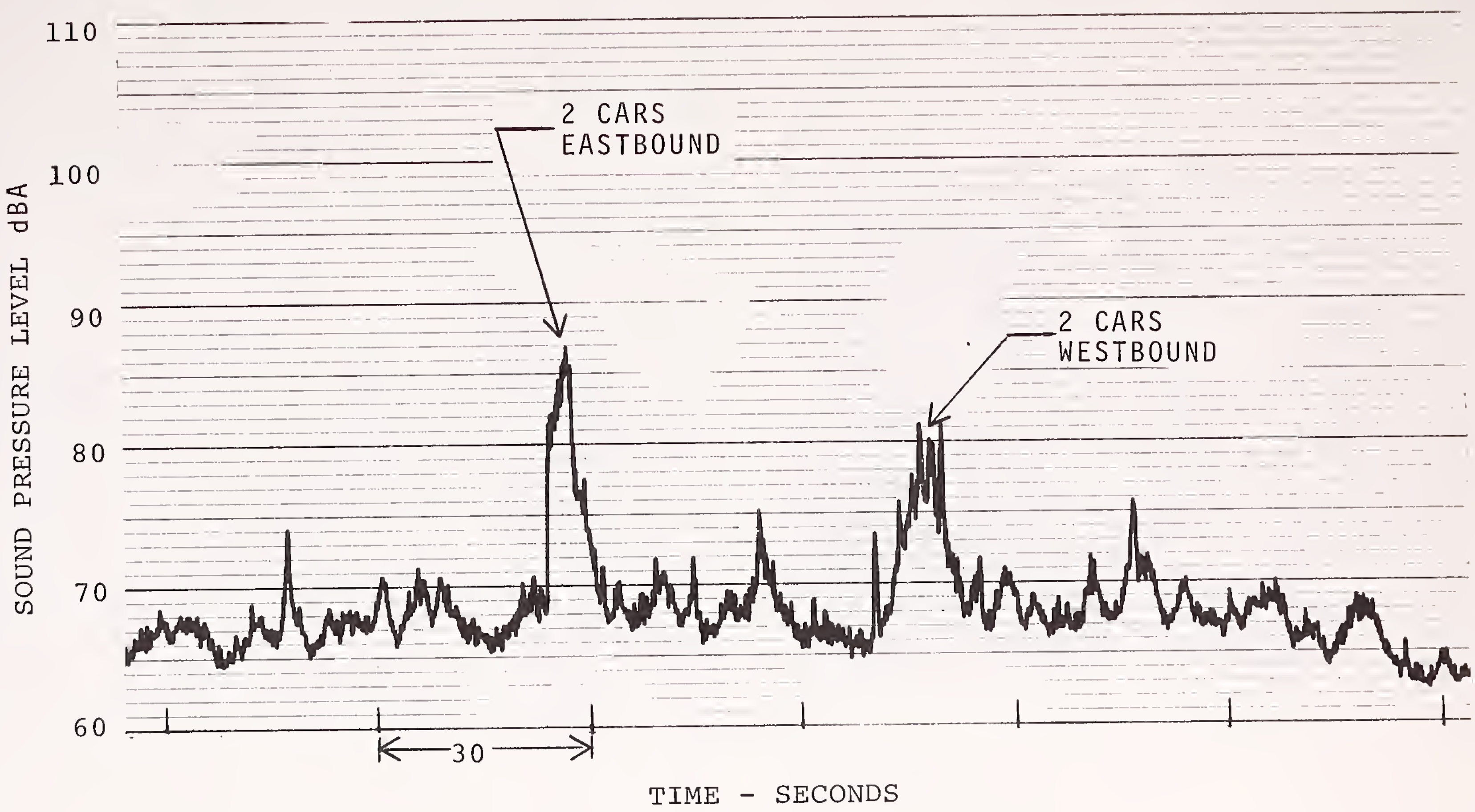


FIGURE 5.14. TYPICAL NOISE TIME HISTORY, CAMDEN COMMUNITY, 12 METRES.

COLLINGSWOOD EMBANKMENT WAYSIDE

SITE DESCRIPTION (see Figure 5.15)

East of the concrete viaduct site in Collingswood, the transit system operates on a section of elevated embankment. The tracks are approximately 15 ft (4.6m) above street level and the embankment is retained by vertical concrete walls. A measurement site was selected at Ogden Avenue to survey noise. This vicinity is taken as representative of acoustically similar locations along the PATCO System. The immediate area comprises residential homes and is generally a quiet neighborhood. Collingswood Station is located 2 blocks west of this position.

NOISE CLIMATE (see Table 5.5, Figures 5.15 - 5.26)

Traffic, aircraft, dogs, children at play, all comprise the ambient noise in this community. Transit system noise forms a part of this, but trains generally cannot be heard for more than two blocks from the system. Propulsion system noise appears to be the predominant noise on the rail car.

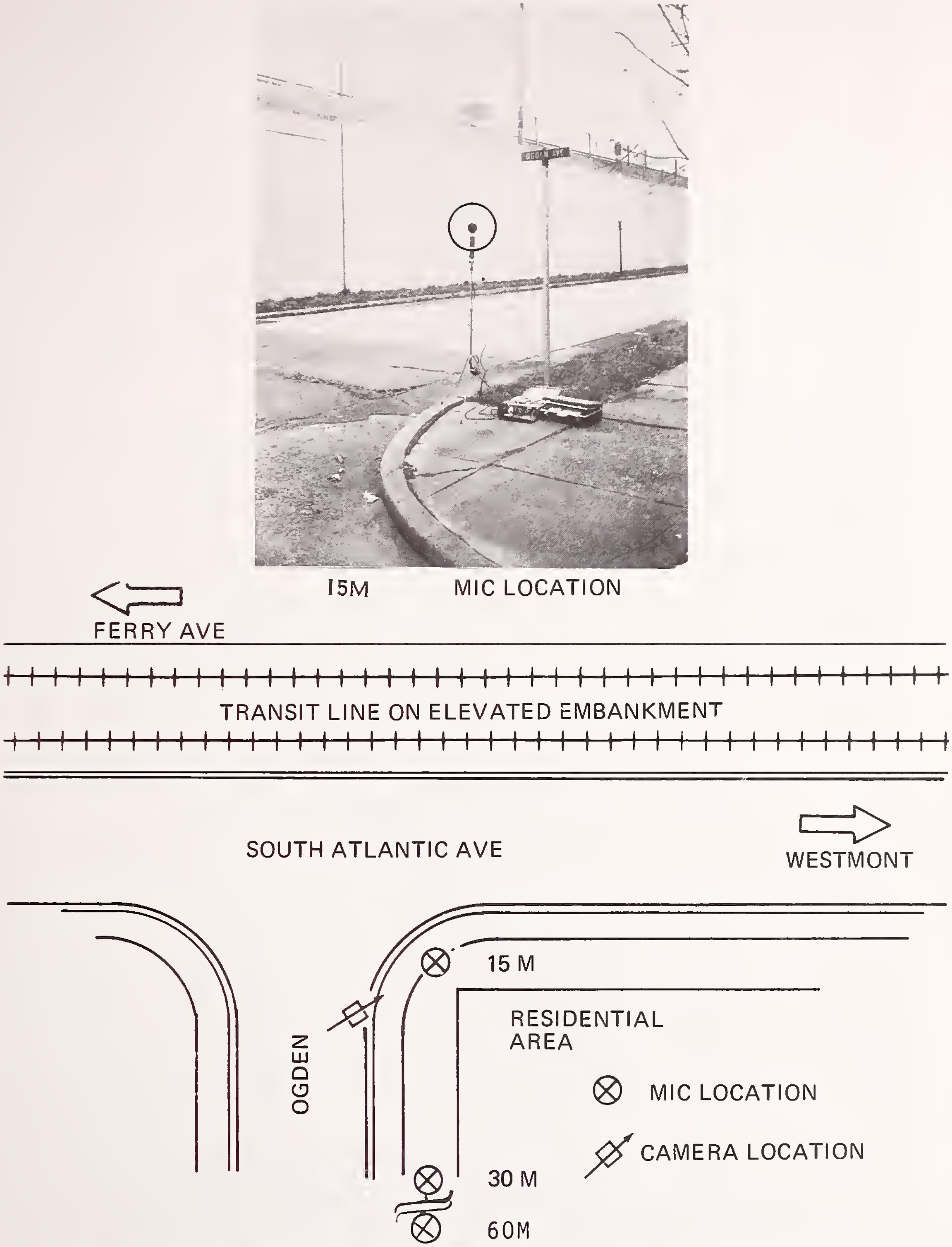


FIGURE 5.15. WAYSIDE MEASUREMENT LOCATION, COLLINGSWOOD ELEVATED EMBANKMENT

TABLE 5.5 SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE, COMMUNITY NOISE, PATCO-OGDEN AND ATLANTIC AVES., COLLINGSWOOD - CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL NEAR a)EAST	AVG MAX LEVEL FAR WEST	AVG L_R NEAR EAST	AVG L_R FAR WEST	CUMULATIVE AMPLITUDE DISTRIBUTION L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
Day	15m	30 min.	Pass-by	b) N	5-2	4-2	5-2	4-2	53	54	58	68	79	67
				dBA	83	74	87	79						
				c) S	2.53	1.71	2.17	1.65						
Rush	15m	30 min.	Pass-by	dBA					54	56	60	71	82	70
Evening	15m	30 min.	Pass-by	dBA					53	54	58	68	77	65
Night	15m	30 min.	Pass-by	dBA					46	46	48	58	73	60
Day	30m	14 min.	Pass-by	dBA					53	53	54	63	80	65
Rush	30m	15 min.	Pass-by	dBA					53	54	58	67	82	68
Evening	30m	15 min.	Pass-by	dBA					49	49	54	65	74	62
Day	60m	8 min.	Pass-by	dBA					53	54	57	64	71	65
Rush	60m	10 min.	Pass-by	dBA					53	56	59	67	78	65
Evening	60m	17 min.	Pass-by	dBA					48	49	51	65	74	61

Notes: a - Track
b - Number of Trains - (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

L_{dn} = 72

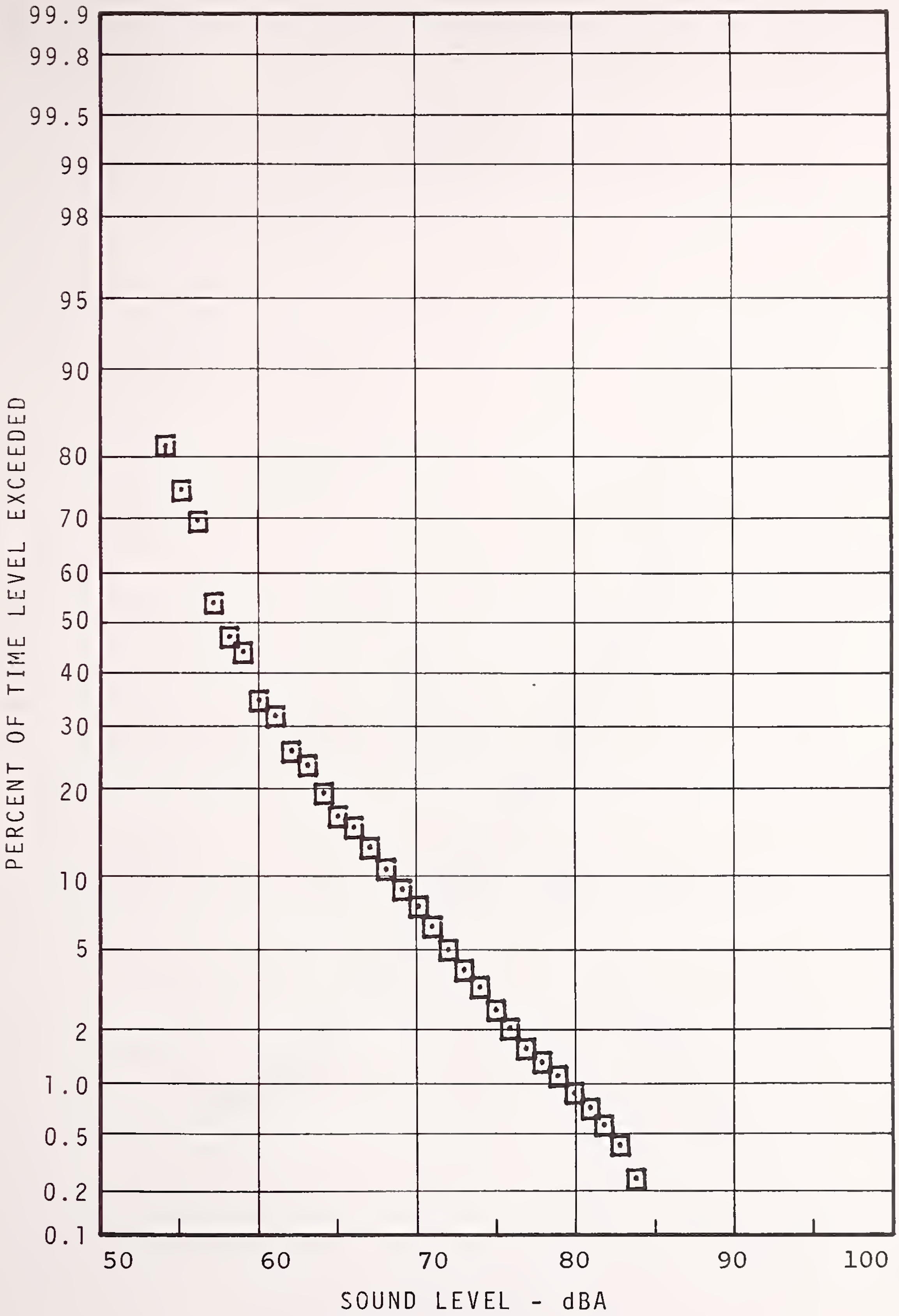


FIGURE 5.16. OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M - DAYTIME.

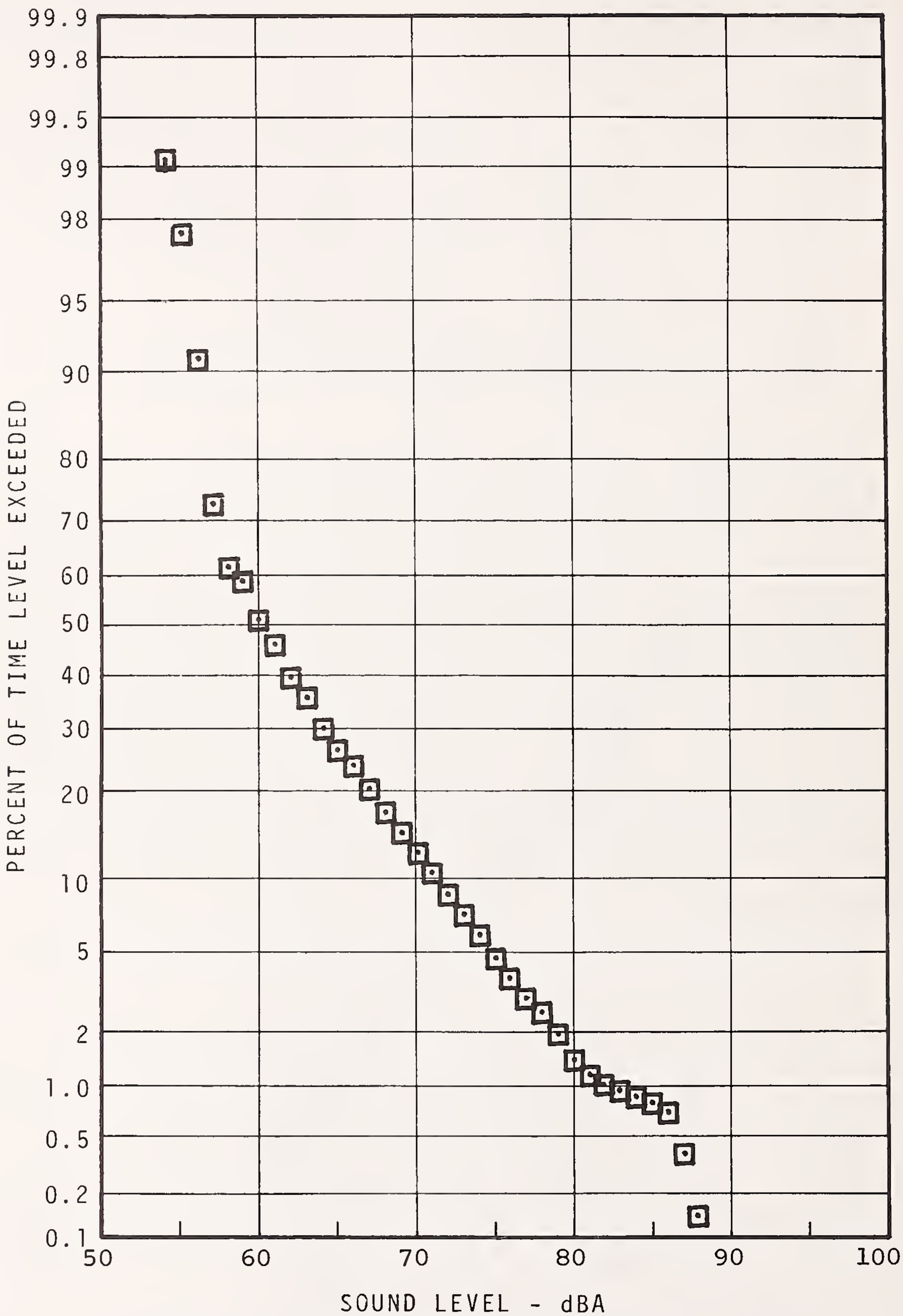


FIGURE 5.17. OGDEN AND ATLANTIC AVES.
COMMUNITY STATISTICAL DISTRIBUTION -
15M - RUSH HOUR.

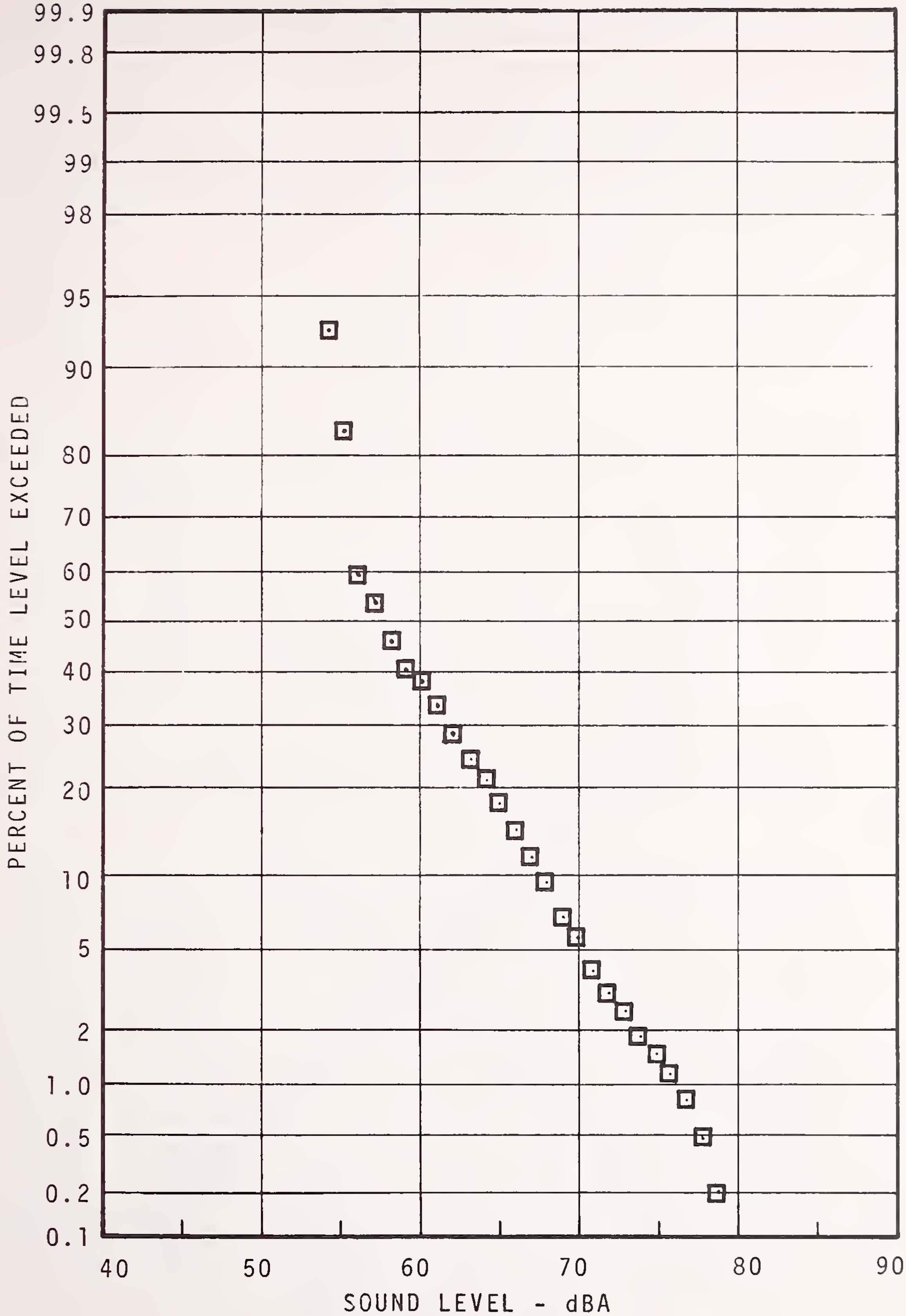


FIGURE 5.18. OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M - EVENING.

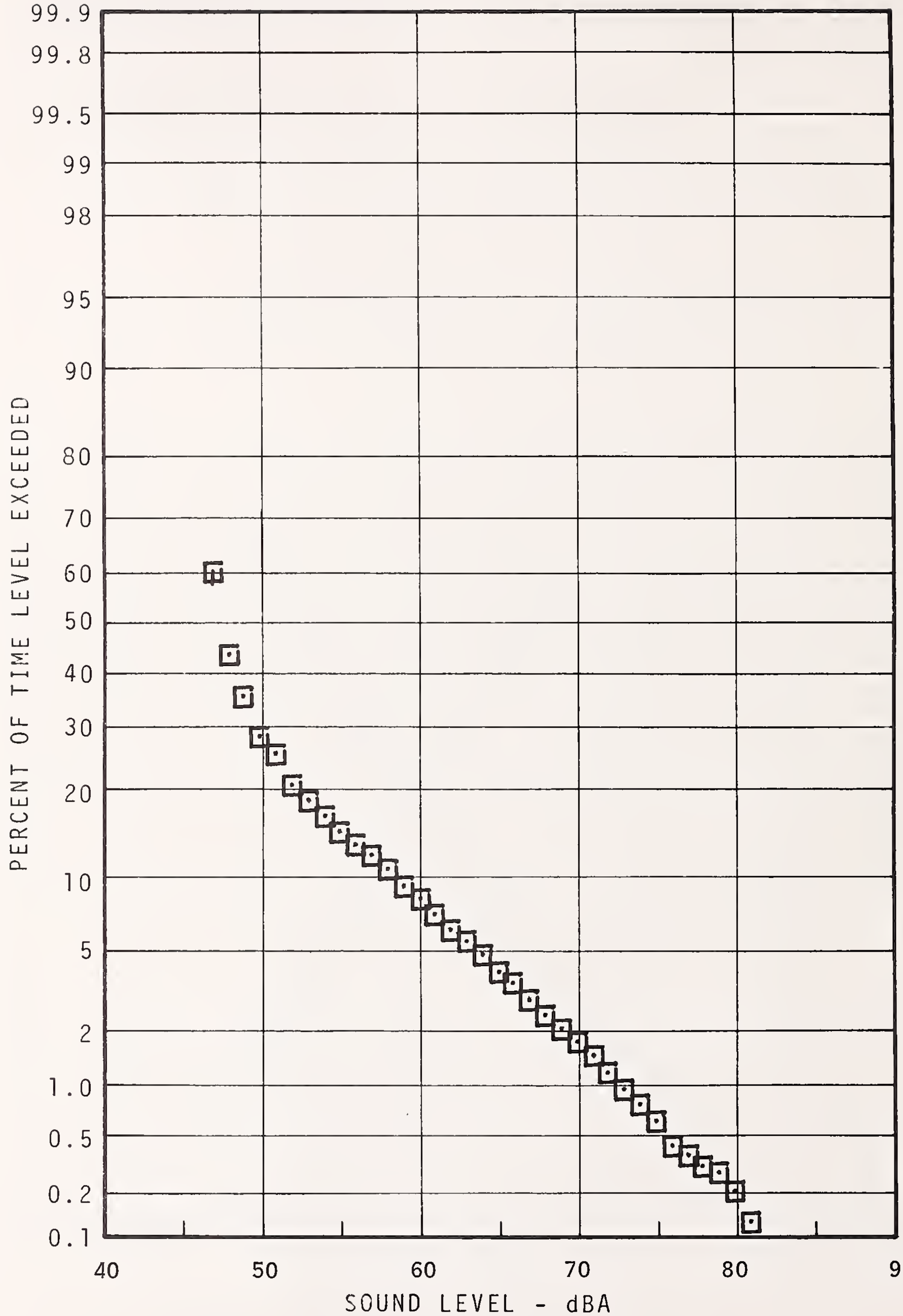


FIGURE 5.19. OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M - NIGHT.

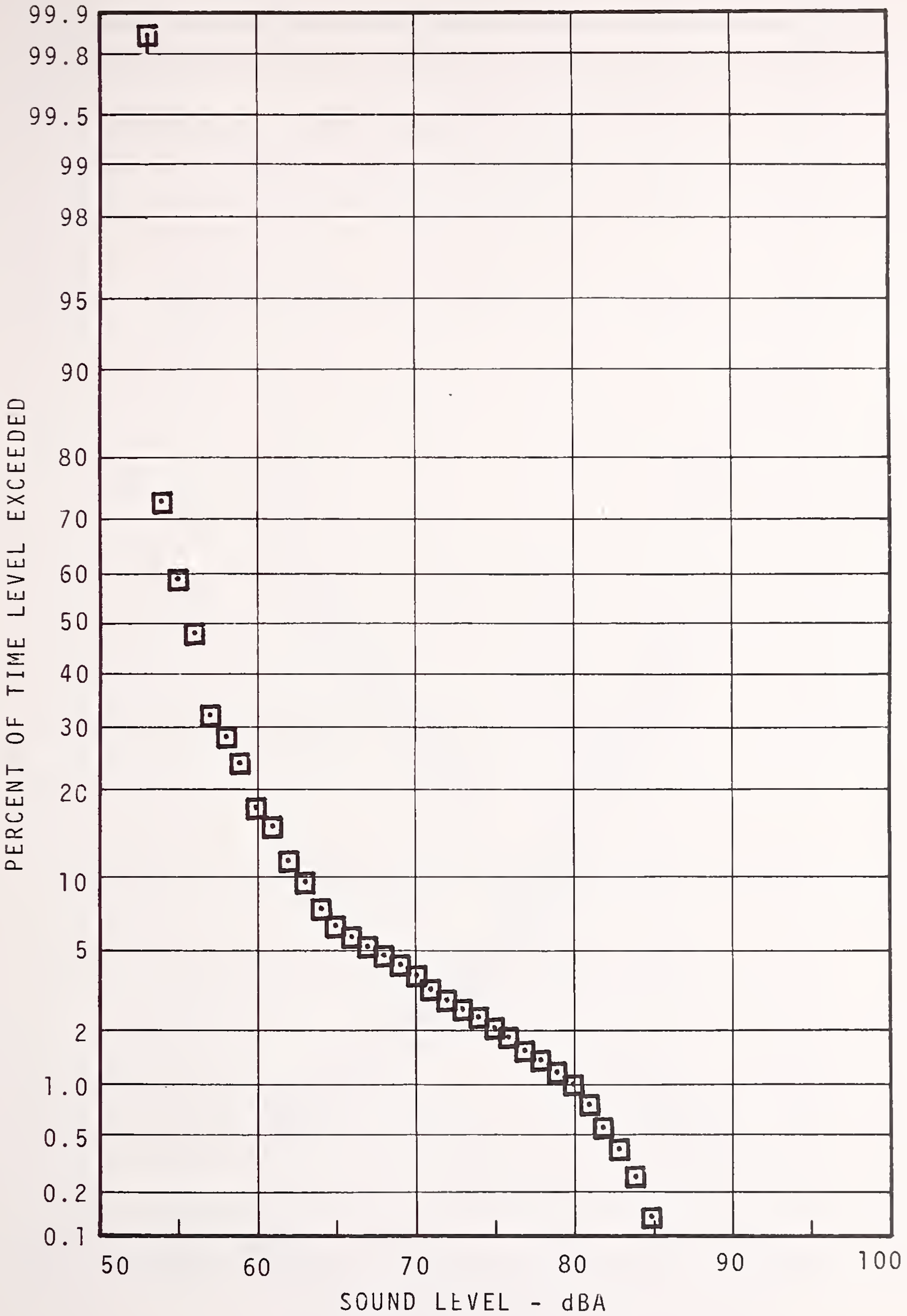


FIGURE 5.20. OGDEN AND ATLANTIC AVES COMMUNITY STATISTICAL DISTRIBUTION - 30M - DAYTIME

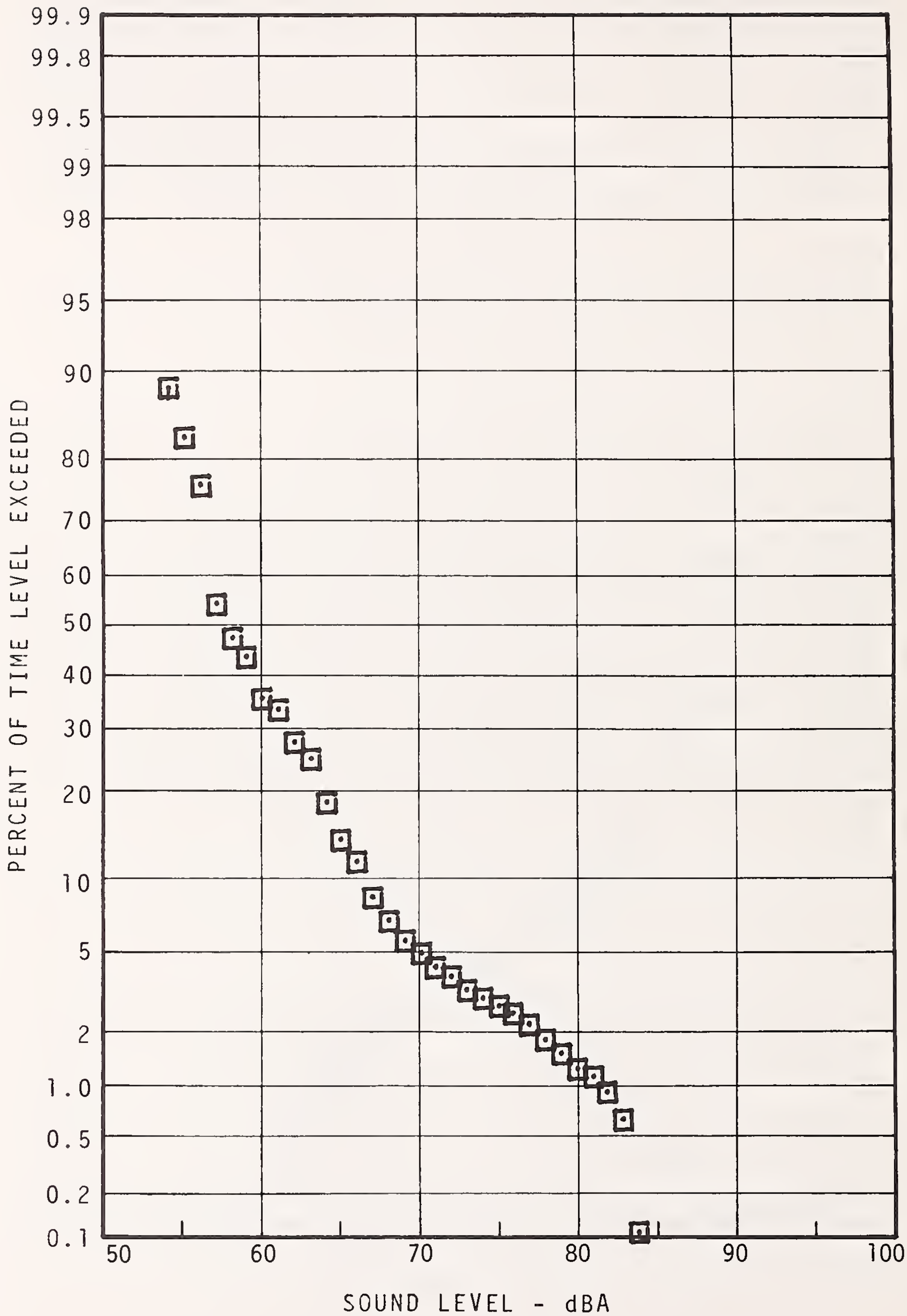


FIGURE 5.21 . OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 30M - RUSH HOUR.

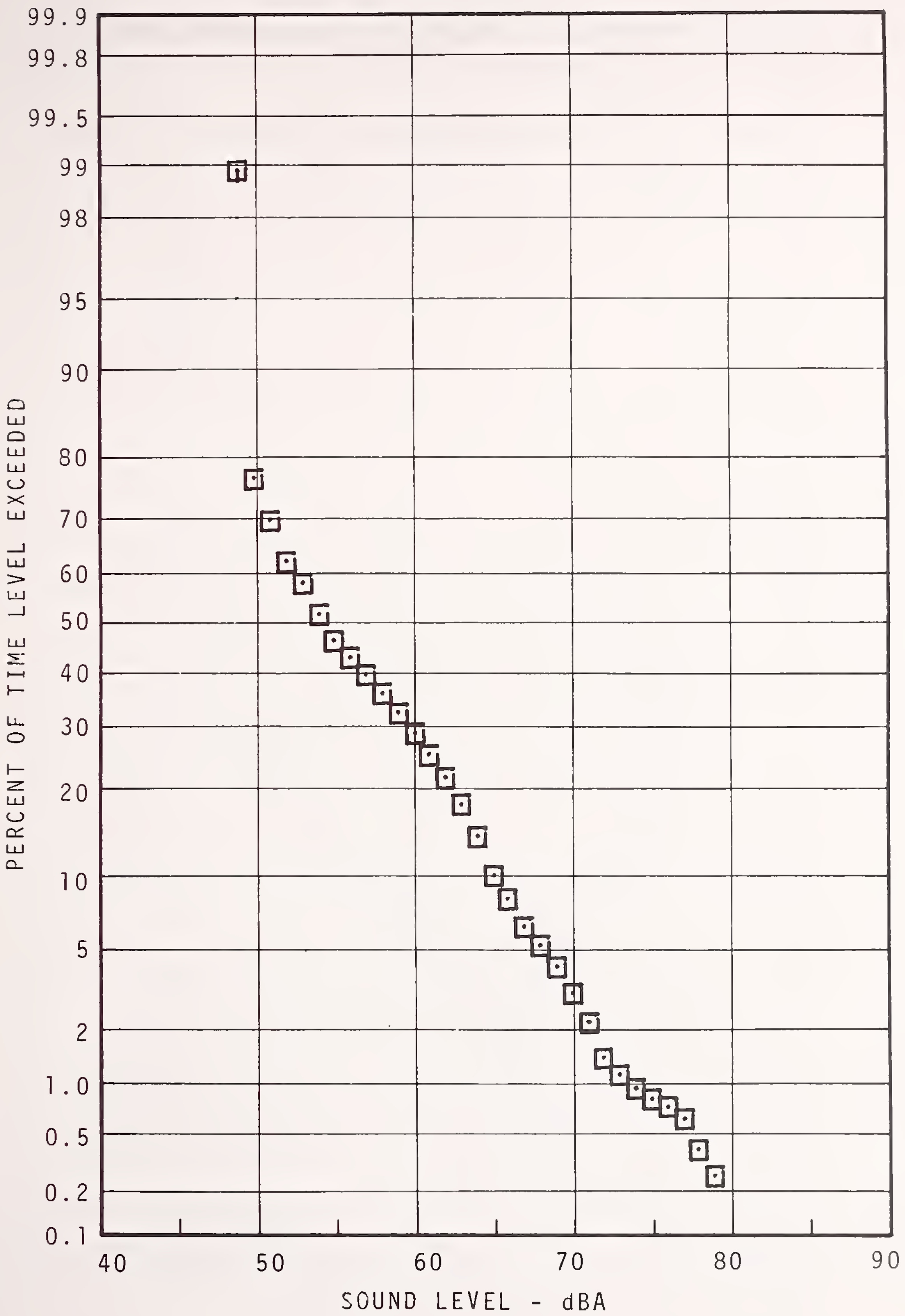


FIGURE 5.22 . OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 30M- EVENING.

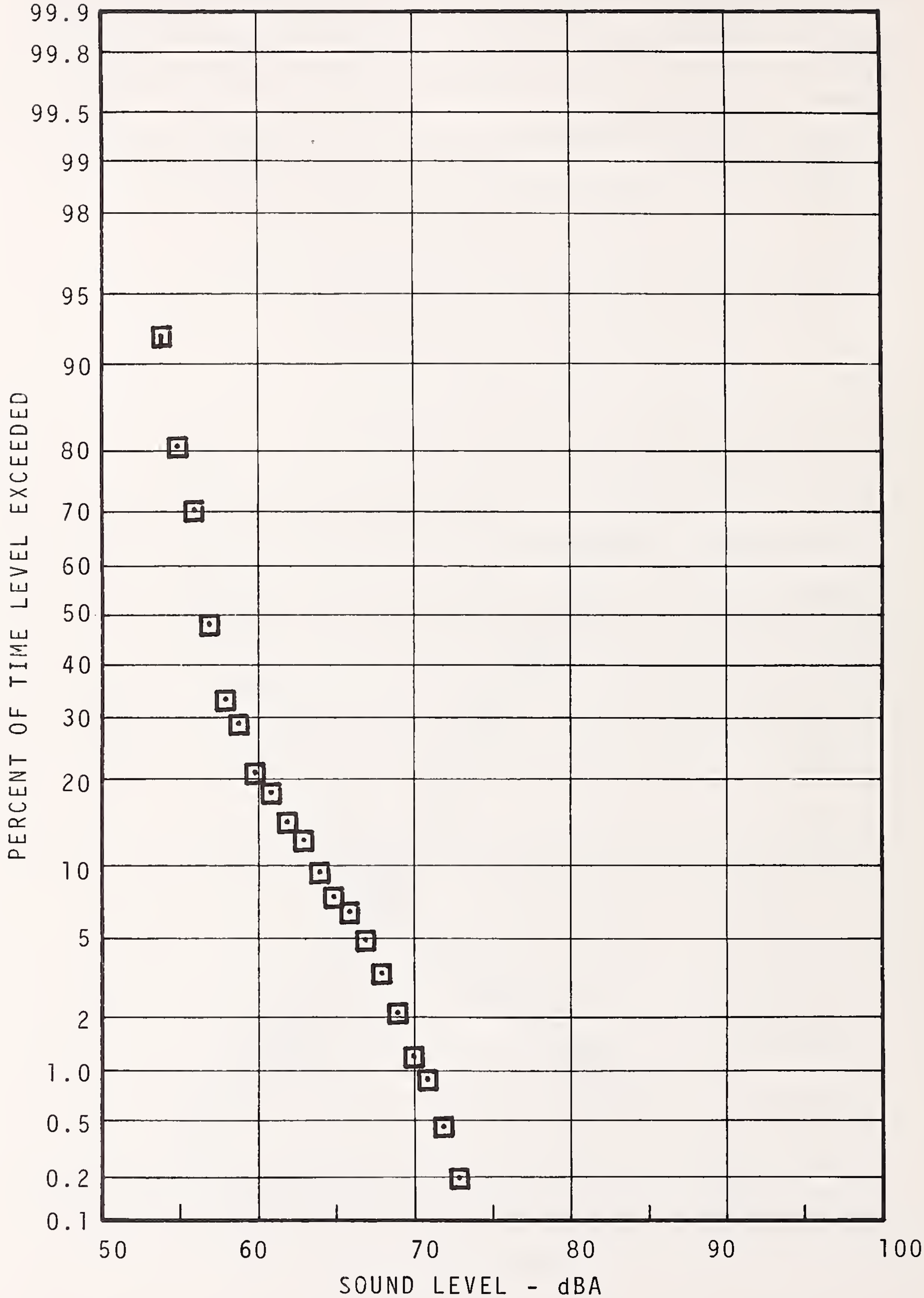


FIGURE 5.23 . OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 60M-DAYTIME.

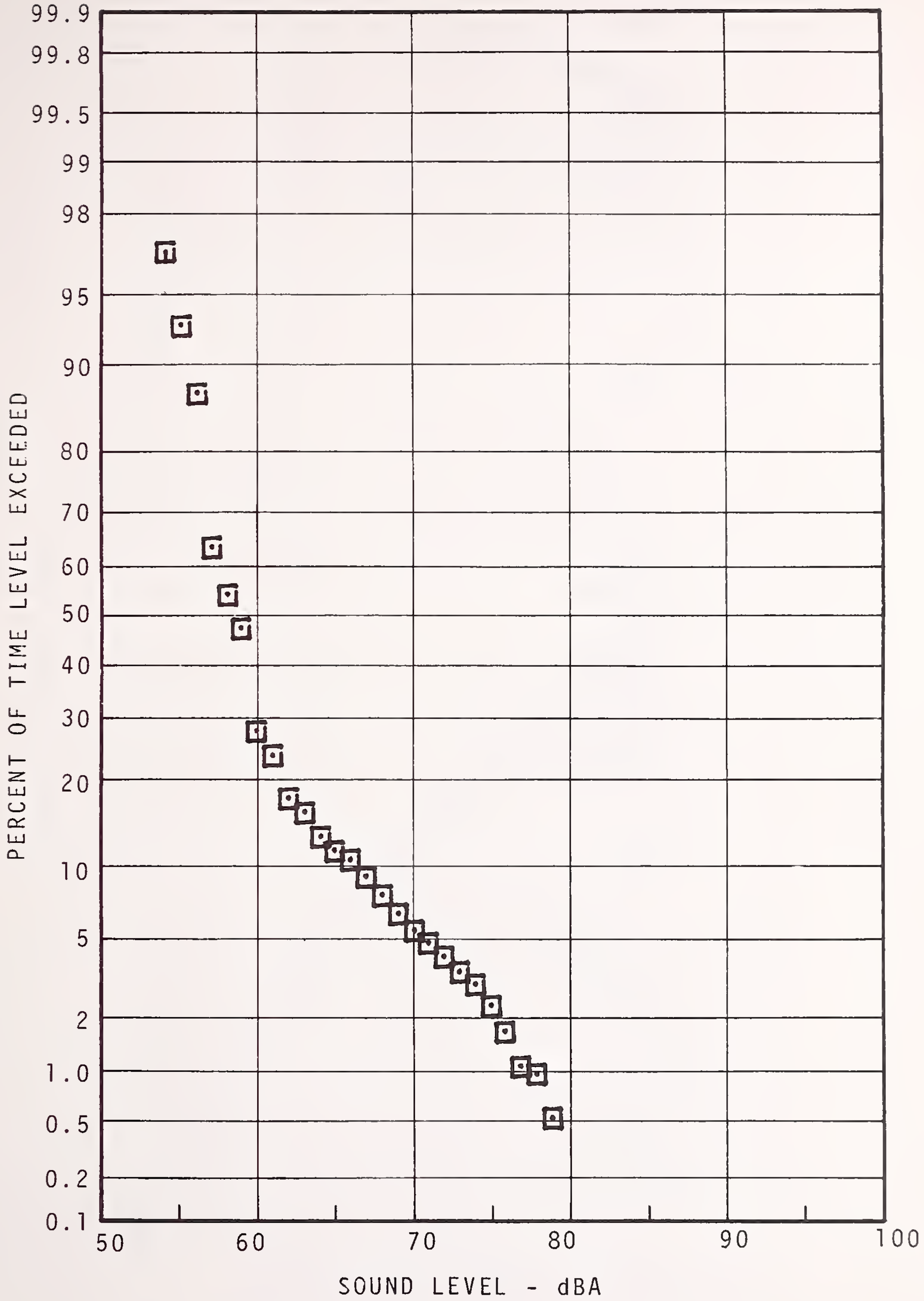


FIGURE 5.24 . OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION -60M - RUSH HOUR.

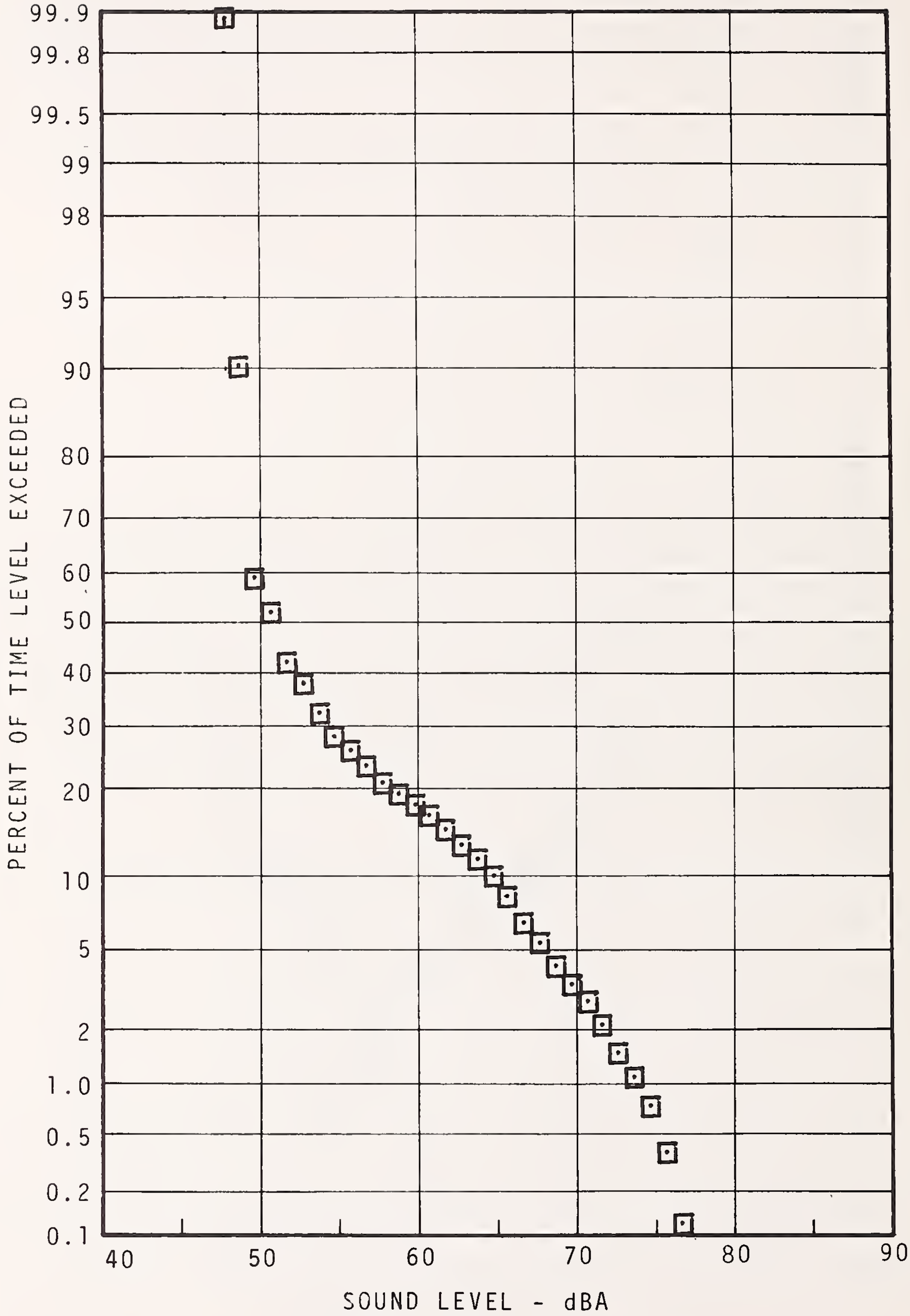


FIGURE 5.25. OGDEN AND ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 60M - EVENING.

