UMTA-MA-06-0025-78-12

ISE ASSESSMENT OF THE GREATER CLEVELAND REGIONAL TRANSIT AUTHORITY HEAVY RAIL TRANSIT SYSTEM

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OCTOBER 1978

INTERIM REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF TECHNOLOGY DEVELOPMENT AND DEPLOYMENT
Office of Rail and Construction Technology
Washington DC 20590

NOTICE

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MA-06-0025-78-12		

4. Title and Subtitle
Noise Assessment of the Greater Cleveland Regional Transit Authority Heavy Rail Transit System

5. Report Date
October 1978

6. Performing Organization Code
8-2791

7. Author(s)
R. H. Spencer and E. G. Hinterkeuser

8. Performing Organization Report No.
DOT-TSC-UMTA-78-44

9. Performing Organization Name and Address
The Boeing Vertol Company *
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10. Work Unit No. (TRAIS)
R9743/UM949

11. Contract or Grant No.
DOT-TSC-850

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Office of Technology Development and Deployment
Office of Rail and Construction Technology
2100 Second Street S.W., Washington, D.C. 20590

13. Type of Report and Period Covered
Interim Report
October 1974-July 1975

14. Sponsoring Agency Code
UTD-30

15. Supplementary Notes
*Under contract to: U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, Cambridge, Massachusetts 02142.

16. Abstract

This report describes the noise climate on and near the Greater Cleveland Regional Transit Authority (RTA), formerly the Cleveland Transit System (CTS), Airport 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 RTA urban rail transit line has approximately 19 miles of two-way revenue track (of which about one mile is in subway), and 18 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), are estimated to be in the 80 to 84 dBA interval for 75 percent of the RTA route mileage in St. Louis cars, and for 95 percent of the route in modified Pullman cars. Sound levels in standard Pullman cars are in the 85 to 89 dBA interval for 63 percent of the RTA route. Wayside L_A(Max) levels, at 15m (50 ft) from the near track, are in the 90 to 99 dBA interval for all above ground route mileage. Station L_A(Max) levels range from 77 to 88 dBA and are in the 80 to 84 dBA interval for 89 percent of RTA 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.

17. Key Words
Noise, Rapid Transit, Transportation Noise, Measurement Methodology, Instrumentation, Data Analysis, Community Noise, Station Platform Noise, Vehicle Noise.

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	186	

Form DOT F 1700.7 (8-72)

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 Cleveland Transit System was provided by Mr. Elmer Malcomb. Dr. Leonard Kurzweil of the Transportation Systems Center directed the final technical editing of the report.

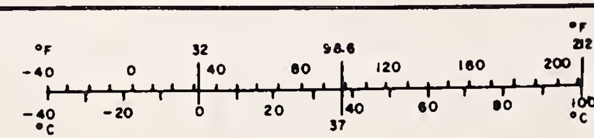
METRIC CONVERSION FACTORS

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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$L_A(\text{Max})$ - 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 - $L_A(\text{Max}) + 10 \log T_5$, in dBA

T_5 - Duration between the 5 dBA-down-from-$L_A(\text{Max})$ 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

$$W_i' \ (0700\text{-}1900) = 1$$

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

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

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 Greater Cleveland Regional Transit Authority (RTA) Airport Line, described in this report, consists of approximately 19 miles of two-way revenue track of which 9.5 are in-cut, 7.8 are at-grade, one mile is underground, and about 0.7 miles are on an elevated embankment.

Welded rail is used on the RTA with a track guage of 4 feet 8¼ inches, ¼ inch tighter than standard railroad gauge. The difference between wheel and track gauge appears to excite flange modes of the wheel which result in flange "singing."

St. Louis transit cars, built in 1955 to 1958 are in use, as well as Pullman cars built in 1967. The Pullman cars are air conditioned, but there are normally no acoustical absorption features employed in the car interior. Three experimental cars with cloth-upholstered seats and carpeting were in operation at the time noise measurements were taken, and noise levels inside these cars were about 5 dBA lower than in the standard Pullman cars.

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 RTA Airport Line.

TABLE 1.1. AVERAGE MAXIMUM A-WEIGHTED SOUND LEVEL DISTRIBUTIONS FOR THE RTA SYSTEM

	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)	0/0/0	0/0/5	75/37/95	25/63/0	0/0/0	0/0/0
Wayside at 15 m (50 ft) Distance (Percent of Above Ground Route Mileage)	0	0	0	0	49	51
Station Platform (Percent of Stations)	0	5.5	89	5.5	0	0

*St. Louis/Pullman/Modified Pullman Cars

2. INTRODUCTION

2.1 Program Scope

This report describes the noise climate of the Greater Cleveland Regional Transit Authority (RTA), formerly the Cleveland Transit System (CTS). The work is part of a noise assessment study by this contractor which included RTA, the Southeastern Pennsylvania Transportation Authority (SEPTA), the Port Authority Transit Corporation (PATCO), and the San Francisco Bay Area Rapid Transit (BART) System. 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, PATCO, 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 RTA 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 RTA, or Airport Rapid Rail System 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 RTA 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