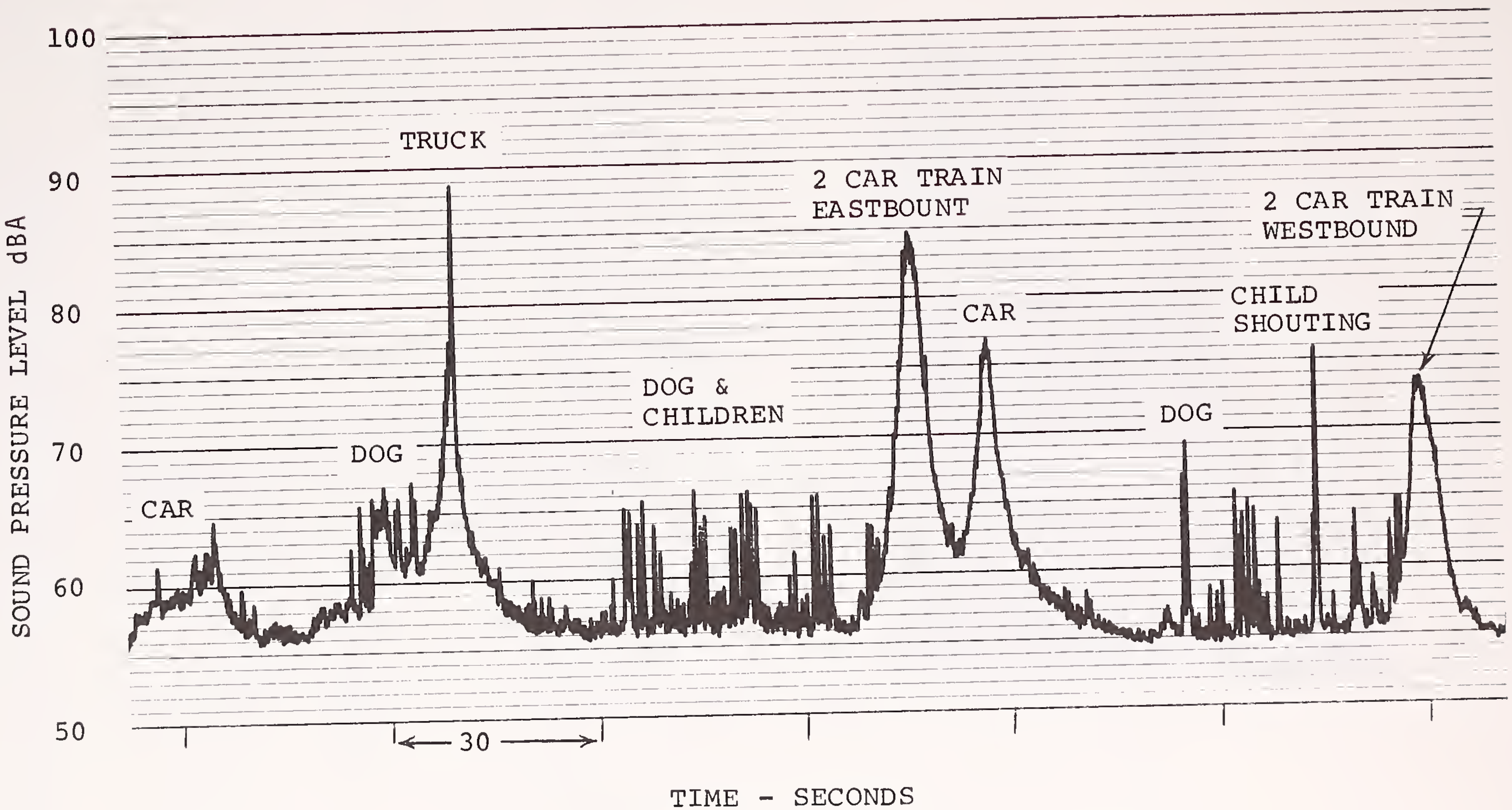


FIGURE 5.26. TYPICAL TIME HISTORY, OGDEN & ATLANTIC, WAYSIDE

COLLINGSWOOD VIADUCT WAYSIDE

SITE DESCRIPTION (see Figure 5.27)

At this location, the transit line operates over concrete viaduct. The line is located over a grass island separating North and South Atlantic Avenue. Each side of the right-of-way is composed of primarily residential homes with some places of business. At the measurement site there is a 2 story building consisting of a store with apartment overhead, and a church parking lot on the opposite side of Dayton Avenue. The region under the viaduct is open to the north side of the line. Collingswood Station is located approximately 4 blocks east of this site.

NOISE CLIMATE (see Table 5.6, Figures 5.28 - 5.39)

Collingswood is a quiet residential community, but the noise of the transit system does not intrude in this locale. Traffic noise on the street is frequently of greater amplitude than the rail system noise, and barking dogs, aircraft in overflight and other community sounds comprise the ambient noise in this area.

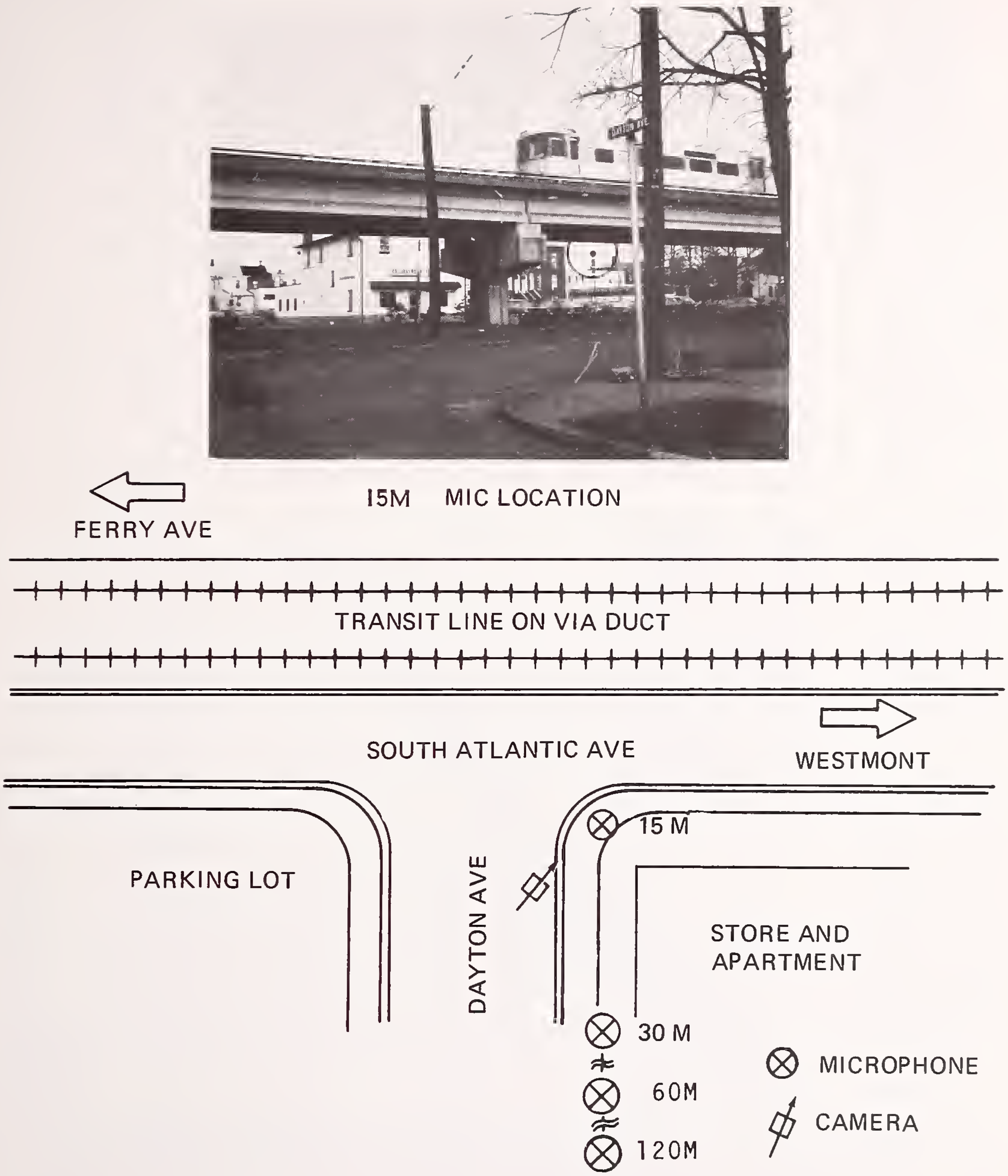


FIGURE 5.27. WAYSIDE MEASUREMENT LOCATION, COLLINGSWOOD. CONCRETE VIADUCT

TABLE 5.6 SUMMARY OF MEASUREMENT RESULTS FOR DAYTON & SOUTH ATLANTIC COMMUNITY

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					EAST	WEST	EAST	WEST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	15 m	30 min	Pass-by	b) N	6—6	1—6	6—6	1—6	55	56	59	70	62	67
				dBA	94	87	102	87						
				c) S	2.84		2.09							
				N		3—4		3—4						
				dBA		86		94						
				S		1.26		2.57						
Rush	15m	30 min.	Pass-by	dBA					61	62	64	73	91	76
Evening	15m	30 min.	Pass-by	dBA					62	63	64	71	82	72
Night	15m	30 min.	Pass-by	dBA					48	49	53	66	79	65
Day	30m	8 min.	Pass-by	dBA					53	54	57	63	79	67
Rush	30m	15 min.	Pass-by	dBA					56	57	61	69	86	73
Evening	30m	15 min.	Pass-by	dBA					50	51	55	65	76	64
Day	60m	8 min.	Pass-by	dBA					53	54	57	64	75	63
Rush	60m	15 min.	Pass-by	dBA					56	57	59	68	82	68
Evening	60m	15 min.	Pass-by	dBA					48	49	50	57	70	59
Day	120m	5 min.	Pass-by	dBA					56	57	61	69	75	66

Notes: a - Track
b - Number of Trains – (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

$L_{dn} = 78$

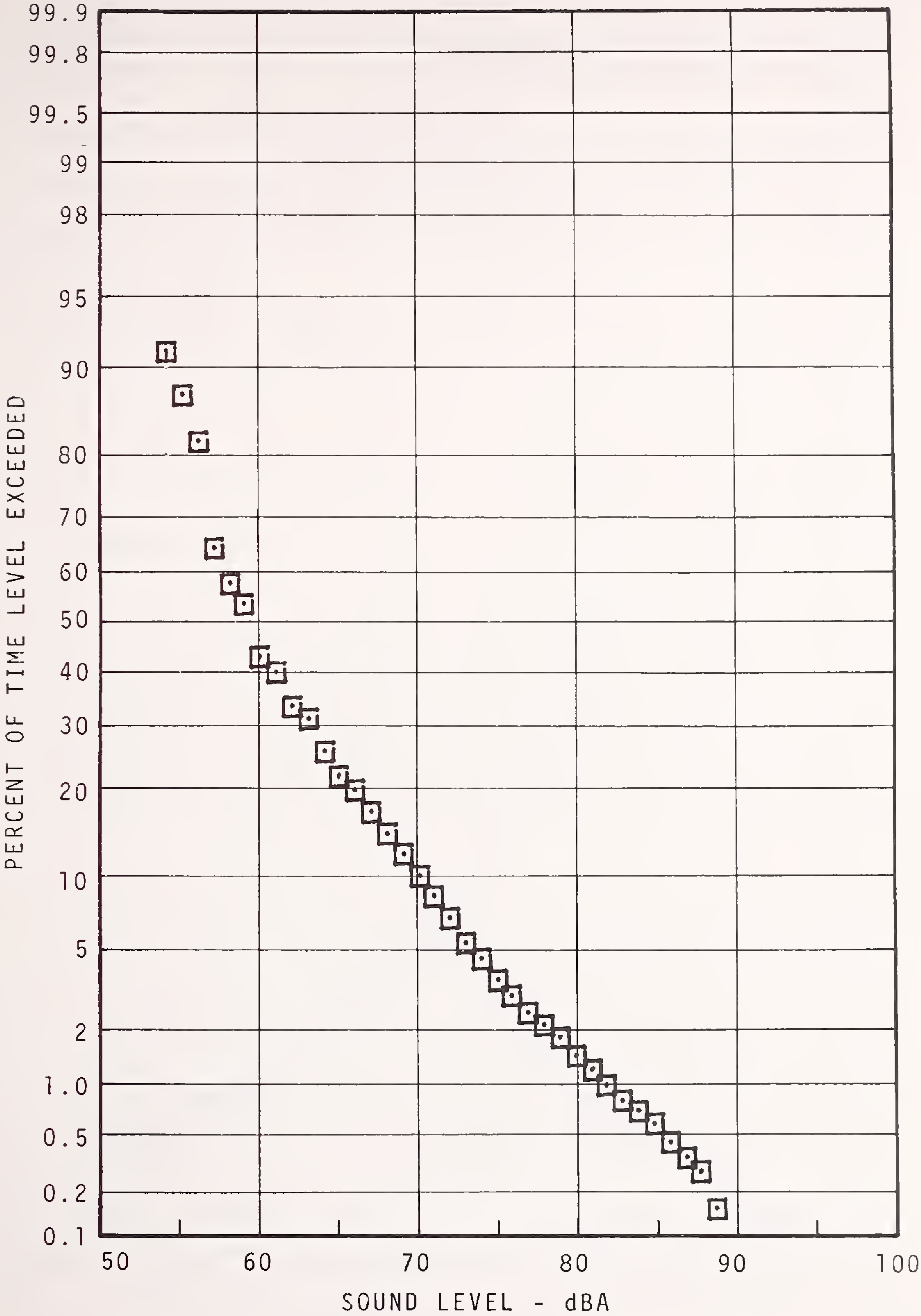


FIGURE 5.28. DAYTON AND SOUTH ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M - DAYTIME.

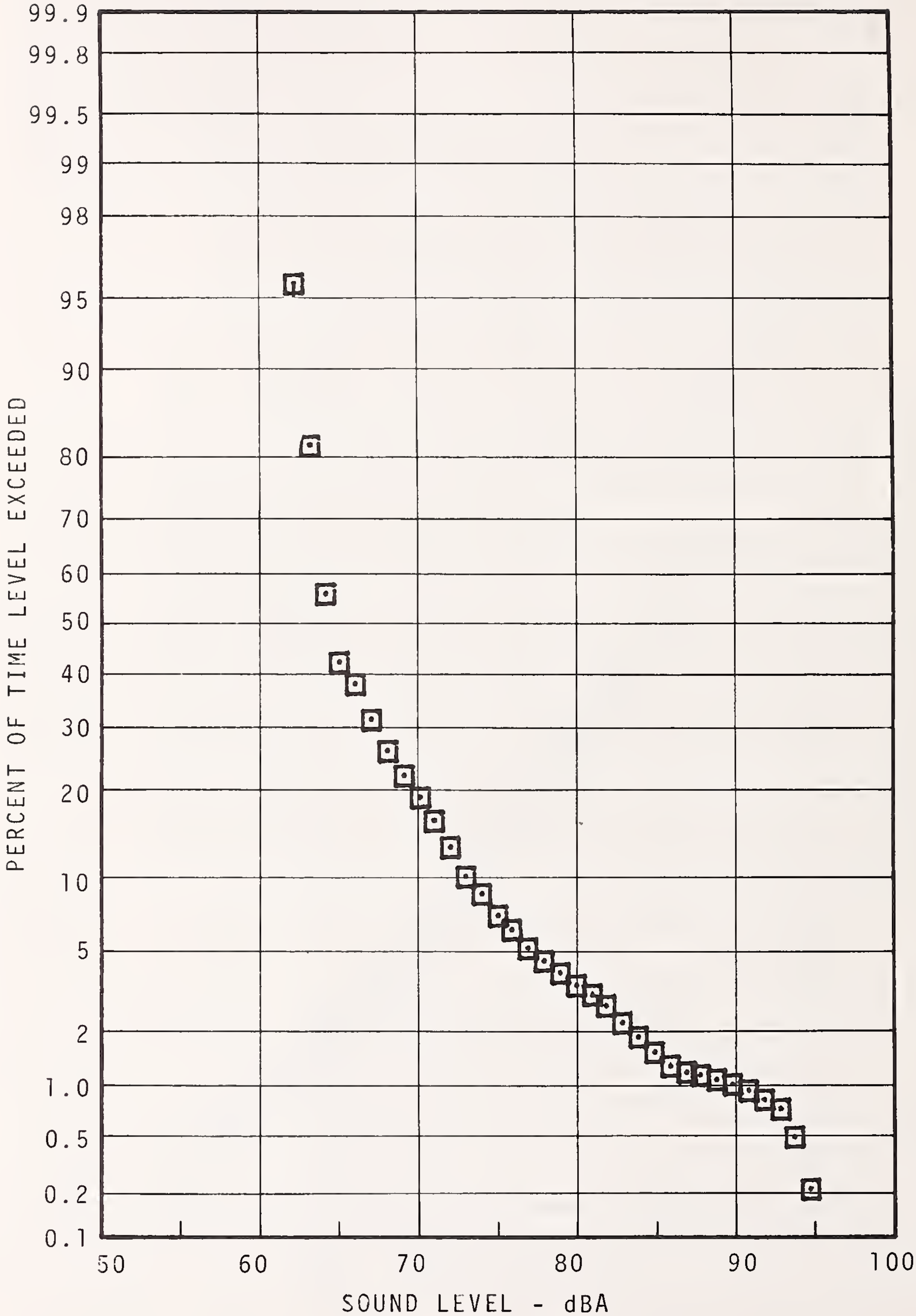


FIGURE 5.29. COLLINGSWOOD COMMUNITY STATISTICAL DISTRIBUTION - 15M FROM CONCRETE VIA-DUCT - RUSH HOUR.

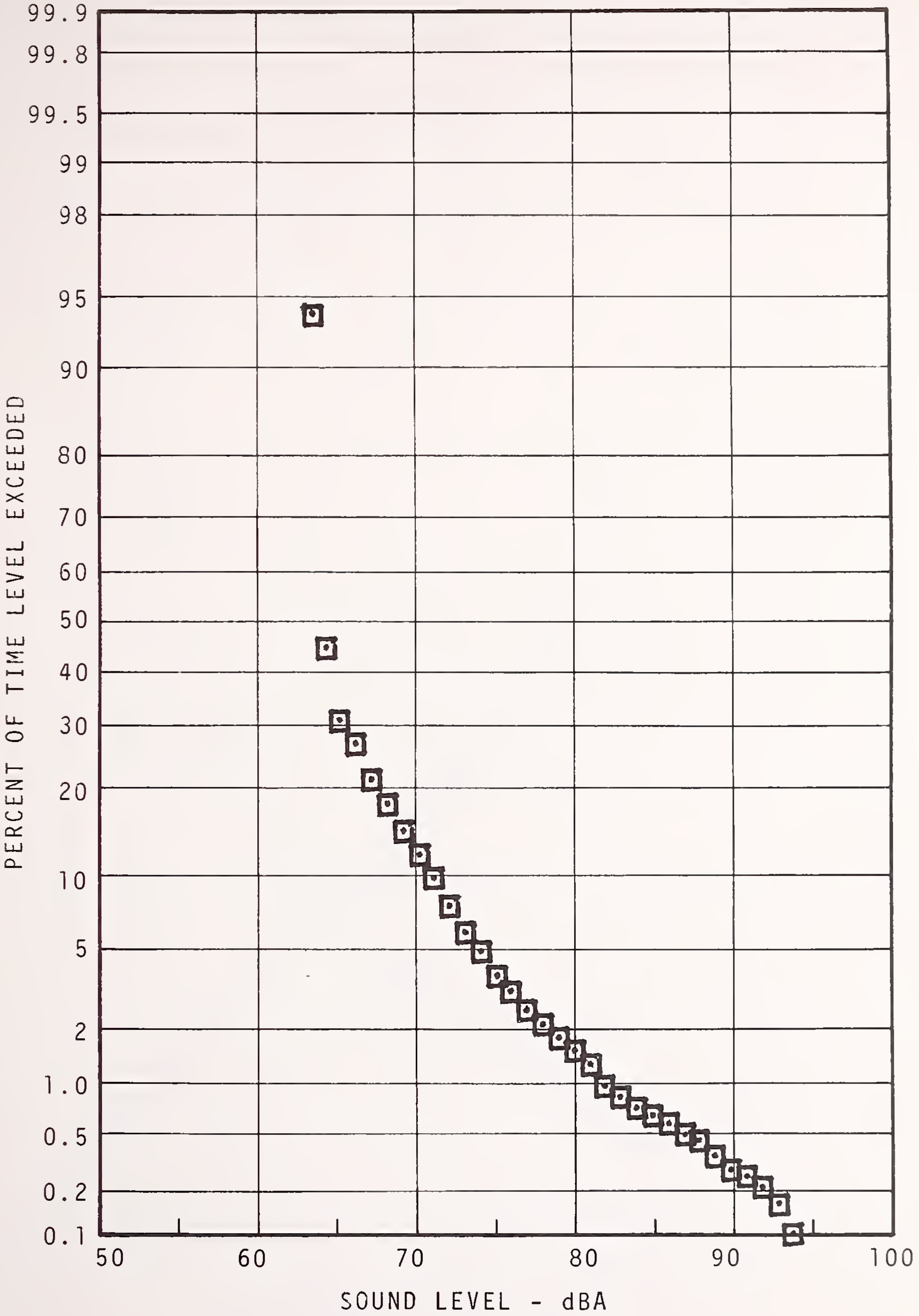


FIGURE 5.30. DAYTON AND SOUTH ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M - EVENING.

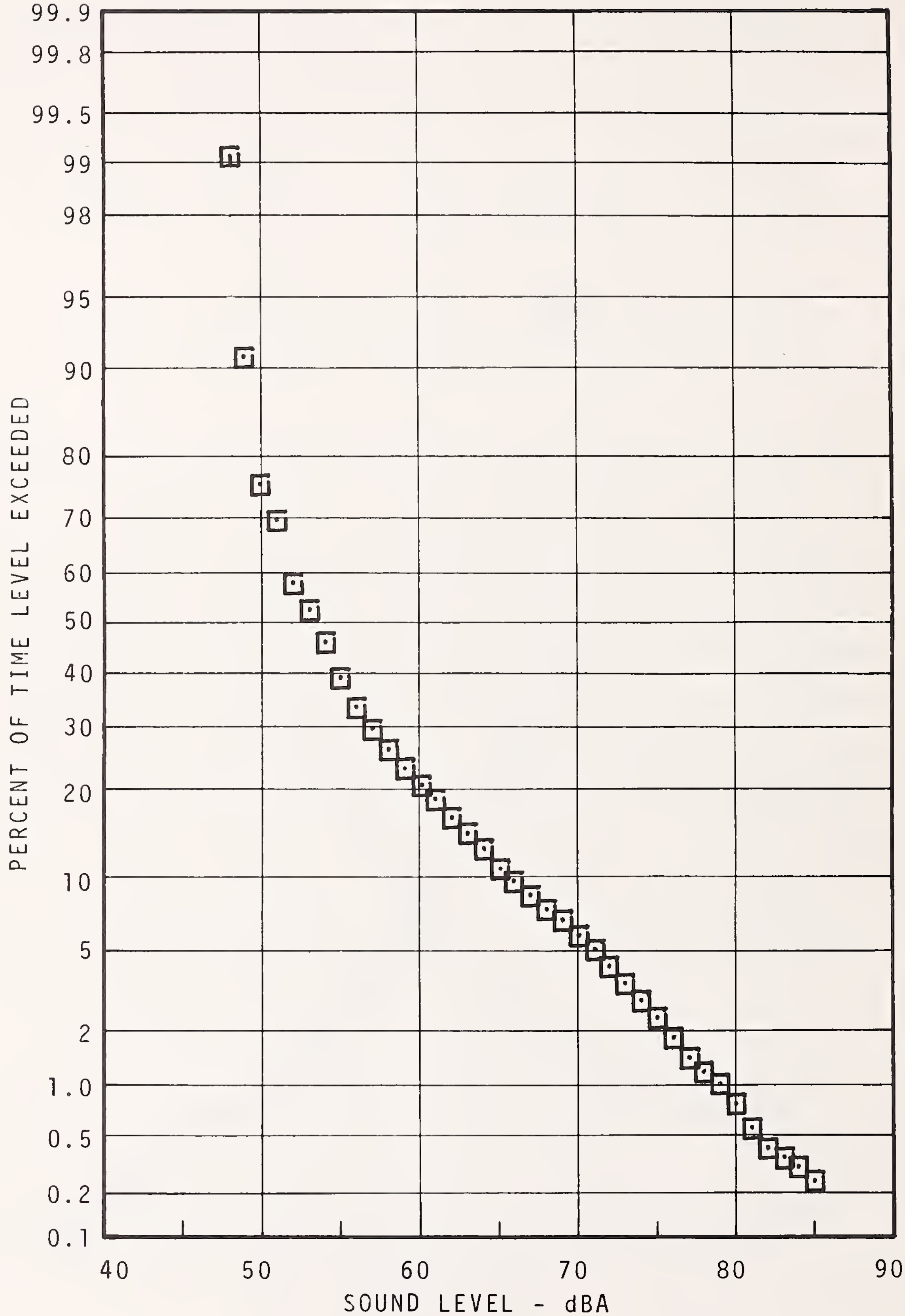


FIGURE 5.31. DAYTON AND ATLANTIC AVE. COMMUNITY STATISTICAL DISTRIBUTION - 15M - NIGHT.

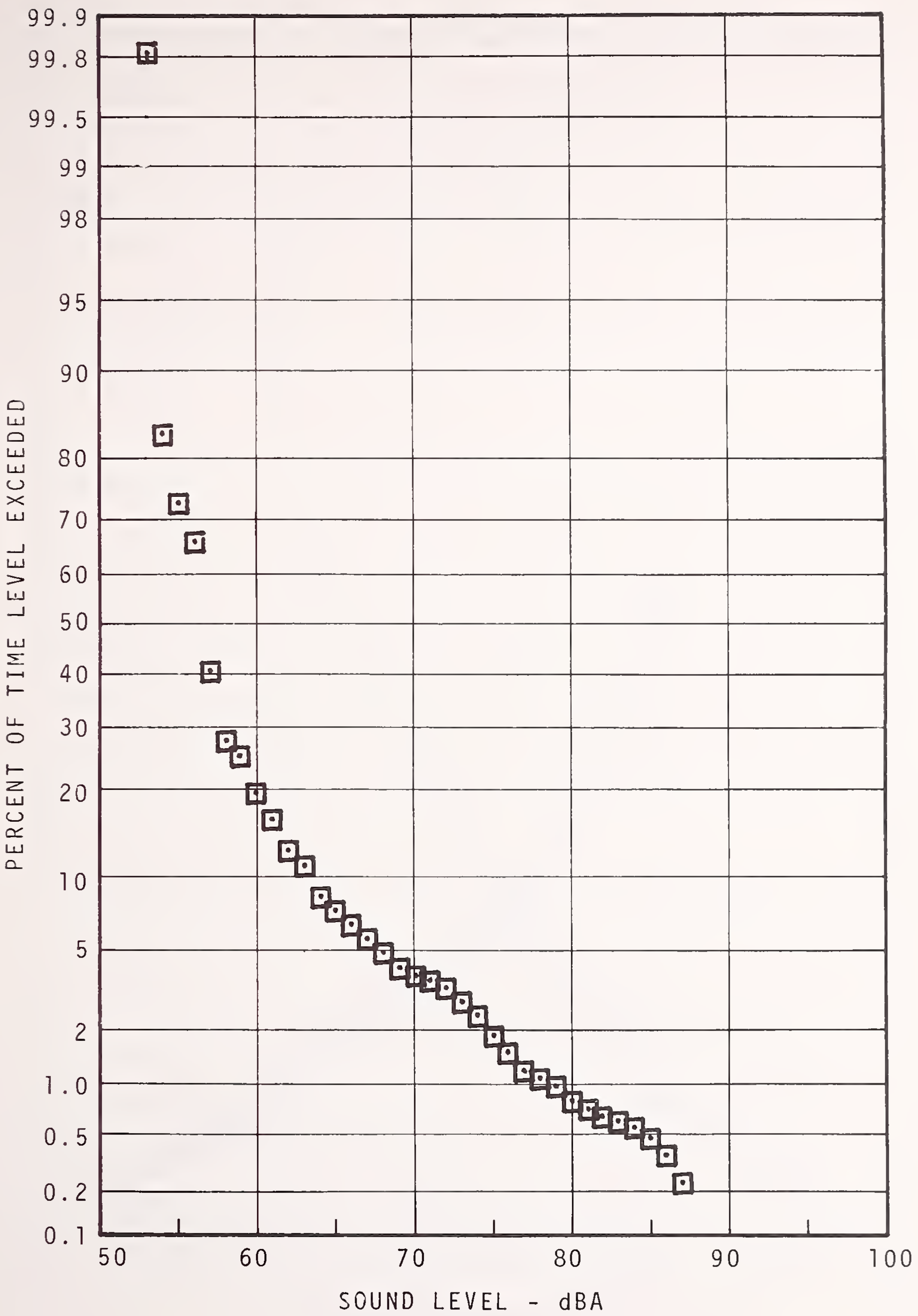


FIGURE 5.32. DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY AND STATISTICAL DISTRIBUTIONS - 30M - DAYTIME.

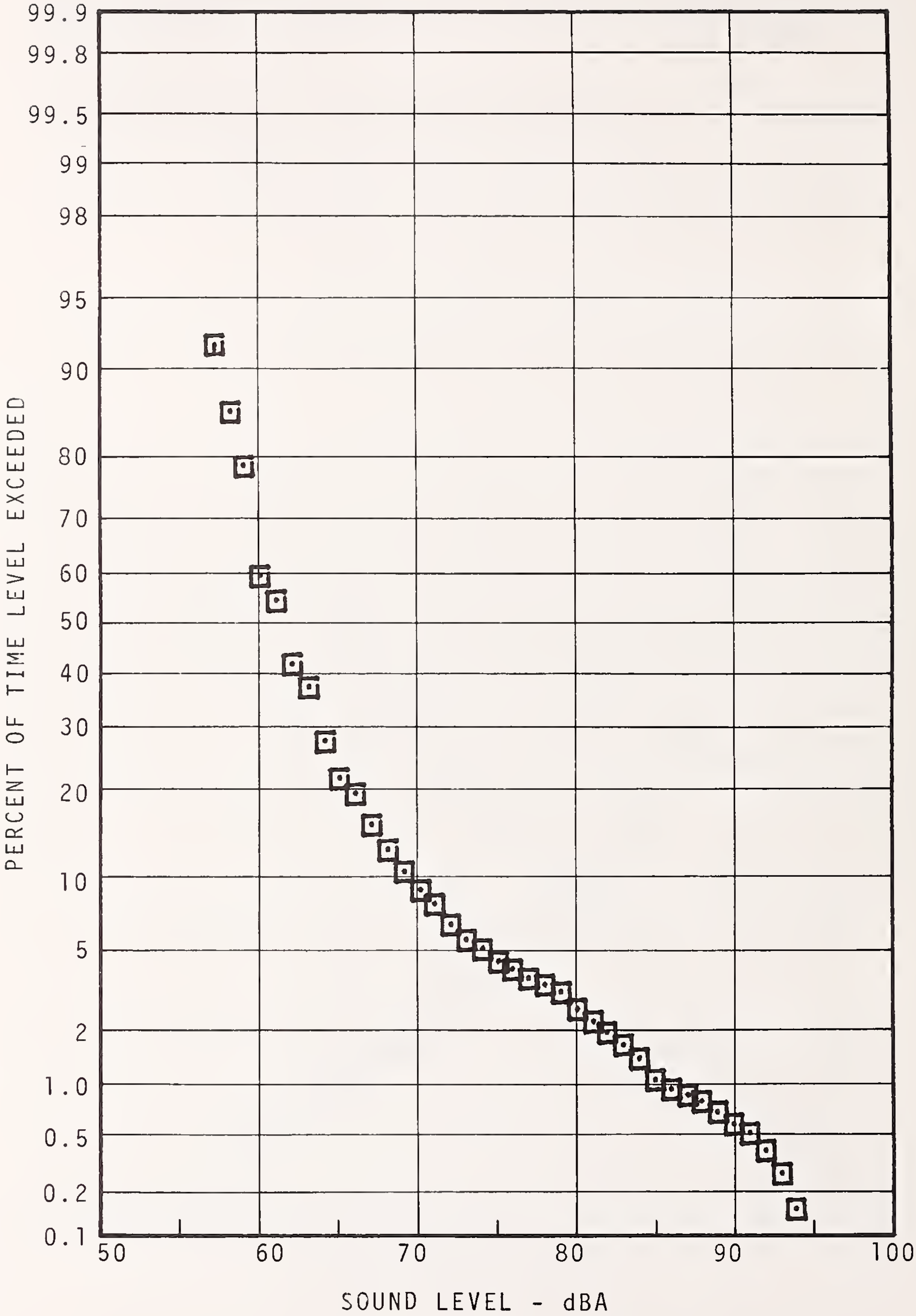


FIGURE 5.33. DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 30M - RUSH HOUR.

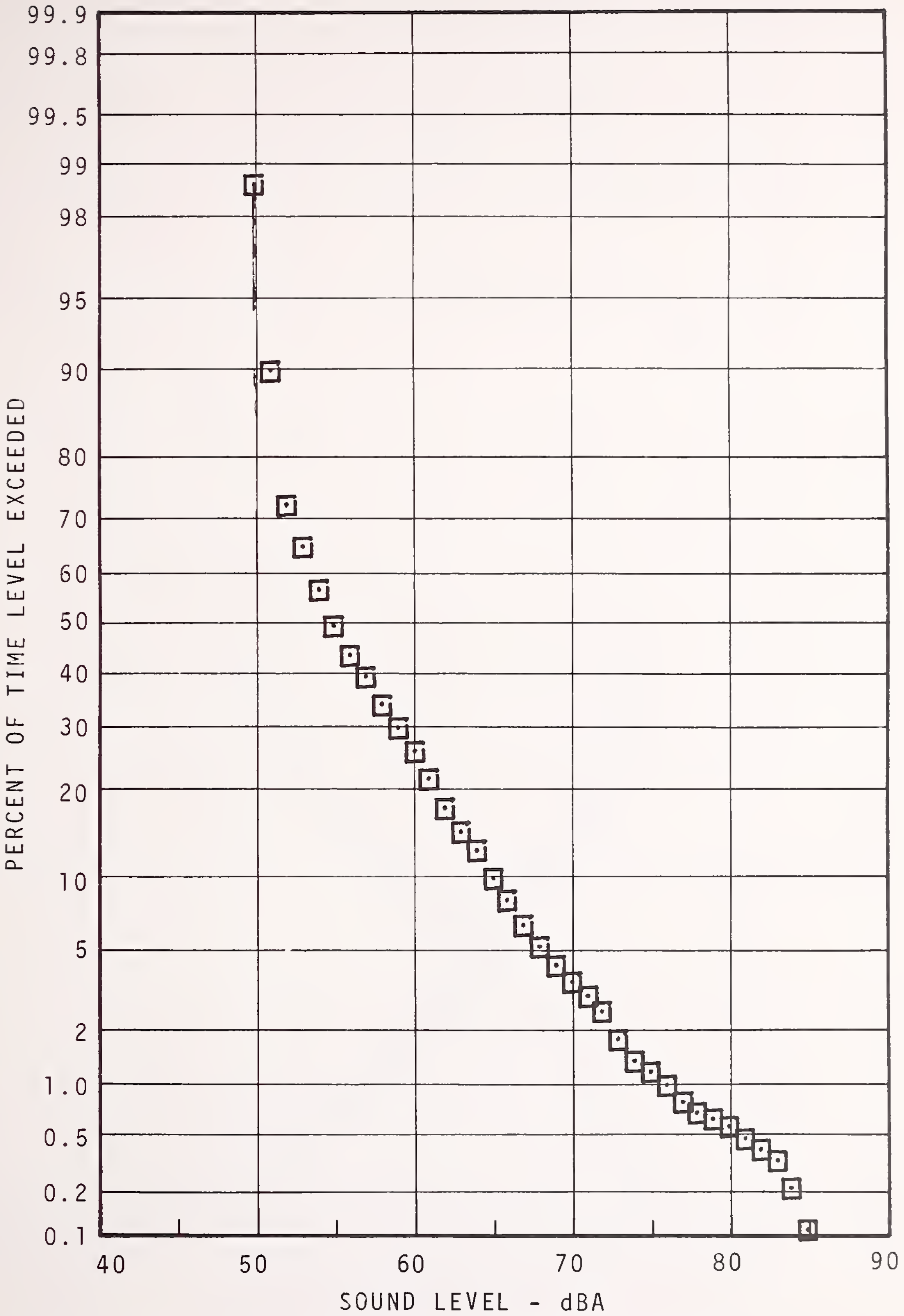


FIGURE 5.34. DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 30M - EVENING.

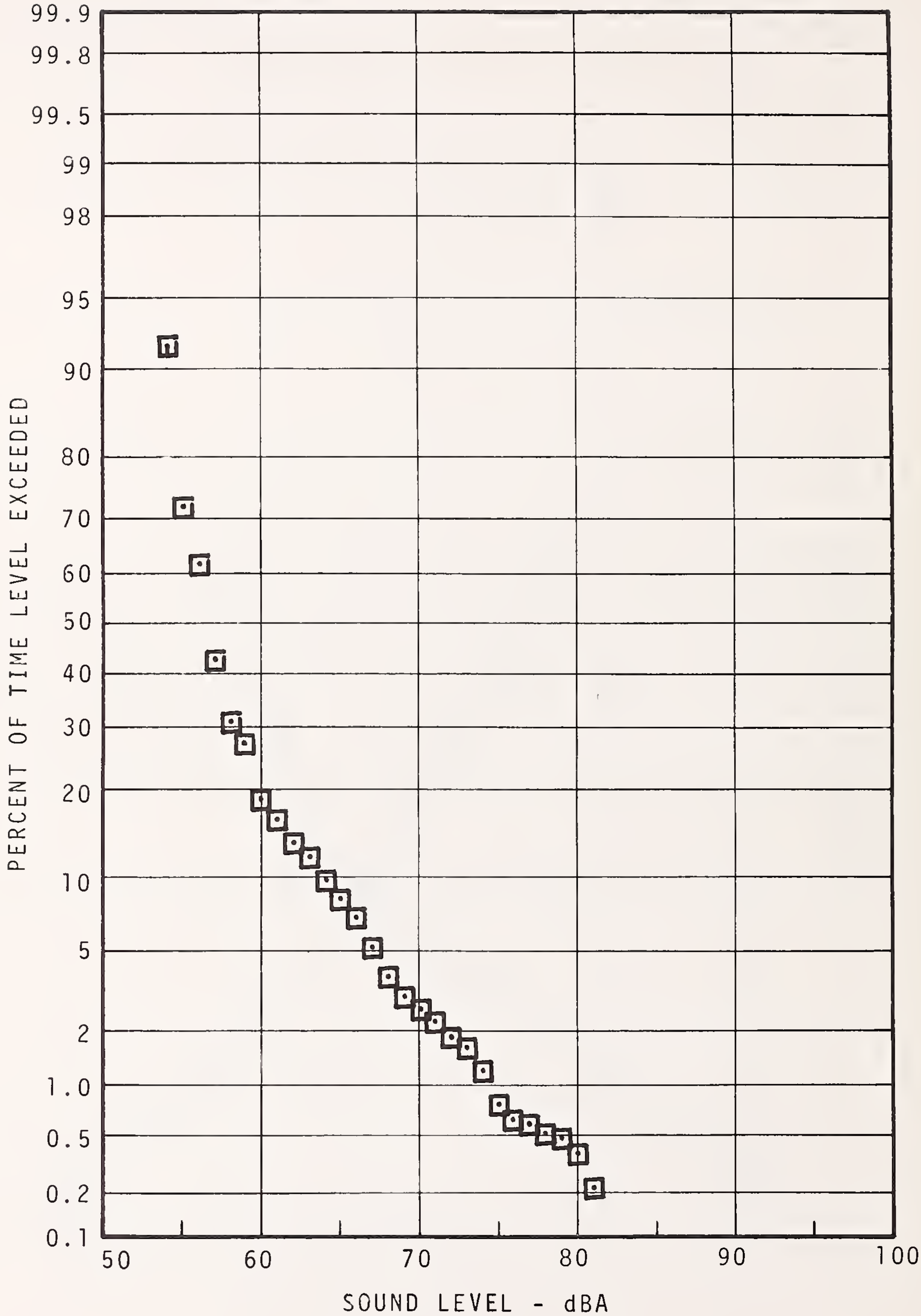


FIGURE 5.35 . DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 60M - DAYTIME.

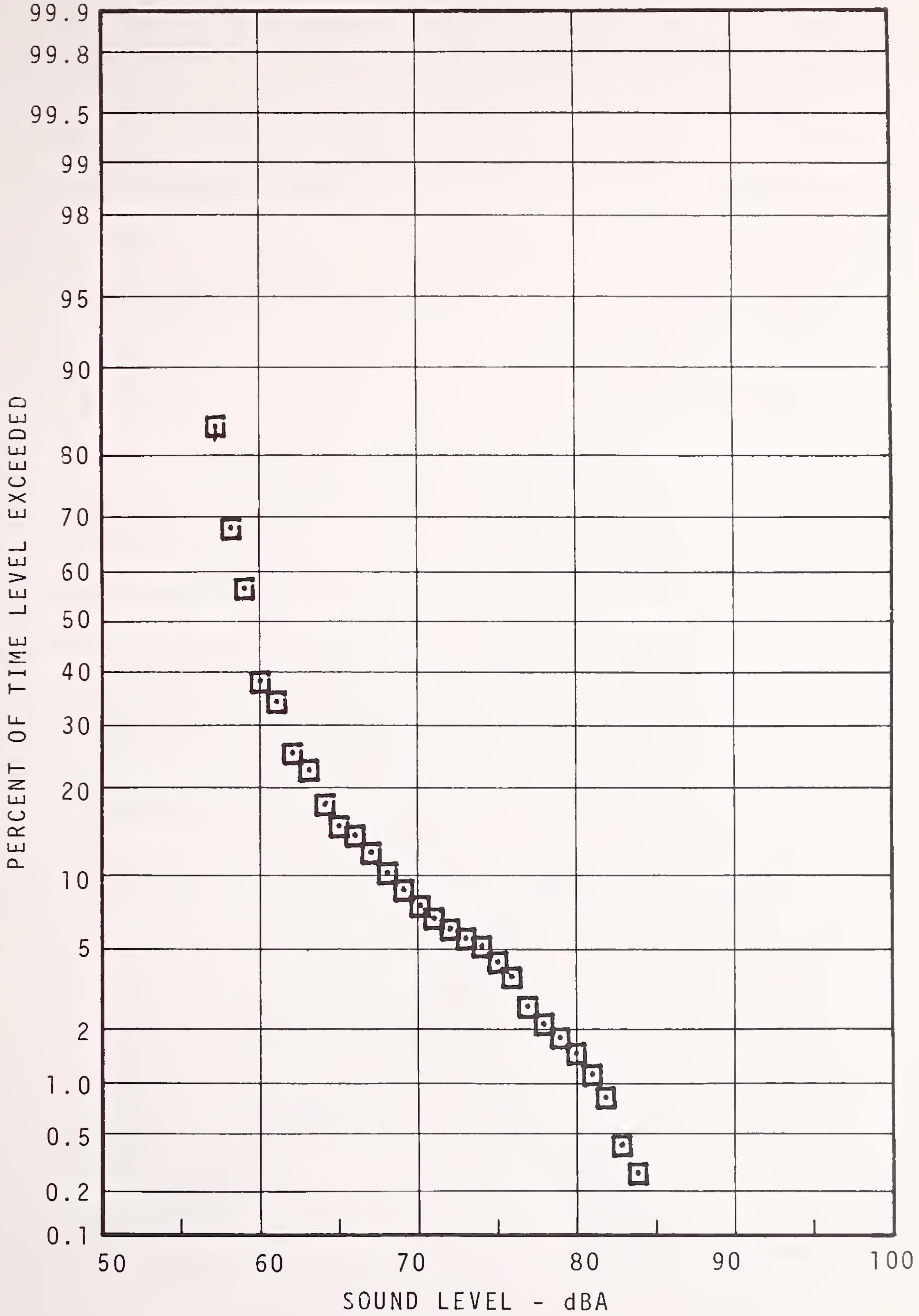


FIGURE 5.36. DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 60M - RUSH HOUR.