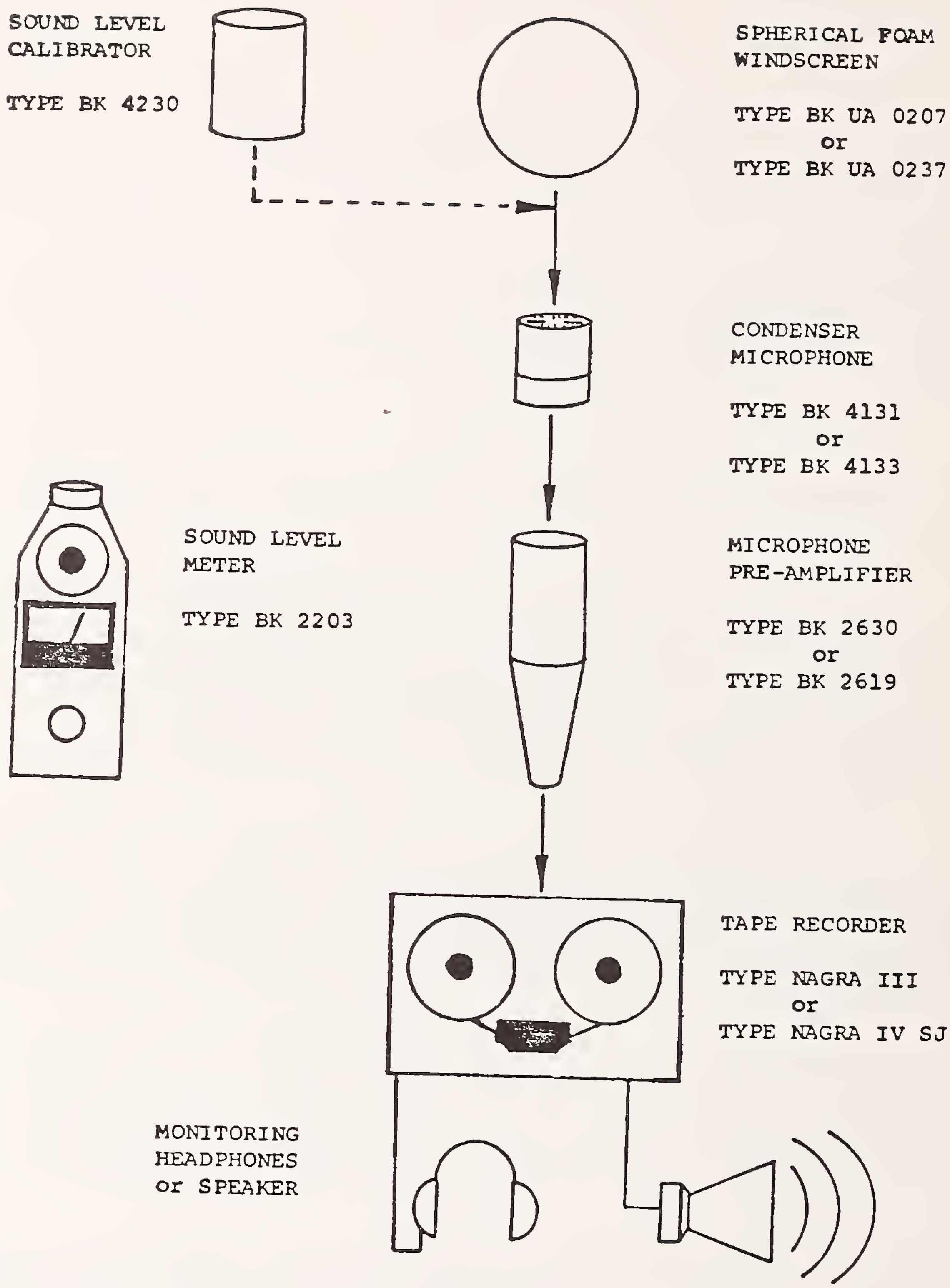


FIGURE 4.1. TYPICAL DATA ACQUISITION SYSTEM

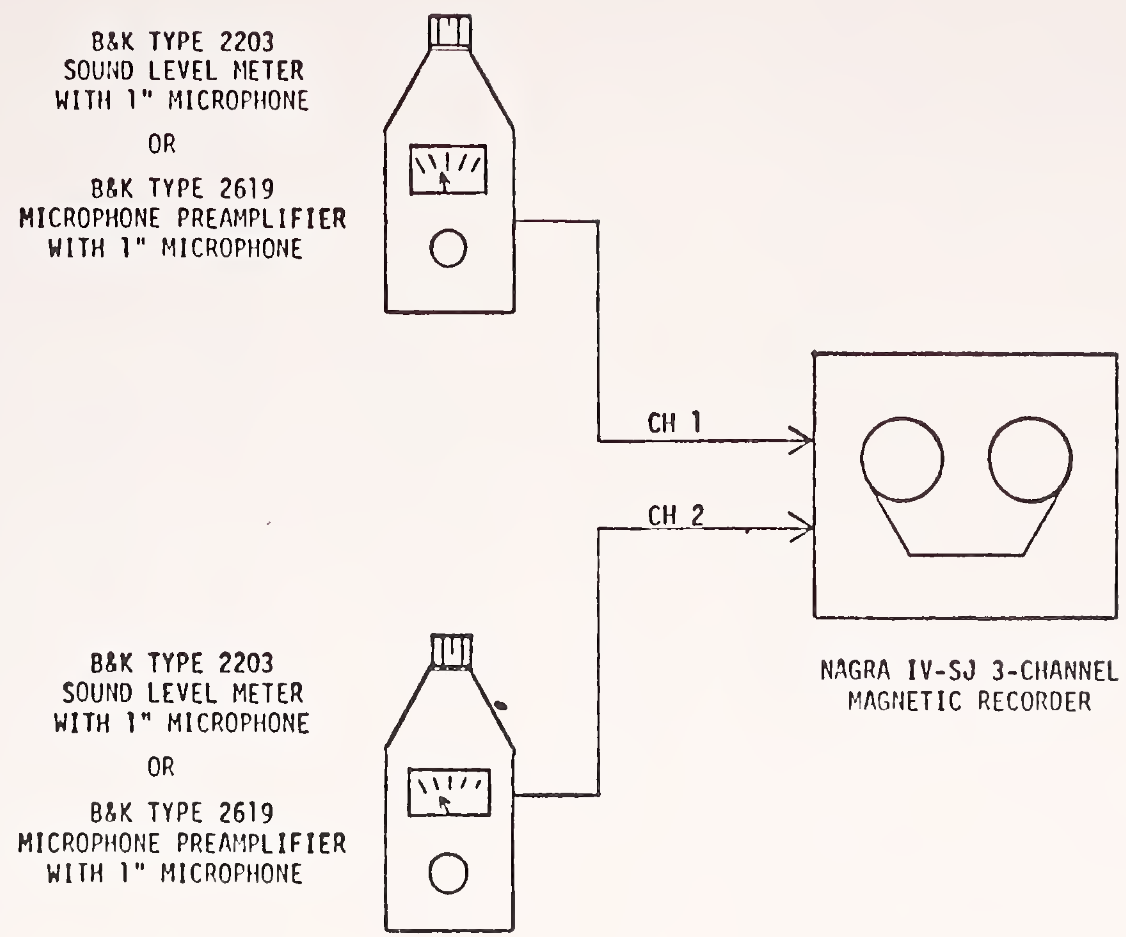


FIGURE 4.2. BLOCK DIAGRAM OF NOISE MEASUREMENT INSTRUMENTATION

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.