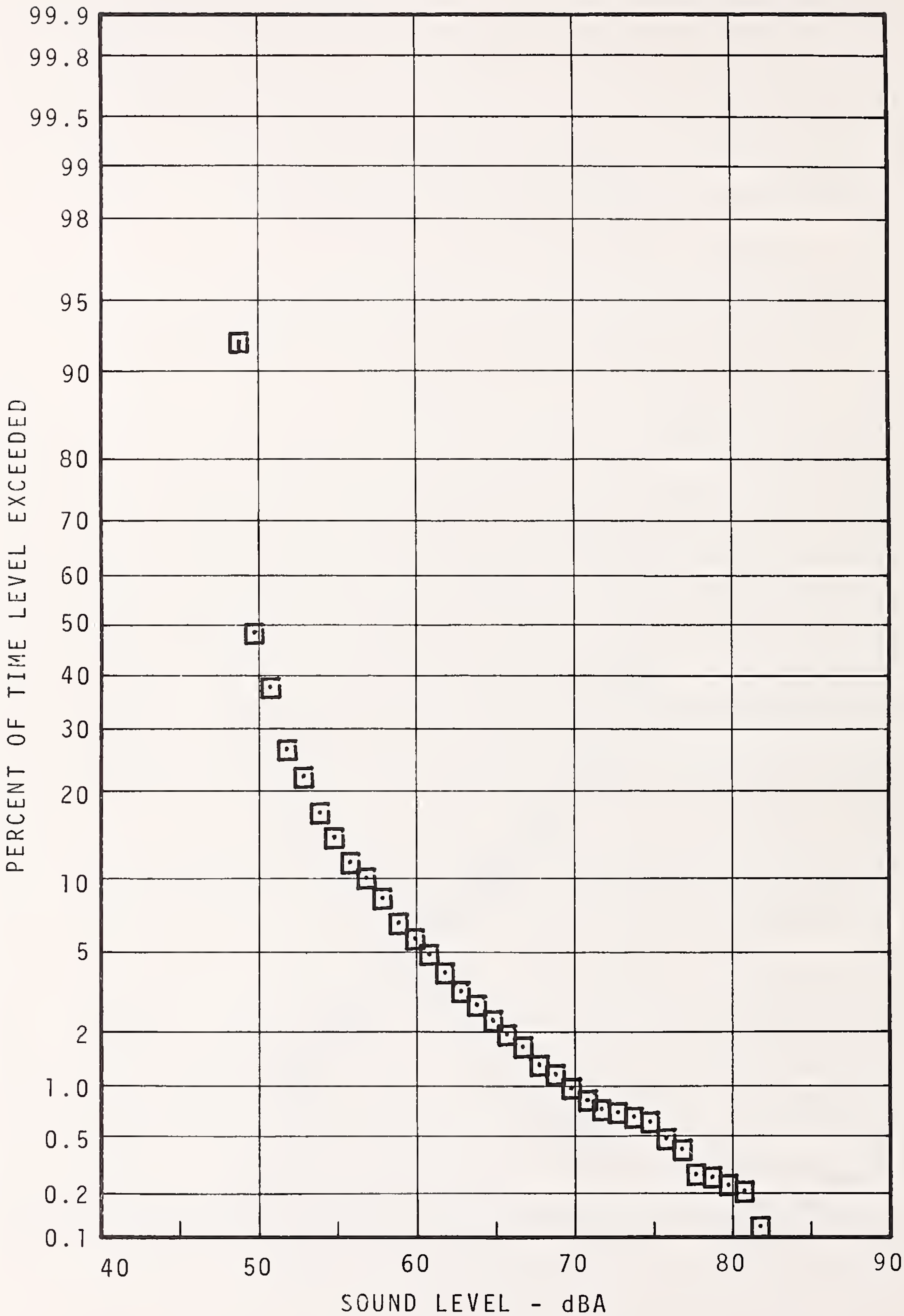


FIGURE 5.37 . DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 60M - EVENING.

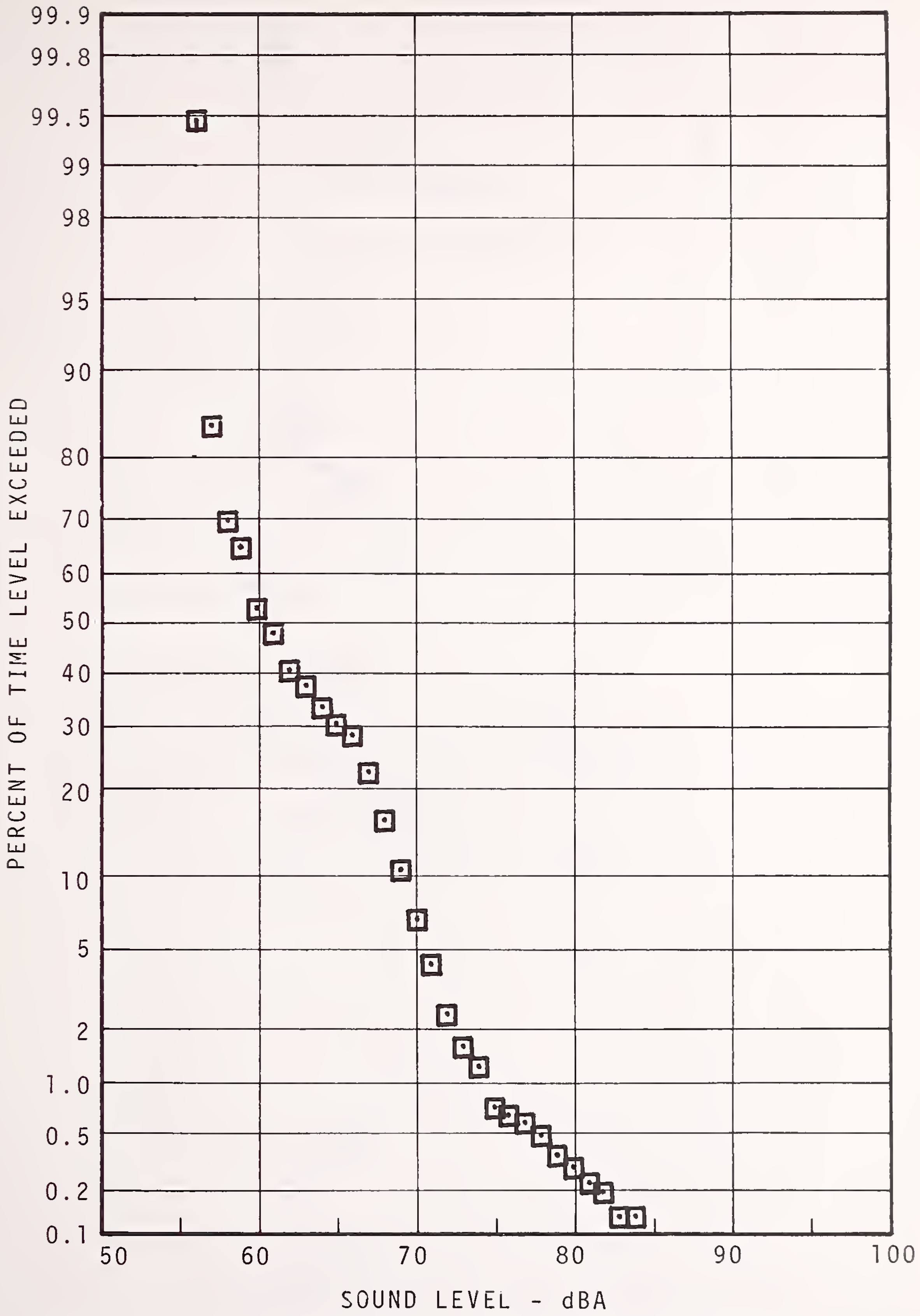


FIGURE 5.38. DAYTON AND SOUTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 120M - DAYTIME.

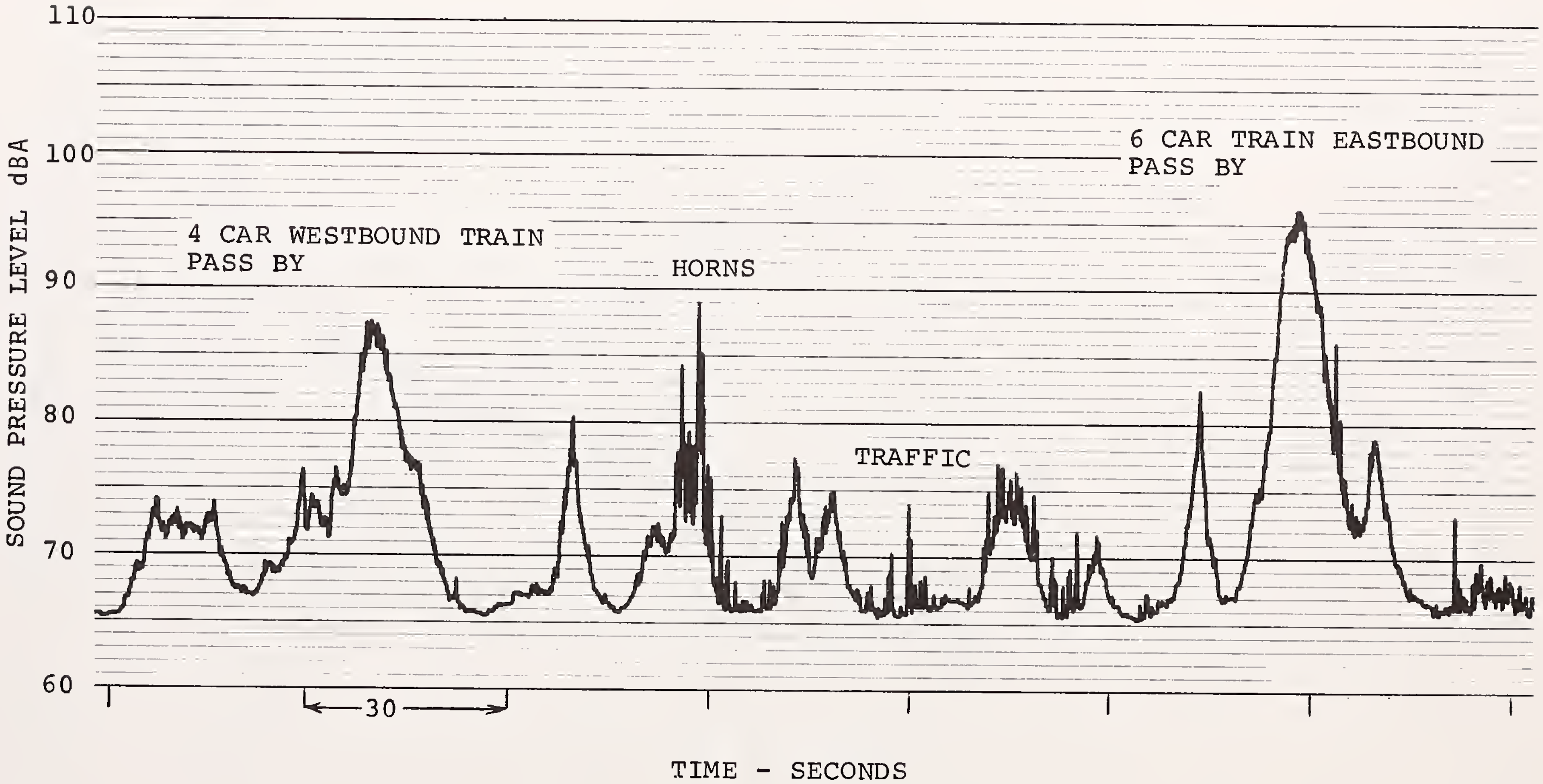


FIGURE 5.39. TYPICAL TIME HISTORY, DAYTON & SOUTH ATLANTIC, WAYSIDE

WESTMONT WAYSIDE

SITE DESCRIPTION (see Figure 5.40)

A special measurement location was selected adjacent to a high rise (11 story) apartment building, Roher Towers, in Westmont. The transit system is on concrete viaduct in this region and passes within 25 meters of the apartment building. This site was selected to document the effect of reflected energy on noise at a 15 meter location. Most of the surrounding region is occupied by single family 2 and 3 story dwellings. Westmont Station is 2 blocks east of this site.

NOISE CLIMATE (see Table 5.7, Figures 5.41 - 5.42)

This location is in a quiet neighborhood in Westmont. There are no through streets immediately adjacent to the apartment, although traffic noise from Haddon Avenue, a busy commercial and business district is audible. Occasionally, noise due to automobiles parking in the Roher Towers parking lot located under the viaduct was noted. Train passbys were a predominant noise source due to their proximity to the apartment.

15 M MIC POSITION

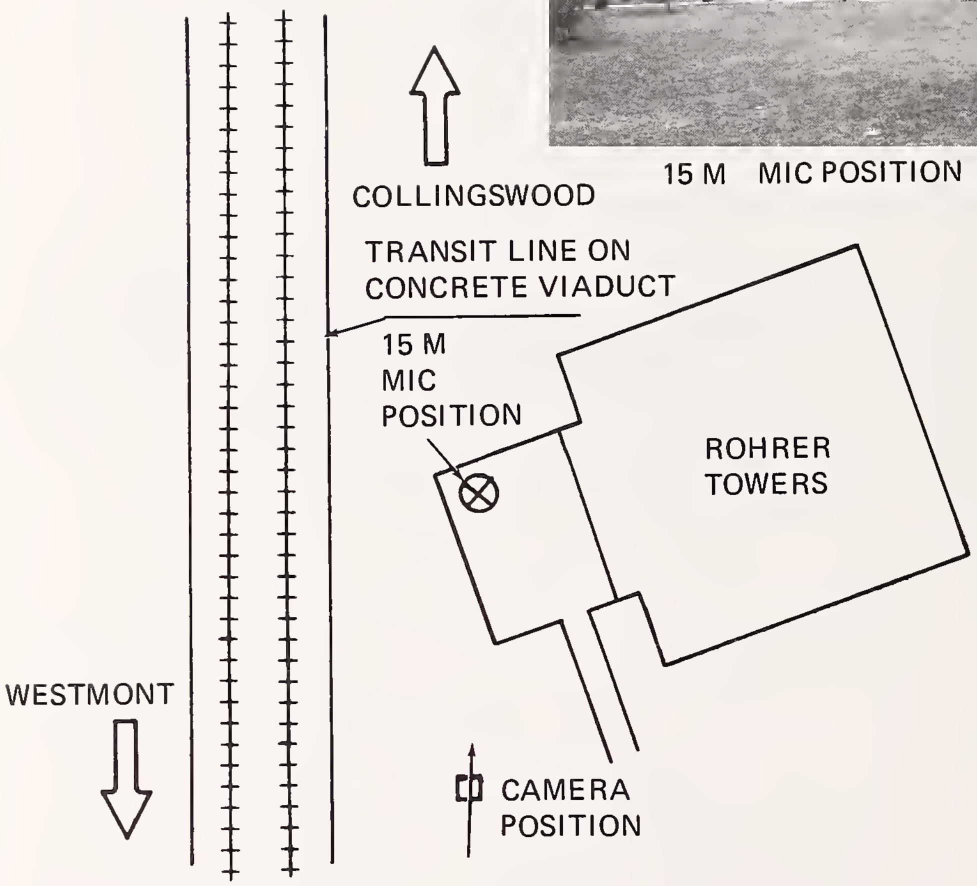


FIGURE 5.40. WAYSIDE MEASUREMENT SITE, WESTMONT.

TABLE 5.7 SUMMARY OF MEASUREMENT RESULTS FOR 7-MINUTE SAMPLE, COMMUNITY NOISE, PATCO-WESTMONT-ROHRER TOWERS
CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR						
					a)WEST	EAST	WEST	EAST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Rush	15m	7 min.	Pass-by	b) N	2-6	1-6	2-6	1-6	53	53	56	64	85	72
				dBA	93	86	100	92						
				c)S	1.06	-	1.06	-						
				N		1-5		1-5						
				dBA		85		92						
				S		-		-						

Notes: a - Track
b - Number of Trains - (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

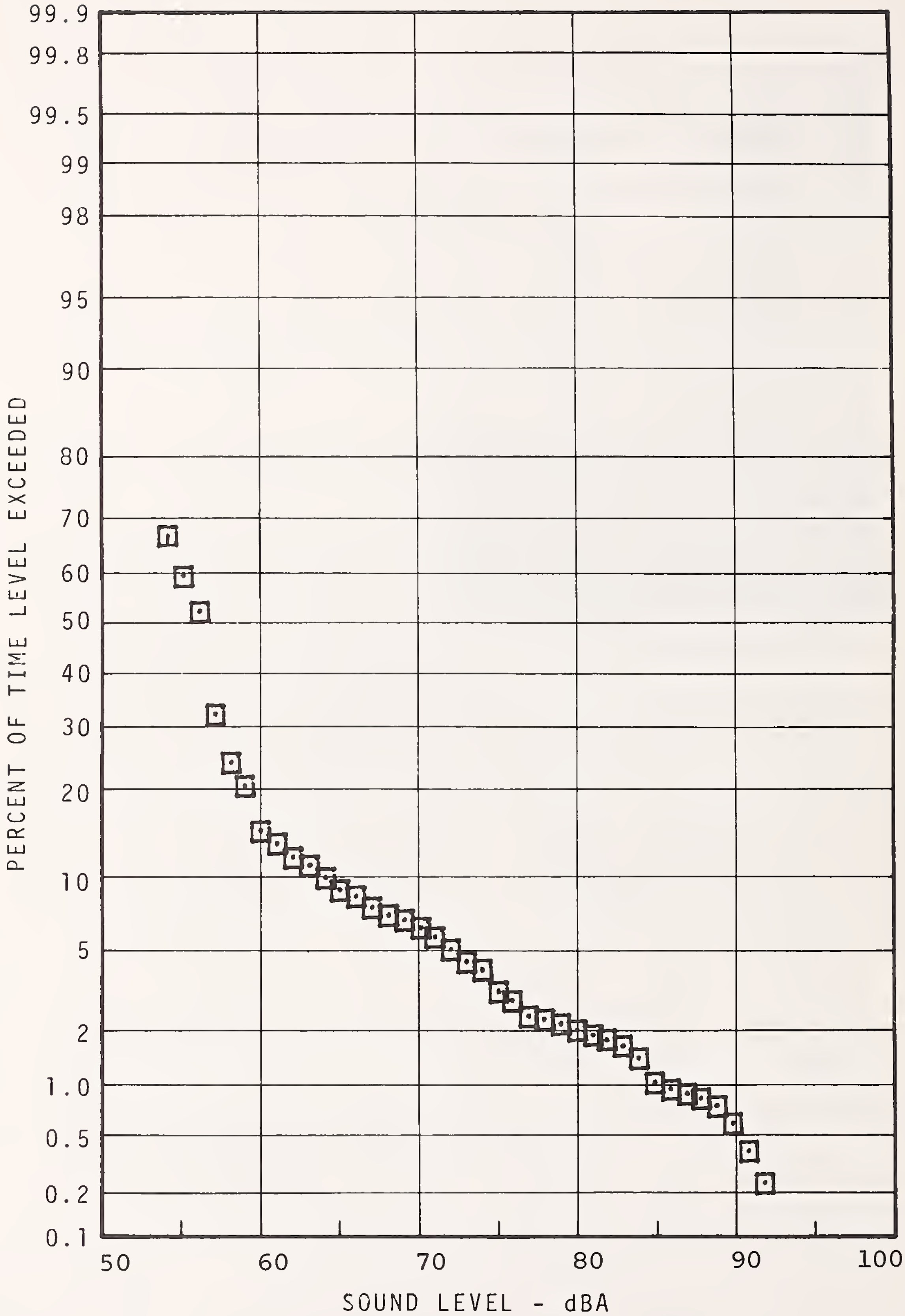


FIGURE 5.41. WESTMONT (ROHRER TOWERS) COMMUNITY STATISTICAL DISTRIBUTION - RUSH HOUR.

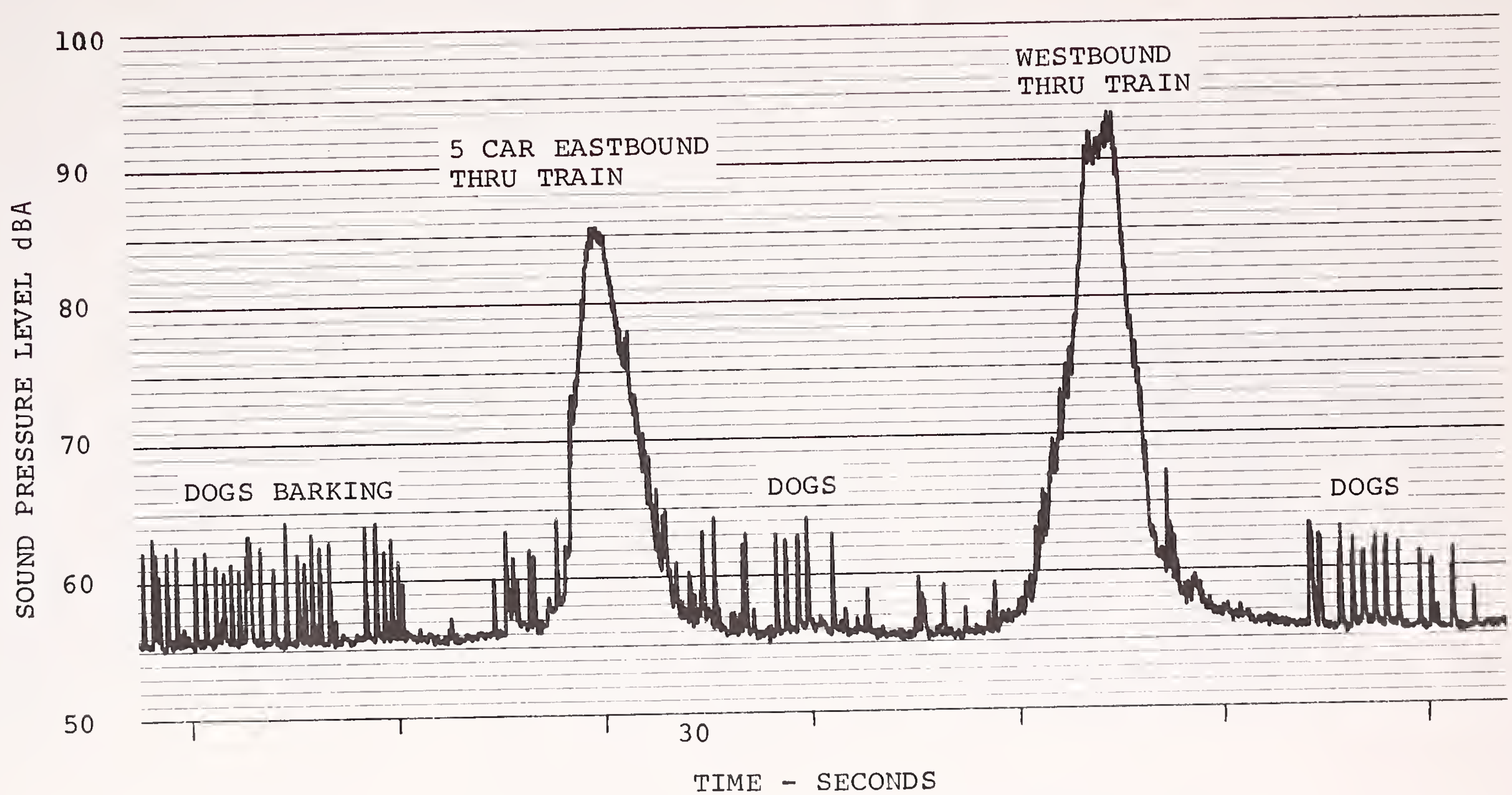


FIGURE 5.42. TYPICAL TIME HISTORY, WESTMONT, WAYSIDE

HADDONFIELD WAYSIDE

SITE DESCRIPTION (see Figure 5.43)

The transit system is located in a cutting through Haddonfield. To document this, a site was selected at Redman Avenue which crosses the transit system at Atlantic Avenue which parallels the transit right-of-way. East of Redman Avenue, Atlantic Avenue is a little-used unpaved road. The Pennsylvania Reading Seashore Line (PRSL) is also located in this cut, although it operates approximately 10 ft below the grade of the PATCO system. This vicinity is a residential neighborhood and is approximately 1-1/2 blocks from the Haddonfield Station.

NOISE CLIMATE (see Table 5.8, Figures 5.44 - 5.52)

Haddonfield is a quiet residential neighborhood with an ambient noise consisting of occasional vehicle traffic, aircraft overflights, barking dogs, children, et cetera. The noise of the transit system is lower than when operating at grade owing to its location in the cut. Occasionally, a PRSL train may also pass by, although this line is virtually unused. At night time the background noise is quite low.

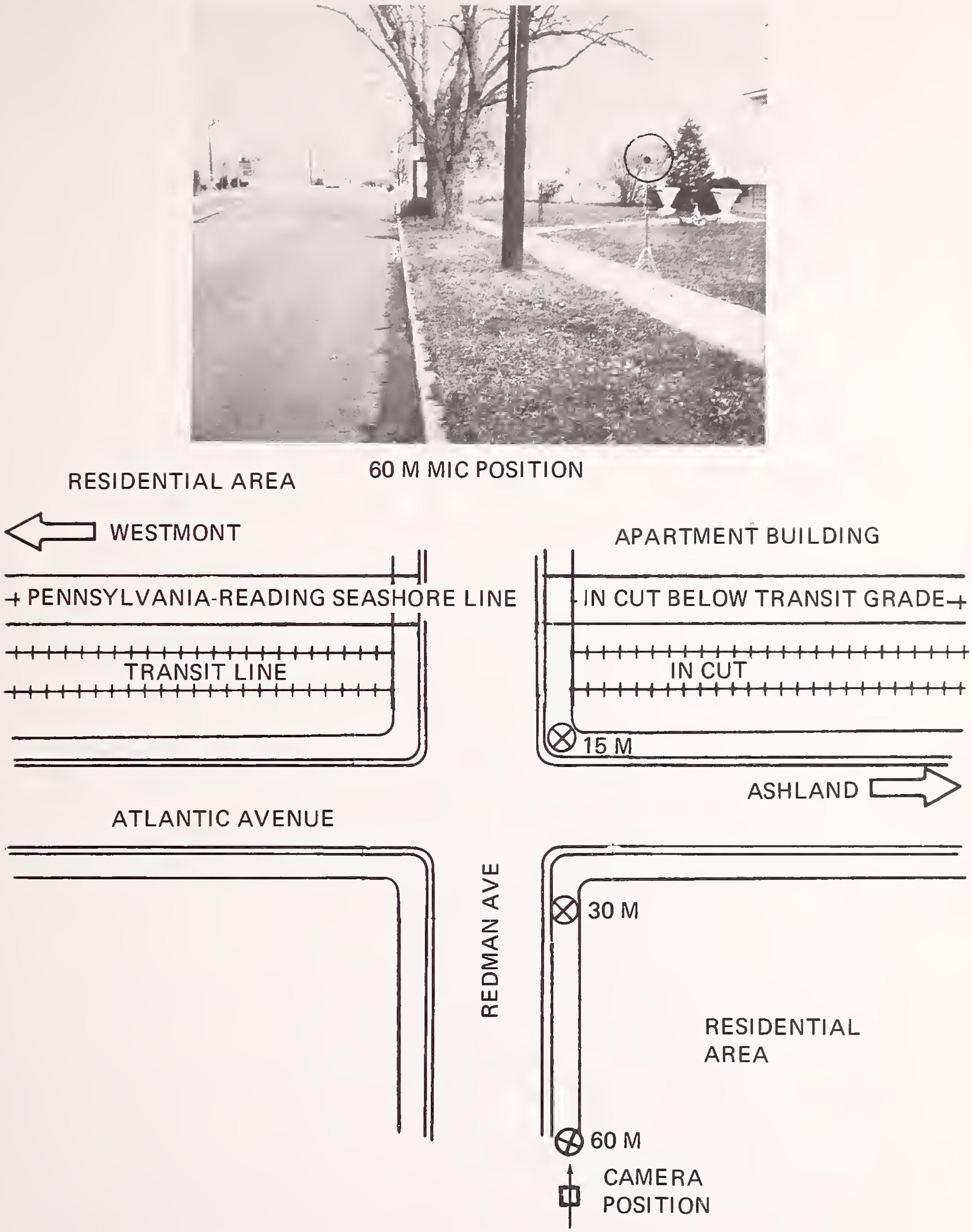


FIGURE 5.43. WAYSIDE MEASUREMENT SITE, HADDONFIELD

TABLE 5.8 SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE, COMMUNITY NOISE - PATCO-REDMAN AND NORTH ATLANTIC AVES. CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR						
					a) EAST	WEST	EAST	WEST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	15m	30 min.	Pass-by	b) N	4-2	5-2	4-2	5-2	52	53	57	68	76	64
				dBA	76	73	80	80						
				c) S	2.68	1.15	2.95	1.46						
Rush	15m	30 min.	Pass-by	dBA					53	54	60	71	77	66
Evening	15m	30 min.	Pass-by	dBA					48	49	52	62	70	59
Night	15m	30 min.	Pass-by	dBA					62	63	64	64	71	65
Day	30m	15 min.	Pass-by	dBA					53	54	56	66	73	63
Evening	30m	15 min.	Pass-by	dBA					48	49	53	64	70	60
Day	60m	15 min.	Pass-by	dBA					53	54	56	65	74	62
Evening	60m	15 min.	Pass-by	dBA					46	48	50	60	68	57
Night	60m	15 min.	Pass-by	dBA					62	63	63	64	66	63

Notes: a - Track
b - Number of Trains - (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

Ldn = 68

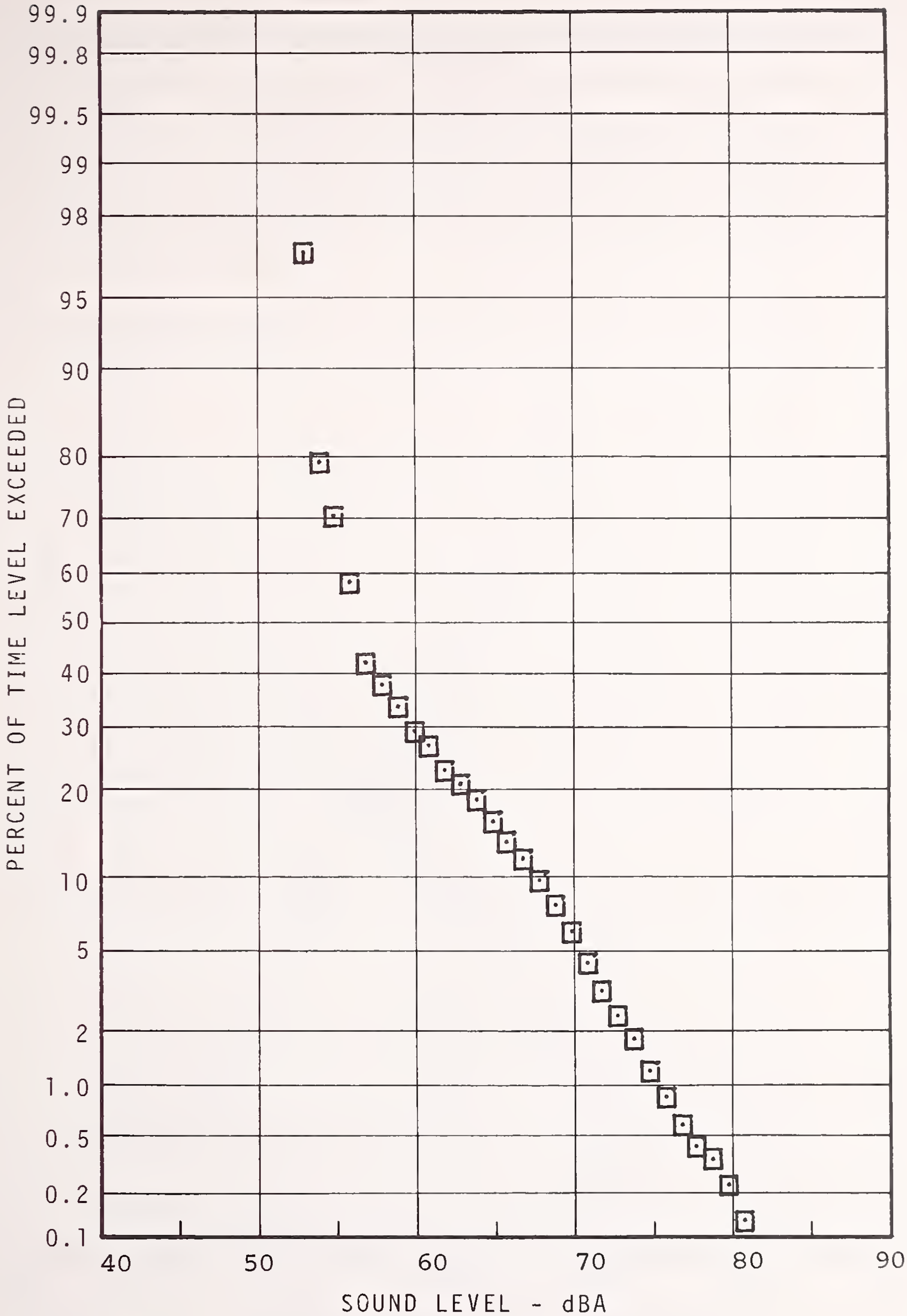


FIGURE 5.44. REDMAN AND NORTH ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M DAYTIME.

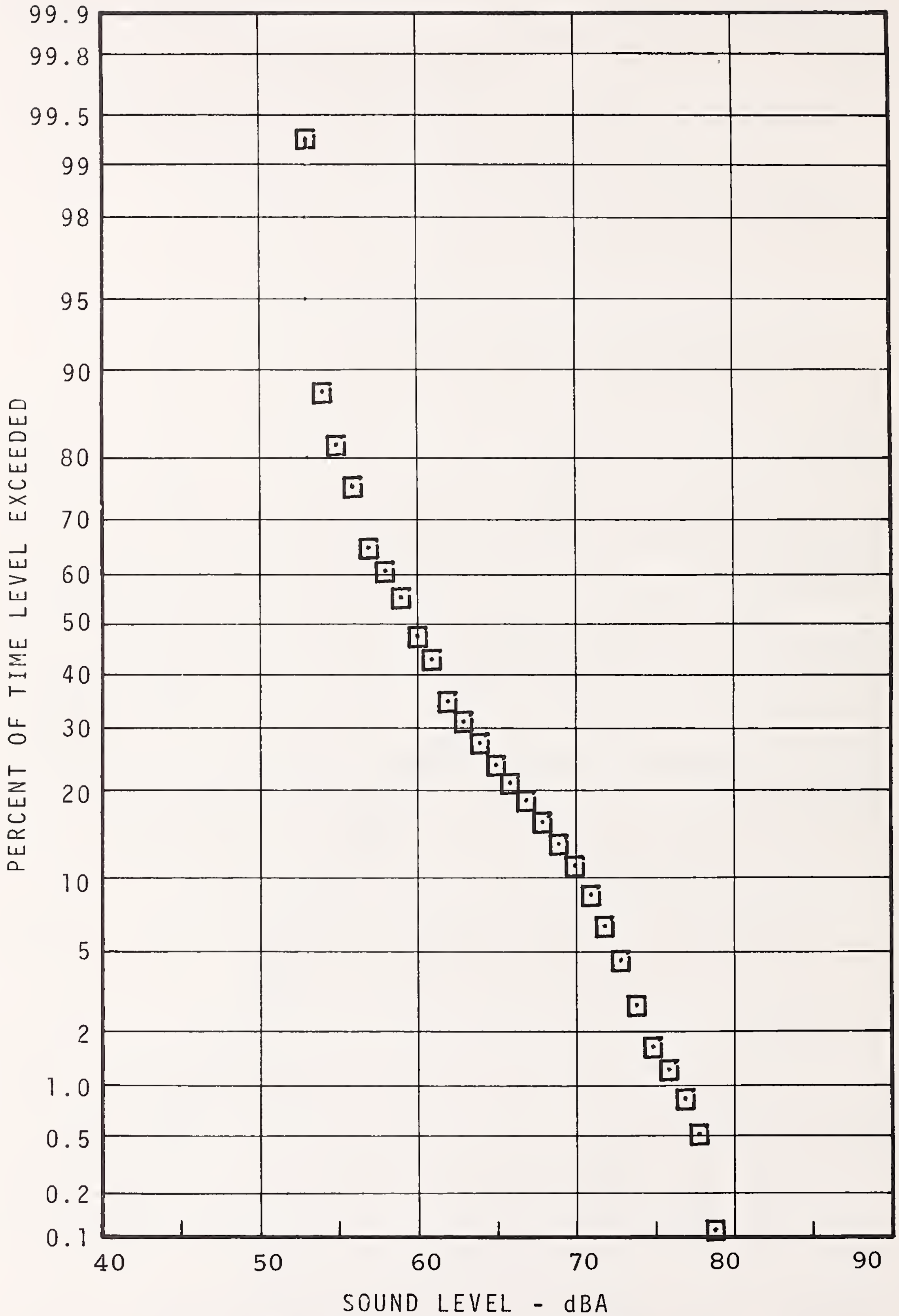


FIGURE 5.45. REDMAN AND NORTH ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M RUSH HOUR.

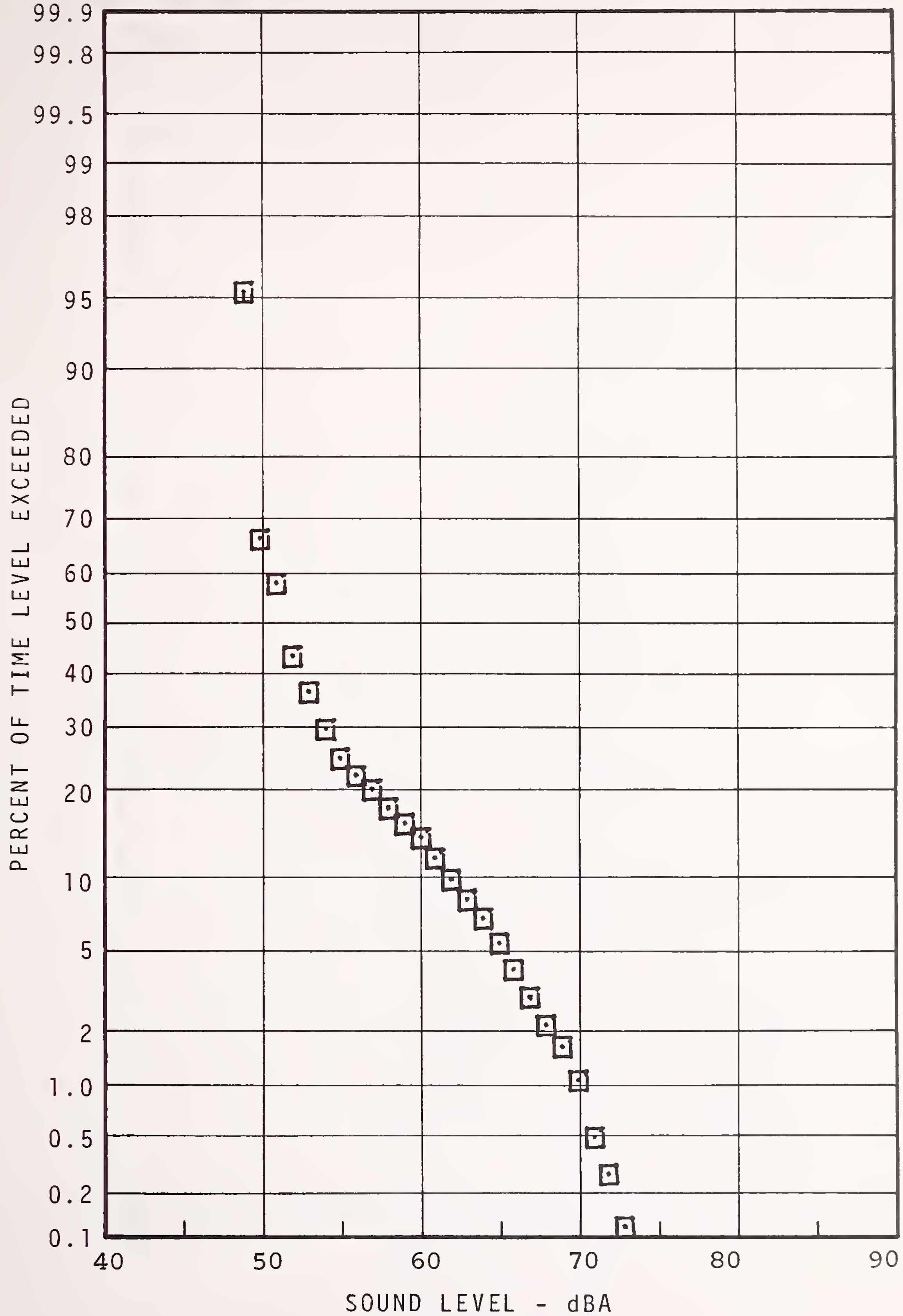


FIGURE 5.46. REDMAN AND NORTH ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION - 15M EVENING.

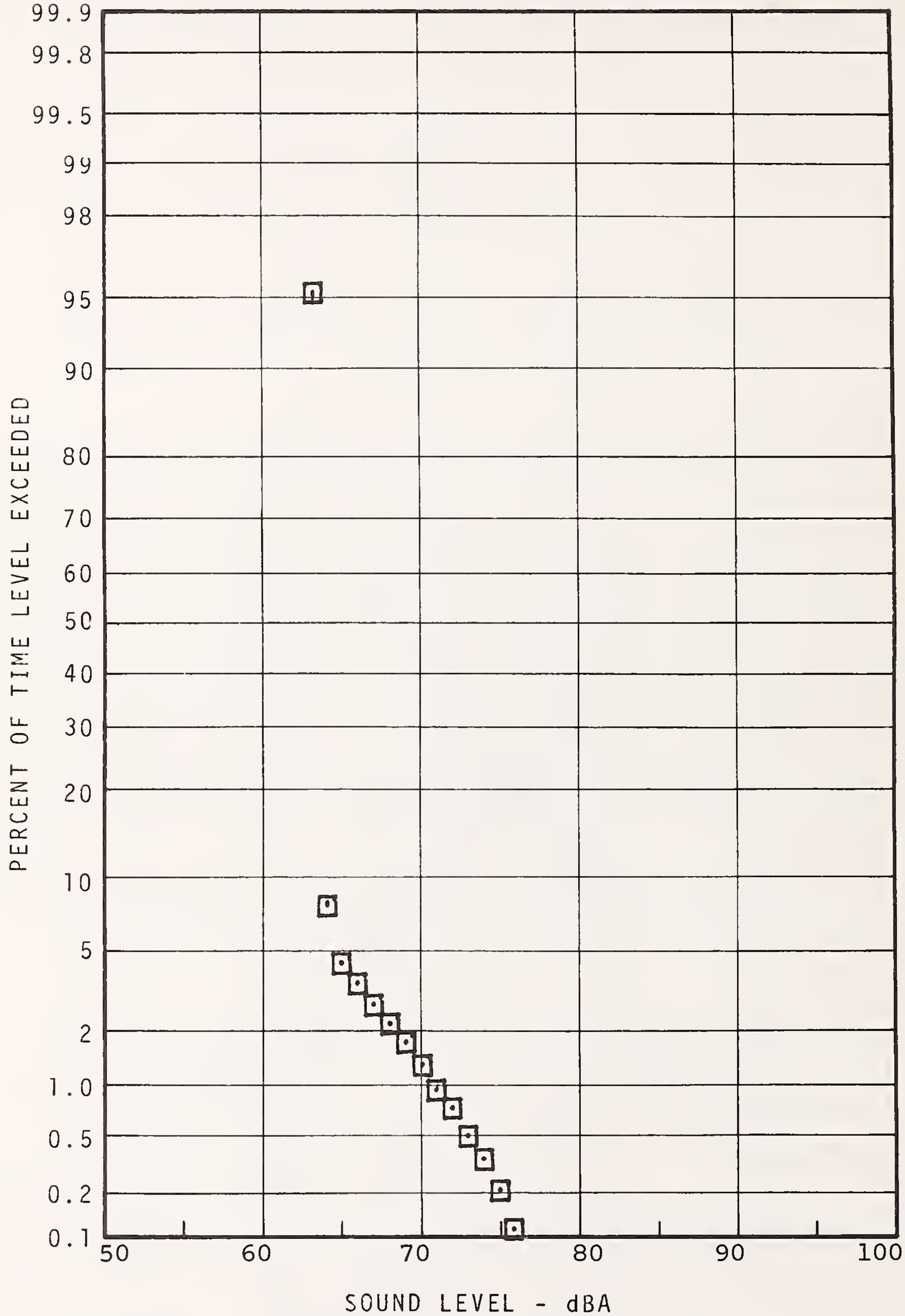


FIGURE 5.47. REDMAN AND NORTH ATLANTIC AVES. COMMUNITY STATISTICAL DISTRIBUTION -15M NIGHT.

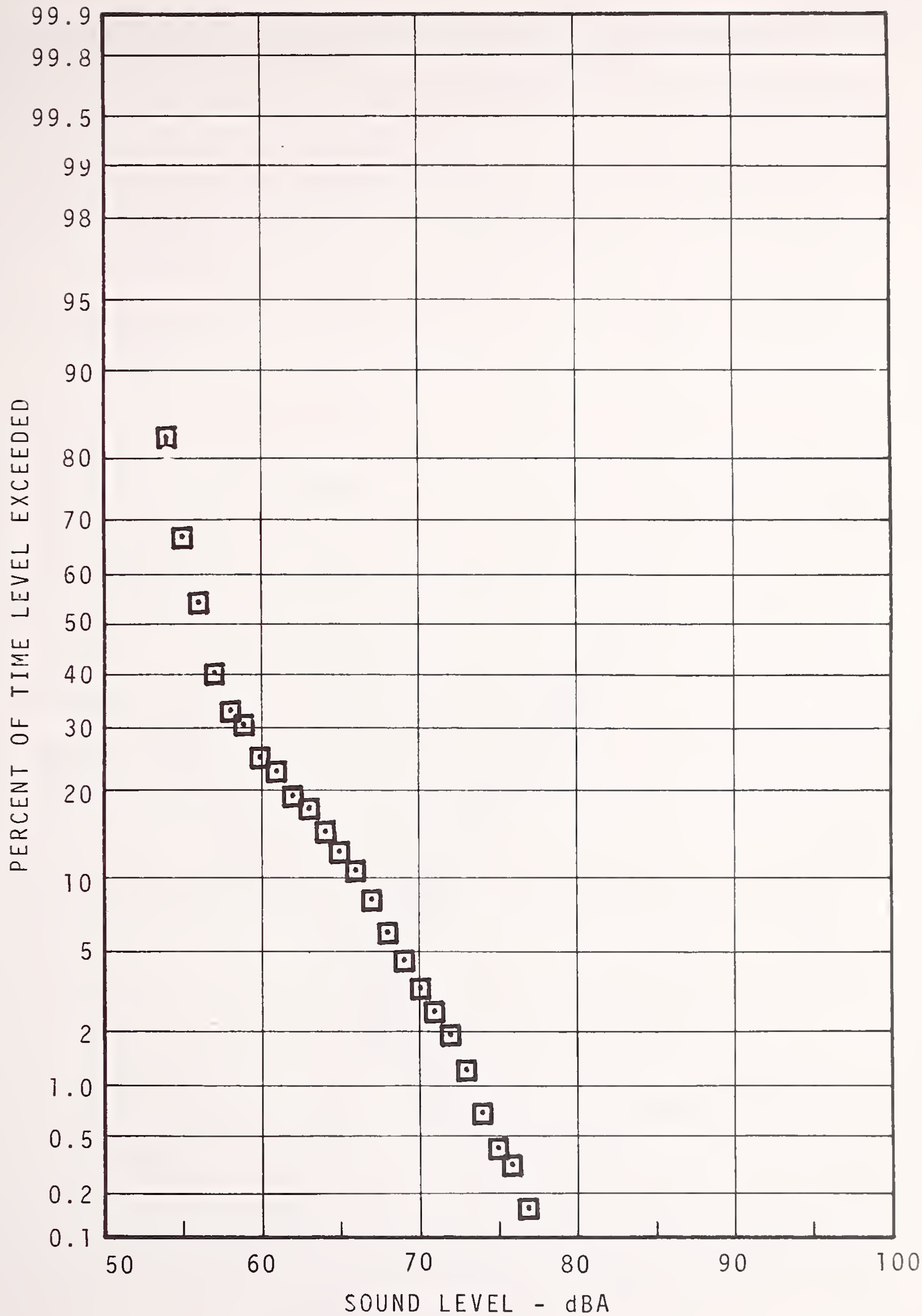


FIGURE 5.48. REDMAN AND NORTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 30M - DAYTIME

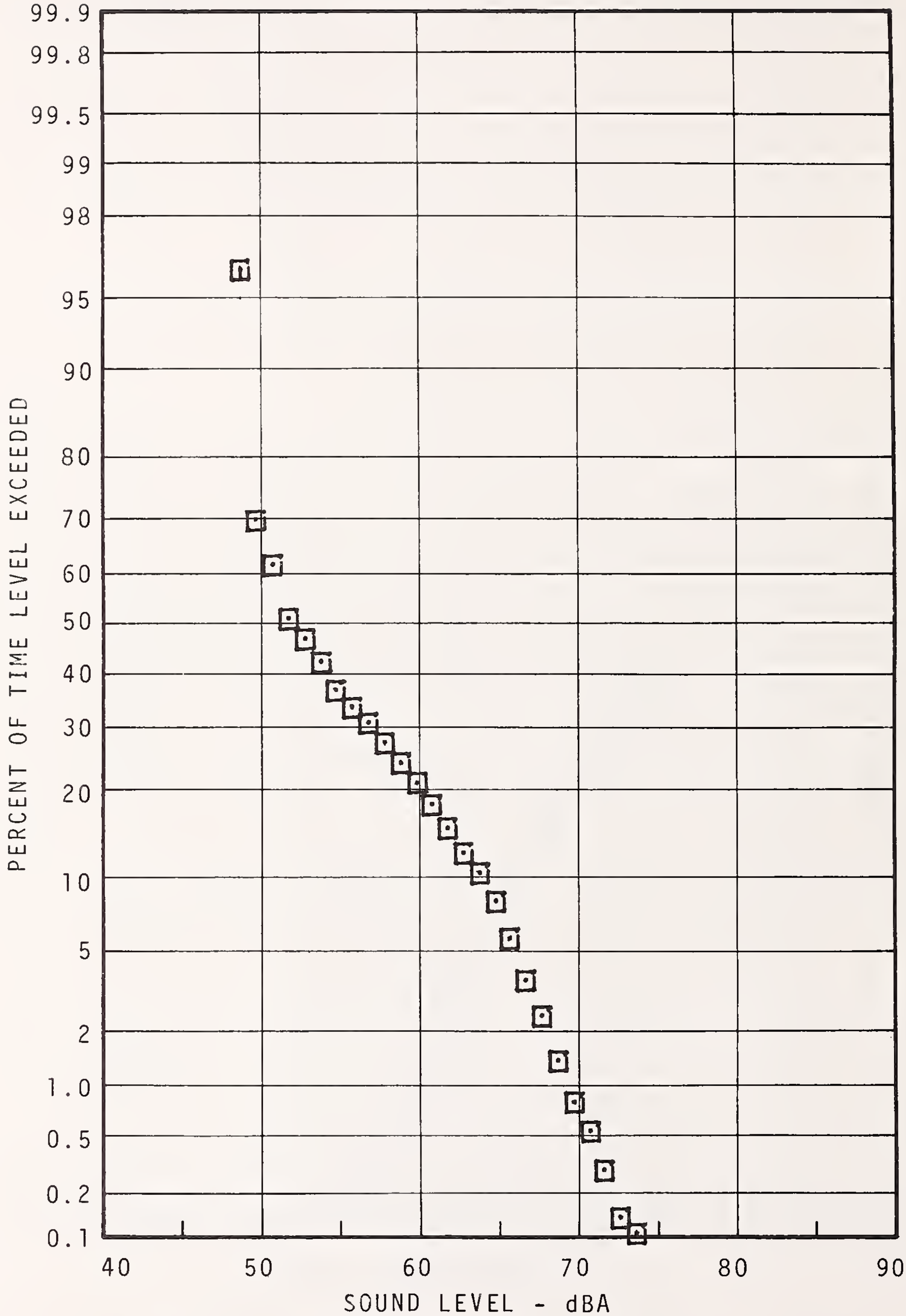


FIGURE 5.49. REDMAN AND NORTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 30M - EVENING

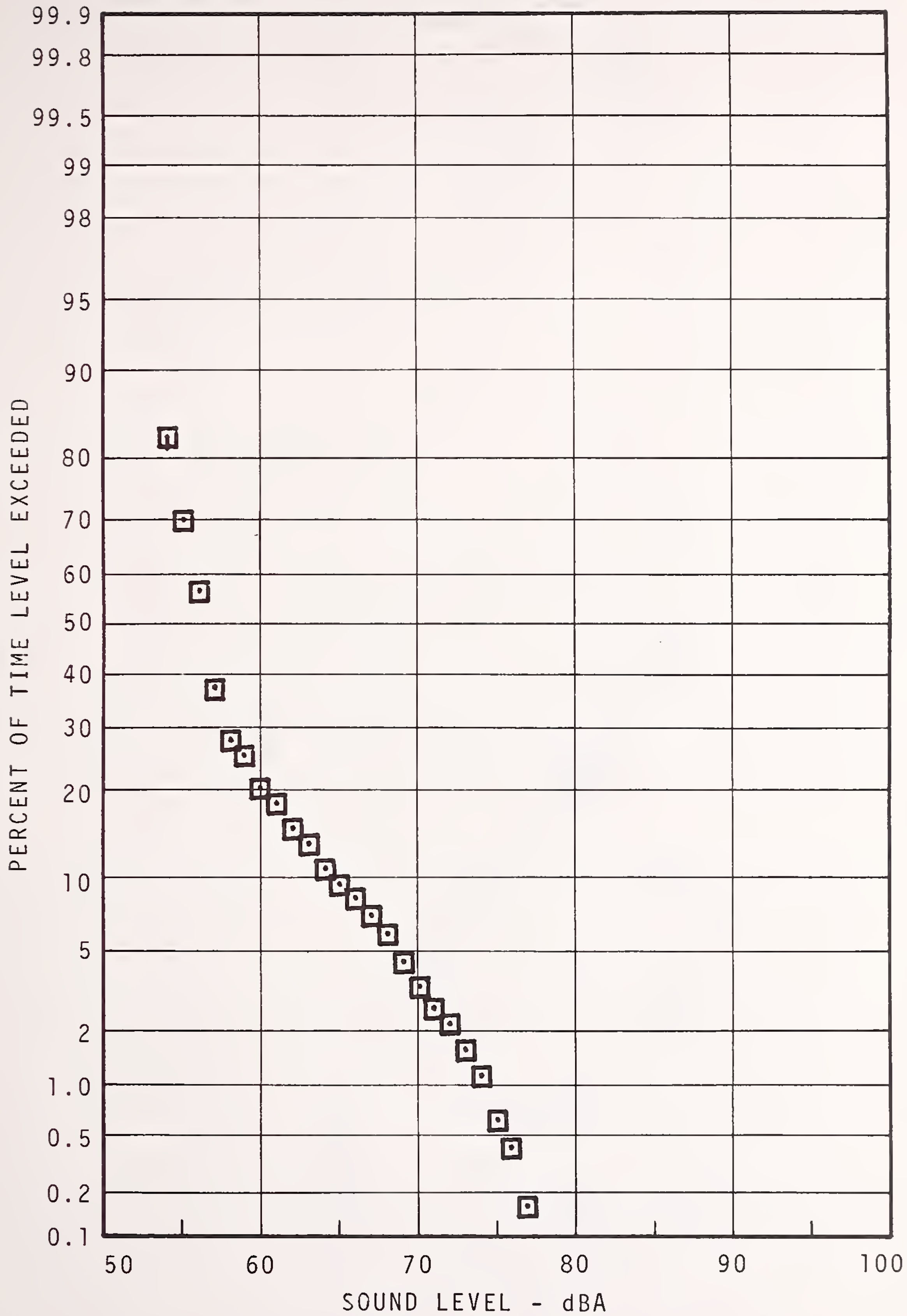


FIGURE 5.50. REDMAN AND NORTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 60M - DAYTIME.

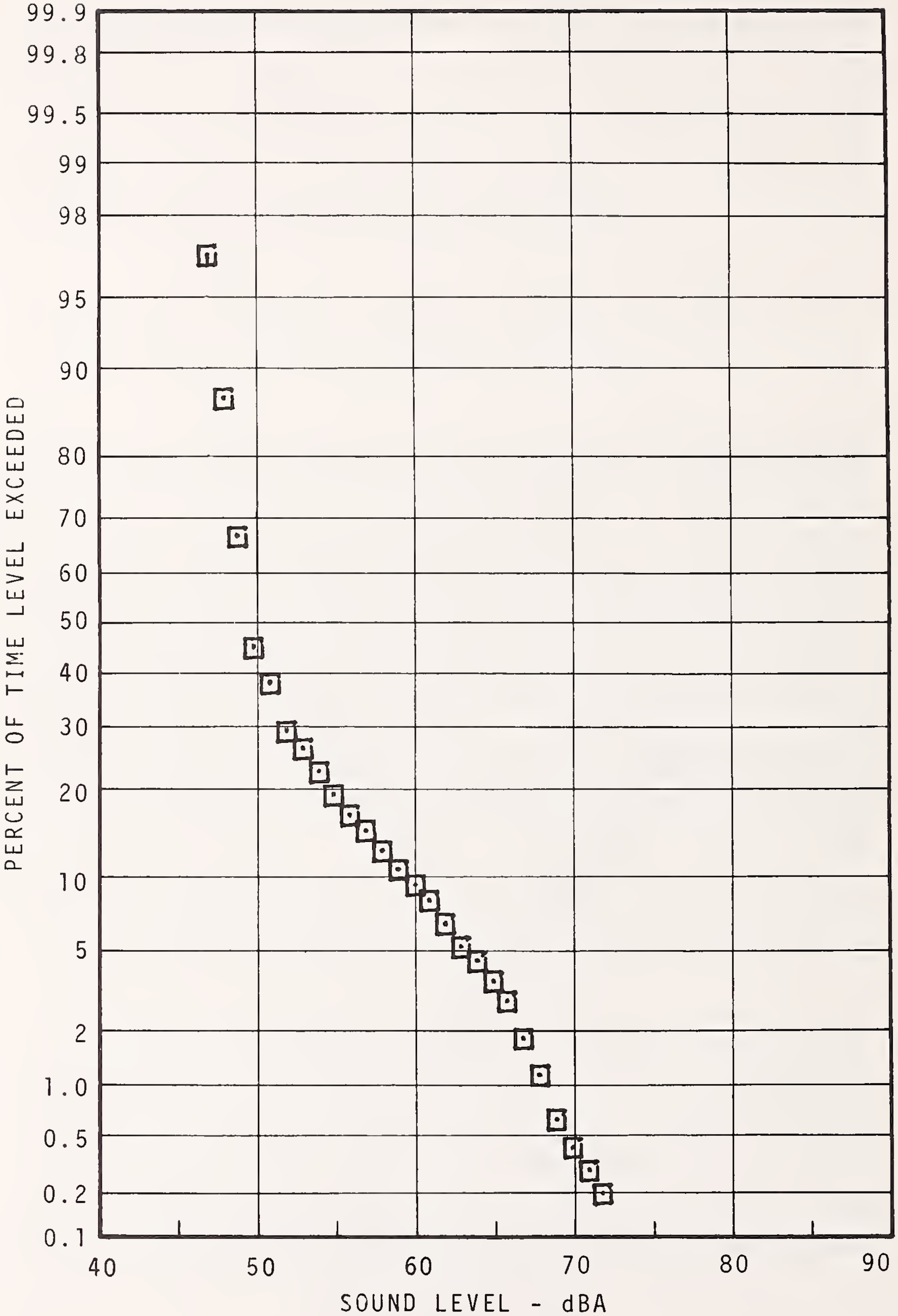


FIGURE 5.51 . REDMAN AND NORTH ATLANTIC AVENUES COMMUNITY STATISTICAL DISTRIBUTION - 60M - EVENING.

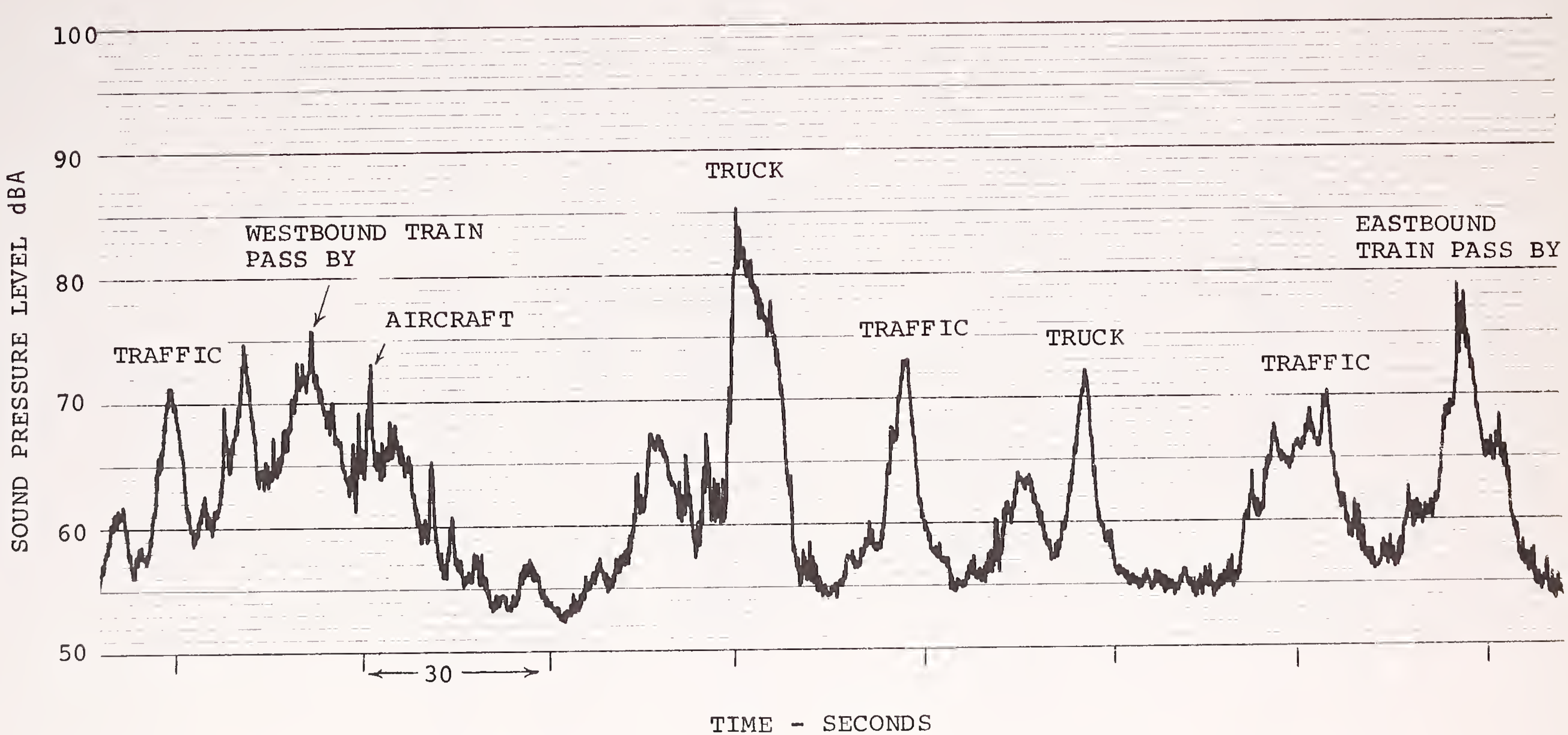


FIGURE 5.52. TYPICAL TIME HISTORY, HADDONFIELD, WAYSIDE

5.2.2 Station Platform

The following stations were surveyed for the platform noise environment.

The Broadway Station in Camden is an underground island platform station. Track is of the older Broad-Ridge construction type, except that the rail has been field-welded to eliminate joints.

City Hall underground station in Camden is an island platform station, but here patrons are exposed to considerable wheel squeal.

Ferry Avenue Station, located on an elevated embankment, is subject to both local and express train noise. One end of this station is unique to the system in that a split center platform requires a wider-than-normal station width. A train is frequently parked in the tail track and this shields patrons at this end of the platform from train noise on the opposite side.

Collingswood Station is of the center platform type on concrete viaduct.

Haddonfield Station is also unique in that it is the only platform located in a cut. The vertical concrete walls of the cut increase the noise level environment of the patrons on this station platform.

15-16th Street and Locust Street Stations, underground are at the Philadelphia end of the system. Patrons on this platform are exposed to both the noises of trains arriving and departing plus the noise of trains on storage tracks near 16th Street.

9th and 10th Street and Locust Street Stations are typical of other underground island platform stations on the system.

BROADWAY STATION

STATION DESCRIPTION (see Figure 5.53)

Broadway Station is an underground island platform station and had originally been part of the Broad Street Subway system which operated across the Benjamin Franklin Bridge in Philadelphia. It is of concrete construction with no acoustical treatment. This is one of the two stations located within the city of Camden. West of Broadway the speed limit is restricted to 40 mph or less. Trains accelerate to the normal operating speed of 75 mph east of Broadway.

NOISE CLIMATE (see Table 5.9, Figures 5.54 - 5.58)

In many respects, the noise climate of this station is similar to other underground stations on the system. Trains operating between Broadway and City Hall emit squeal which is audible on the station platform. In addition, westbound trains sound the horn when departing from the platform.

CENTER OF TRAIN

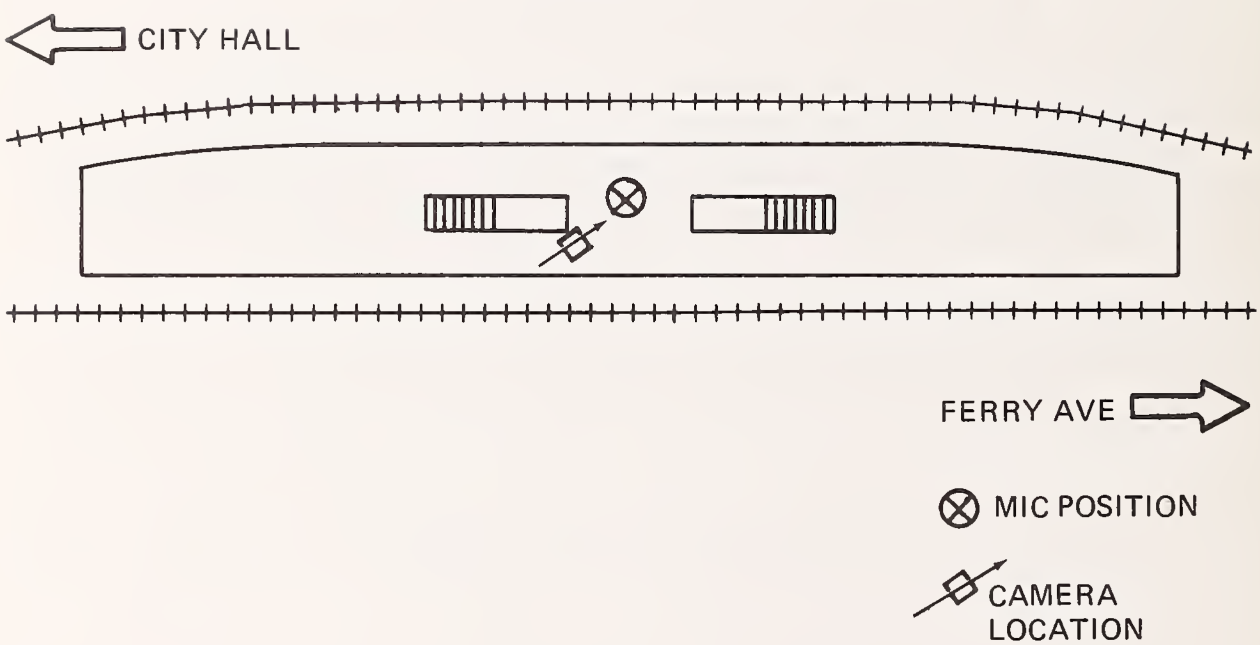


FIGURE 5.53. BROADWAY SUBWAY STATION PLATFORM

TABLE 5.9 SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE, STATION NOISE - PATCO-BROADWAY CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR						
					a)WEST	EAST	WEST	EAST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	Center of stopped train	30 min.	ARRIVE	b)N	6-2	5-2	6-2	5-2	62	62	63	78	88	75
				dBA	85	84	94	91						
				c)S	1.17	4.72	1.45	2.26						
			DEPART	N	6-2	5-2	4-2	5-2						
				dBA	83	85	90	93						
				S	3.74	4.56	2.32	2.25						
Rush	Center of stopped train	30 min.	ARRIVAL AND DEPARTURE	dBA					62	63	64	81	88	77
Evening	Center of stopped train	30 min.		dBA					56	58	62	73	90	75
Night	Center of stopped train	30 min.		dBA					63	63	64	80	88	76

Notes: a - Track
b - Number of Trains - (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

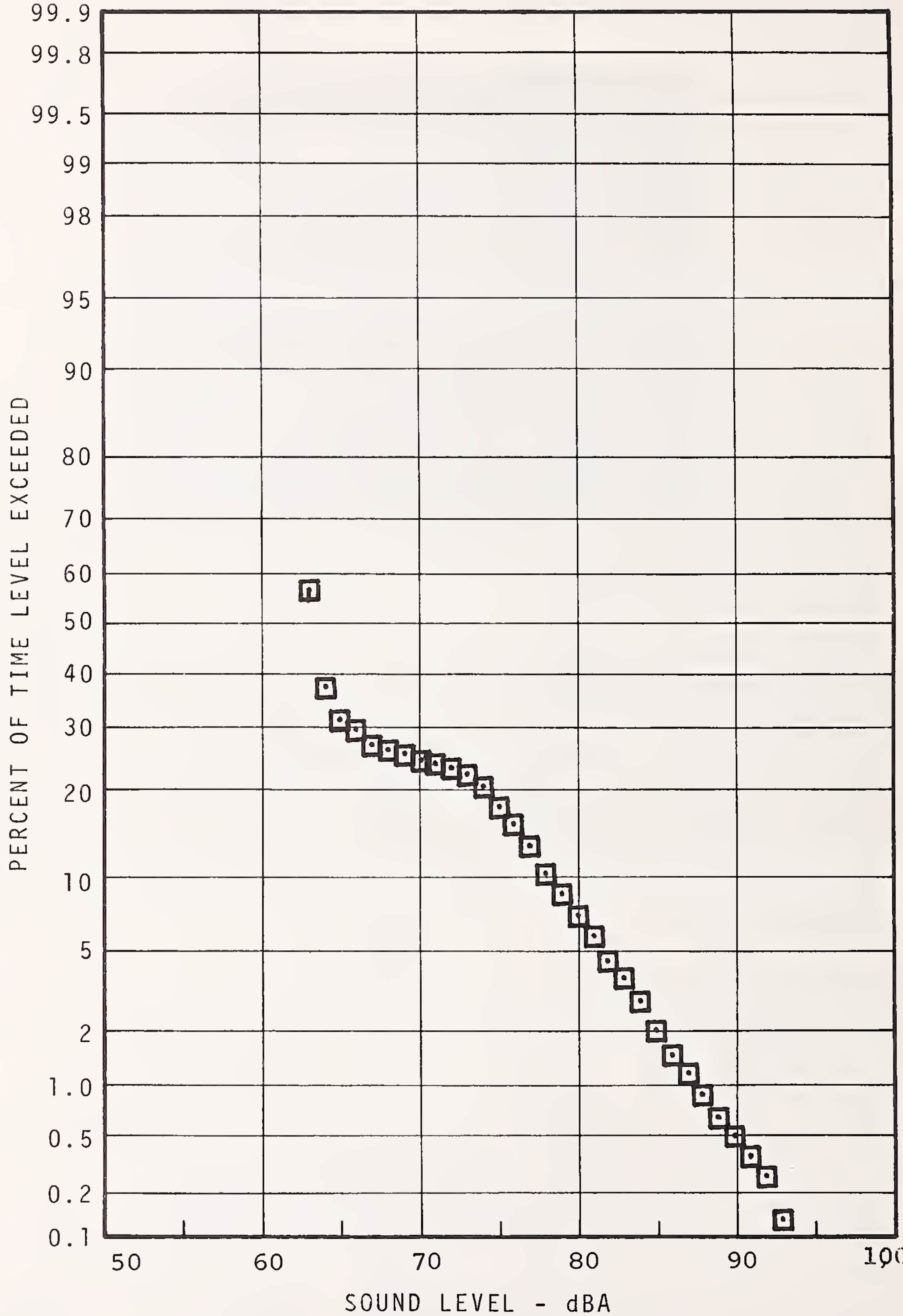


FIGURE 5.54. BROADWAY STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - DAYTIME.

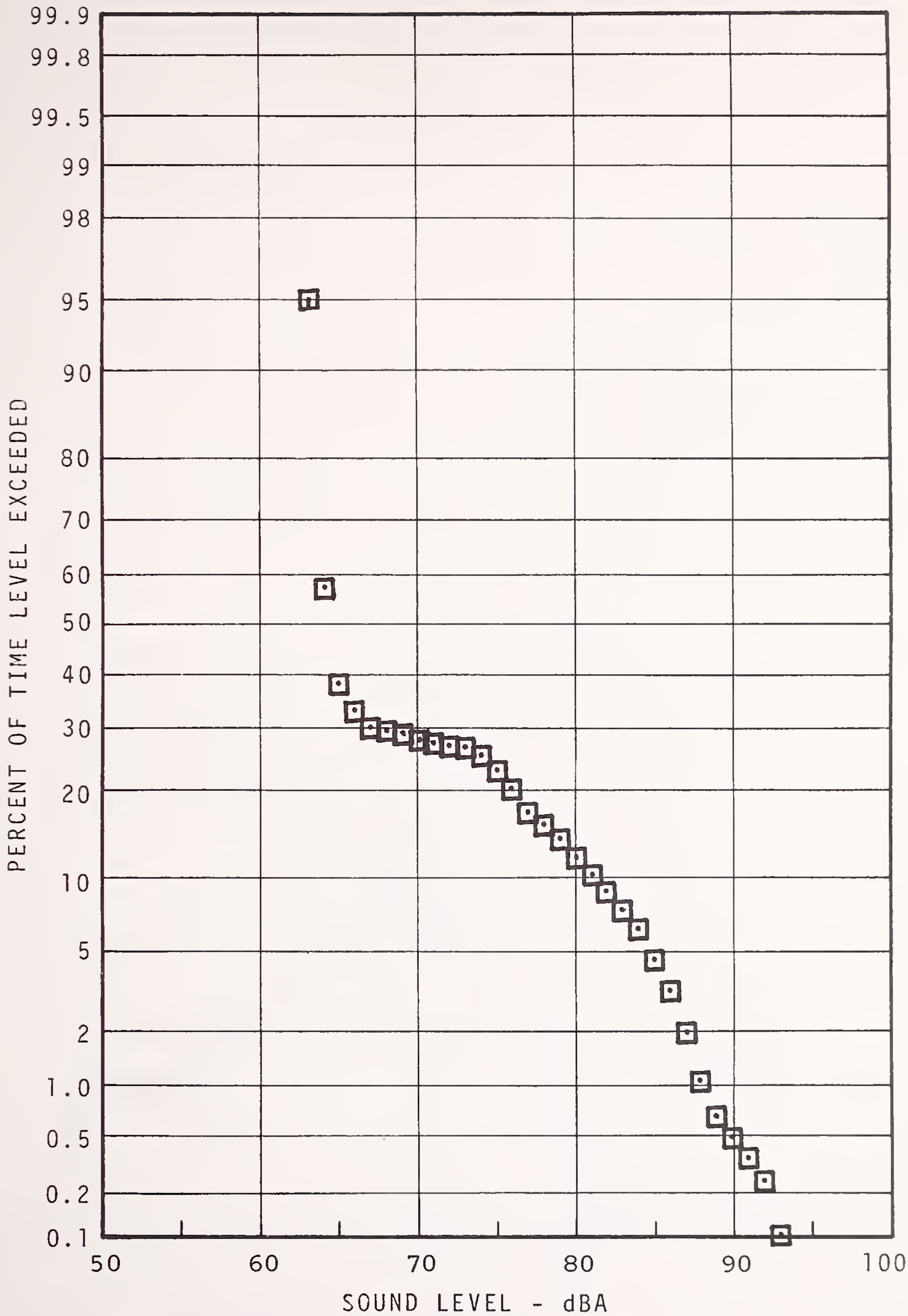


FIGURE 5.55. BROADWAY STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - RUSH HOUR.

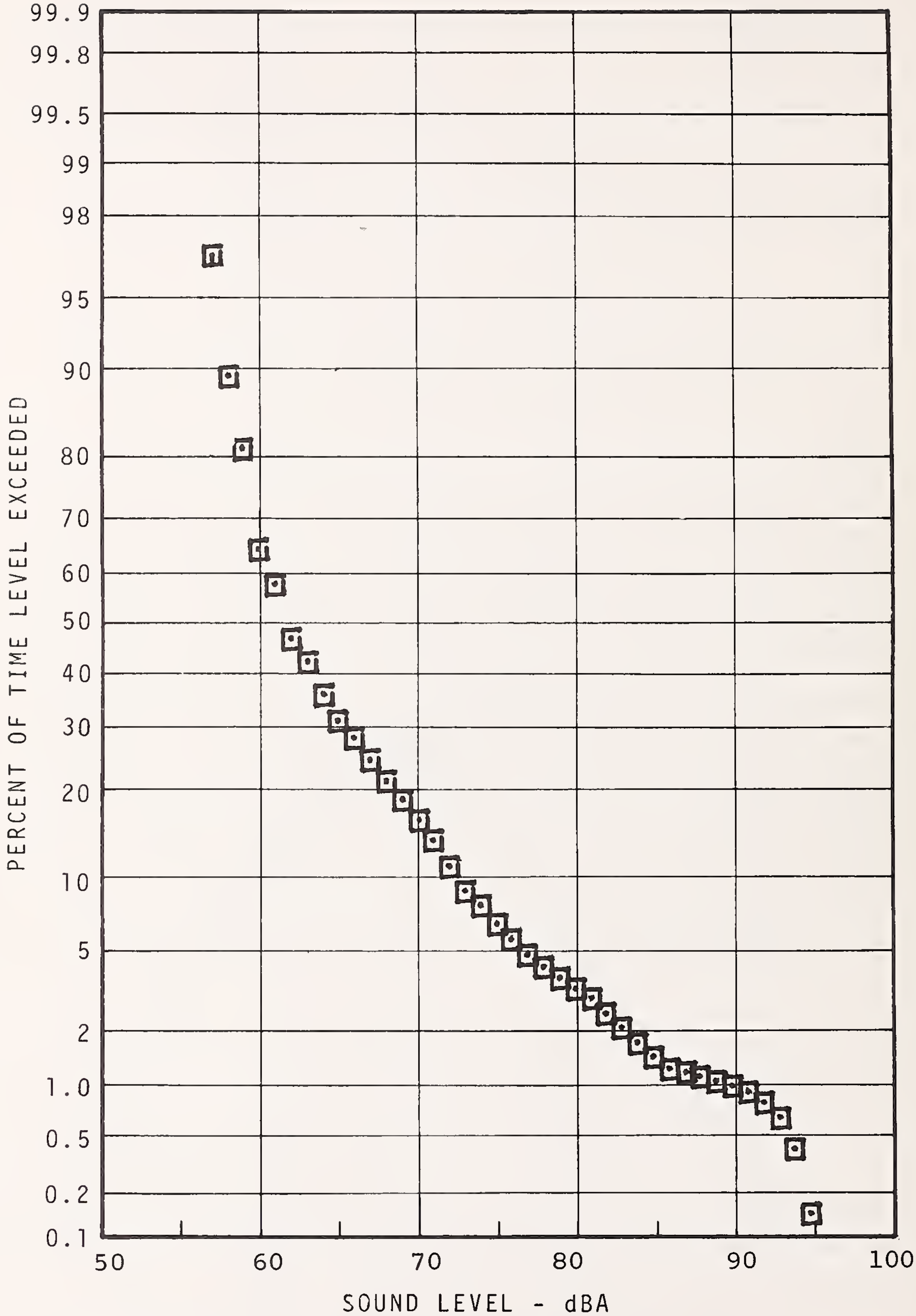


FIGURE 5.56. BROADWAY STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - EVENING.

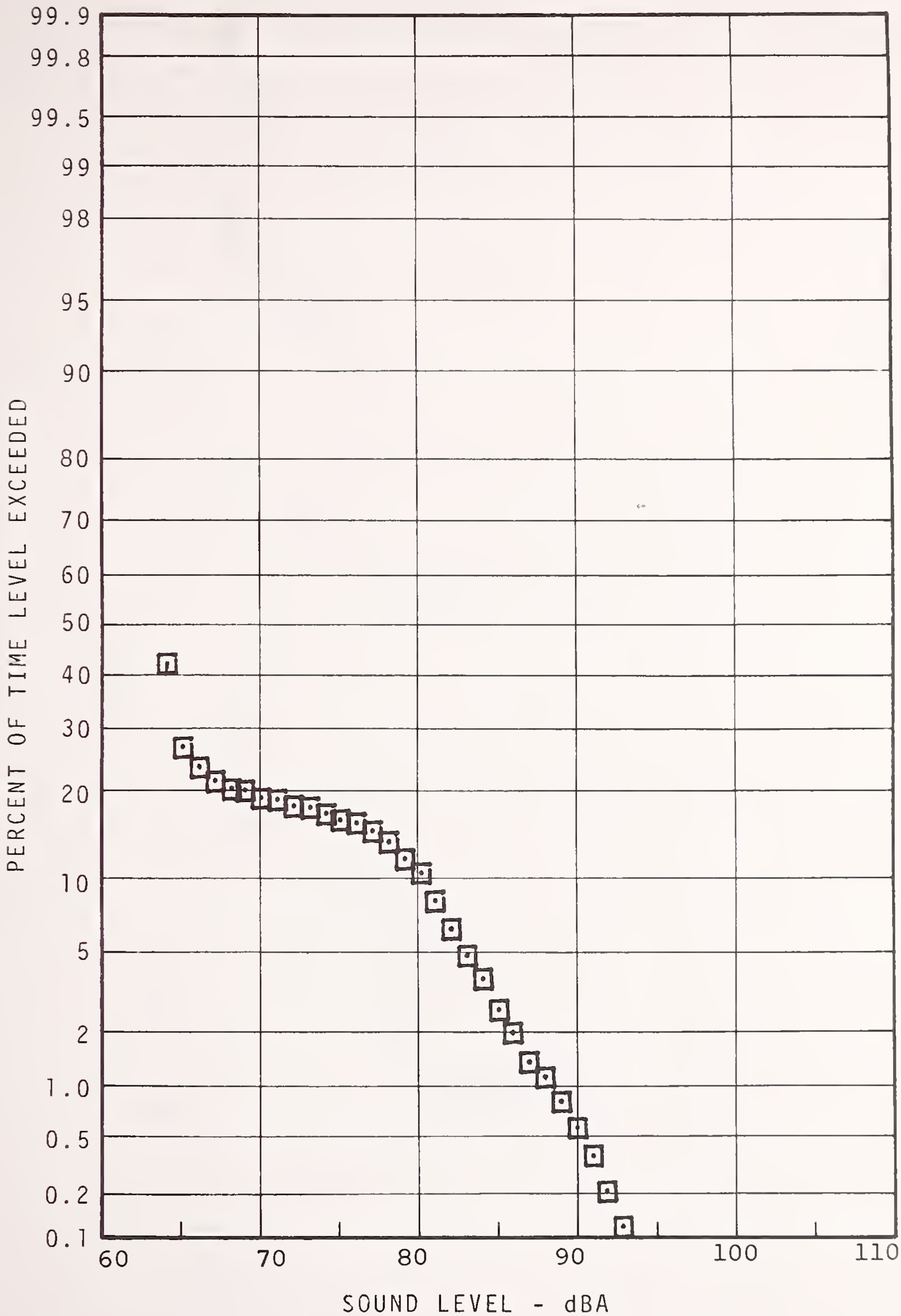


FIGURE 5.57. BROADWAY STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - NIGHT.

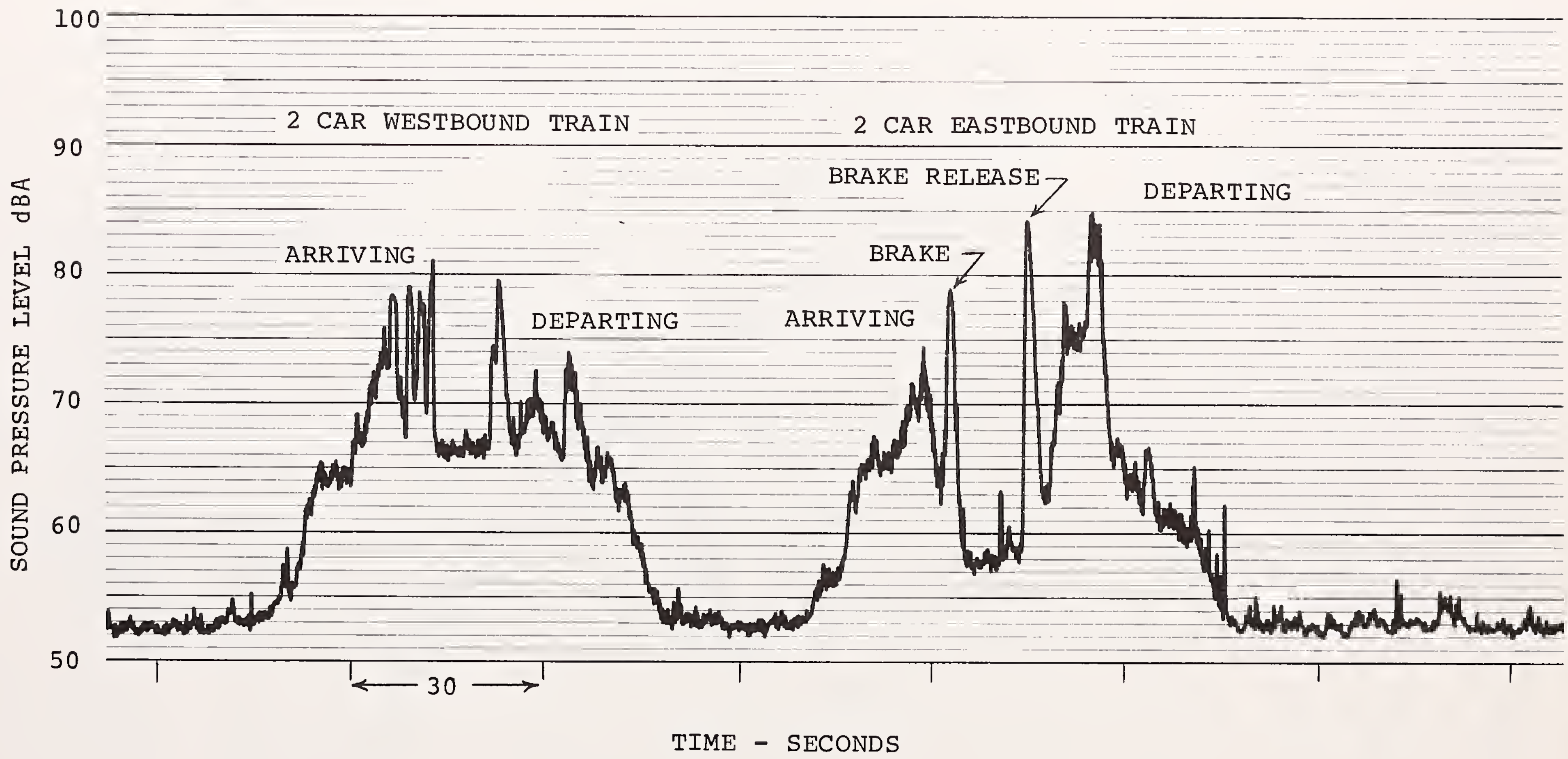


FIGURE 5.58. TYPICAL TIME HISTORY, BROADWAY, STATION

CITY HALL STATION

STATION DESCRIPTION (see Figure 5.59)

City Hall Station (Camden) is an island platform station which is very similar in construction to the Snyder Avenue Station on the Broad Street Subway in Philadelphia. It is of concrete construction with no acoustical treatment. A direct comparison of noise levels in these two stations permits noise levels of two types of vehicles (on separate systems) to be made. This station had previously been served by the Broad Street Subway spur which operated across the Benjamin Franklin Bridge in Philadelphia.

NOISE CLIMATE (see Table 5.10, Figures 5.60 - 5.61)

The noise environment at City Hall Station is similar to other underground stations on the system. However, some wheel squeal at the east end of the station can be heard as trains negotiate the curve leading to the Benjamin Franklin Bridge and at the west end of the platform from the curve between City Hall and Broadway Stations.

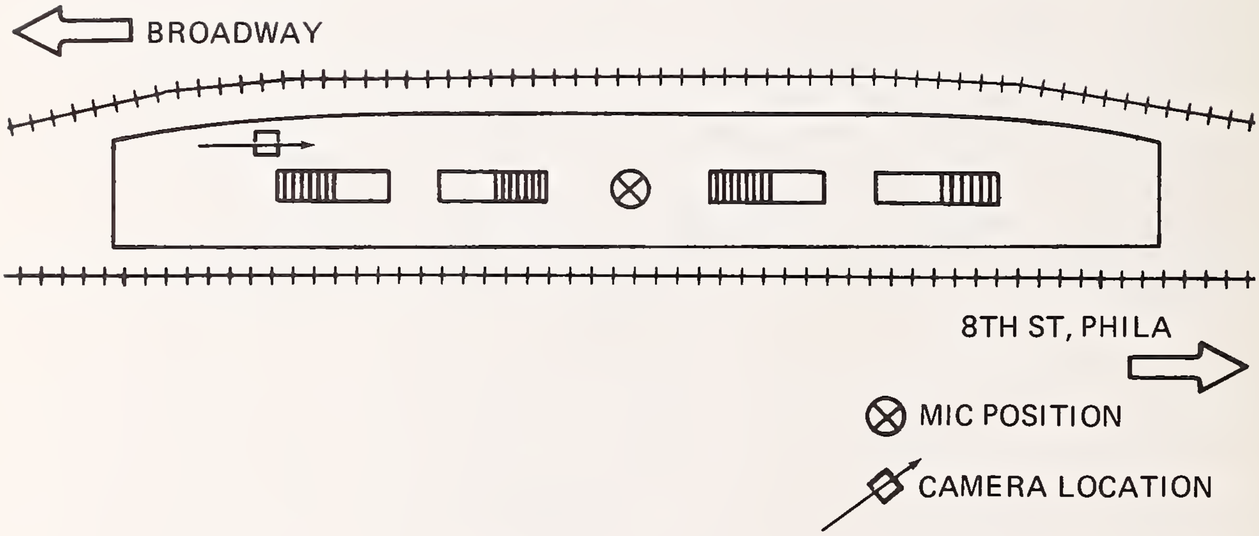


FIGURE 5.59. CITY HALL SUBWAY STATION PLATFORM

TABLE 5.10 SUMMARY OF MEASUREMENT RESULTS FOR STATION NOISE, PATCO-CITY HALL

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Rush	Center of stopped train	30 min	Arrival and Departure	dBA					63	64	69	86	93	81

Notes: a - Track
b - Number of Trains – (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

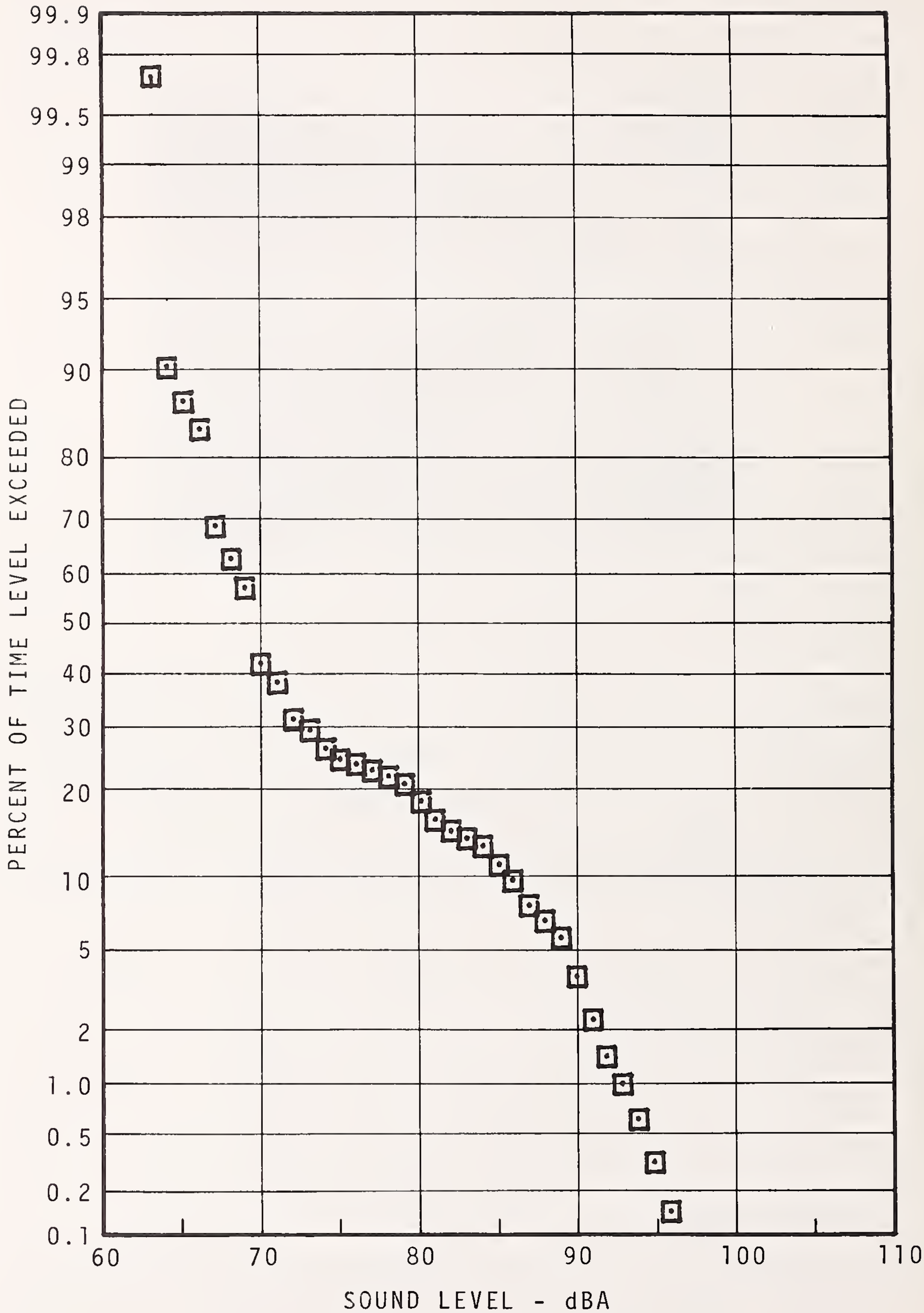


FIGURE 5.60 . CITY HALL STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - RUSH HOUR.