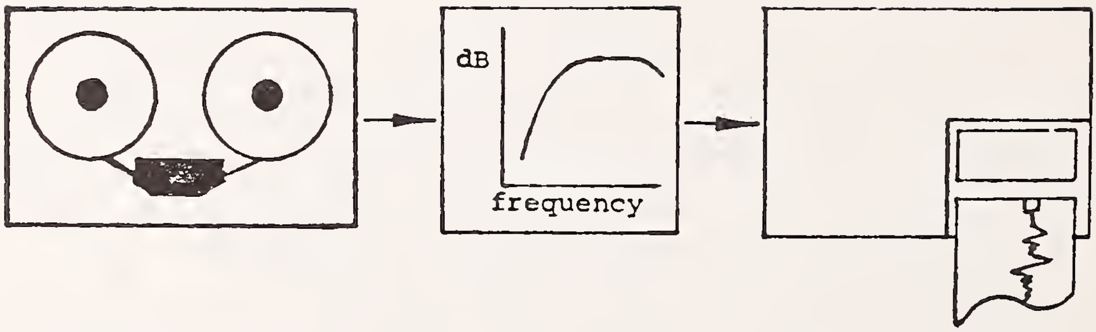
4.2 Data Analysis

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

- o Station Noise: Passby
  Train Arrival
  Train Departure
  Train Stopped
- o 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