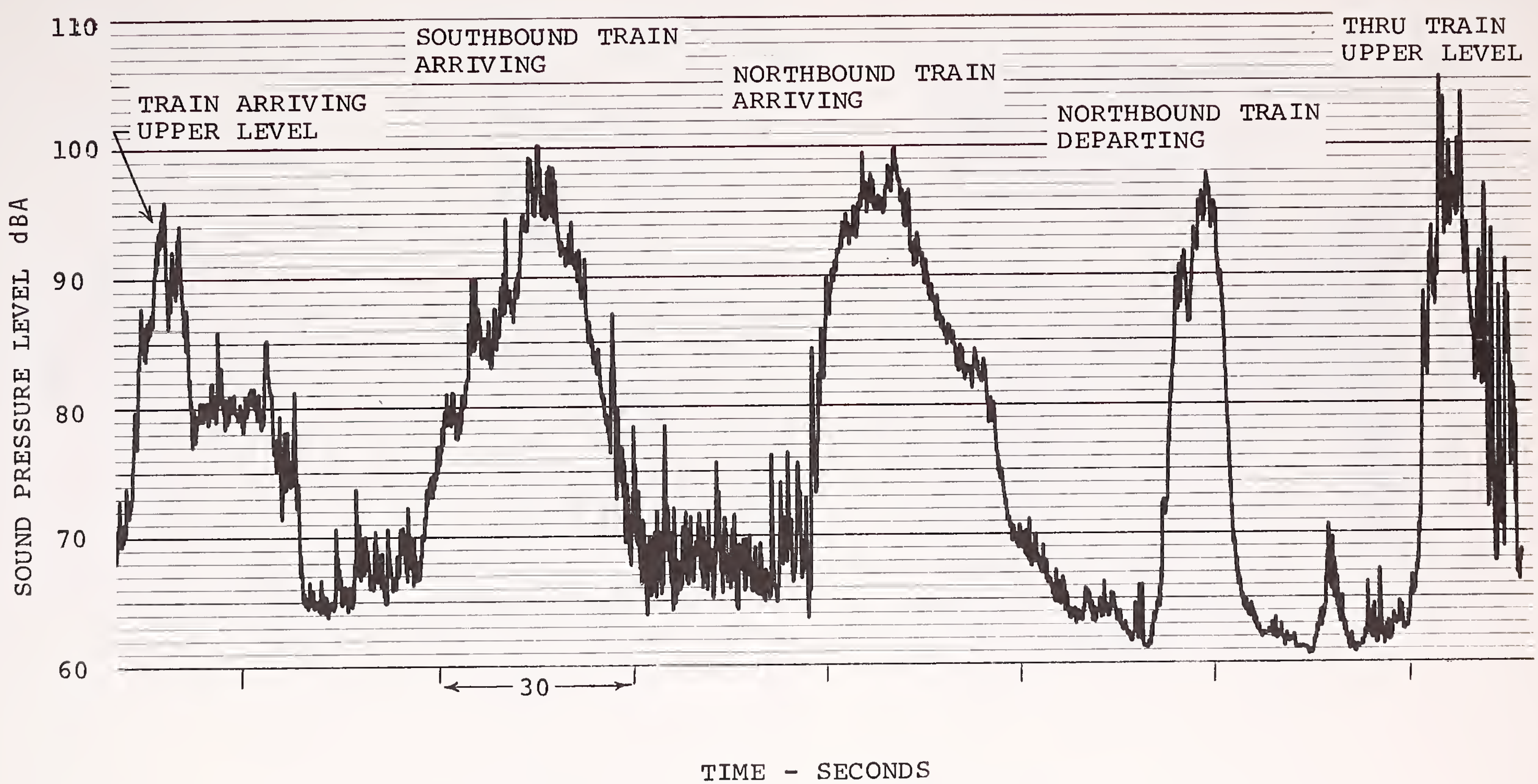


FIGURE 5.61. TYPICAL TIME HISTORY, CITY HALL STATION

FERRY AVENUE STATION

STATION DESCRIPTION (see Figure 5.62)

Ferry Avenue Station is an island platform station located on elevated embankment. At the west end of the station a third track divides the center platform into two island platforms. This track is used by trains which operate between 15th/16th and Locust in Philadelphia and Ferry Avenue during rush hours only. On the north side of the station there is an industrial area. The south side is composed of a parking lot for transit system patrons. There are no single family homes visible from the station platform but at a distance of approximately 500 ft there are two office buildings, one of which contains commercial establishments and an apartment complex. Patrons enter and exit by way of a stairway at the platform and an underground passage to the parking lot.

NOISE CLIMATE (see Table 5.11, Figures 5.63 - 5.65)

The ambient noise at the station arises from nearby vehicular traffic. Some platform positions shield this noise and the background level is very low. The train noise is below background level while approaching the platform and often cannot be heard until it is within a distance of less than 100 ft. When a local train is parked in the tail track, patrons are shielded from trains operating on the far track. Express trains present higher noise levels to patrons than those which stop at Ferry Avenue.

CENTER OF TRAIN

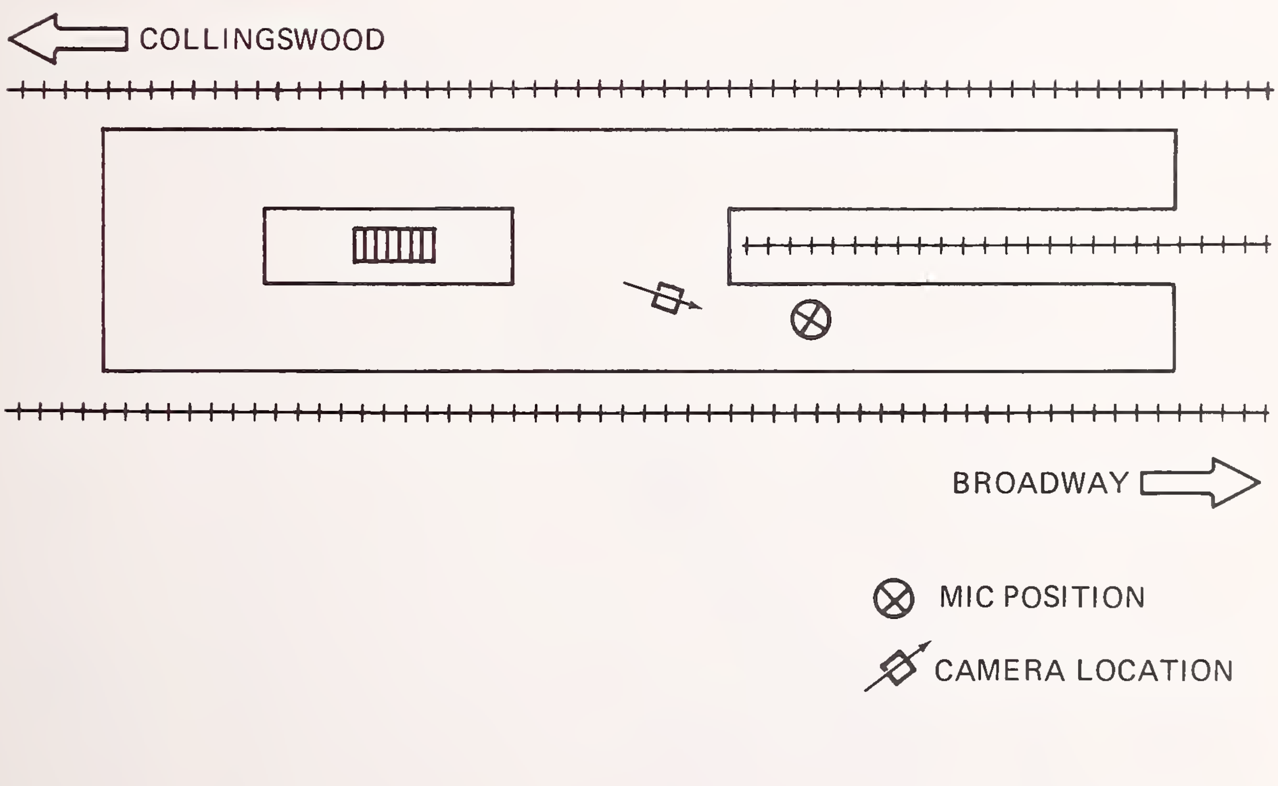


FIGURE 5.62. FERRY AVE STATION PLATFORM ON ELEVATED EMBANKMENT

TABLE 5.11 SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE STATION NOISE - PATCO-FERRY AVENUE CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL NEAR	AVG MAX LEVEL FAR	AVG L_R NEAR	AVG L_R FAR	CUMULATIVE AMPLITUDE DISTRIBUTION L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
					a)WEST	EAST	WEST	EAST						
DAY	Center of stopped train	30 min.	ARRIVAL	b)N	6-2	6-2	5-2	5-2	53	54	57	65	75	64
				dBA	70	73	75	79						
				c)S	3.75	3.60	2.38	2.69						
			DEPARTURE	N	6-2	6-2	3-2	1-2						
				dBA	69	63	78	65.4						
				S	3.02	3.19	1.88	-						
Evening	End of stopped train	30 min.	Arrival & Departure	dBA					53	54	57	64	75	63

Notes: a - Track
b - Number of Trains - (e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

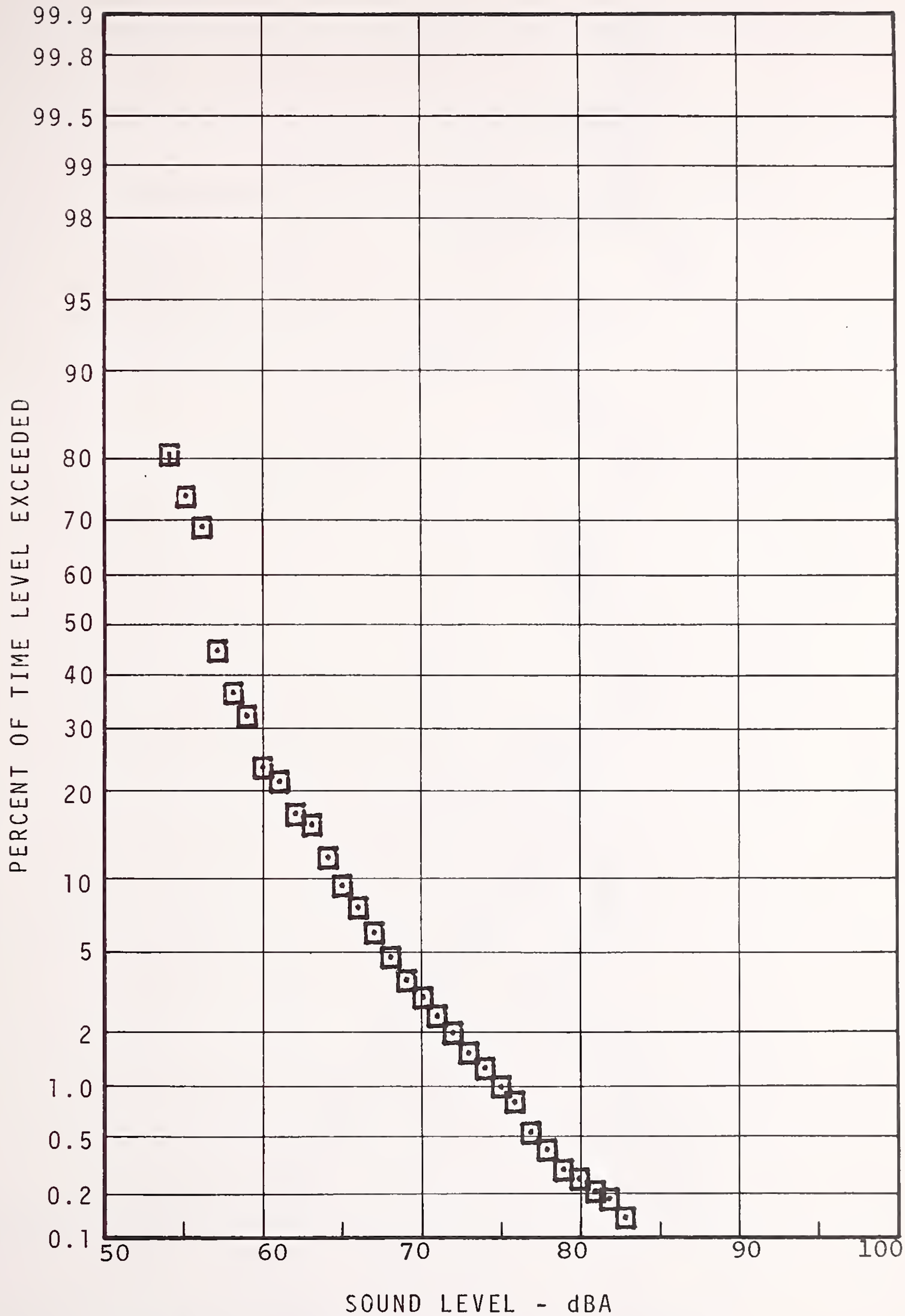


FIGURE 5.63. FERRY AVE. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER DAYTIME.

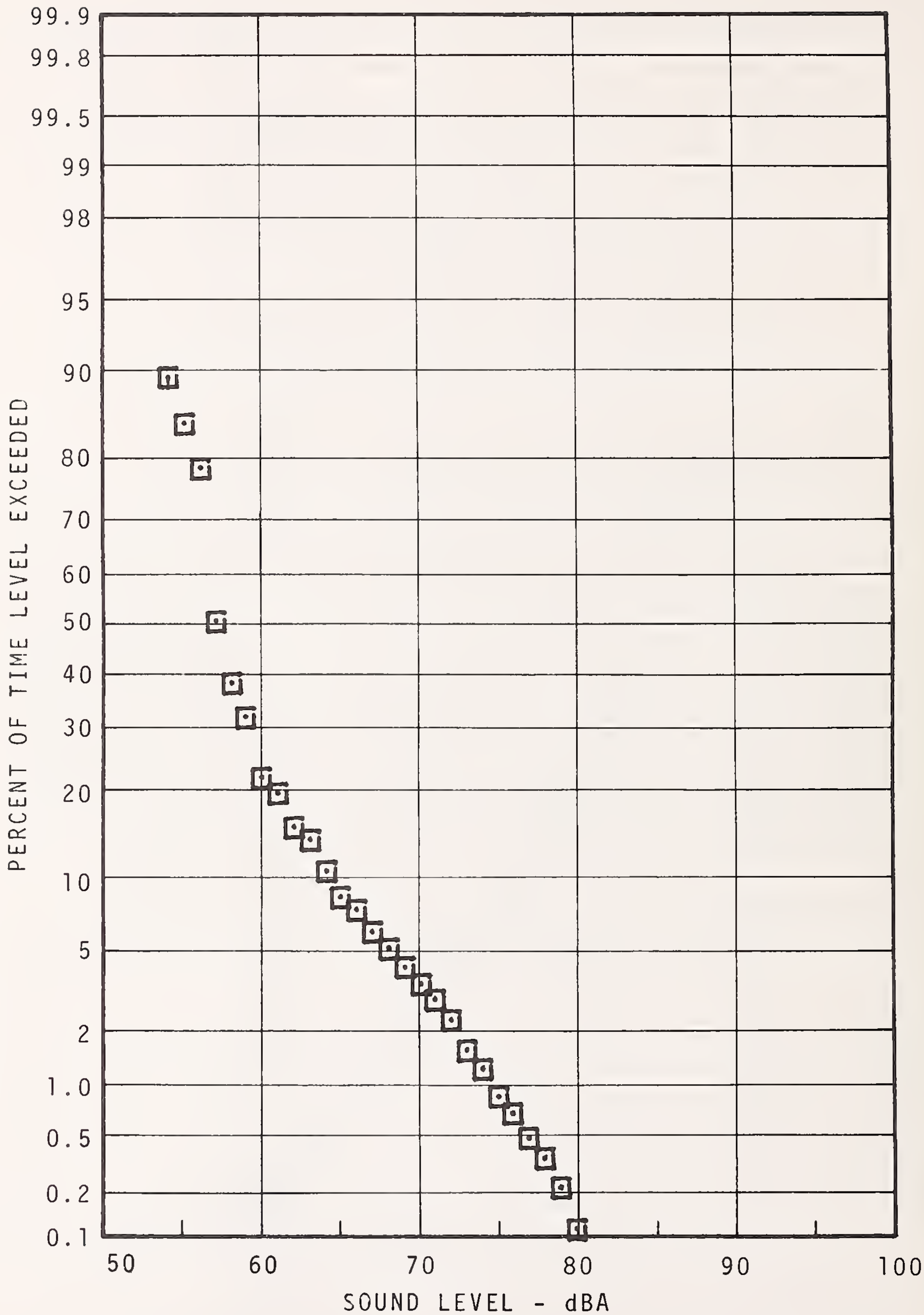


FIGURE 5.64. FERRY AVENUE STATION PLATFORM STATISTICAL DISTRIBUTION - END-EVENING.

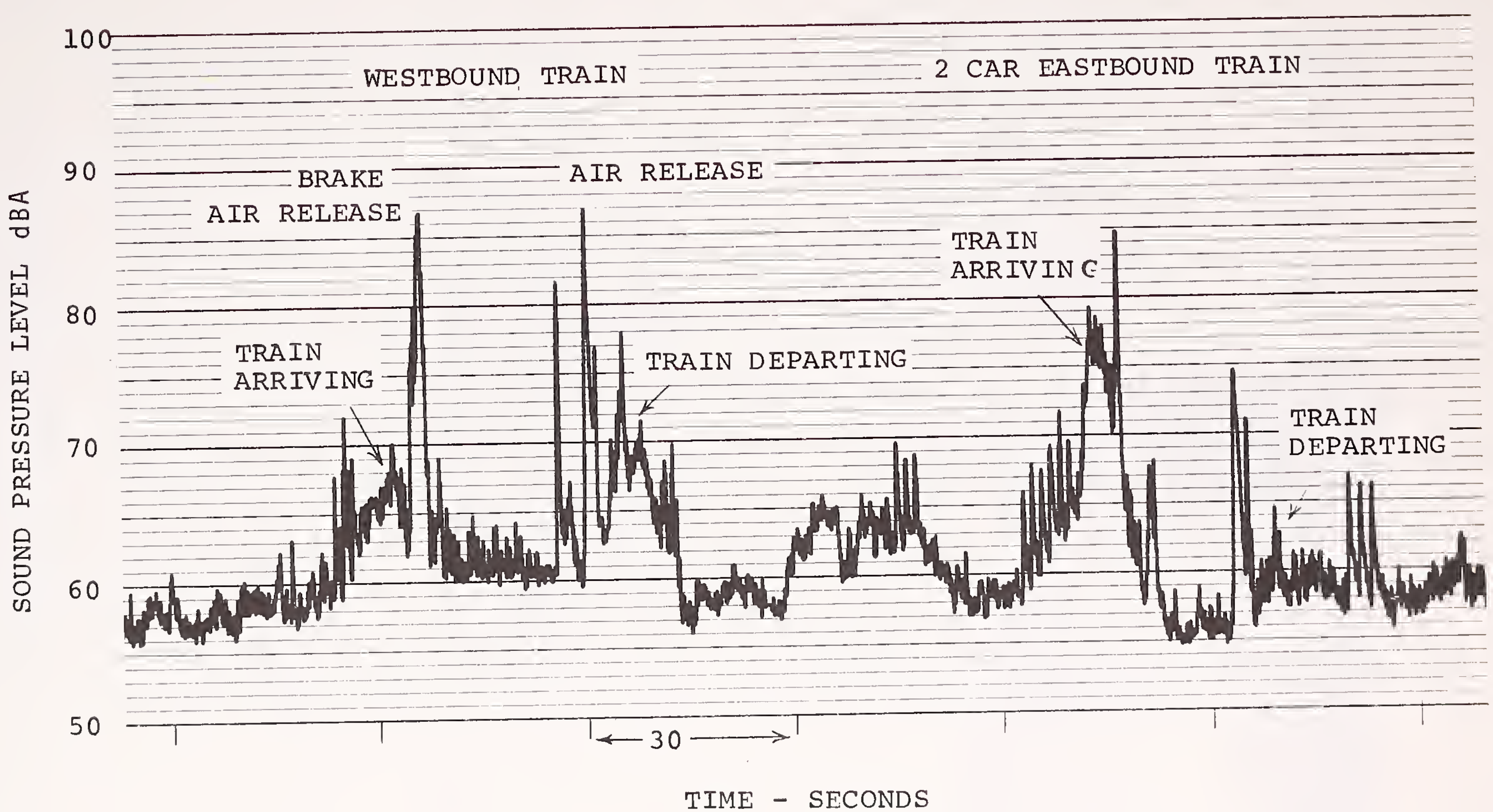


FIGURE 5.65. TYPICAL TIME HISTORY, FERRY AVE. STATION

COLLINGSWOOD STATION

STATION DESCRIPTION (see Figure 5.66)

Collingswood is an island platform station on concrete viaduct. Patrons enter and exit from ground level through a ground level waiting room and ticket vending area. A parking area is located alongside and underneath the viaduct. The neighborhood adjoining the right-of-way in Collingswood is predominately residential with many houses located within approximately 50 feet (15m) from the track centerline on the south side, and adjacent to the parking lot on the north side, a distance from the track of approximately 200 ft (60m). Beyond the station limits houses are within 50-75 ft (15-23m) on both sides of the right-of-way.

NOISE CLIMATE (see Table 5.12, Figures 5.67 - 5.71)

On the station platform the view down the track is quite open and when the trains arrive, they are audible for a distance of several hundred feet. The noise is due to the propulsion system, since wheel/rail noise is lower. Community noise is primarily ground level street traffic and is generally of a very low level.

END OF TRAIN

CENTER OF TRAIN

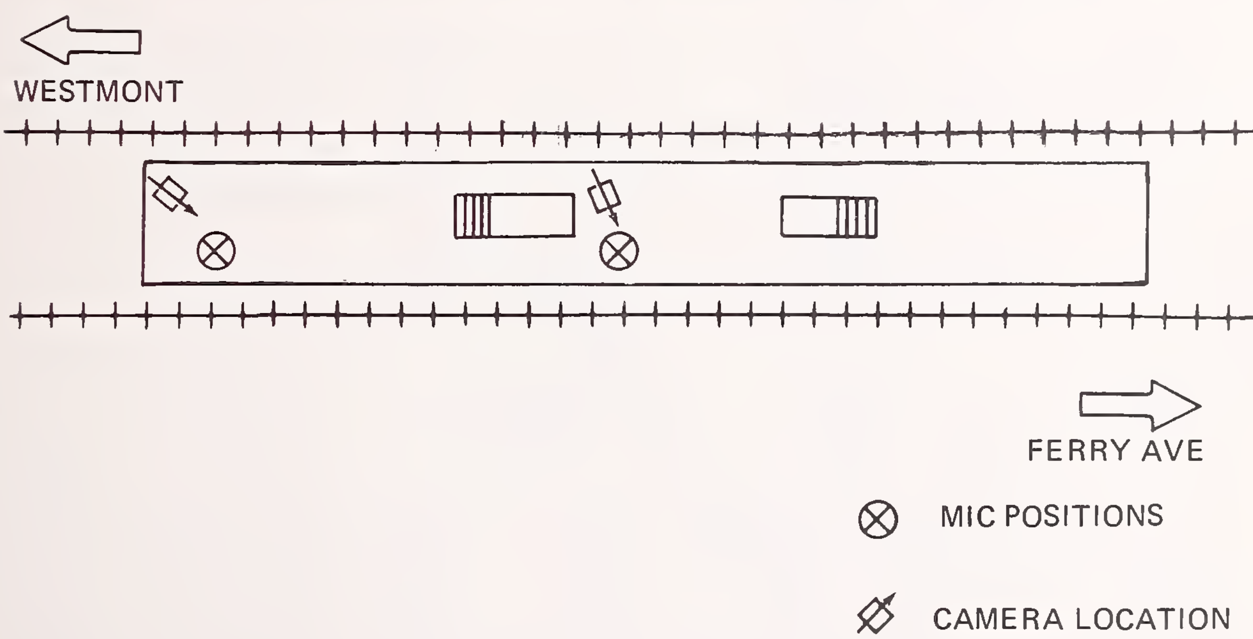


FIGURE 5.66. COLLINGSWOOD STATION PLATFORM ON CONCRETE VIADUCT

TABLE 5.12 SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE STATION NOISE - PATCO-COLLINGSWOOD CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL NEAR	AVG MAX LEVEL FAR	AVG L_R NEAR	AVG L_R FAR	CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					a)WEST	EAST	WEST	EAST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
DAY	Center of stopped train	30 min.	ARRIVAL	b)N	4-2	4-2	4-2	2-2	56	56	58	68	79	66
				dBA	76	71	83	80						
				c)S	2.80	2.14	2.01	2.40						
			DEPARTURE	N	4-2	4-2	4-2	3-2						
				dBA	72	74	78	79						
				S	0.96	4.37	2.05	5.55						
RUSH	Center of stopped train	30 min.	ARRIVAL AND DEPARTURE	dBA					60	61	62	75	86	73
EVENING	Center of stopped train	30 min.		dBA					53	54	57	71	81	69
NIGHT	Center of stopped train	20 min.		dBA					55	58	63	71	81	69

Notes: a - Track
b - Number of Trains -(e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

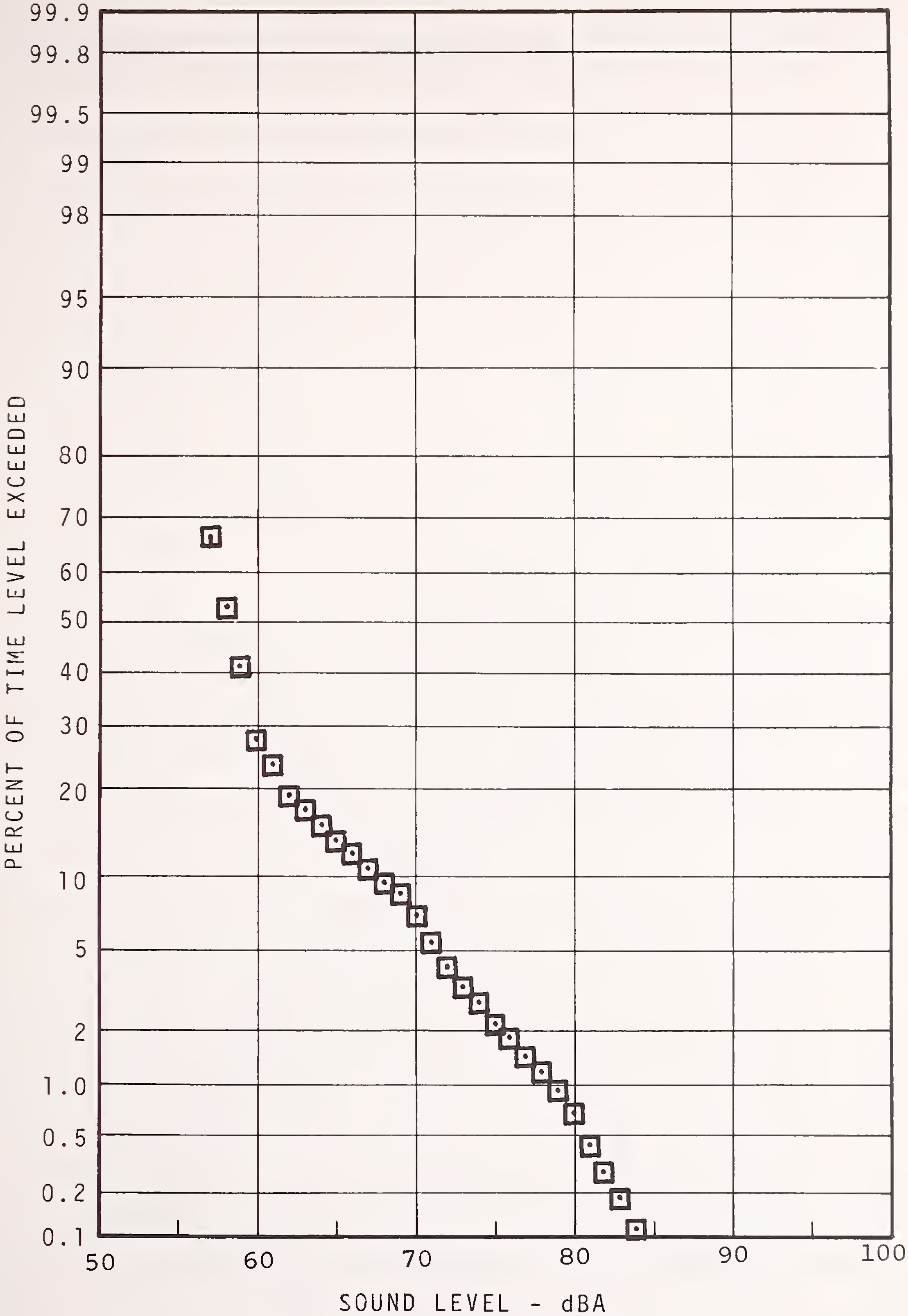


FIGURE 5.67. COLLINGSWOOD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER DAYTIME.

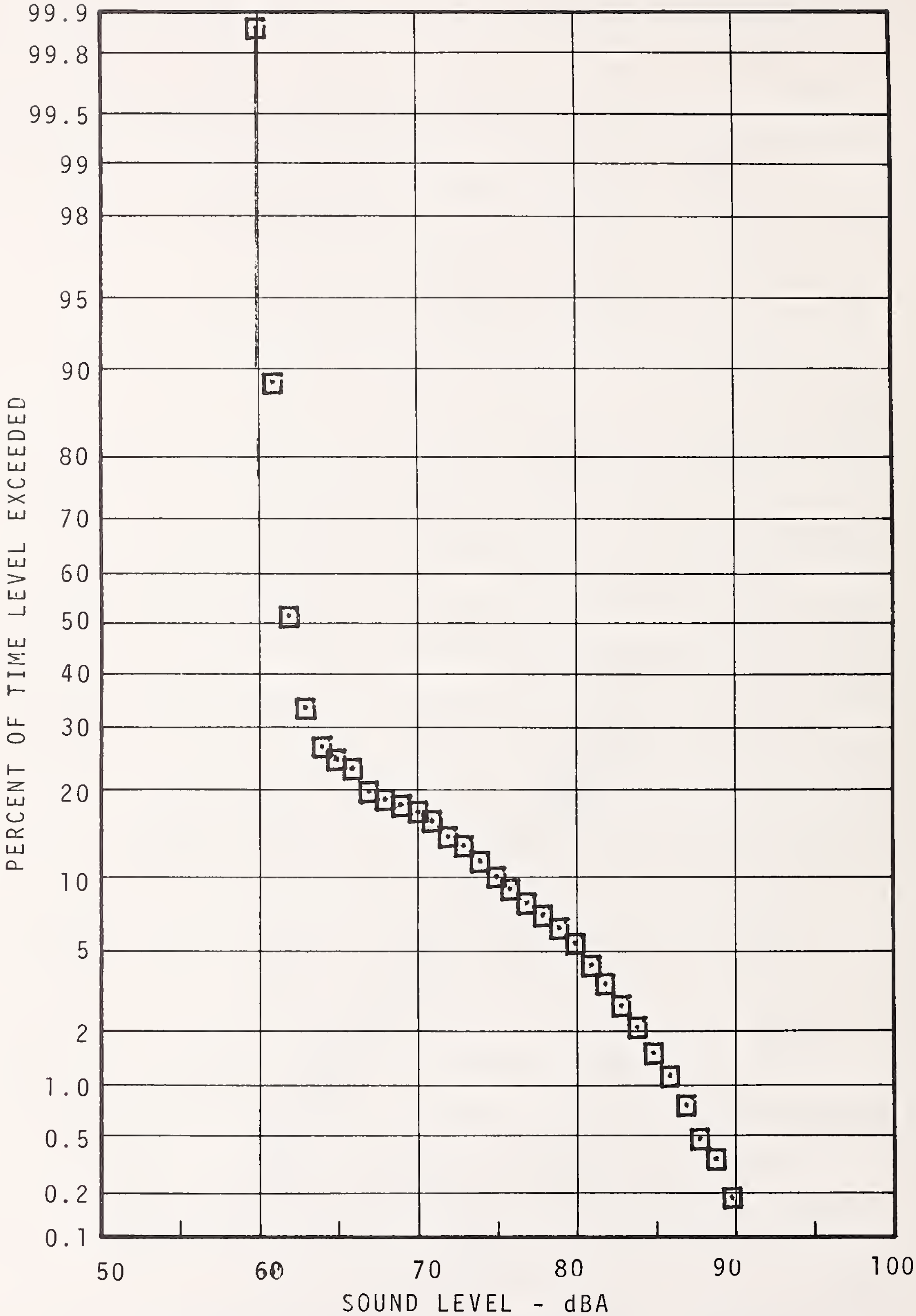


FIGURE 5.68. COLLINGSWOOD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - RUSH HOUR.

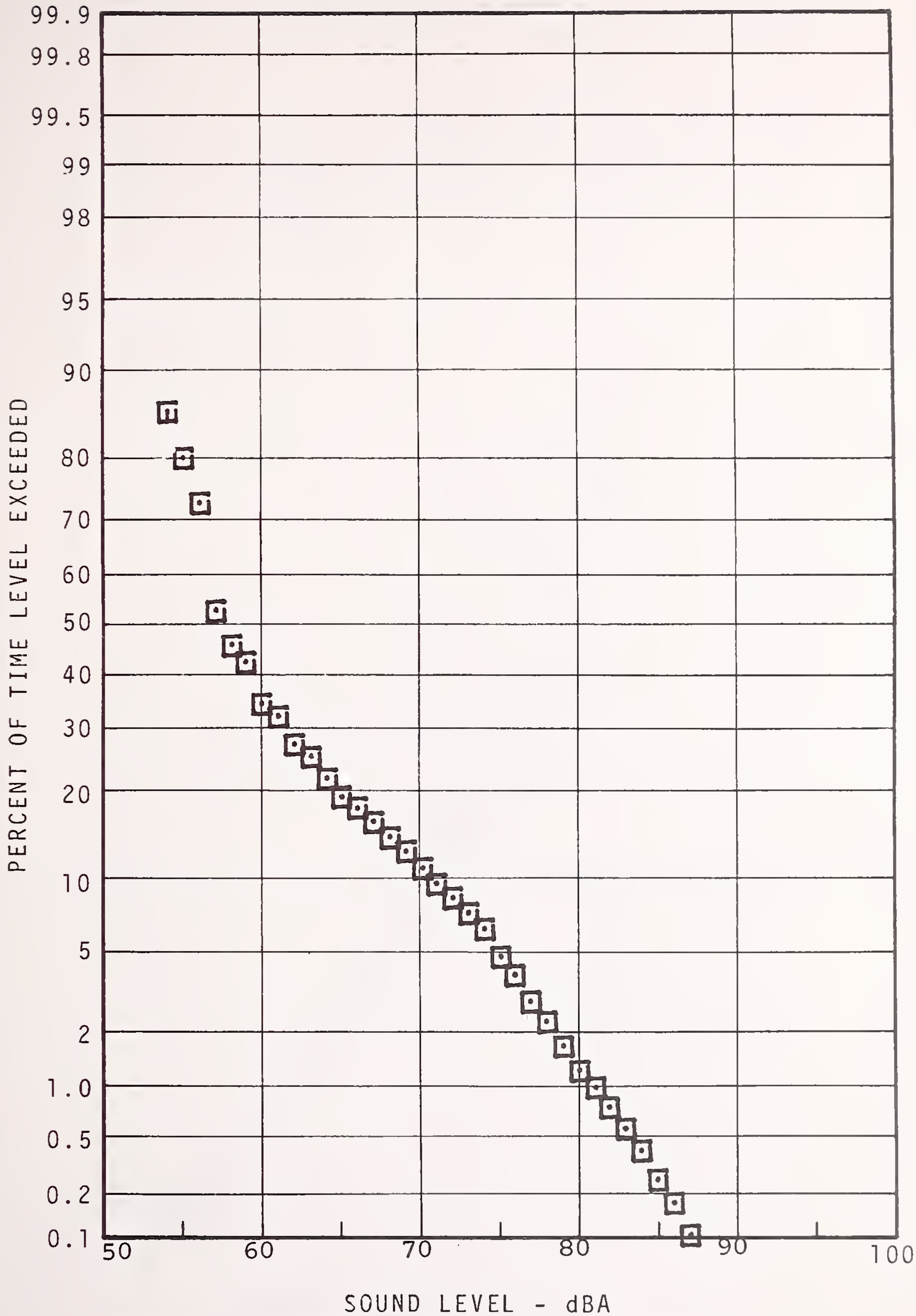


FIGURE 5.69. COLLINGSWOOD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER EVENING.

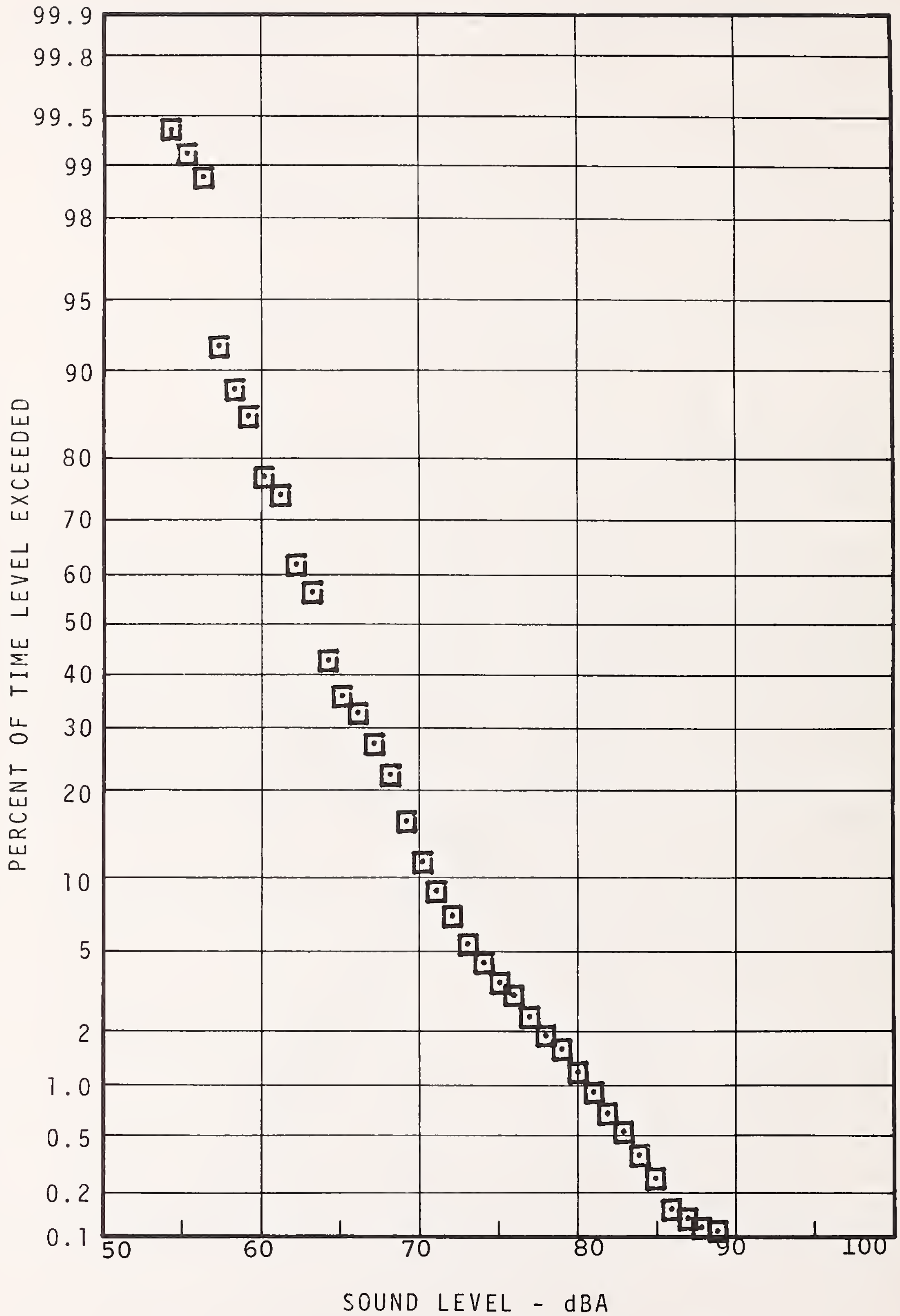


FIGURE 5.70. COLLINGSWOOD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER NIGHT.

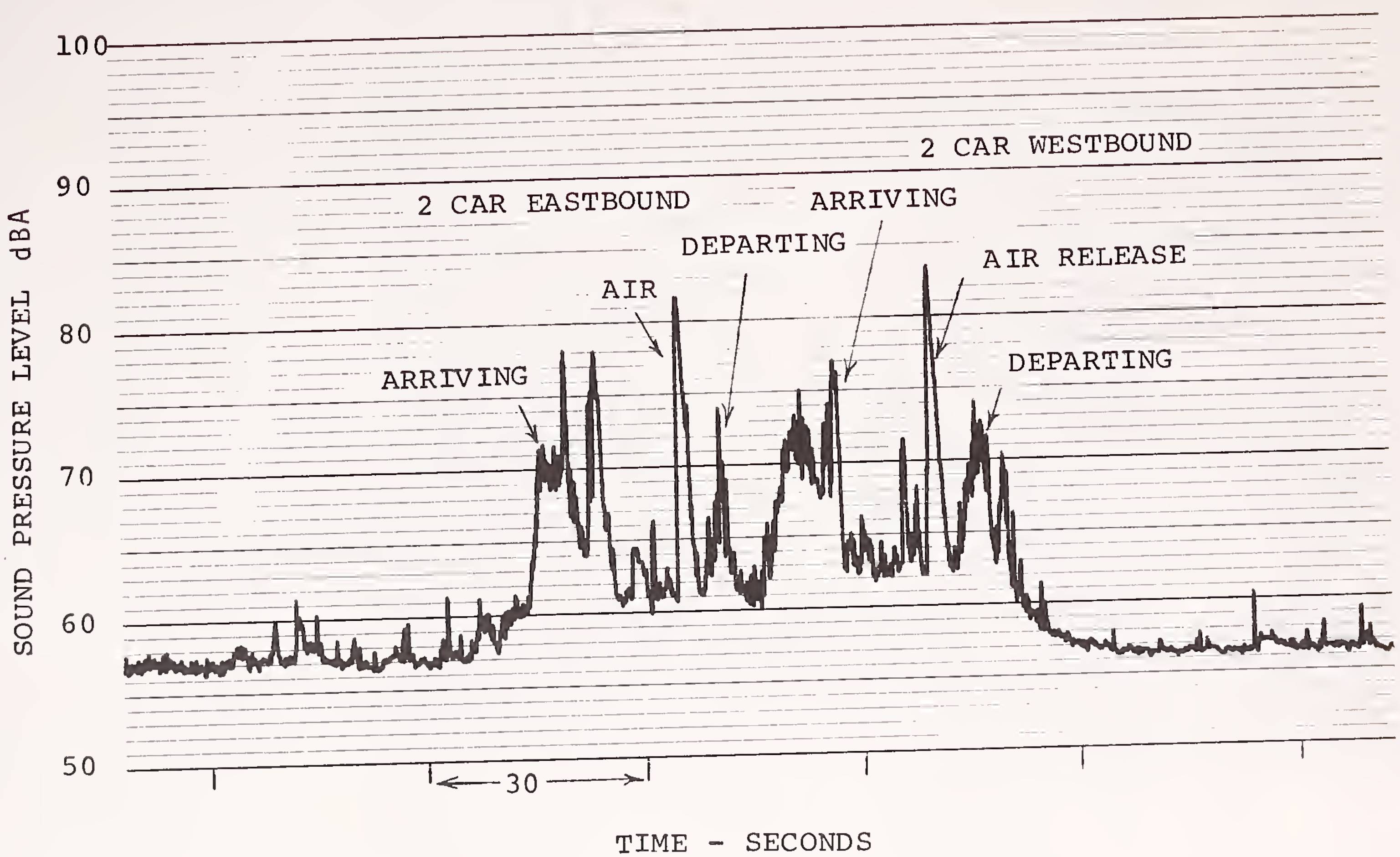


FIGURE 5.71. TYPICAL TIME HISTORY, COLLINGSWOOD STATION

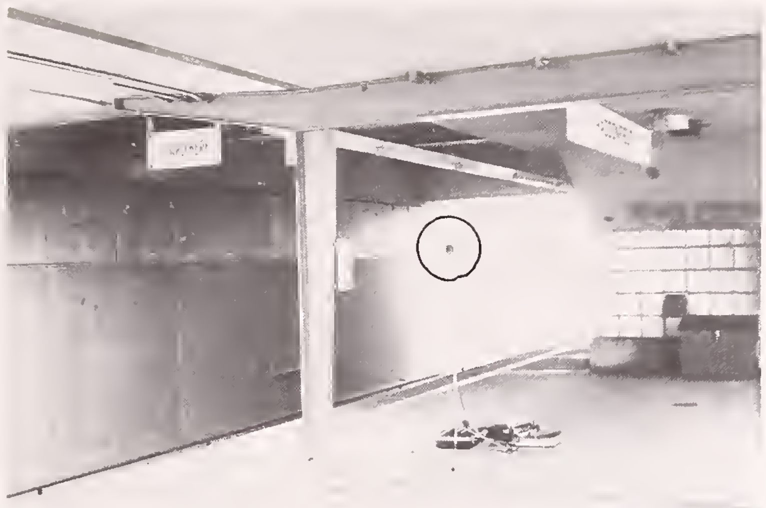
HADDONFIELD STATION

STATION DESCRIPTION (see Figure 5.72)

Haddonfield is an island platform station located in a cutting through the town. The tracks are approximately 15 ft. below grade. On the north side of the transit tracks and immediately adjacent to them is a single track right-of-way of the Pennsylvania Reading Seashore Lines. This track is depressed approximately ten ft. below PATCO track level. The sidewalls of the cut are vertical concrete. There are a number of vehicle overpasses at street grade. At street level there is parking on both sides of the track, with residential homes on the south and primarily commercial and business establishments on the north side. Patrons enter and exit by stairway at the center of the platform to an overhead waiting room and ticket area.

NOISE CLIMATE (see Table 5.13, Figures 5.73 - 5.77)

The noise of an approaching train can be heard for several hundred feet on both sides of the station platform, since car noise is propagated through the concrete channel by reflected waves. Even trains which are out of sight due to curves in the cut are audible before they can be seen. With no trains in the area, the background level is determined largely by a "Dial-a-Ride" bus which idles at street grade. Other sources in the ambient are children's voices, street traffic, church bells, and aircraft flyover noise.