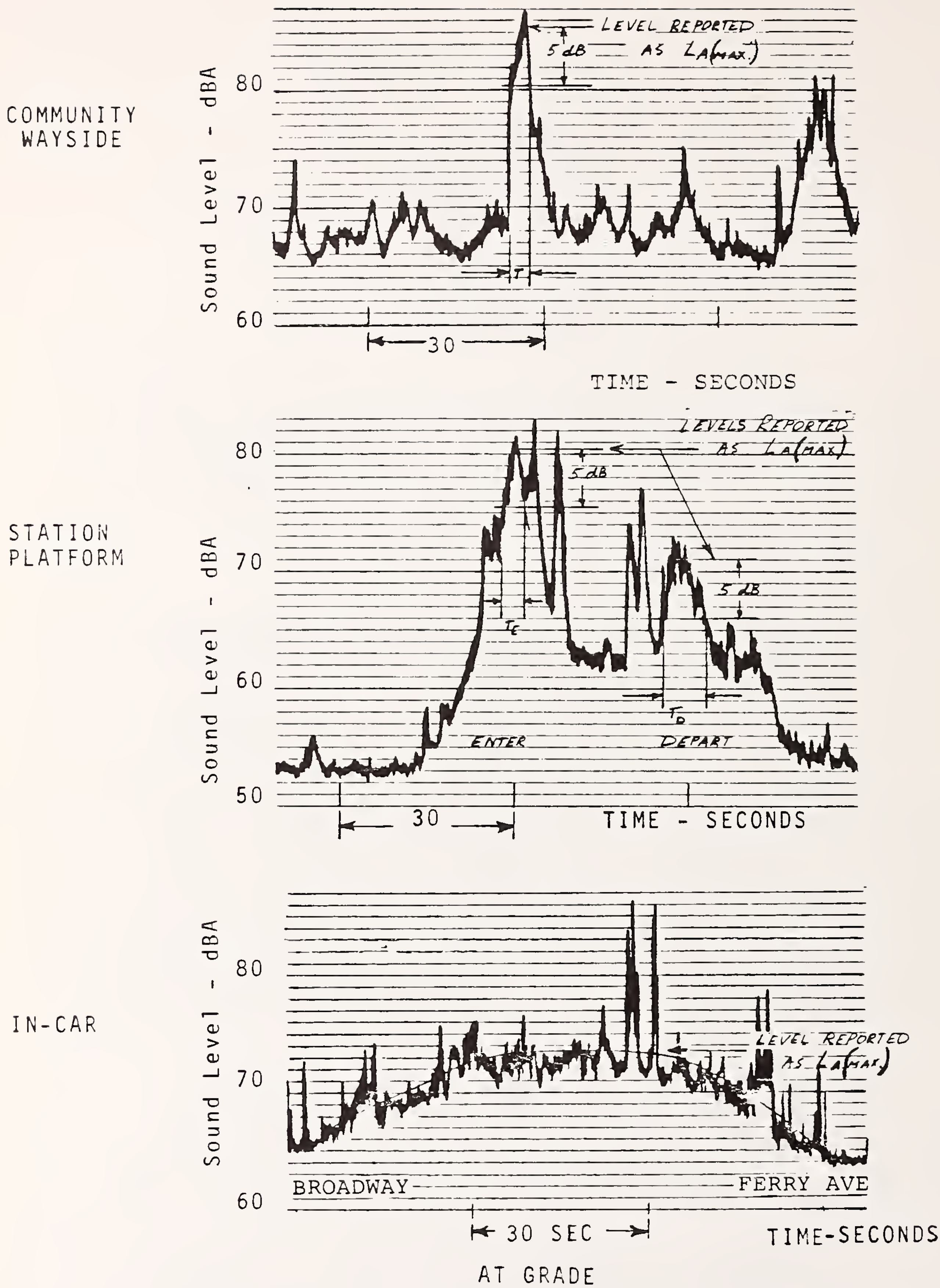
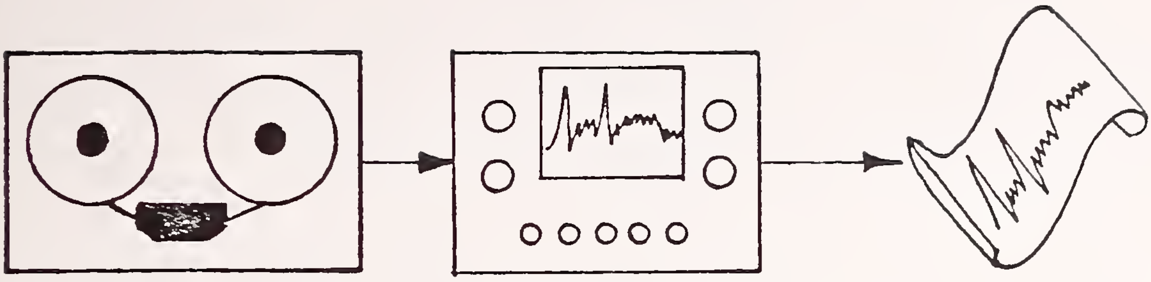


FIGURE 4.4. METHOD OF DETERMINING L_A(Max) AND T_5



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

$$W_i \text{ (7 a.m. - 10 p.m.)} = 1$$

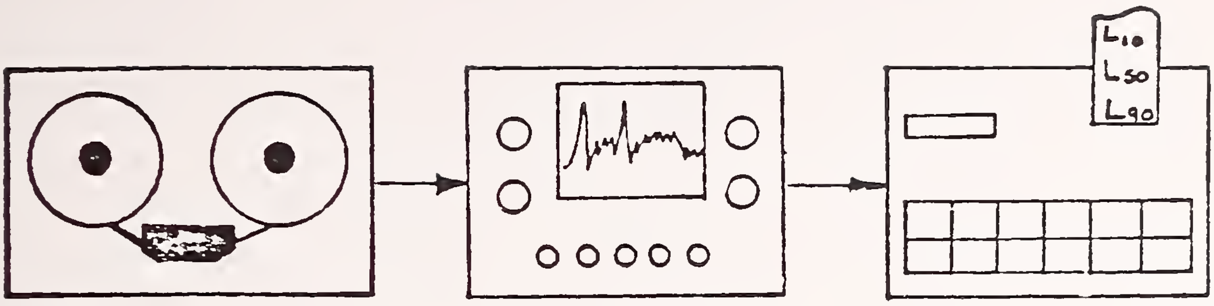
$$W_i \text{ (10 p.m. - 7 a.m.)} = 10$$

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 Cleveland Transit System rapid transit line (Airport Line) has the route structure shown in Figure 5.1. The system is 19 miles (30.6 km) in length with 18 stations. The eastern portion of the line from the Cleveland Union Terminal to Windermere Station was opened in 1955. Five months later, the section from Union Terminal to West 117th-Madison was opened. Addition of the Triskett and West Park Stations at the western end of the line was completed in 1958. In 1968 the four-mile extension to Cleveland Hopkins International Airport was opened, including the Puritas and Brookpark Stations. The average running time from Windermere to Airport is 36 minutes.

Roadbed - The roadbed consists of wood tie, rock ballast, and AREA-100 welded rail. Most of the track runs on-grade over right-of-way formerly utilized by the New York Central. Along the western portion of the line, the system parallels the Penn Central through mixed industrial, business, and residential communities. It parallels the Norfolk and Western tracks at the eastern end of the line.

There are two underground track sections on the system - one near the Airport Station, 0.48 mile in length, and the other at the downtown station, Public Square located in the Cleveland Union Terminal, 0.5 mile in length.

Between West 117th-Madison and West 25th-Lorain, and between Campus and East 105th-Quincy, the system is located in a cut. From Superior to Windermere, the roadbed is on elevated embankment.

Where the roadbed is in a cut, a vertical concrete retaining wall is occasionally used on one side of the line.

The underground Airport Station has one ventilation fan rated at 20,000 cfm which was installed so as to satisfy a 60 dBA noise criterion. The passenger tunnel is heated during the winter by a 50 kw, 2000 cfm forced air system.

Short curve radii which produce wheel squeal are located at the Windermere yard approach tracks, and entering and exiting the Public Square Station. Intermittent moderate squeal noise or flange "sing" can be heard on most curves and on tangent track as well. Track gauge at CTS is 4 feet 8-1/4 inches, 1/4-in. tighter than standard railroad gauge, with wheel gauge set for