CENTER OF TRAIN

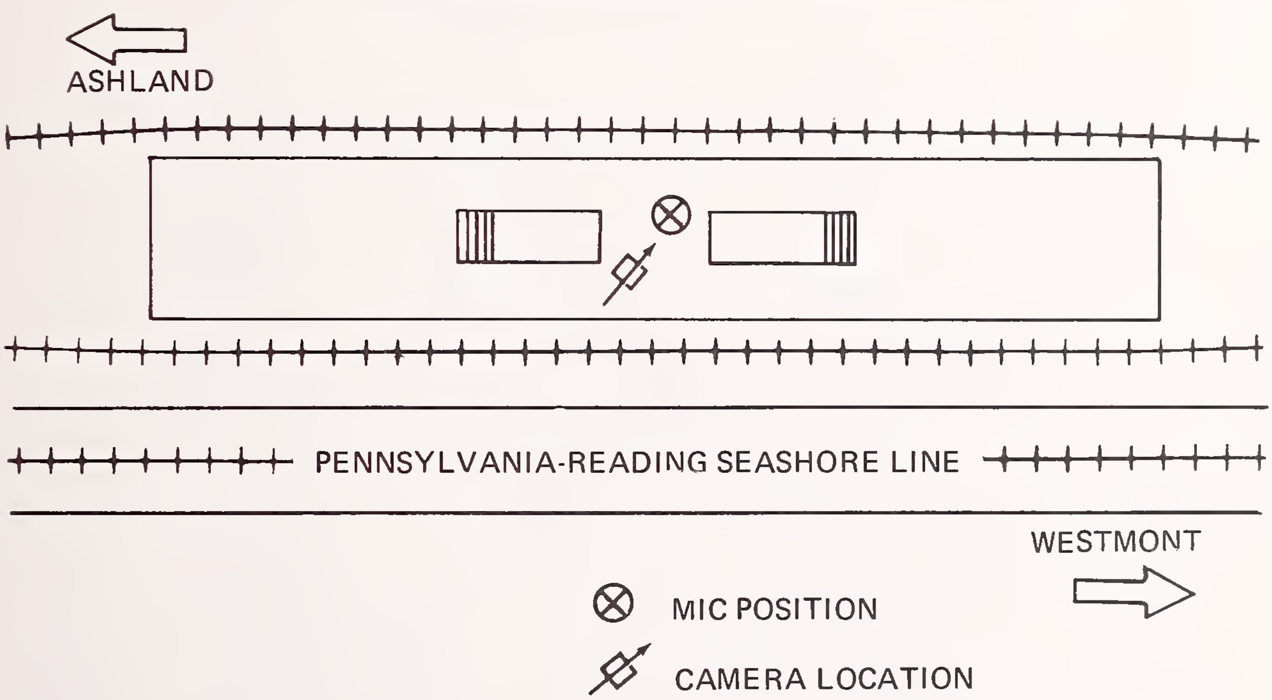


FIGURE 5.72. HADDONFIELD STATION PLATFORM IN CUT

TABLE 5.13. SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE, STATION NOISE - PATCO-HADDONFIELD
CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL NEAR	AVG MAX LEVEL FAR	AVG L_R NEAR	AVG L_R FAR	CUMULATIVE AMPLITUDE DISTRIBUTION L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
					a)EAST	WEST	EAST	WEST						
DAY	Center of stopped train	30 min.	ARRIVAL	b)N	4-2	5-2	4-2	5-2	59	61	62	71	82	70
				dBA	82	77	87	85						
				c)S	4.02	4.67	2.04	1.08						
			DEPARTURE	N	4-2	5-2	4-2	5-2						
				dBA	81	75	87	83						
				S	4.55	2.41	1.65	2.41						
RUSH	Center of stopped train	30 min.	ARRIVAL AND DEPARTURE	dBA					56	57	59	72	81	69
EVENING	Center of stopped train	30 min.		dBA					56	57	60	70	79	68
NIGHT	Center of stopped train	30 min.		dBA					56	57	58	69	78	66

Notes: a - Track
b - Number of Trains -(e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

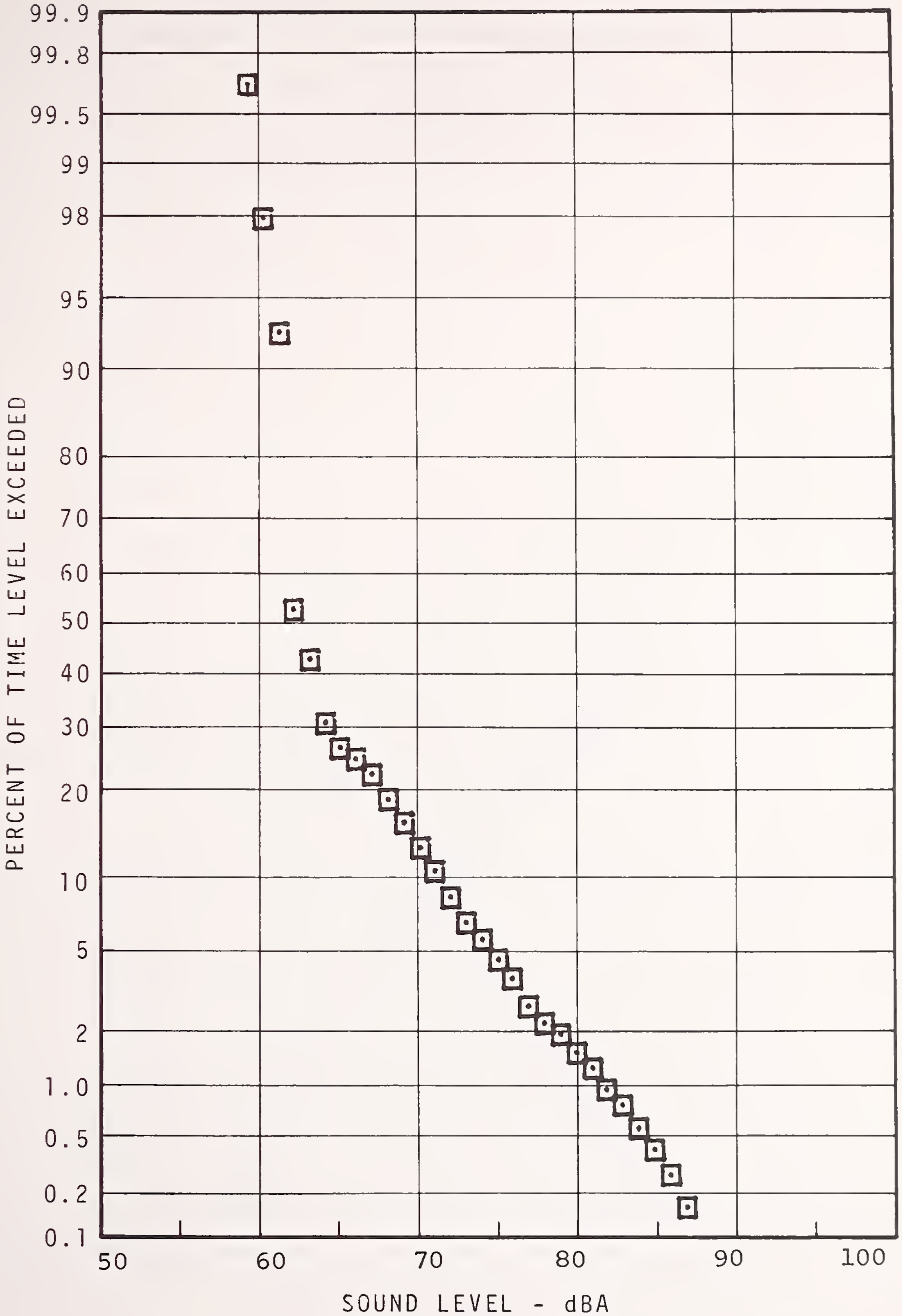


FIGURE 5.73. HADDONFIELD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - DAYTIME.

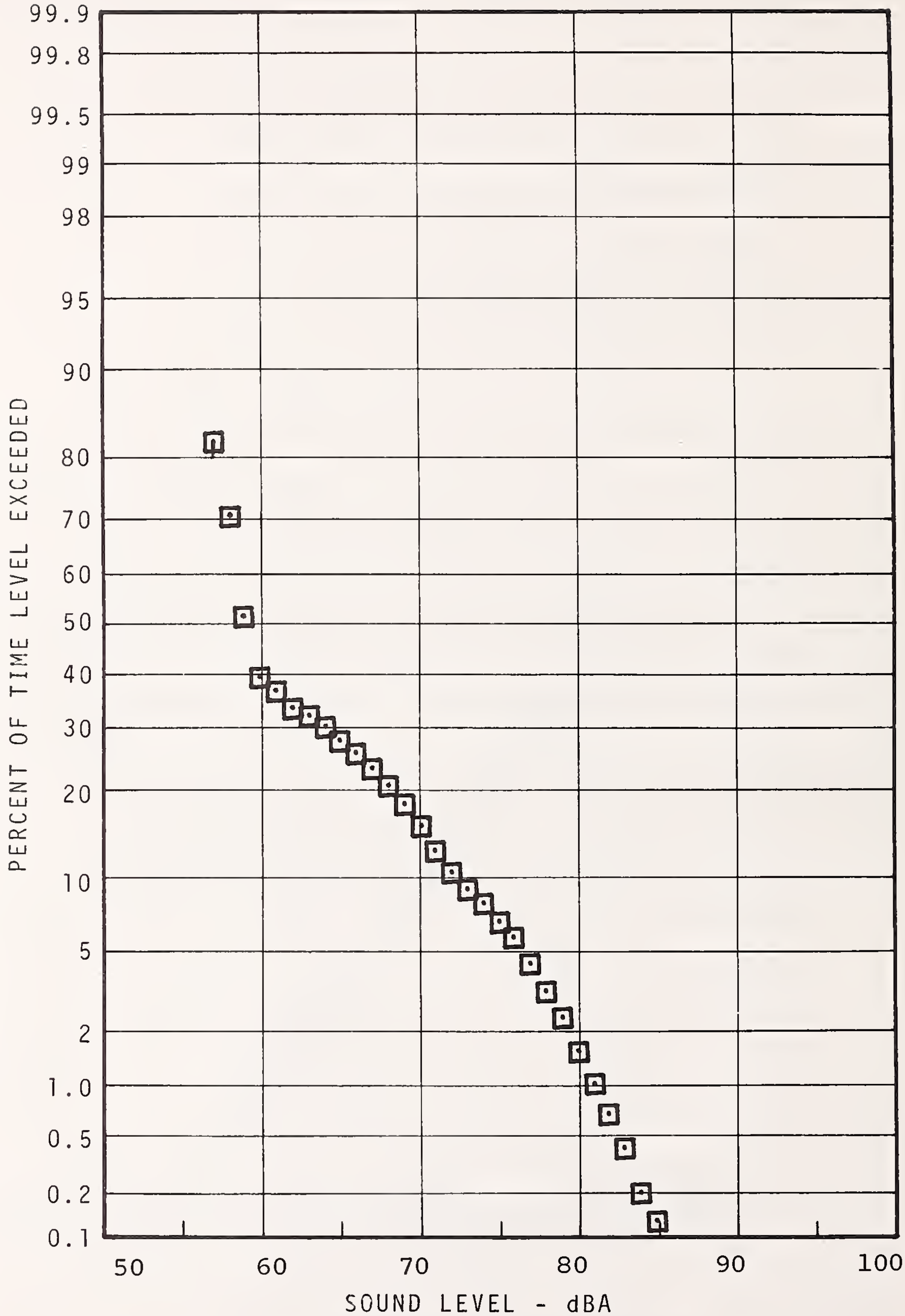


FIGURE 5.74. HADDONFIELD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - RUSH HOUR.

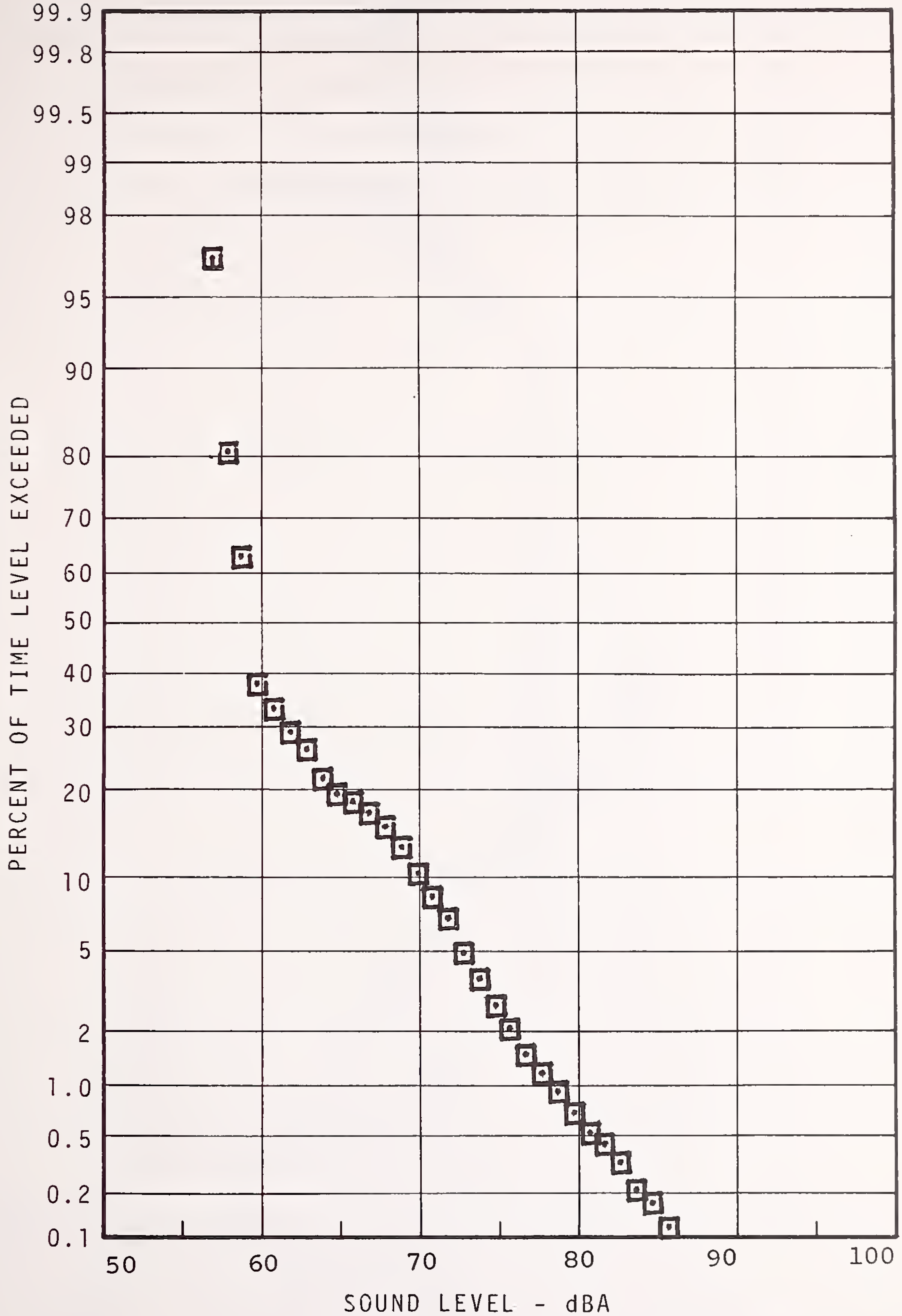


FIGURE 5.75. HADDONFIELD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER-EVENING.

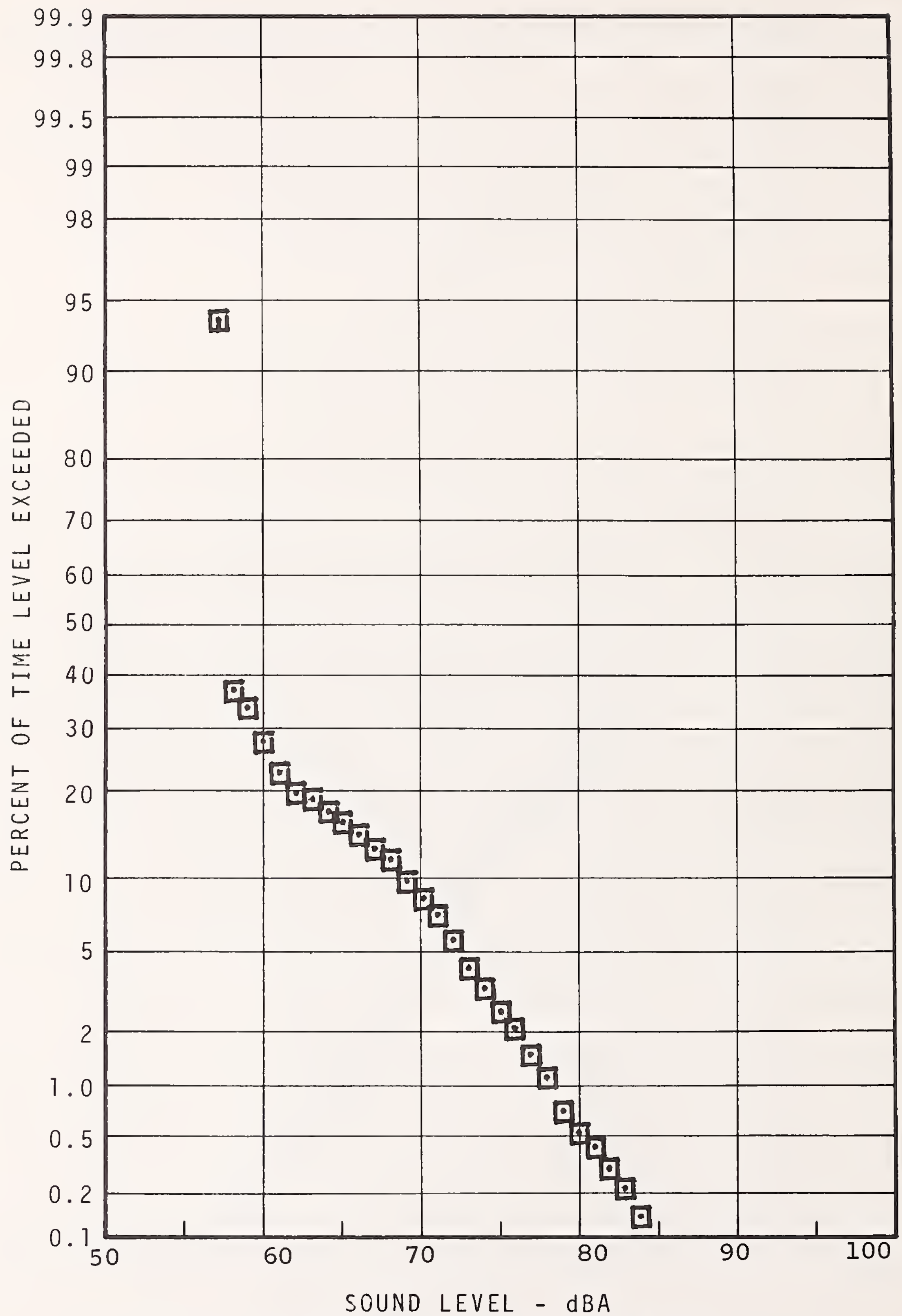


FIGURE 5.76. HADDONFIELD STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - NIGHT.

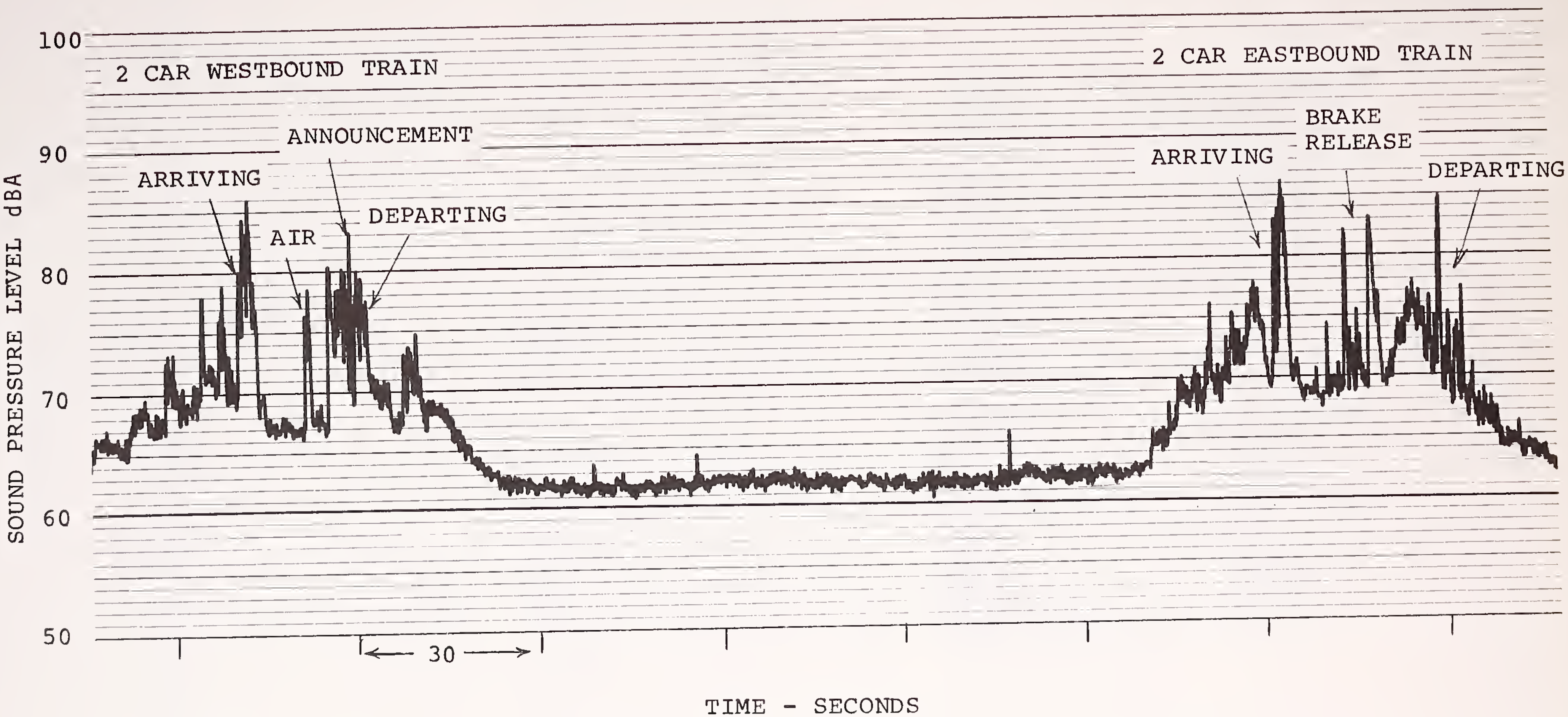


FIGURE 5.77. TYPICAL TIME HISTORY, HADDONFIELD STATION

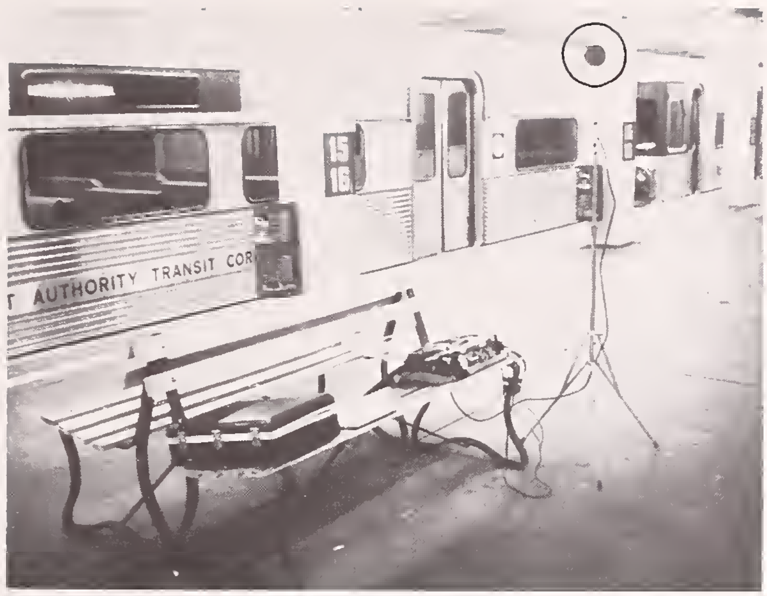
15TH/16TH AND LOCUST STATION

STATION DESCRIPTION (see Figure 5.78)

The station at 15th/16th and Locust is underground terminus of the PATCO Line in Philadelphia. It is an island platform station with center stairways leading to an overhead mezzanine which is also below grade. Storage tracks and crossovers are located beyond the west end of the platform. The construction of the station is concrete with ceramic tiles used on sides of the stairways.

NOISE CLIMATE (see Table 5.14, Figures 5.79 - 5.83)

As a train approaches and decelerates, the noise of the traction motor fans is an identifying feature of the acoustic signature in the station. Stopped trains display equipment blower and (depending on the season) air conditioner cooling fan and blower noise. This undercar equipment noise is also audible at the mezzanine level. As the car departs there is some squeal as brakes are released. With no cars in the station, ventilator fan noise can be heard at the west end of the platform, although there is generally a train in the station awaiting departure which masks this noise. The drainage of an underground stream is a continuous noise of low level also audible when a train is not present.



CENTER OF TRAIN

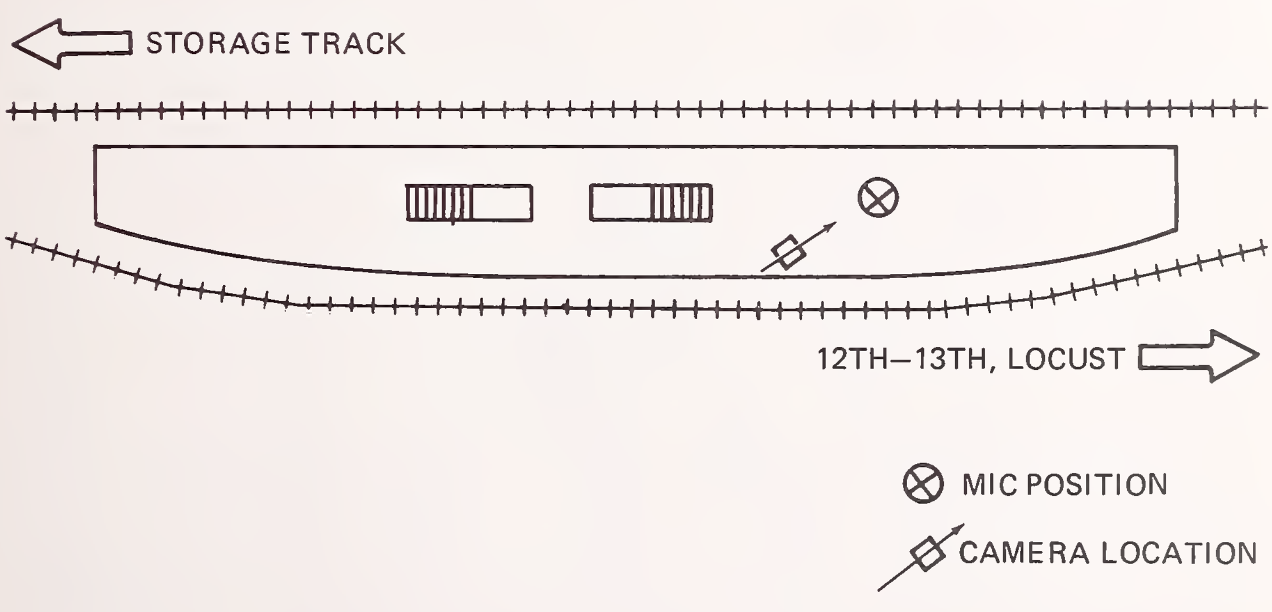


FIGURE 5.78. 15TH/16TH AND LOCUST SUBWAY STATION PLATFORM

TABLE 5.14. SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE, STATION NOISE - PATCO-15th-16th AND LOCUSTS STS. CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL NEAR a)WEST	AVG MAX LEVEL FAR EAST	AVG L_R NEAR WEST	AVG L_R FAR EAST	CUMULATIVE AMPLITUDE DISTRIBUTION L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
DAY	Center of stopped train	30 min.	ARRIVAL	b)N	4-2	5-2	4-2	5-2	63	63	72	82	88	77
				dBA	88	86	96	95						
				c)S	2.40	2.95	1.72	2.75						
			DEPARTURE	N	4-2	5-2	4-2	5-2						
				dBA	82	86	91	95						
				S	1.32	1.56	1.43	0.87						
RUSH	Center of stopped train	30 min.	ARRIVAL AND DEPARTURE	dBA					60	64	80	86	94	83
EVENING	Center of stopped train	30 min.		dBA					54	56	64	82	88	78
NIGHT	Center of stopped train	30 min.		dBA					63	63	64	72	84	72

Notes: a - Track
b - Number of Trains -(e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

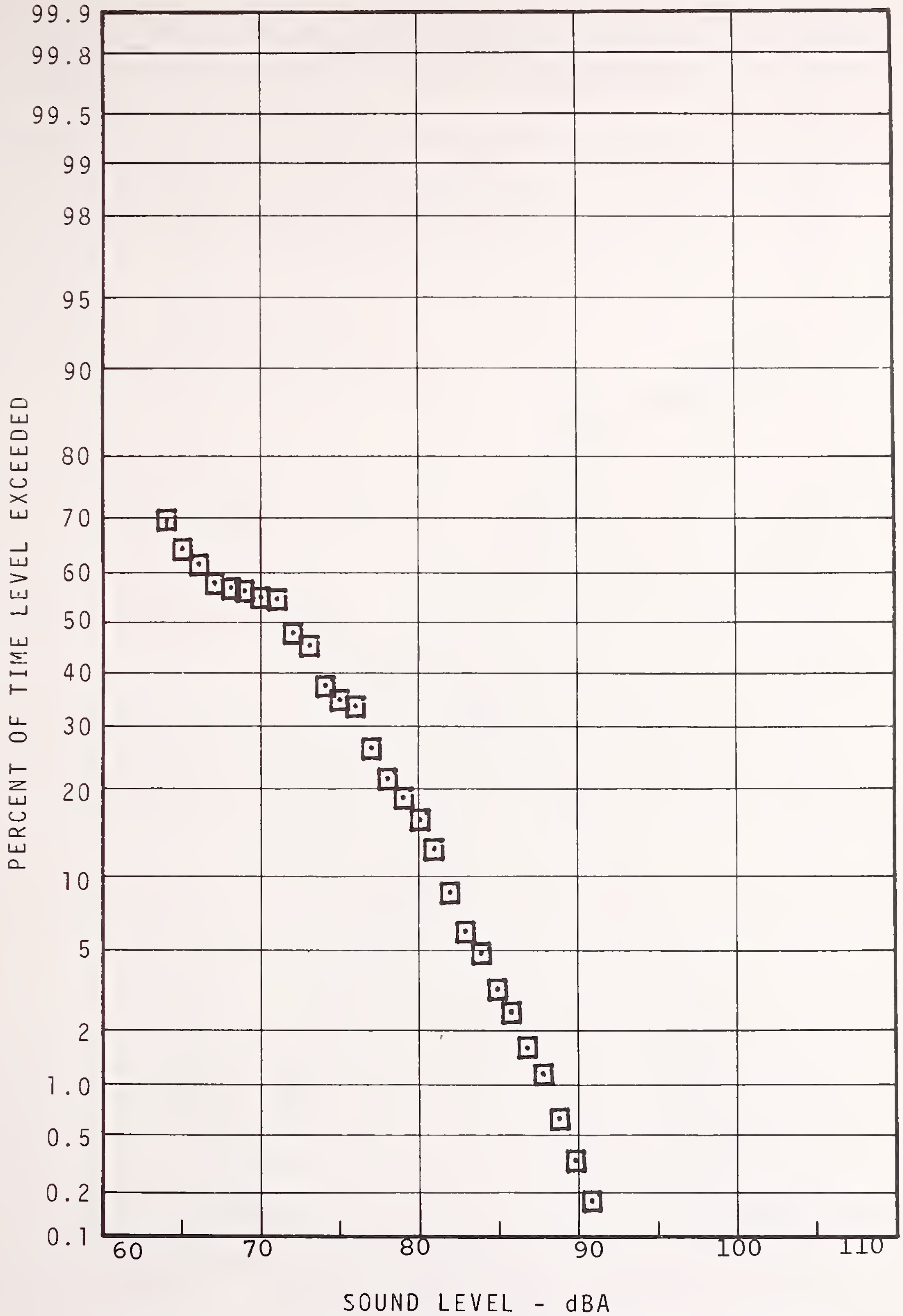


FIGURE 5.79. 15th - 16th AND LOCUST STS. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - DAYTIME

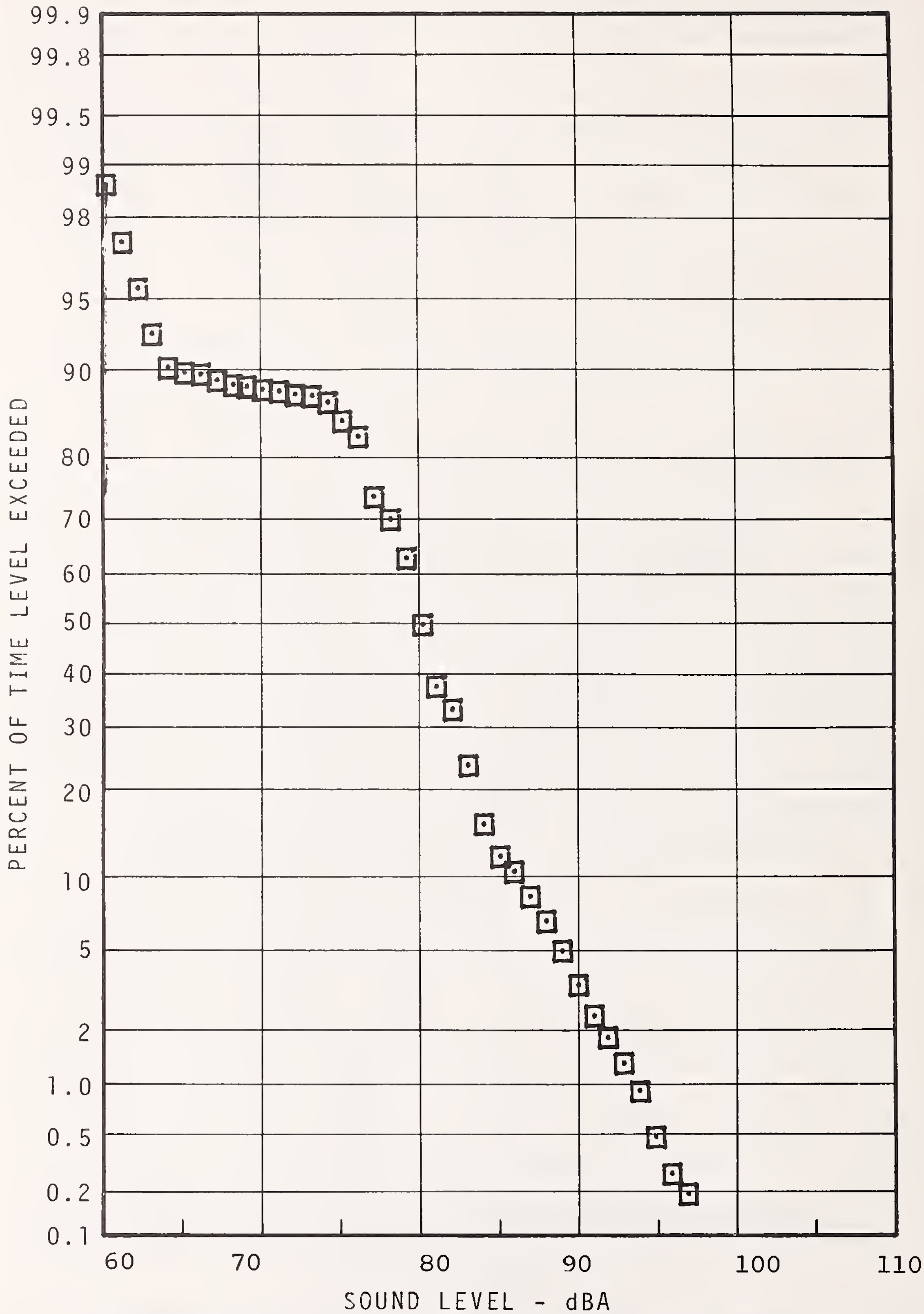


FIGURE 5.80. 15TH - 16TH AND LOCUST STS. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - RUSH HOUR.

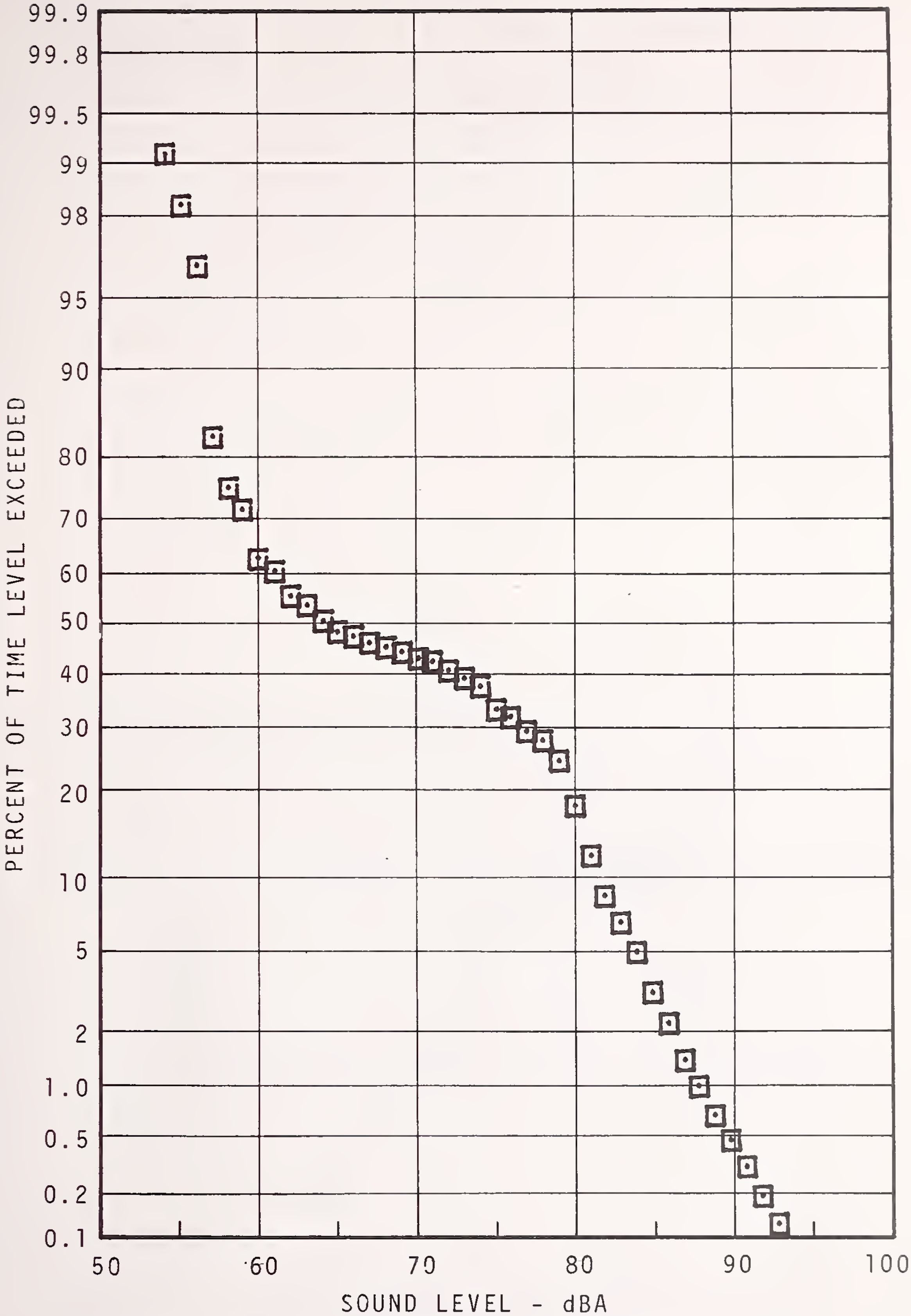


FIGURE 5.81. 15TH - 16TH AND LOCUST STS. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - EVENING.

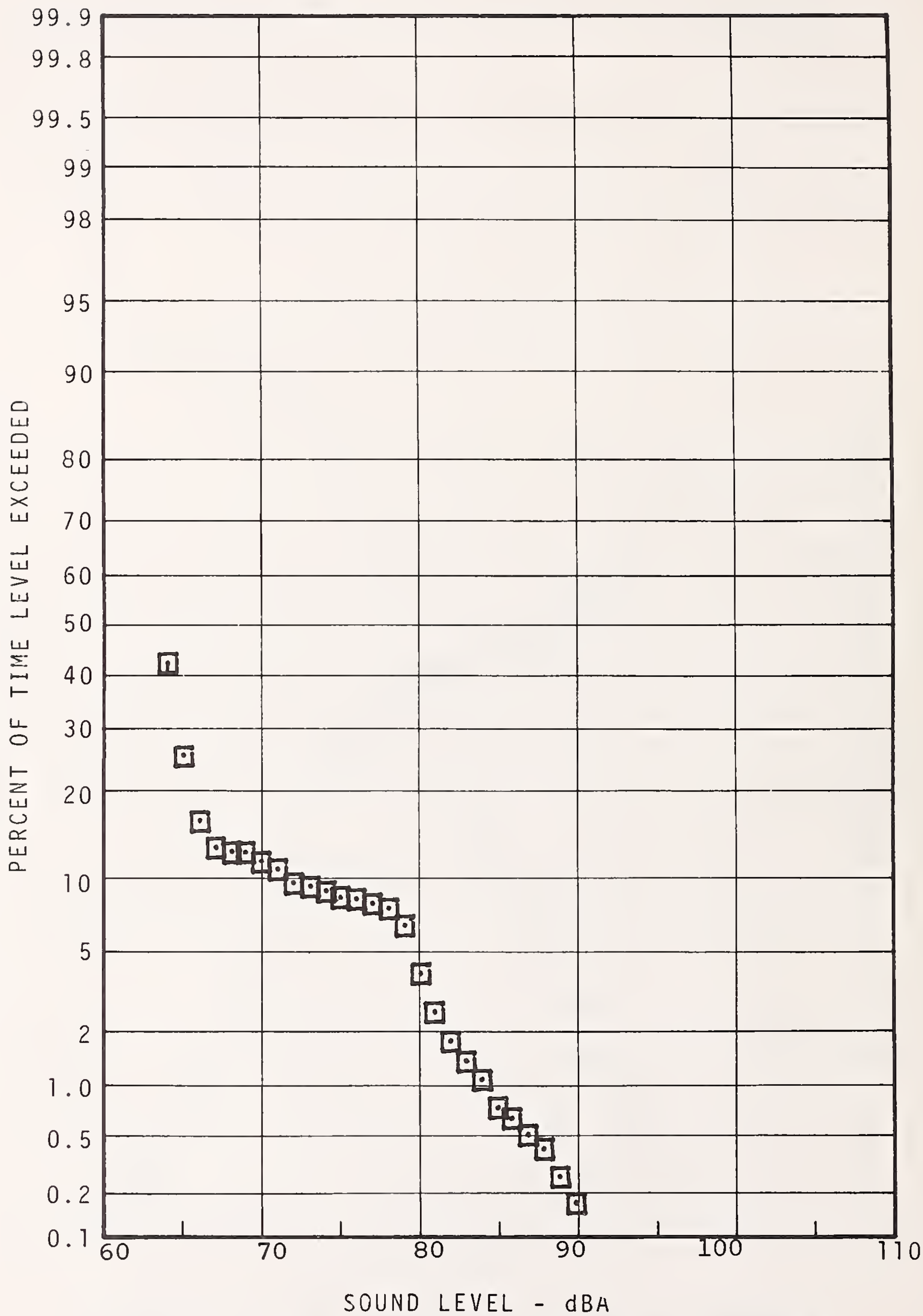
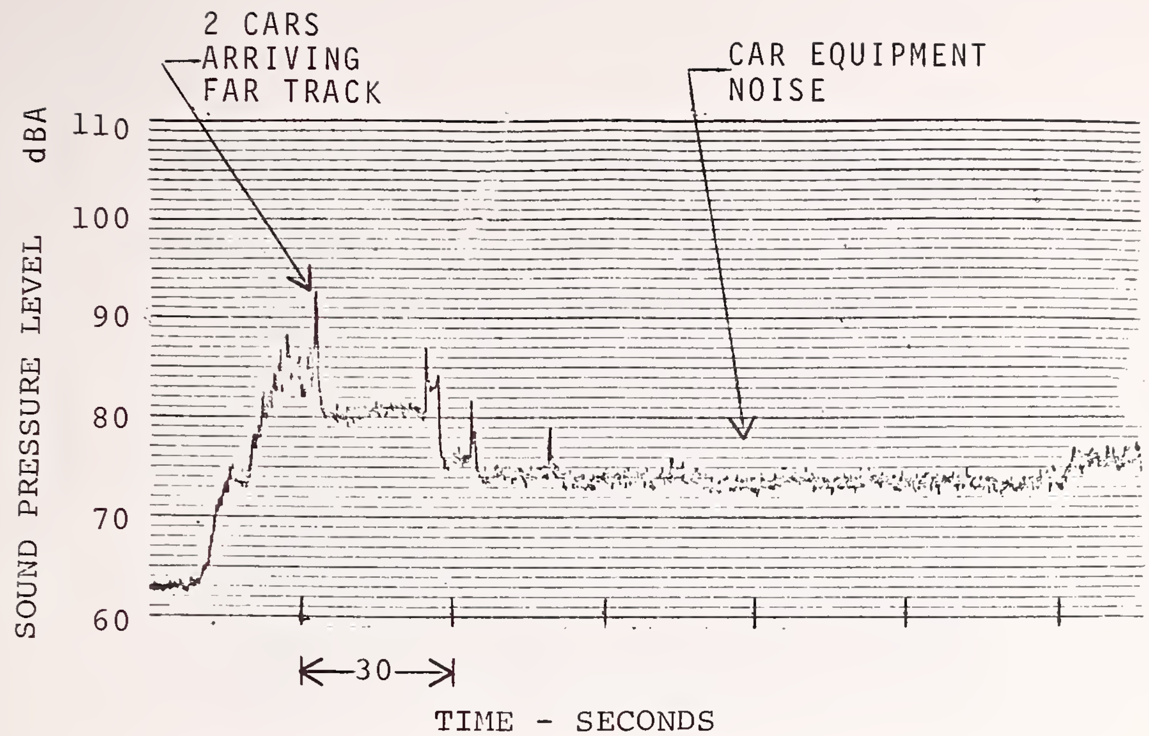


FIGURE 5.82. 15TH - 16TH AND LOCUST STS. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - NIGHT.



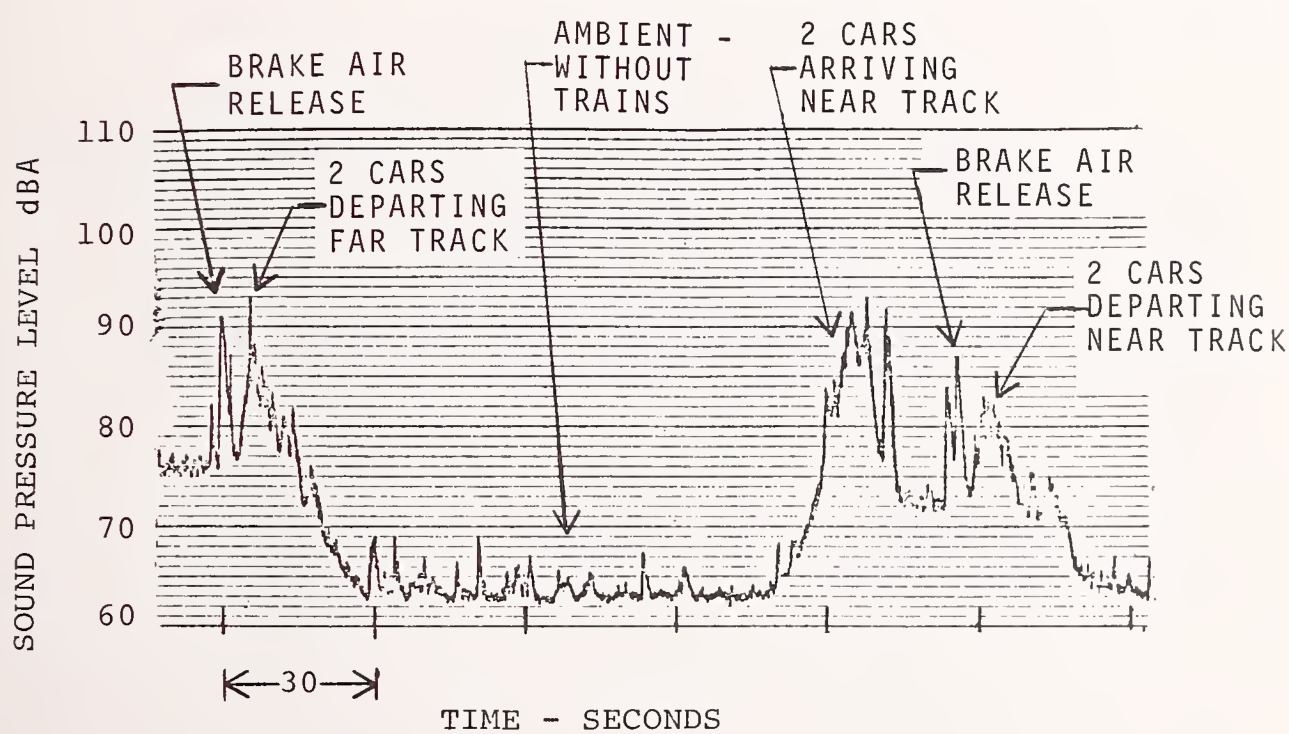


FIGURE 5.83. TYPICAL NOISE TIME HISTORY, 15-16 ST TERMINAL, CENTER PLATFORM

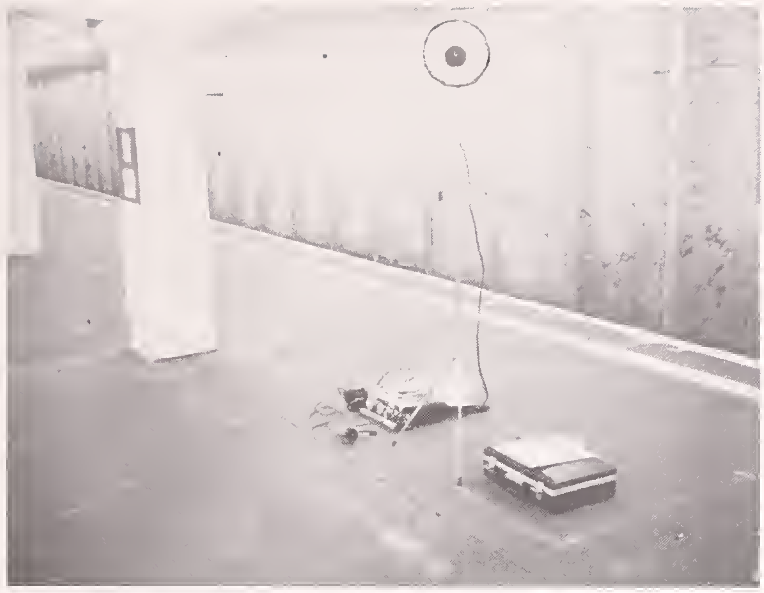
9TH/10TH AND LOCUST STATION

STATION DESCRIPTION (see Figure 5.84)

The station at 9th/10th and Locust is a typical underground station on the PATCO Line. It is an island platform station similar in construction to 15th/16th Street. Stairways in the center exit to a mezzanine level. As with all stations on the Philadelphia side, the platforms are elevated on piers. In certain regions above the track and platform, there are steel grates open to the mezzanine area. This venting leads indirectly to the street level. The automatic ticketing area is located on the mezzanine level.

NOISE CLIMATE (see Table 5.15, Figures 5.85 - 5.87)

The noise climate at 9th and 10th Street Station is, in many respects, similar to that of 15th and 16th Street. However, unlike 15th/16th, where trains arrive only from the east (it is the western terminal), 9th and 10th Street Station has trains arriving and departing both eastbound and westbound. There are longer periods with no trains present than is true for 15th/16th. On the mezzanine above platform level, both train noise from below and vehicular traffic noise from street level are audible.



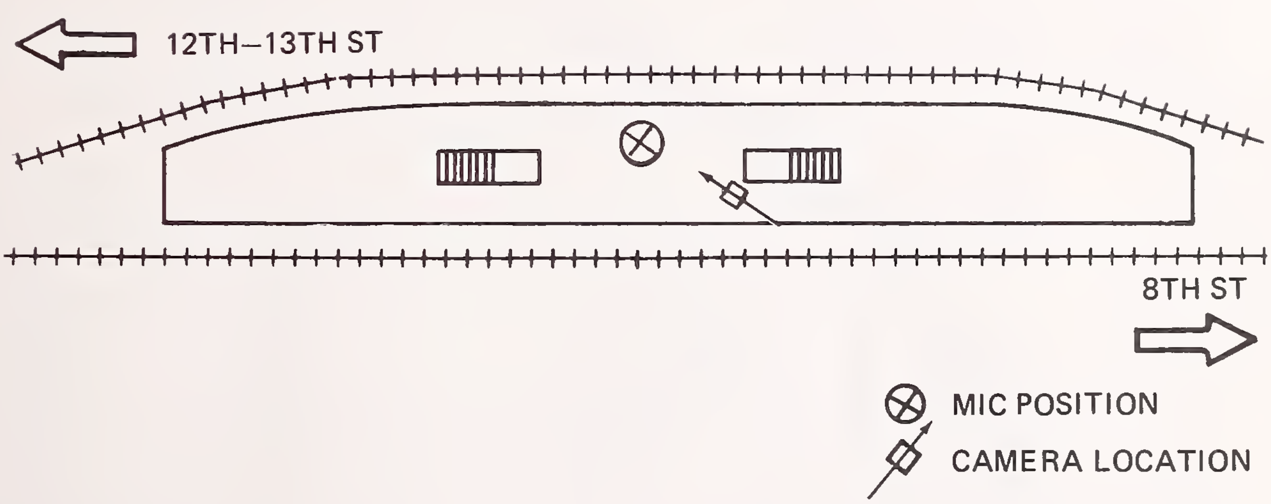


FIGURE 5.84. 9TH-10TH STREET SUBWAY STATION PLATFORM

TABLE 5.15. SUMMARY OF MEASUREMENT RESULTS FOR 30-MINUTE SAMPLE, STATION NOISE - PATCO-9th-10th STS.
CAR TYPE: BUDD

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL NEAR	AVG MAX LEVEL FAR	AVG L_R NEAR	AVG L_R FAR	CUMULATIVE AMPLITUDE DISTRIBUTION L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{eq}
					a)WEST	EAST	WEST	EAST						
DAY	Center of stopped train	30 min.	ARRIVAL	b)N	5-2	4-2	5-2	4-2	57	58	63	83	91	79
				dBA	88	90	96	98						
				c)S	1.80	0.75	1.98	1.02						
			DEPARTURE	N	5-2	4-2	5-2	4-2						
				dBA	89	90	98	96						
				S	3.49	2.35	3.25	1.56						
RUSH	Center of stopped train	30 min.	ARRIVAL AND DEPARTURE	dBA					58	60	63	86	94	83

Notes: a - Track
b - Number of Trains -(e.g.: 4-2 means four 2-car trains)
c - Standard Deviation of Level

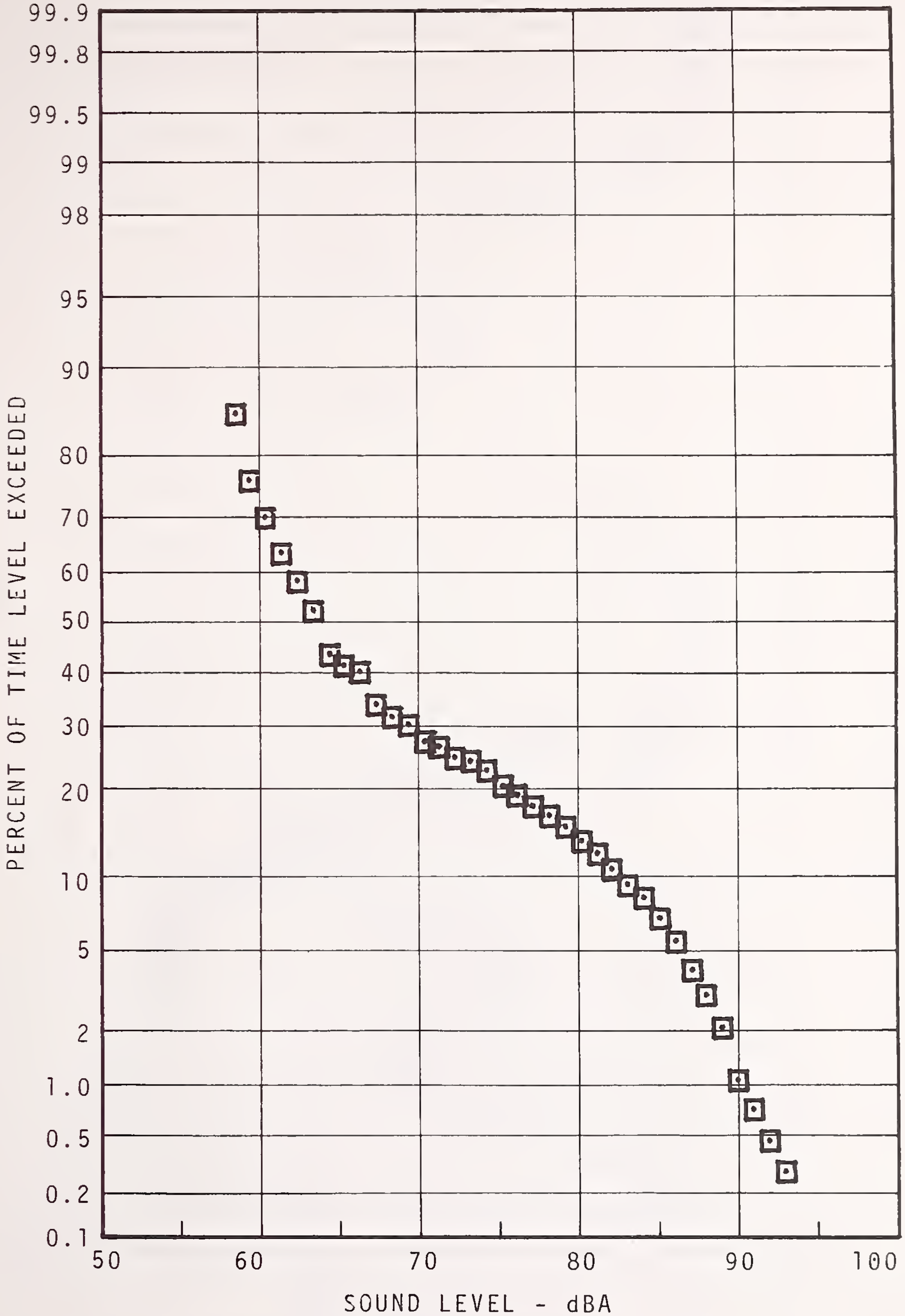


FIGURE 5.85. 9TH - 10TH STS. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER,- DAYTIME

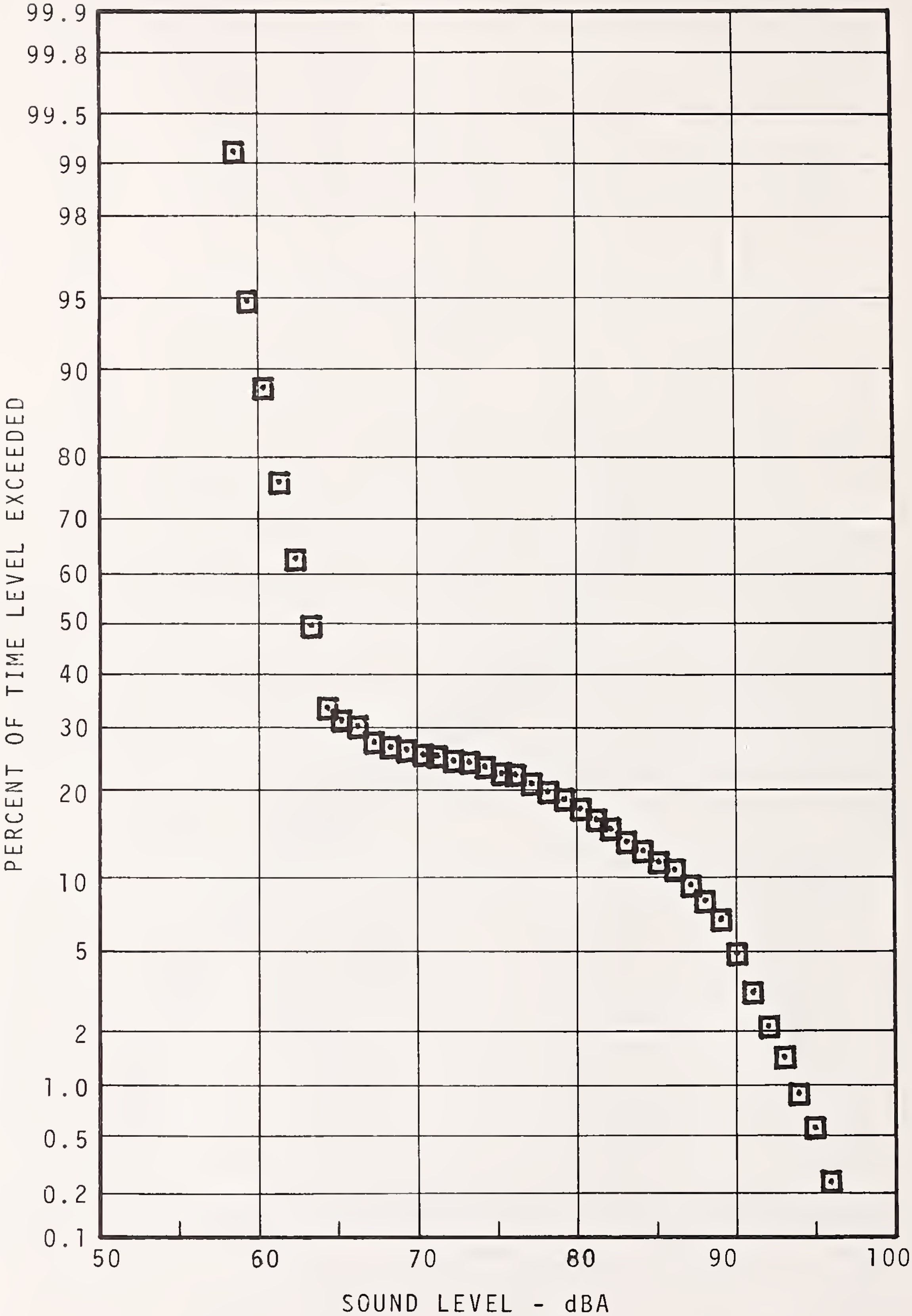


FIGURE 5.86. 9TH - 10TH STS. STATION PLATFORM STATISTICAL DISTRIBUTION - CENTER - RUSH HOUR

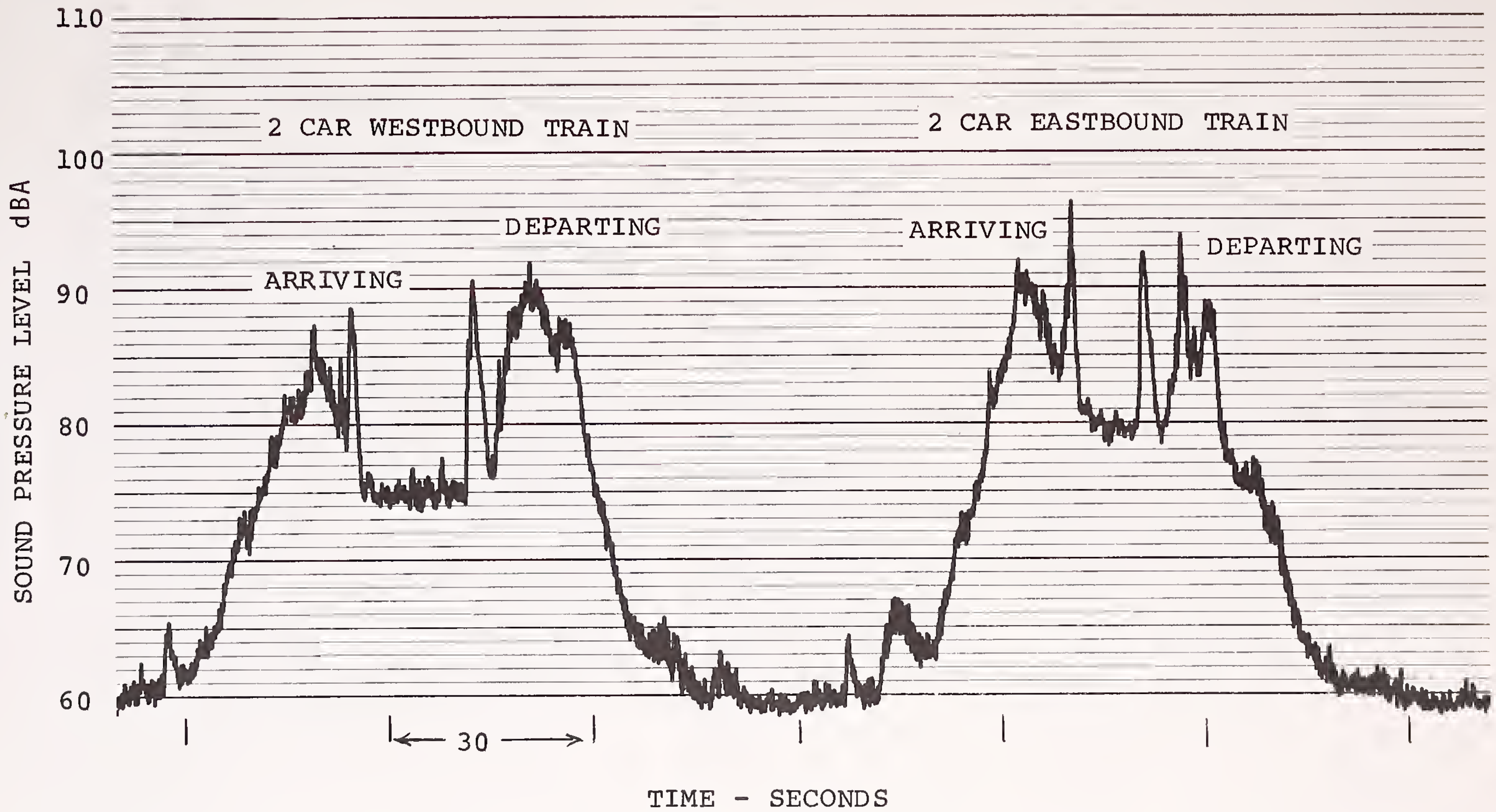


FIGURE 5.87. TYPICAL TIME HISTORY, 9TH-10TH & LOCUST, STATION

5.2.3 Vehicle Interior

The in-car surveys were conducted on the PATCO Line according to the general measurement methodology outlined previously. Single and double cars were surveyed headed east-and-west bound.

A complete round trip was made in November 1974 on each of the two types of cars in service on the High Speed Line. An eastbound trip was made on car S (for single)-105, followed by a west-bound trip on car number S-120. Several days later, a noise survey was conducted on car number D (for double)-205 going west, followed by an east-bound trip on car D-227. Instrumentation problems with the microphone recording the motorman's environment on car D-205 caused a repeat to be made for this data on Car D-228, again heading west.

Car Description - Budd Car (see Figure 5.88)

Single cars differ from double car types in that each single car carries its own motor-generator and air-compressor, whereas a double car, which is part of a married pair, carries either a motor-generator or an air-compressor. In addition, single cars, which can be operated as a one-car train, have a motorman's cab and controls at each end of the car, whereas each of the double cars have only one cab and control position.

All cars are provided with air-conditioning and heating systems, and air spring suspension for a generally smooth and quiet ride. A public address system in the cars is used to announce upcoming station stops. All cars are equipped with two sets of bi-parting sliding doors in each side and swinging end doors in both ends. The car floor construction from bottom to top is as follows: stainless steel pan, insulating material applied as a coating to the inside of the pan, an airspace and plymetal flooring. On the car interior the floor is covered with vinyl tile. The operator's compartment is located in the left front corner of the car. It has an enclosure from the floor to the bottom of the windows and a low glass panel behind the operator's head and shoulders. Passenger seats are upholstered with high resiliency polyurethane foam. Air is continuously recirculated and replaced from the outside throughout the car from air ducts running the length of the car in the ceiling colinear with the fluorescent lighting. Wheel slip-slide protection and good wheel maintenance result in low wheel rail noise levels due to the absence of wheel flats.

Noise Climate (see Table 5.16, Figures 5.89 - 5.97)

The subjective impression of an observer is that the interior of the Budd vehicle is quiet, even at high speeds. The predominant noise is due to the propulsion system motor fan whine. Wheel/rail noise is low except when passing over insulating joints of track or track-crossovers. Occasionally, in high speed operation (75 mph), a low frequency boom, or rumble and some door rattling is associated with the passing of a train going at high speed in the opposite direction on adjacent track.

When the car is stopped at a station with the doors open, the noise of the motor generator fans and/or the air compressor on the car is audible. Also audible is the air-conditioning system cooling fan noise.

Additional audible noises occur primarily in the Camden and Philadelphia vicinity of the tracks. Here the noise level changes level and character each time an underground section is encountered. Squeal noise is audible at each end of the Benjamin Franklin Bridge in curves and at other underground curves at Broadway, Franklin Square (not in use), 8th and Market, and 9th and 10th Street Stations. Prior to approach to an underground curve the train horn is sounded for safety reasons. It is also sounded prior to approach to an underground station if no stop is to be made.

CENTER OF CAR

OPERATOR'S LOCATION

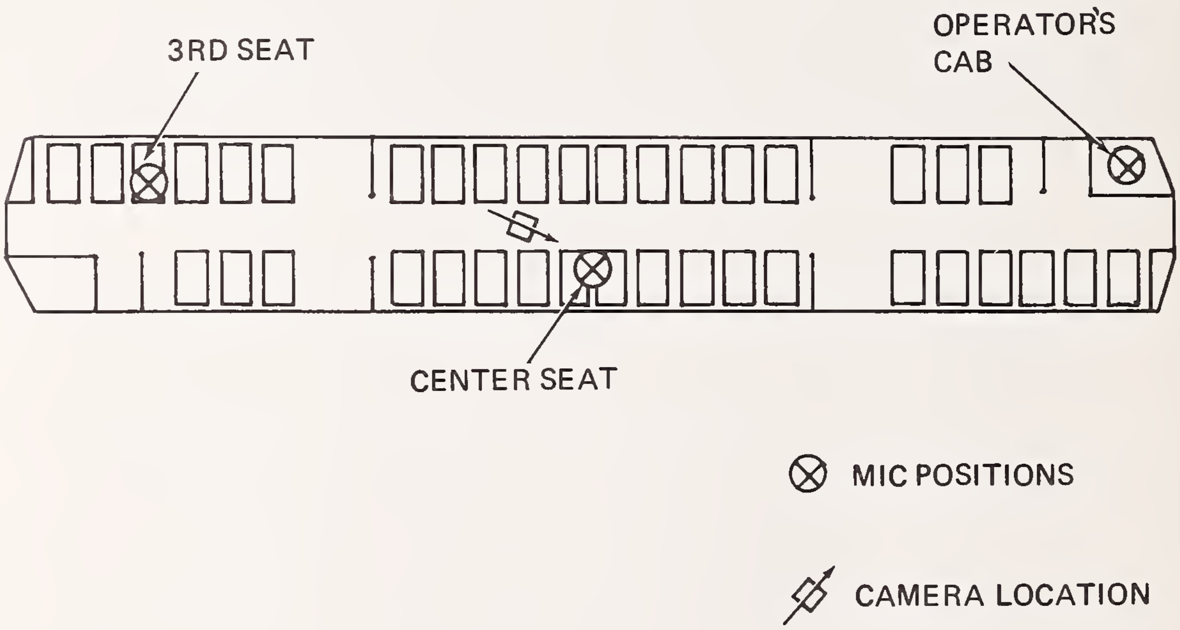


FIGURE 5.88. IN-CAR MEASUREMENT LOCATIONS, PATCO BUDD CAR - SINGLE CAR

TABLE 5.16 SUMMARY OF MEASUREMENT RESULTS FOR 1960 BUDD CARS - INTERIOR NOISE LEVELS

CAR TYPE	MIC POSITION	SAMPLE TIME	TRAIN HEADING	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Single	Center	25 Min.	East	dBA					64	66	71	76	81	73
	Truck			dBA					66	68	73	79	84	75
	Center	27 Min.	West	dBA					73	74	80	87	93	83
	Truck			dBA					75	76	84	91	95	87
Double	Center	24 Min.	East	dBA					73	74	80	85	92	82
	Truck			dBA					75	77	82	88	92	84
	Center	26 Min.	West	dBA					63	65	71	76	82	73
	Truck			dBA					55	56	62	68	73	64