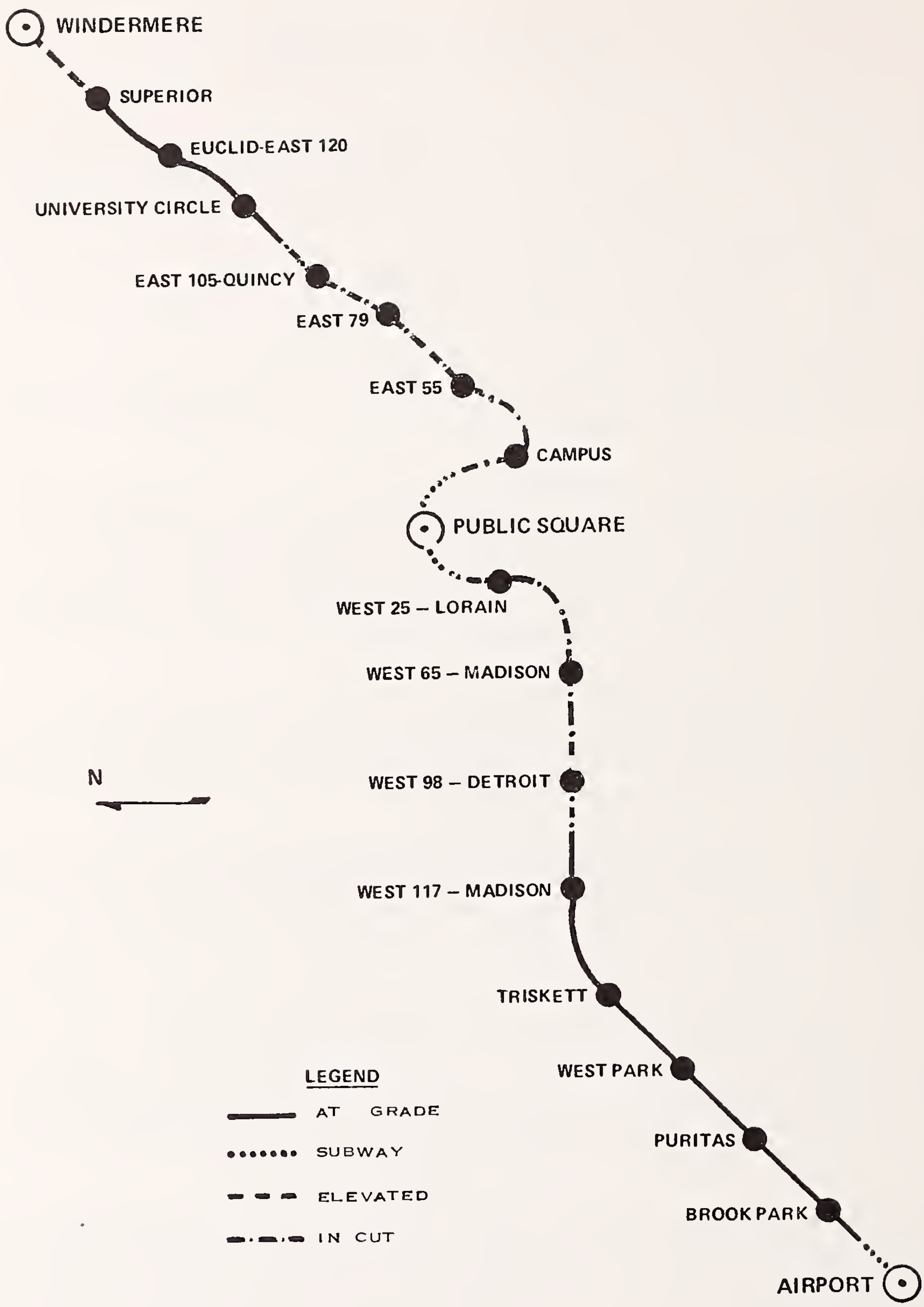


FIGURE 5.1. CLEVELAND RAPID TRANSIT ROUTE 66 SYSTEM SCHEMATIC

standard track gauge. The resulting mismatch between wheel and track gauge appears to excite flange modes of the wheel which result in flange "singing." Inspection of the wheel reveals that the fillet between the flange and tire on cars at CTS is a smaller radius than on other systems, confirming that the flanges receive more excitation at CTS than was observed on other systems.

Most residential areas are located between 200 and 300 feet (60 and 90 meters) from the centerline of the track with the exception of a section east of Triskett Station where some lower income homes adjoin the right-of-way within about 25-30 feet (7.5-9 meters).

Rail Vehicles - The following table lists the railcars in use at CTS.

Table 5.1. CTS Railcar Inventory - Airport Rapid Transit

Series	Make	Year	Number
Single Cars			
101-112	St. Louis	1955	12
113-118	St. Louis	1958	6
151-170	Pullman	1967	20
		Total Single	38
Double Cars			
201-256	St. Louis	1955	56
257-270	St. Louis	1953	14
		Total Double	70

Basic car construction is illustrated in Figures 5.2 and 5.3. Other features, such as speed, ventilation system, propulsion system, truck design, etc., are listed in Tables 5.2 and 5.3.

The cars are operated with approximately six minutes of headway on weekdays at peak travel periods, with 10 to 15 minutes on Saturdays and Sundays. There is no acoustical absorption in the car interior with the exception of three experimental Pullman cars whose floors and sidewall kick panels are covered with carpeting. The latter cars also have cloth-upholstered seats rather than the vinyl seats used on the standard cars. Average in-car noise levels of the modified car are 4.5 dBA lower than the standard configuration.

Table 5·2. Specification of St. Louis Car

Length of Car	48'6" single car 97'6" double unit
Height, Rail to Roof	11'9"
Width, at Floor Level	10'
Width, at Window Level	10'
Weight, Empty	56,000 pounds
Total Weight, Pounds Per Foot	1,155 pounds
Weight, Loaded	72,500 pounds
Seating Capacity	54 passengers 55 passengers = 109
Motors (4 per car)	55 HP each
Free Running Speed	47 MPH
Windows	Solex Safety Glass; laminated; stationary
Heating and Ventilating	Thermostatically controlled heat and air

Table 5.3. Specification of Pullman Standard Car

Length over Anticlimbers	70'0"
Extreme Width	10'5"
Height to Locked-Down Pantograph	13'6"
Weight	64,000 pounds
Construction	Stainless Steel with Fiberglass Ends
Seats	80, Transverse Seating, Flexible
Top Speed	55 MPH, governed
Air Conditioning	10 Tons, Electromechanical, Safety Injectair
Heating	Waste Heat supplemented by Electric Strip Heaters
Braking	Combination Dynamic and Pneumatic
Brake Units	8, with Composition Shoes
Communication Systems	Public Address, Signal Bell, Signal Buzzer
Power Supply	600 VDC Overhead Wire
Traction Motors	4, 100 HP GE-1250
Trucks	Inboard Bearing, Air-Coil Spring Suspension, 28-Inch Wheels LFM-Rockwell MPT-2