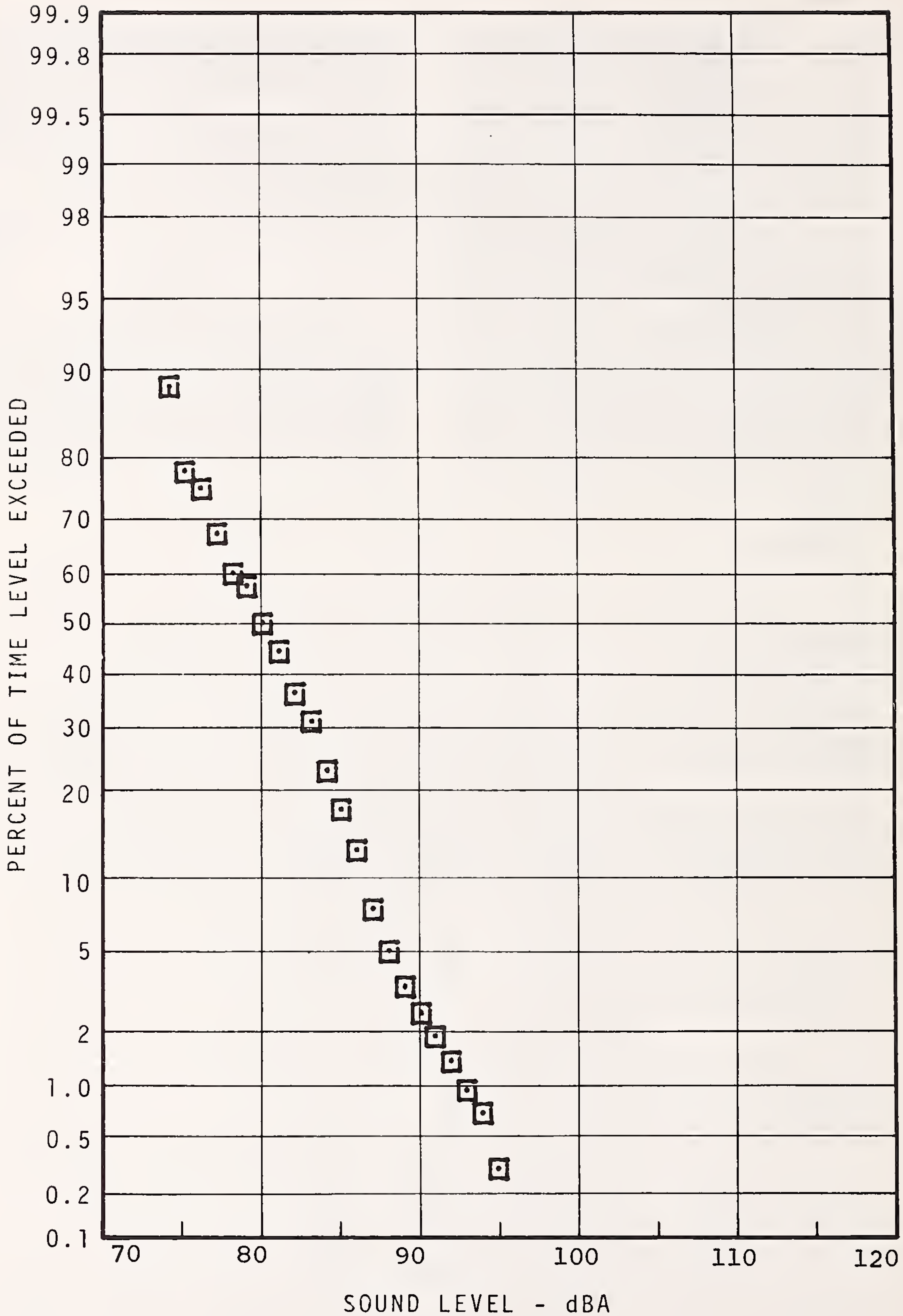


FIGURE 5.89. BUDD IN-CAR STATISTICAL DISTRIBUTION
LINDENWOLD-TO-PHILA., CENTER CAR
SINGLE CAR

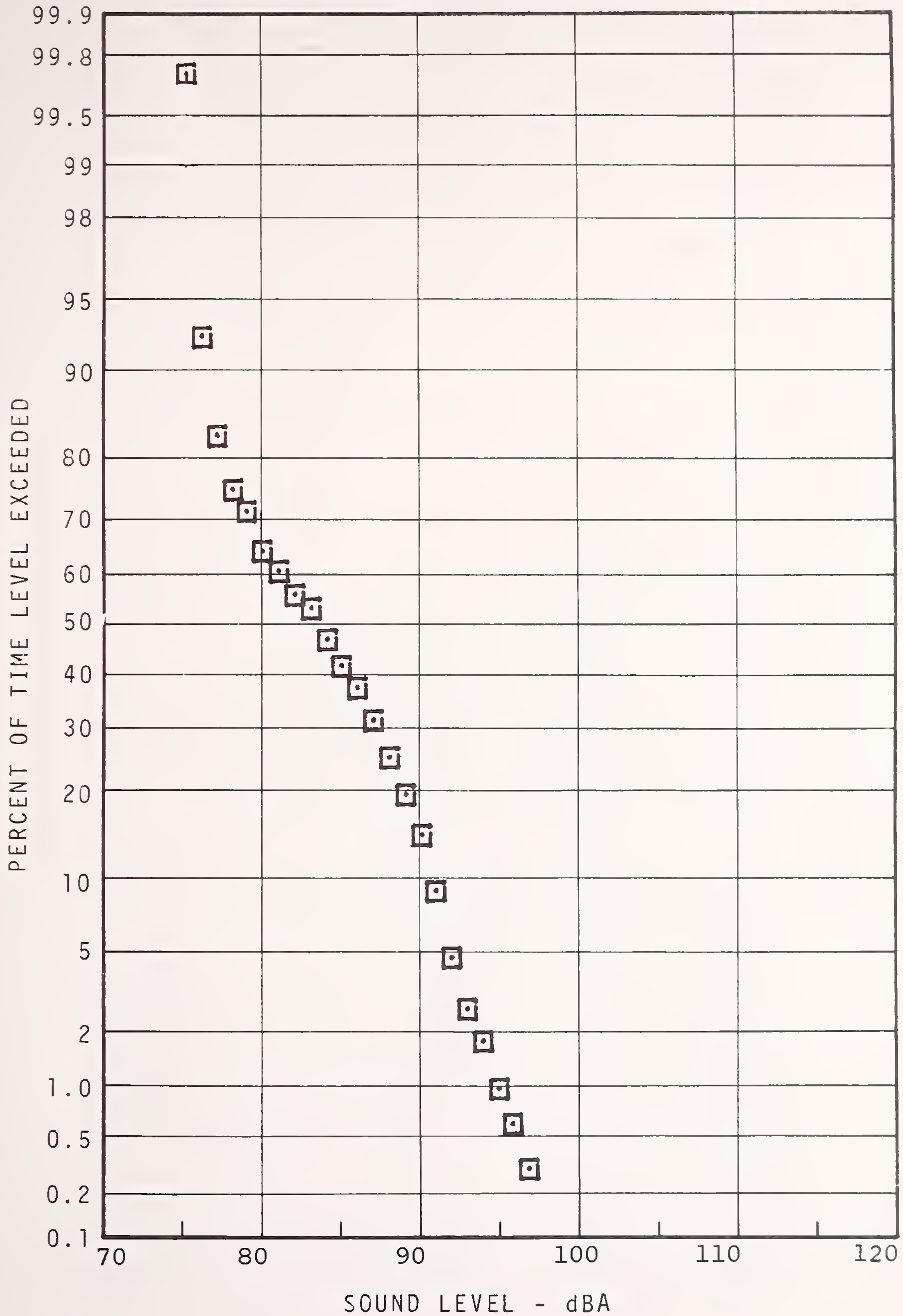


FIGURE 5.90. BUDD IN-CAR STATISTICAL DISTRIBUTION
LINDENWOLD-TO-PHILA., OVER TRUCK
SINGLE CAR

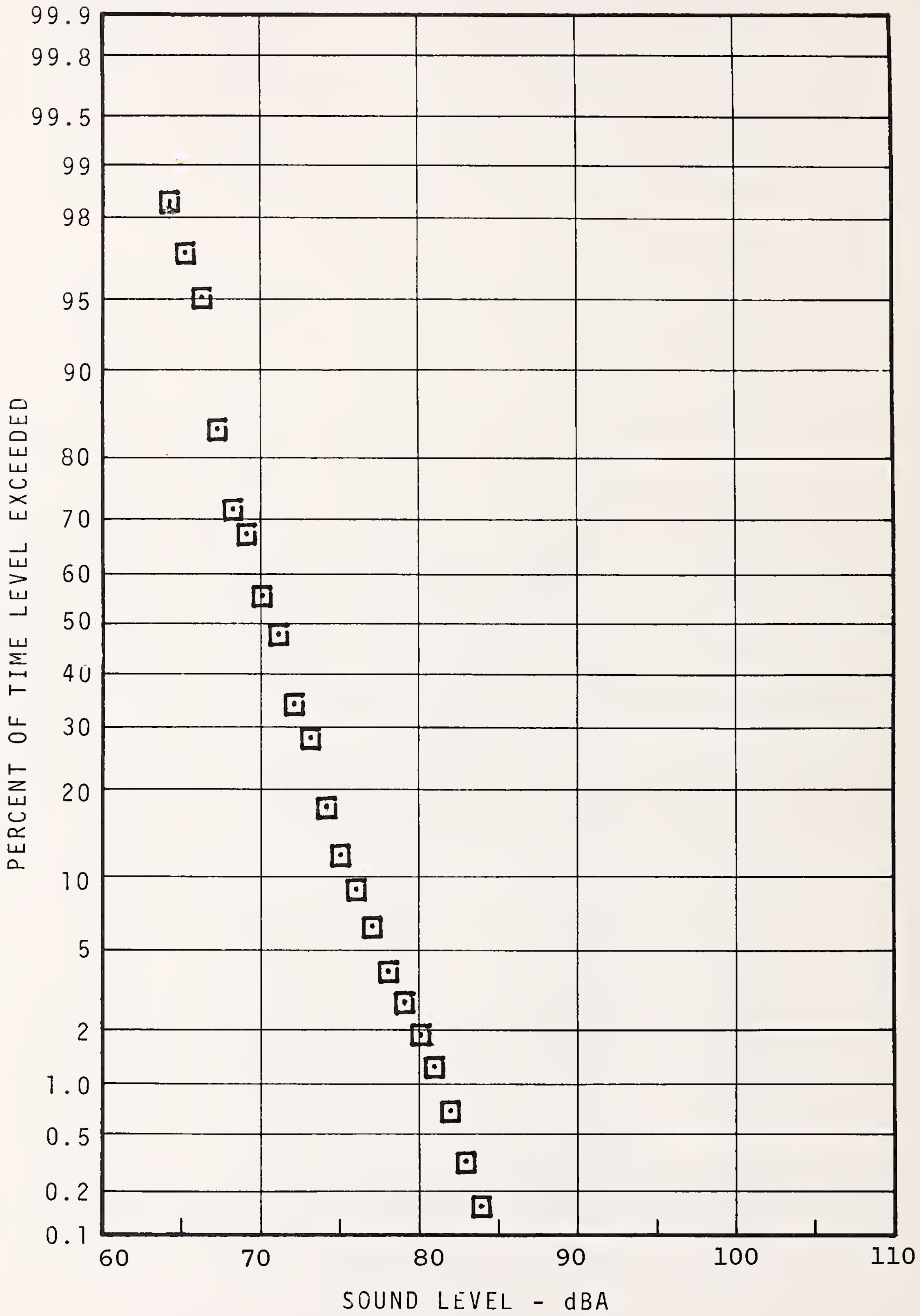


FIGURE 5.91. BUDD IN-CAR STATISTICAL DISTRIBUTION, PHILA.-TO-LINDENWOLD, CENTER CAR SINGLE CAR

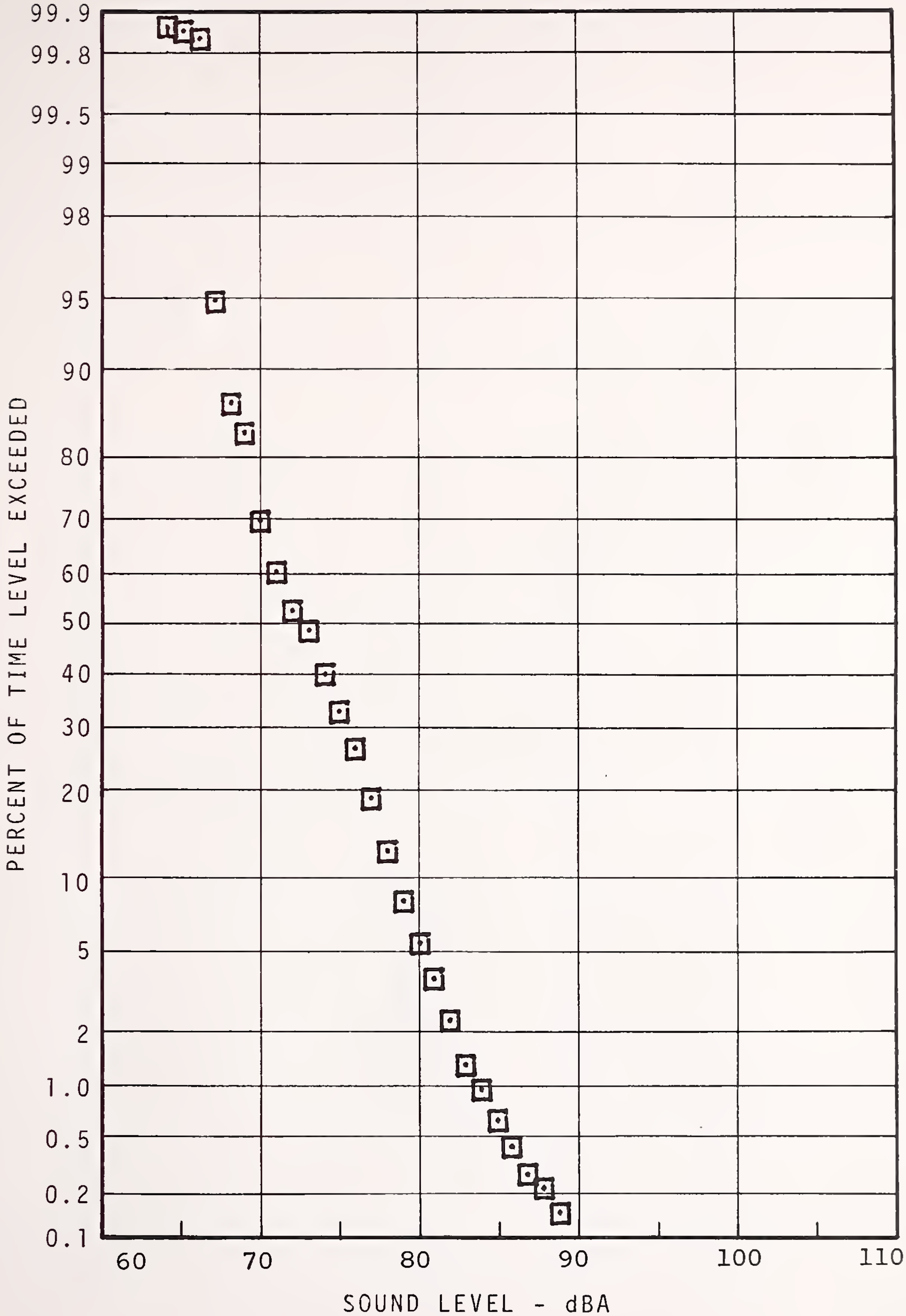


FIGURE 5.92. BUDD IN-CAR STATISTICAL DISTRIBUTION, PHILA.-TO-LINDENWOLD, OVER TRUCK SINGLE CAR

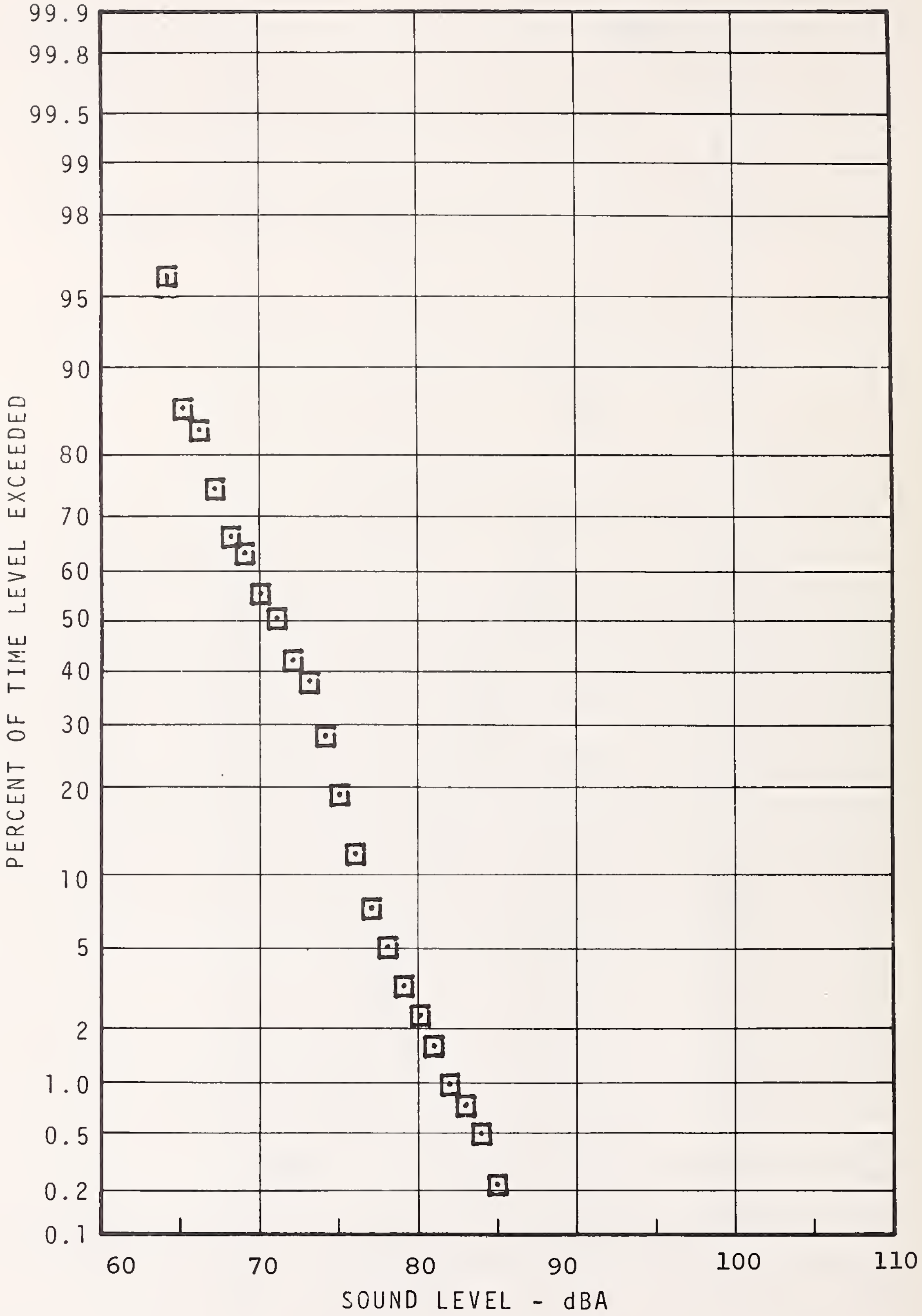


FIGURE 5.93. BUDD IN-CAR STATISTICAL DISTRIBUTION
LINDENWOLD-TO-PHILA., CENTER CAR
DOUBLE CAR

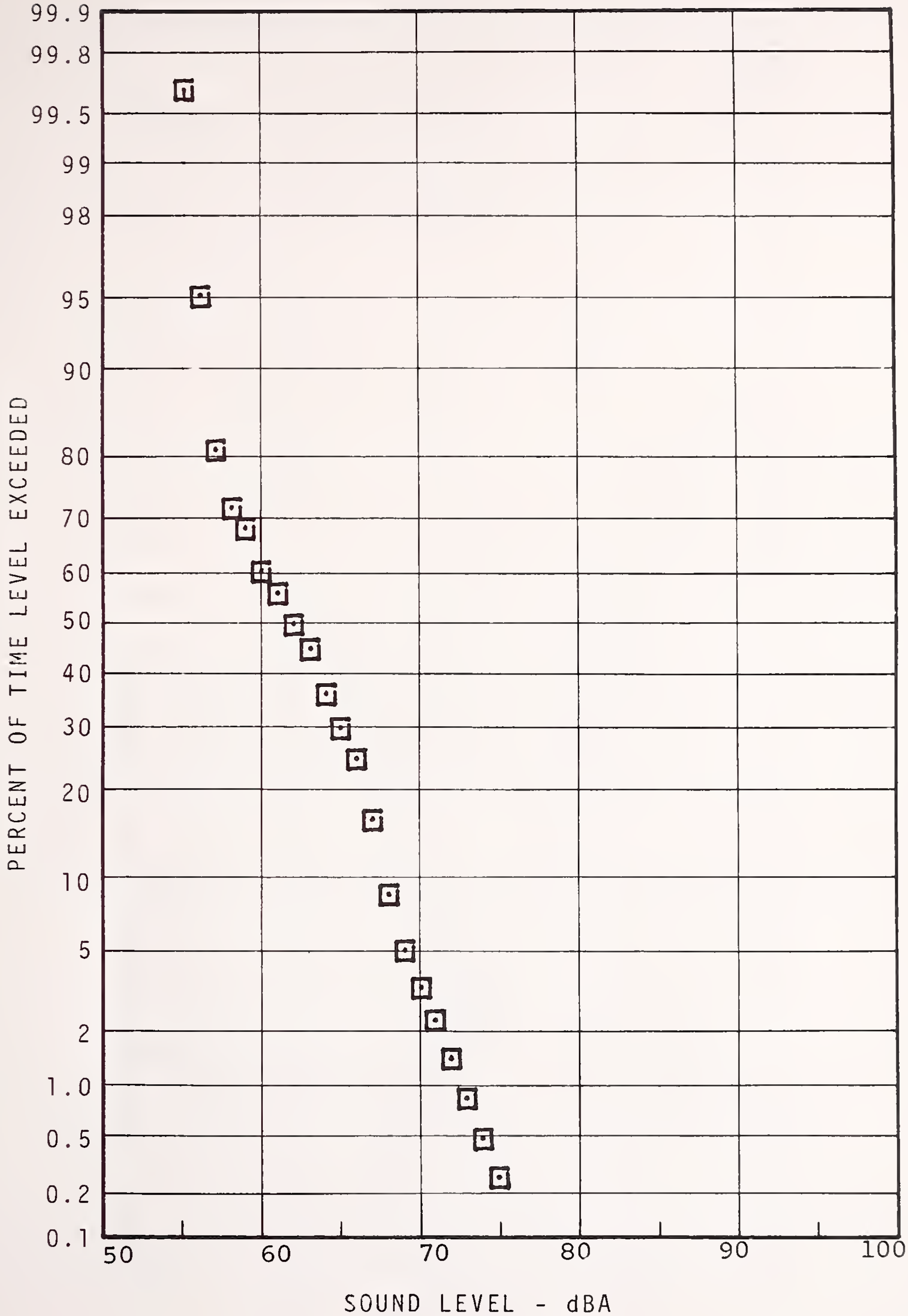


FIGURE 5.94. BUDD IN-CAR STATISTICAL DISTRIBUTION, LINDENWOLD-TO-PHILA., OVER TRUCK DOUBLE CAR

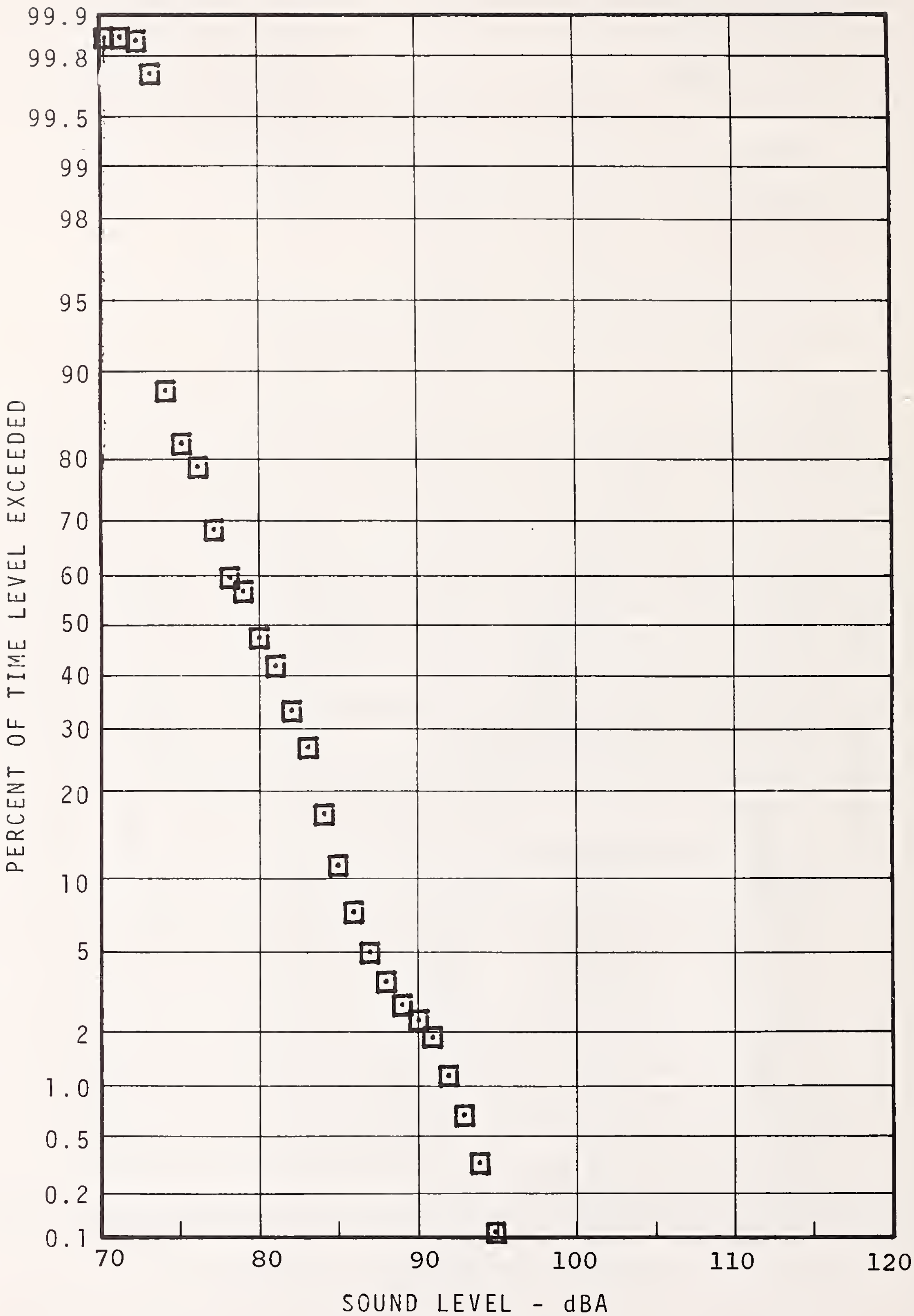


FIGURE 5.95. BUDD IN-CAR STATISTICAL DISTRIBUTION
PHILA.-TO-LINDENWOLD, CENTER CAR
DOUBLE CAR

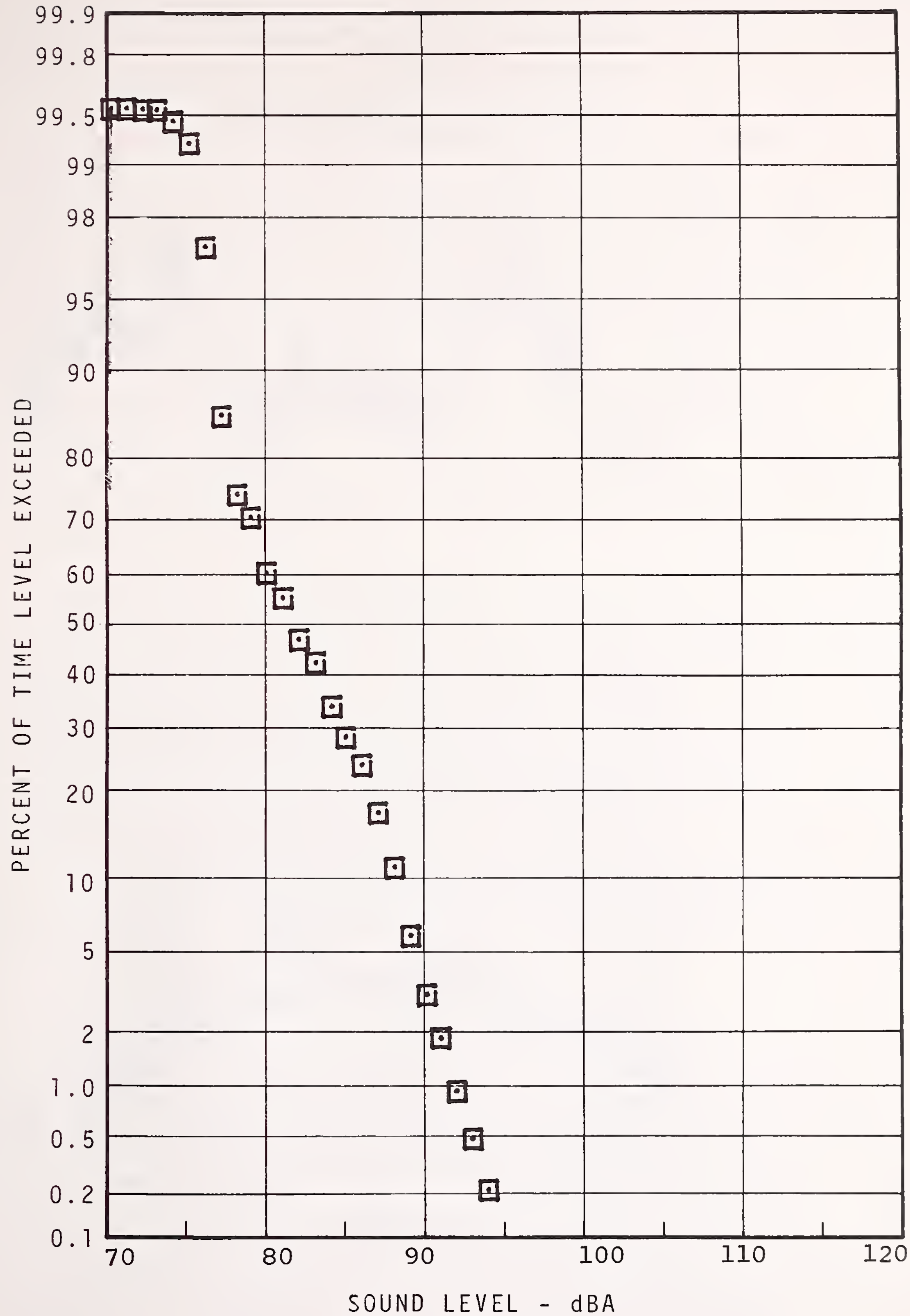


FIGURE 5.96. BUDD IN-CAR STATISTICAL DISTRIBUTION PHILA.-TO-LINDENWOLD, OVER TRUCK DOUBLE CAR

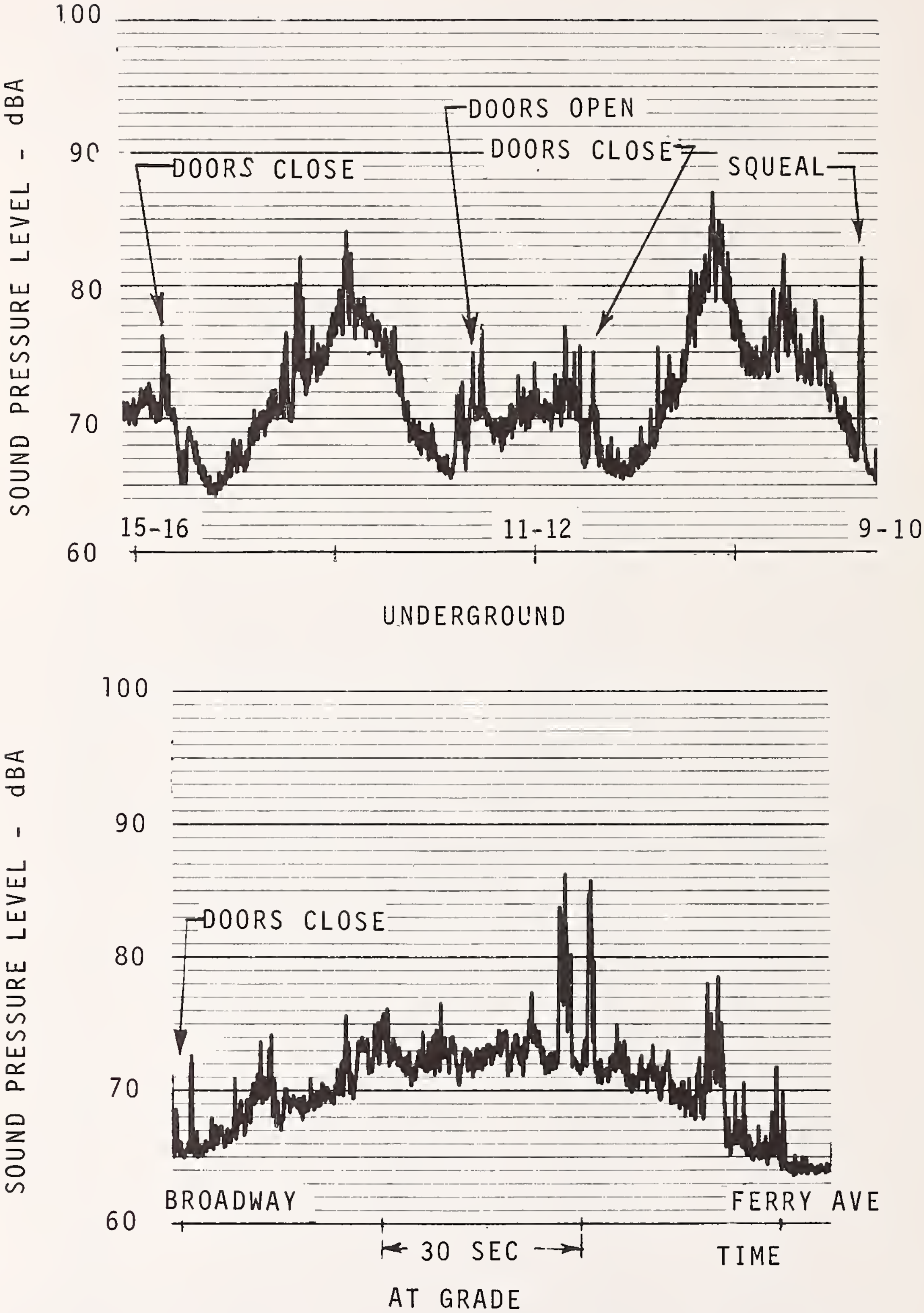


FIGURE 5.97. TIME HISTORY OF IN CAR NOISE ENVIRONMENT PATCO HIGH SPEED LINE

6. TRANSIT SYSTEM LINE SUMMARY

6.1 General

The data reported in Section 5, recorded for representative community, station platform and in-car locations, is summarized for the entire line in the following tables and illustrations. For example, general information regarding system operating factors (cars/train, headway, noise measurement periods) are presented in Table 6.1 to illustrate the rationale for selecting time intervals, or 'windows' when noise measurements were obtained. Although daytime measurements were used for illustration purposes in the tables, calculation of day-night equivalent sound levels have been based on daytime, rush hour, evening, and night measurements. The quantities used in the L_{dn} calculation have also been identified in Table 6.1.

Tables summarizing noise recorded at each community and station location evaluated in the program have been included in Section 5. This information has been further generalized to provide an over-all view of the noise climate of the PATCO system and this data is presented in Table 6.2. Wayside noise shown represents an average of the passby maximum levels in one direction analyzed as reported in Section 4. Station noise reported in this same table represents an average of the maximum level L_A(Max) recorded for each train observed during the recorded interval. This maximum level may occur either for the arrival or departure of the train. In-car data shown represents the plateau level achieved at a center car location between stations. A summary of PATCO track construction is presented in Figure 6.1.

6.2 Community Noise

Noise levels measured for each type of segment, and illustrated in Table 6.2, are representative of other similar track segments for that line. For example, measurements which were taken at the elevated embankment site between Collingswood and Westmont apply also to the elevated embankment sites which were not measured, between Broadway and Ferry Ave, Ferry Ave. and Collingswood, Westmont and Haddonfield and east of Haddonfield. The type of community along the right-of-way, its distance (D) from the near track to most nearby

TABLE 6.1. GENERALIZED OPERATING SUMMARY AND INPUT FOR L_{dn} CALCULATION
PORT AUTHORITY TRANSIT CORPORATION

	AM						PM				AM	
TIME OF DAY	6	8	10	12	2	4	6	8	10	12	2	4
CARS/TRAIN	2	6		2		6	2		1		2	
HEADWAY, MIN	15 | 10	5		7½		6-2		7½		10 | 15	60	
MEAS. WINDOW PATCO	NIGHT	RUSH		DAY		RUSH		EVE			NIGHT	
PROGRAM				DAY		RUSH		EVE			NIGHT	
WEIGHTING FACTOR →	10	←			1			→	←		10	→

Period	Meas. L_{eq}	w_i	T (hrs.)
5-6:30	NIGHT	10	1.5
6:30-7	RUSH	10	0.5
7-9:30	RUSH	1	2.5
9:30-3:30	DAY	1	6
3:30-6:30	RUSH	1	3
6:30-10	EVE	10	3.5
10-12	EVE	10	2
12-5	NIGHT	10	5

TABLE 6.2. NOISE MEASUREMENT SUMMARY - PATCO TRANSIT SYSTEM - DAYTIME

Station	Inter Station Distance (Miles)	Average Time Between Stations (Min.)	Track Constr.	No. Cars Per Train	Type Roadbed	Wayside Noise dB A 15m - Near Track		A	B	C	In-Station Noise[2] dB A	In-Car Noise Mid Car dB A Single	Double
15th-16th St. Phila.			JOINTED & WELDED RAIL: ½ TIMBER IN CONCRETE	2	UNDERGROUND						86		
	0.28	1			UNDERGROUND							80	77
12th-13th St.					UNDERGROUND								
	0.29	1			UNDERGROUND							84	82
9th-10th St.					UNDERGROUND						89		
	0.43	2			UNDERGROUND							77	75
8th St.					UNDERGROUND								
	2.28	5			B.F. BRIDGE	82[1] (CURVE)						73	72
City Hall, Camden					UNDERGROUND								
	0.25	1			UNDERGROUND							76	80
Broadway					UNDERGROUND		D	100	50		84[1] (Curve)		
	2.16	3	Welded Rail, Wood Tie in Rock Ballast		EL EMB		L	10	12			73	75
Ferry Ave.					EL EMB		D	100	50		70		
	1.61	2			EL EMB	94 (CONC VIA)	L	7	10			73	74
Collingswood					CONC. VIADUCT		D	—	75		74		
	1.05	2			EL EMB	83 (EL EMB)	L	—	11			73	74
Westmont					Concrete viaduct	93 (CONC VIA)	D	100	100	—			
	0.87	1			EL EMB.		L	3	3	3		72	74
Haddonfield					In Cut	76 (IN CUT)	D	50	150	—	80		
	3.19	3			EL EMB		L	11	13	9		76	76
Ashland					EL EMB		D	—	200	—			
	1.79	2			EL EMB		L	—	2	17		76	76
Lindenwold					EL EMB								
	14.20 mi	23. min.											

1. - SQUEAL SITE (CAMDEN)
2. - CENTER OF STOPPED TRAIN (AVG OF MAX. ENT, DEP, NEAR & FAR TRACKS)

A - INDUSTRIAL/COMMERCIAL
B - RESIDENTIAL
C - OPEN (> 100m)
D - DISTANCE FROM RIGHT-OF-WAY TO BUILDING LINE - FT.
L - LENGTH OF SINGLE TRACK AFFECTED - THOU'S OF FT.

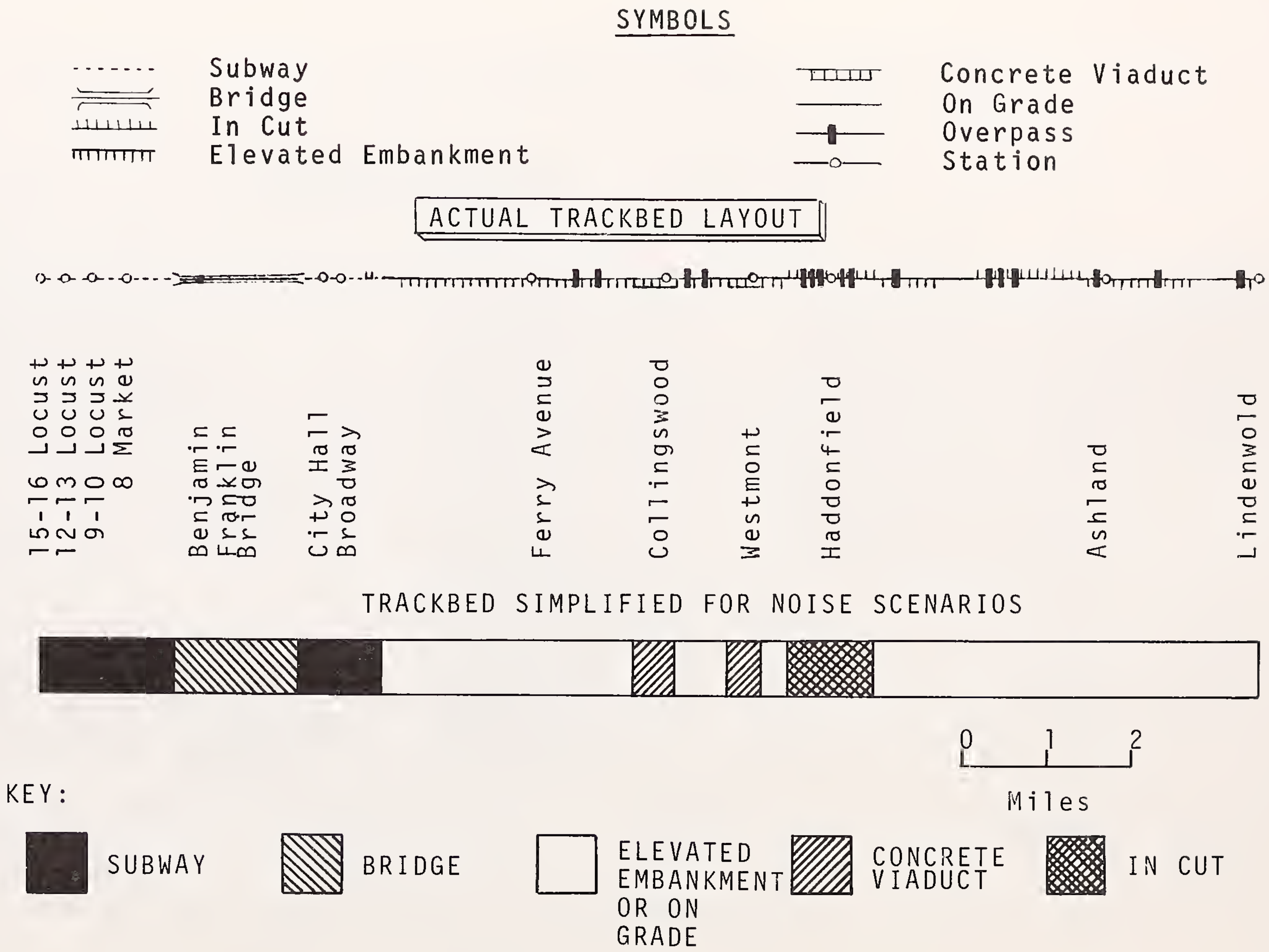


FIGURE 6.1. PATCO LINDENWOLD LINE- TRACK CONSTRUCTION SUMMARY

structures and the length of right-of-way (L) associated with industrial, residential and open field are also shown. Since each side of the right-of-way may border varying types of communities, the distance (L) shown in Table 6.2 between stations actually totals twice the inter-station distance.

The noise of the PATCO system in the community appears to be quite acceptable based on the lack of complaints received by PATCO. Where the system operates underground, it is inaudible at street level and this was verified at several locations and by several observers. Noise of the system measured in the community is highest where the roadbed is elevated on concrete viaduct. It is thought that this results partly due to noise radiated from the structure, but primarily from direct radiation of the undercar equipment and wheel/rail noise to a wayside observer that would normally be reflected and scattered from earth and ballast at the side of the right-of-way.

6.3 Station Noise

Lowest station noise levels were measured where the platform was located on elevated embankment. The combination of earth fill and reduced ground reflecting surface area appears to be the reason for this. Stations located on concrete viaduct exhibited slightly higher levels (4 dBA) with the station located in a cut (Haddonfield) displaying the highest measured level except for subway operation (80 dBA). The sound channel created by the concrete sidewalls of the cut results in higher levels for station platform patrons for greater lengths of time than for any other type of station above ground.

At the Benjamin Franklin Bridge Plaza, noise levels are higher than for any above-ground stations as this is a location where wheel squeal is generated. Rails are lubricated in this region when squeal amplitude builds up. Noise levels measured during the survey were lower than observed during the pre-measurement site selection survey.

As might be anticipated, the underground stations display the highest noise signatures of all those measured on the PATCO system.

On-line stations underground have noise levels which are nearly 20 dBA higher than the above ground stations located on elevated embankment. The terminal at 15th-16th/Locust has a 3 dBA lower noise signature due to slower approach speeds to the station. In each case, reverberation times appear to be substantially longer than for above-ground stations, although no measurements were taken to document this statement.

6.4 In-Car Noise

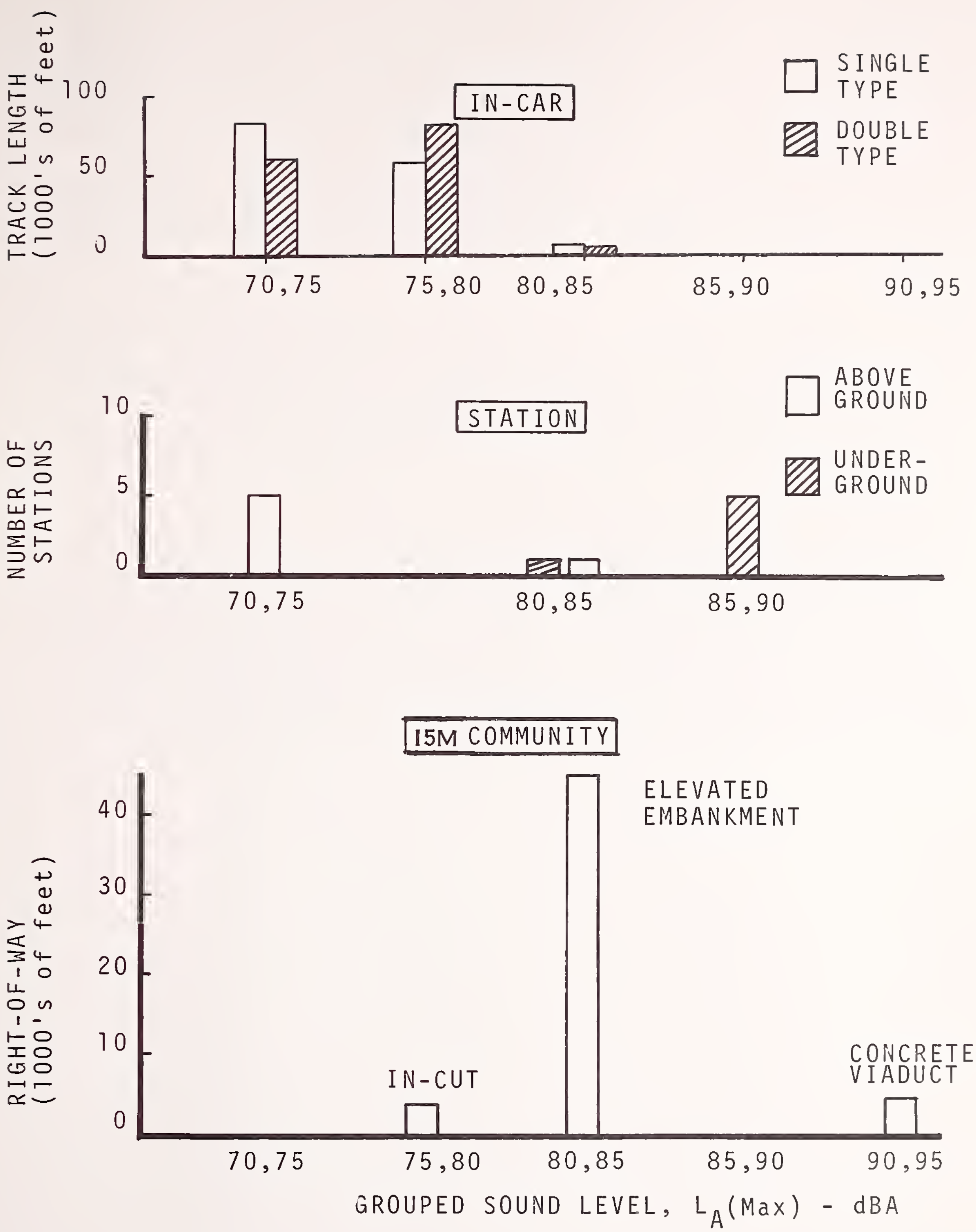
In-car noise is lowest above ground and during operation on elevated embankment and concrete viaduct. East of Westmont, trains operate in a cut with concrete vertical walls, thus increasing the noise over previous at-grade stations. East of Haddonfield, the longer inter-station distances allow higher speeds. Crossing the Delaware River bridge, levels in the car are lower than in either Camden or Philadelphia since operation within both cities is underground. Noise in the car is 5-10 dBA higher in the subway than above ground due to the reflective, reverberant field produced by that environment. Wheel squeal is produced on most underground curves in the subway.

6.5 PATCO Noise Summary

A graphic summary of community, station and in-car noise at PATCO is presented in Figure 6.2. The levels have been grouped into 5 dBA ranges of noise from 70-75, 75-80, 80-85, 85-90 and 90-95 dBA. It should be noted that in-car measurements were obtained in the second car of a multicar train and the notation on Figure 6.2 refering to single type and double type cars is meant to differeniate between cars which are independently capable of operation (single) as opposed to those which operate only as permanently coupled pairs (double).

Patrons in underground stations are exposed to higher noise levels than patrons at stations located on elevated embankment. Noise levels at Haddonfield (located in a cut) lie between those measured for underground and elevated embankment stations.

It should be noted that while no attempt was made to measure vehicle speeds during passby in high speed territory, at each wayside location the trains were operating at equivalent speed somewhat below the maximum of 75 mph (120 kph). At the Benjamin Franklin Bridge Plaza train speeds were substantially lower, approximately 30 mph (48 kph) when eastbound.



NOTE: GROUPED SOUND LEVEL INTERVAL INCLUDES LOWER, BUT NOT UPPER ENDPOINT.

FIGURE 6.2. SUMMARY OF PATCO NOISE ENVIRONMENT

Lowest wayside noise levels were measured when the system operates in a cut, due to the reflection of acoustic energy vertically. However, the concentration of acoustic energy in the cut causes Haddonfield Station patrons to be aware of an approaching or departing train for 20-30 seconds longer than patrons on other station platforms. However, the 15m community noise with the trains operating in a cut was 17-18 dBA lower than measured adjacent to concrete viaduct.

Data recorded adjacent to elevated embankment was 10 dBA lower than for concrete viaduct but 7 dBA higher than for operation in a cut. Although the system operates at grade at certain locations between Haddonfield and Lindenwold, the total percentage is small compared with the other designated roadbed types, and for simplicity, these sections have been included in the elevated embankment category. It is estimated that the levels adjacent to the at-grade sections would not differ by more than 3 dBA from those measured at elevated embankment sites.

Noise at the wayside (15m) can be characterized predominantly by the elevated embankment site. Approximatel 86% of the community noise lies in the grouped data from 80-85 dBA with remaining wayside characterized nearly equally between concrete viaduct (90-95) and in-cut levels (75-80).

7. REFERENCES

1. Kurzweil, L.G.; Lotz, R.; and Apgar, E.G.; "Noise Assessment and Abatement in Rapid Transit Systems"; Report No. UMTA-MA-06-0025-74-8; September 1974.

2. Webster, W.J. and Farinacci, J.W., "Use of Graphic Level Recorders as Indicating Instruments, Part 1: Meeting the Specifications of a Sound Level Meter", Bureau of Noise, New York State Department of Environmental Conservation, Albany, New York, 1974.

3. Shultz, T.J., "Development of an Acoustic Rating Scale for Assessing Annoyance Caused by Wheel/Rail Noise in Urban Mass Transit", Report No. UMTA-MA-06-0025-74-2, February 1974.

APPENDIX A

A STATISTICAL ANALYSIS
OF
SEPTA BROAD STREET SUBWAY STATION NOISE DATA

ASSESSMENT OF URBAN RAIL NOISE CLIMATES
AND
ABATEMENT OPTIONS
FOR
BART, CTS, PATCO AND SEPTA

Prepared by
L. Bukowski Doyle and R. H. Spencer
THE BOEING VERTOL COMPANY
for
DEPARTMENT OF TRANSPORTATION
Transportation Systems Center

CONTRACT DOT-TSC-850

STATISTICAL ANALYSIS OF STATION NOISE MEASUREMENTS

BACKGROUND AND PURPOSE

In sampling the noise climate for the rapid transit systems included in the Urban Rail Noise Assessment Program, it was necessary to establish the number of train passbys required for the data sample to determine whether future reductions of 5dBA or more in system noise could be detected and whether they would be significant for a 95% confidence level. For station noise, additional questions had to be addressed. For example, a transit system patron is exposed to arrival and departure noise and trains operating on near and far tracks and, in some instances, to express train passby noise. It was necessary to determine if all noise events were from the same population and therefore whether to be grouped or separated for the study. Data was sampled in an underground station on the SEPTA Broad Street Subway to investigate these questions. Snyder Avenue was considered typical of many stations on the system.

NOISE SURVEY

One channel of data was recorded on the Snyder Avenue Station northbound platform at the midpoint of a stopped train at standing patron ear level (1.6m above platform level, 2 meters from the platform edge). Six train passbys were recorded in each direction during a one-half hour continuous noise survey.

Time histories of A-weighted sound levels were produced on a B&K 2305 graphic level recorder, set as follows:

Potentiometer	50 dB
Potentiometer Range	50 dB
Lower Limiting Frequency	10 Hz
Writing Speed	200mm/sec.
Rectifier Response	rms
Paper Width	100mm

Peak levels for arriving and departing trains were read for both north- and southbound trains (Table 1).

TABLE I

PEAK A-WEIGHTED SOUND PRESSURE LEVELS - SNYDER AVE. STATION

	L_A(Max) ~ dBA NORTHBOUND ARRIVAL	NORTHBOUND DEPARTURE	SOUTHBOUND ARRIVAL	SOUTHBOUND DEPARTURE
	96	-	101	-
	98	-	95	-
	94	97	97	101
	97	95	97	98
	96	96	100	106
	97	95	97	101
$\bar{x}$	96.3	95.8	97.8	101.5
s	1.4	0.96	2.2	3.3

Means ($\bar{x}$) and standard deviations (s) were calculated for the data samples as follows:

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

where n is the sample size and

$$s = \left[\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1} \right]^{1/2}$$

ANALYSIS OF DATA

Arrivals and departures for both north- and southbound trains were treated as separate events in order to determine whether the recorded samples were from the same population. Also, it was desired to establish with 95% confidence the number of events (passbys) required to ascertain that a future reduction in system noise of 5 dBA or more could be detected when measured by the same methods as those outlined (e.g., same sample size, microphone location, etc.).

The general relationship between mean, standard deviation and sample size for a 95% confidence envelope is known, but in order to establish the sample size it is necessary to secure information on $\bar{x}$ and s for the station noise data after the system noise has been reduced. This, of course, is not a known value until it can be measured. However, it can be assumed that a 5 dBA reduction in the original levels could be achieved and that the standard deviation for the new data set would not differ substantially from the recorded baseline data. With these assumptions, Table II was established.

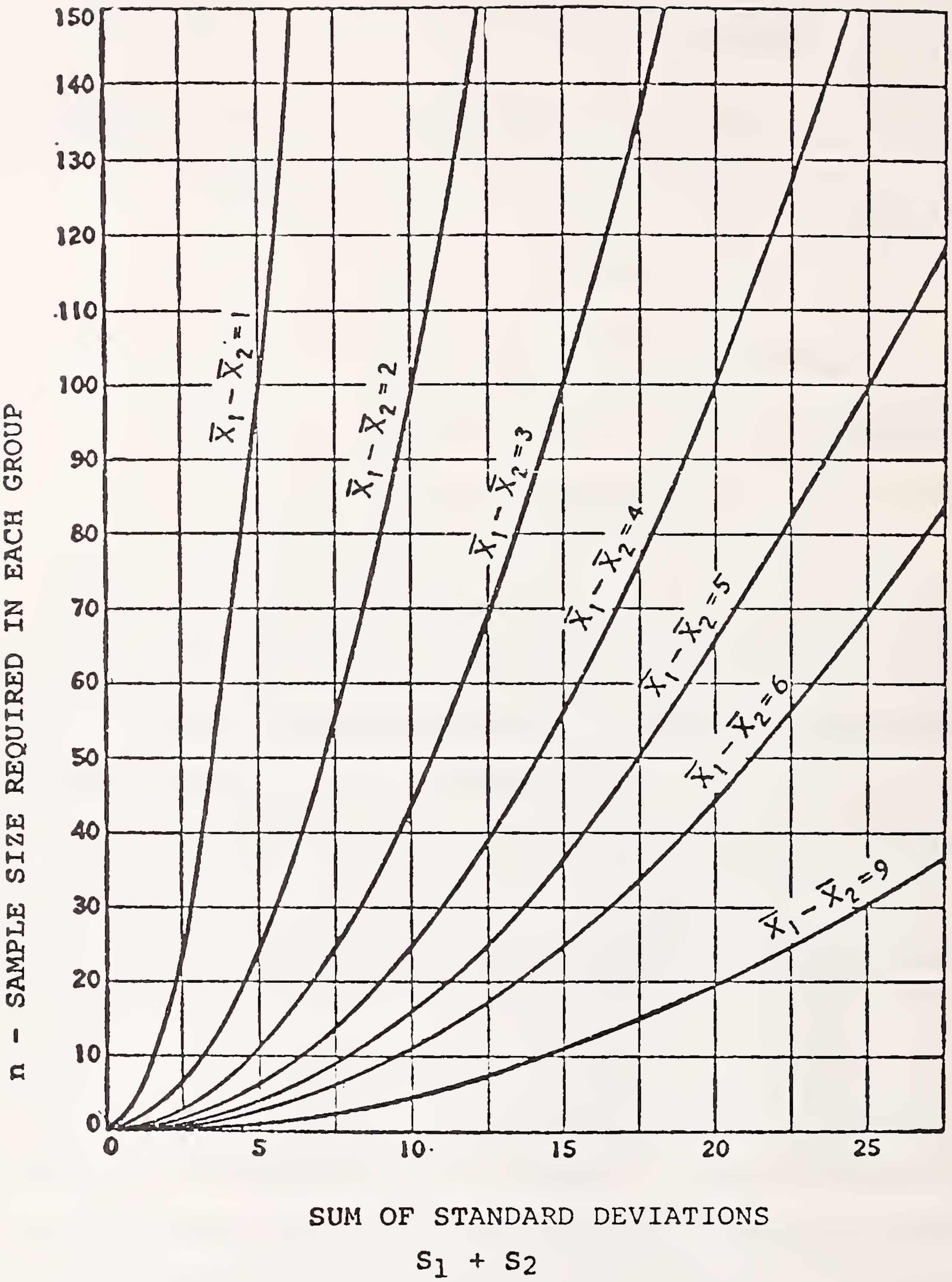
TABLE II

MEAN AND STANDARD DEVIATION OF PASSBY EVENTS

		ARRIVAL		DEPARTURE	
		BASELINE	HYPOTHESIZED	BASELINE	HYPOTHESIZED
NORTHBOUND TRAINS	$\bar{x}$	96.3	91.3	95.8	90.8
	s	1.4	1.4	0.96	0.96
	n	6	6	4	4
SOUTHBOUND TRAINS	$\bar{x}$	97.8	92.8	101.5	96.5
	s	2.2	2.2	3.3	3.3
	n	6	6	4	4

The statistical procedure of analysis of variance has shown that northbound arriving and departing trains and southbound arriving trains can be considered to be from the same population; southbound departing trains however, cannot be considered to be in this population. The difference is thought to result from higher train speeds for southbound departing trains.

The relationship of mean, standard deviation and sample size required to establish significant differences between two sets of data is shown in Figure 1. It is based on the sum of the sample standard deviations and the difference in the sample means. Furthermore, a 95% confidence envelope and equal sample sizes for both groups are assumed. Using the southbound arrival information as an illustration, the baseline data yields a mean of $\bar{x}_1 = 97.8$ and a standard deviation of $s_1 = 2.2$;



FROM L. R. HILL AND P.L. SCHMIDT "GRAPHICAL STATISTICS - AN ENGINEERING APPROACH," WESTINGHOUSE ENGR. MARCH 1950 AND MAY 1950.

FIGURE 1 - NUMBER OF TESTS REQUIRED TO ESTABLISH SIGNIFICANT DIFFERENCES BETWEEN TWO DATA SETS.

the hypothesized data has been reduced by 5 dBA, the minimum desired reduction in system noise, and the standard deviation has been retained at $s_2 = 2.2$. The sample size for both is $n = 6$.

$$s_1 + s_2 = 4.4 \quad \text{and}$$

$$\bar{x}_1 - \bar{x}_2 = 5$$

For this condition, 4 samples in each group are shown to be sufficient to detect a difference in the 2 sets of data (Figure 1). Table III presents the resulting sample sizes required for each set of data.

TABLE III

SAMPLE SIZE FOR STATION DATA

	NORTHBOUND ARRIVAL	NORTHBOUND DEPARTURE	SOUTHBOUND ARRIVAL	SOUTHBOUND DEPARTURE
$\bar{x}_1 - \bar{x}_2$	5	5	5	5
$s_1 + s_2$	2.8	1.92	4.4	6.6
Reqd.Sample Size	3	1	4	6

STUDENT t TEST

To determine if significant differences could be detected in the two sets of data (baseline and hypothesized) the "Student t" test was utilized. The test involves the calculation of the standard deviation of the differences of means, where

$$t = \frac{\text{difference between the means}}{\text{standard deviation of the difference}}$$

If t exceeds certain tabulated values (see Ref. 1), it can be stated there is a difference between two sets of data. The t test assumes that both populations are normally distributed with differing means (μ_1 and μ_2), but similar standard deviations ($\sigma_1 = \sigma_2$). Sample parameters are used to test the population parameters.

A reduction in system noise by 5 dBA was tested as follows:

Test the hypothesis:

$$H_o: \mu_1 - \mu_2 = 5$$

vs $$H_1: \mu_1 - \mu_2 > 5$$

The critical region for the test is:

$$\frac{\bar{x}_1 - \bar{x}_2 - (\mu_1 - \mu_2)}{S_w \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} > t_{n_1+n_2-2\,;\,\alpha}$$

where, $$S_w = \left[\frac{(n_1-1)\,s_1^2 + (n_2-1)\,S_2^2}{n_1 + n_2 - 2}\right]^{1/2}$$

and $\alpha = 0.05$ (i.e. 95% Confidence)

If the critical region is greater than the tabulated t value, the hypothesis must be rejected. From Table II and the baseline and hypothesized northbound arrival data:

MEASURED BASELINE	HYPOTHESIZED DATA
$\bar{x} = 96.3$	$x = 90.8$*
$s_1 = 1.4$	$s_2 = 1.4$
$n_1 = 6$	$n_2 = 6$

*Chosen so that $\bar{x}_1 - \bar{x}_2 \neq 5$, otherwise leading to a trivial case.

Sample calculation: t-test

MEASURED BASELINE	HYPOTHESIZED DATA
$\bar{x}_1 = 96.3$	$\bar{x}_2 = 90.8$
$s_1 = 1.4$	$s_2 = 1.4$
$n_1 = 6$	$n_2 = 6$

$$S_w = \left[\frac{(n_1-1)\,s_1^2 + (n_2-1)\,s_2^2}{n_1+n_2-2}\right]^{1/2}$$

$$= \left[\frac{(6-1)(1.4^2) + (6-1)(1.4)^2}{6+6-2}\right]^{1/2}$$

$$S_w = 1.4$$

From Ref 1; $t_{10};\ 0.05 = 1.812$

$$\frac{96.3 - 90.8 - (5)}{1.4\sqrt{1/6 + 1/6}} > 1.812$$

$$\frac{0.5}{1.4\ (0.578)} > 1.812$$

however, $0.619 \not> 1.812$

Therefore, the first hypothesis, H_o, may be accepted, i.e., the difference of the two means is equal to five.

The second hypothesis, H_1, may be accepted when:

$$\frac{(\bar{x}_1 - \bar{x}_2) - 5}{1.4\ (0.578)} > 1.812$$

or

$$\bar{x}_1 - \bar{x}_2 > (1.812)\ (1.4)\ (0.578) + 5$$

$$\bar{x}_1 - \bar{x}_2 > 6.47$$

CONFIDENCE INTERVALS

If $\bar{x}$ and s_2 are the mean and variance of a sample of size n, and are from normally distributed data $(N(\mu, \sigma^2))$ where μ, σ^2 are unknown, then the confidence interval

$$C.I. = \left[\bar{x} \pm t_{n-1;\ \alpha/2} \frac{s}{\sqrt{n}} \right]$$

is a $100(1-\alpha)\%$ confidence interval for μ. Even though the data set may not be normally distributed, the expression can be applied for most cases.

Sample calculation: Confidence Interval

Using the peak northbound arrival data:

$$C.I. = \left[\bar{x} \pm t_{n-1;\ \alpha/2} \frac{s}{\sqrt{n}} \right]$$

$= .05,\ 1 - \alpha = .95,\ \bar{x} = 96.3,\ s = 1.4,\ n = 6,$

$t_{5};\ 0.025 = 2.571$

$$= \left[96.3 \pm 2.571 \frac{1.4}{\sqrt{6}} \right]$$

$= 96.3 \pm 1.47$

C.I. = 94.8 to 97.8 dBA (95% C.I. for μ).

RESULTS AND CONCLUSIONS

Based on the data sample recorded and the results shown in Table III, it appears that a sample size of n = 6 is adequate for the Snyder Avenue data, considered representative for the Broad Street Subway. This statistical procedure will be followed for the remaining systems to be measured, namely, the

Market-Frankford Line at SEPTA and for CTS. In each case a representative station will be selected for the data sample. Ideally, this procedure should be carried out for each type of station as well as for each community measurement. However, it is adequate to select representative locations for evaluations of required sample sizes.

Although the t test could not be evaluated using actual data for the improved system (no revisions to system noise have been made), the hypothesized data which was chosen such that $\bar{x} - \bar{x}_2 > 5$ indicates that a 5 dBA reduction in noise level in fact can be detected, assuming that the sample size and standard deviation remain the same.

Analysis of variance has shown that northbound arriving and departing trains and southbound arriving trains are from the same population and can be grouped. Southbound departure data if treated statistically would have to be grouped separately for this set of data.

Ref.1 - Holscher, Harry H., Simplified Statistical Analysis, Handbook of Methods, Examples and Tables; Cashners Books, Boston, Mass. 1971.

APPENDIX B

REPORT OF INVENTIONS

A detailed review of the work performed under this contract and the material contained in this report has not disclosed any discoveries or inventions. The work reported here represents a data base of noise measurements on a specific transit system, suitably extrapolated to all locations in and around the system as to provide an assessment of existing noise levels.

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