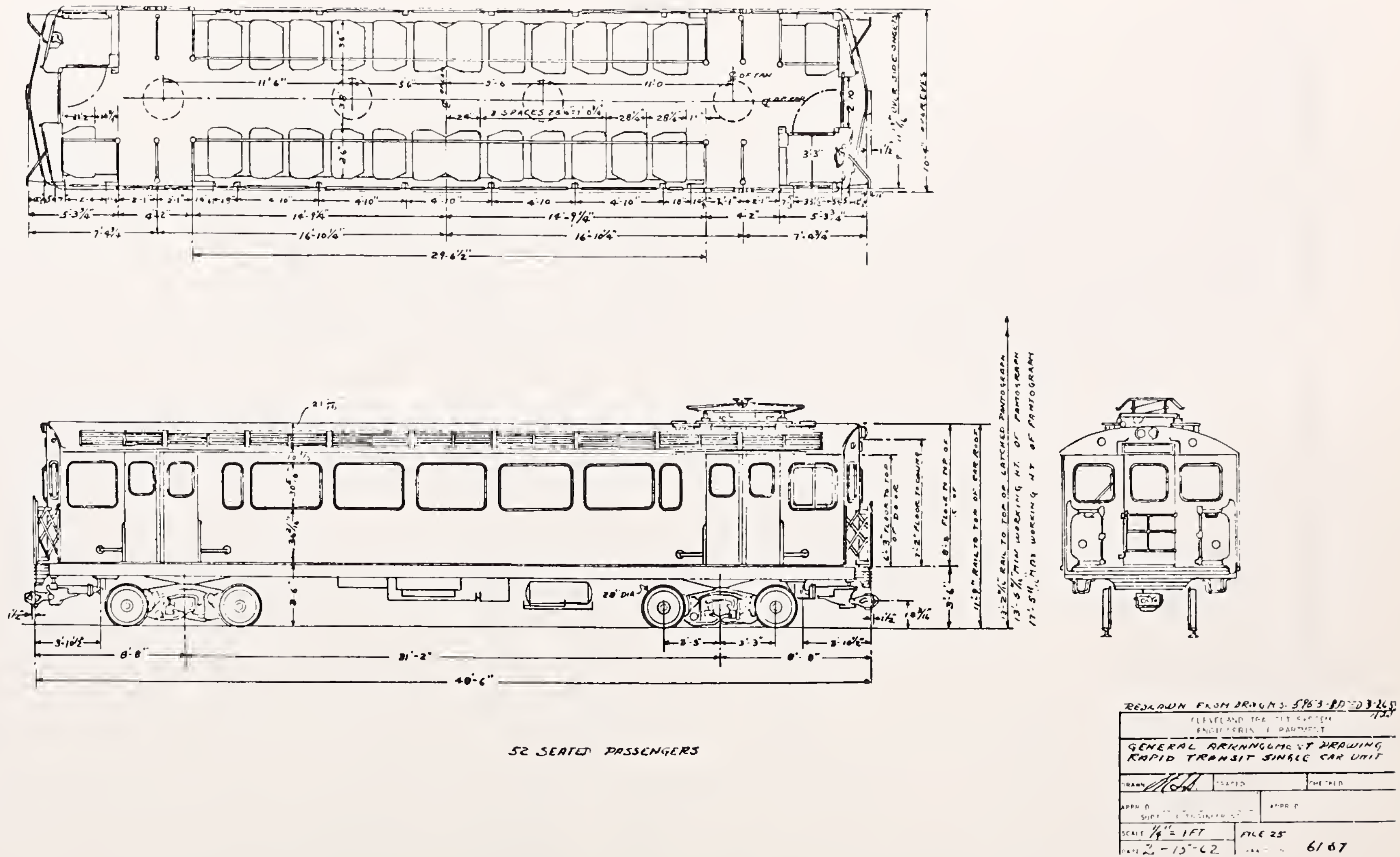


FIGURE 5.2 THREE-VIEW OF ST. LOUIS RAPID TRANSIT CAR.

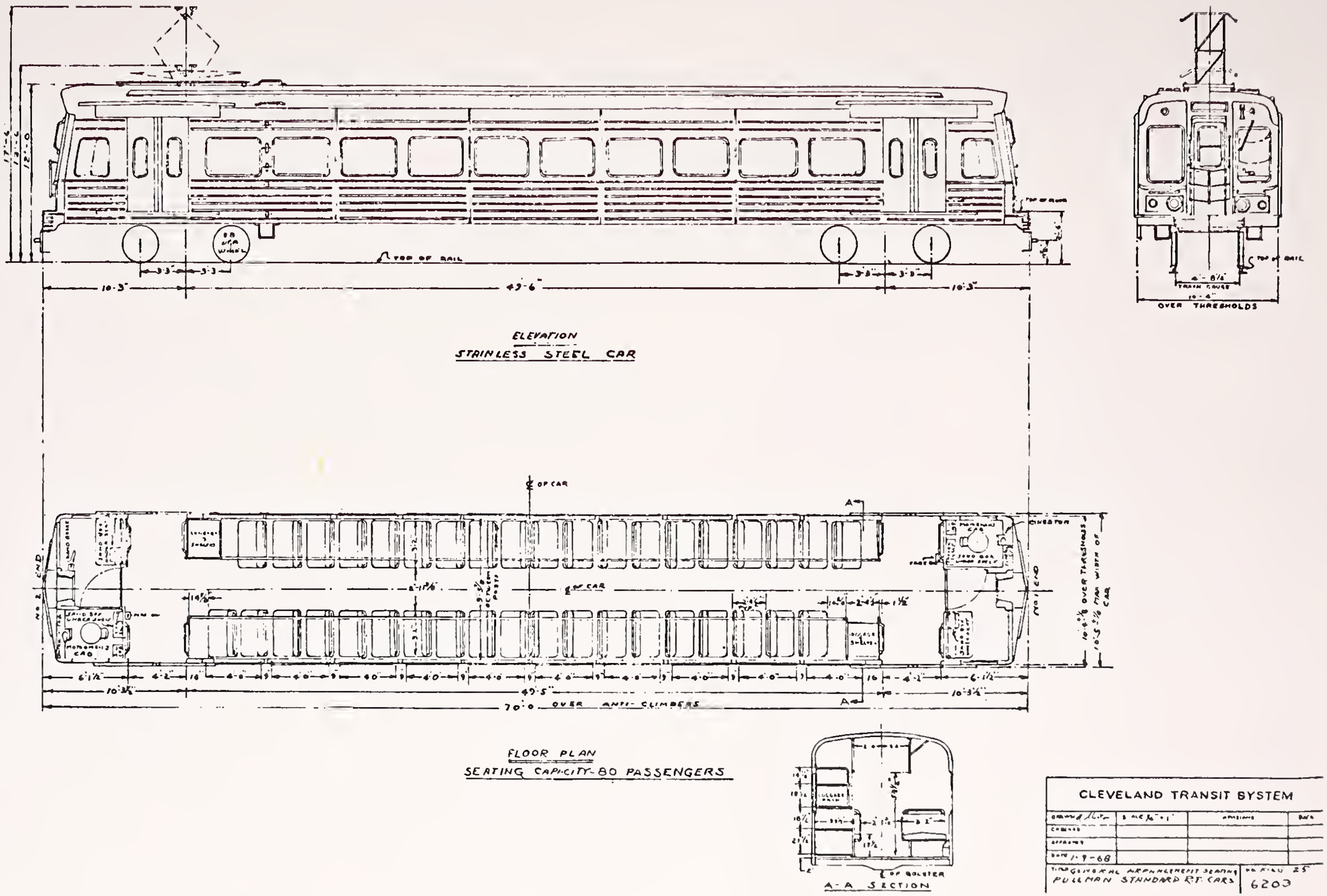


FIGURE 5-3. THREE-VIEW OF PULLMAN STANDARD RAPID TRANSIT CAR

Stations - The two-track system serves patrons through 18 stations with an average station spacing of 1.13 miles (1.82 km). Distances between stations are as shown in Table 5.4.

The majority of stations are center platform style (Figure 5.4). East 55th is the only side platform station and it shares tracks with the Shaker Heights Transit, a light rail system. East 55th is an interchange station between systems. The Shaker Heights Line uses the lower level center platform with the Airport Rapid Line using the side platforms (see Figure 5.35). The only elevated embankment stations are at Superior and Windermere. Underground stations are located at Public Square and at the Airport.

Some center platform stations have vertical dividers in sections which shield patrons on one side of the barriers from the direct radiating train noise on the opposite side. The underground terminal at Public Square Station, which has three tracks divided by two island platforms about 20 feet wide, is primarily a reinforced concrete structure. Some side pillars and beams are covered by an approximate 2-foot wide sheet of corrugated and perforated steel facing.

Table 5.4 Distances Between Stations

	Miles	Km
Windermere to Superior	0.67	1.08
Superior to Euclid	0.88	1.42
Euclid to University Circle	0.87	1.40
University Circle to E. 105th	0.65	1.05
E. 105th to E. 79th	1.17	1.88
E. 79th to E. 55th	1.05	1.69
E. 55th to Public Square	2.55	4.10
Public Square to W. 25th	1.05	1.69
W. 25th to W. 65th	1.94	3.12
W. 65th to W. 98th	1.29	2.08
W. 98th to W. 117th	0.96	1.54
W. 117th to Triskett	1.07	1.72
Triskett to West Park	0.77	1.24
West Park to Puritas	1.26	2.03
Puritas to Brookpark	1.72	2.77
Brookpark to Airport	1.11	1.79
TOTAL	19.02	30.61

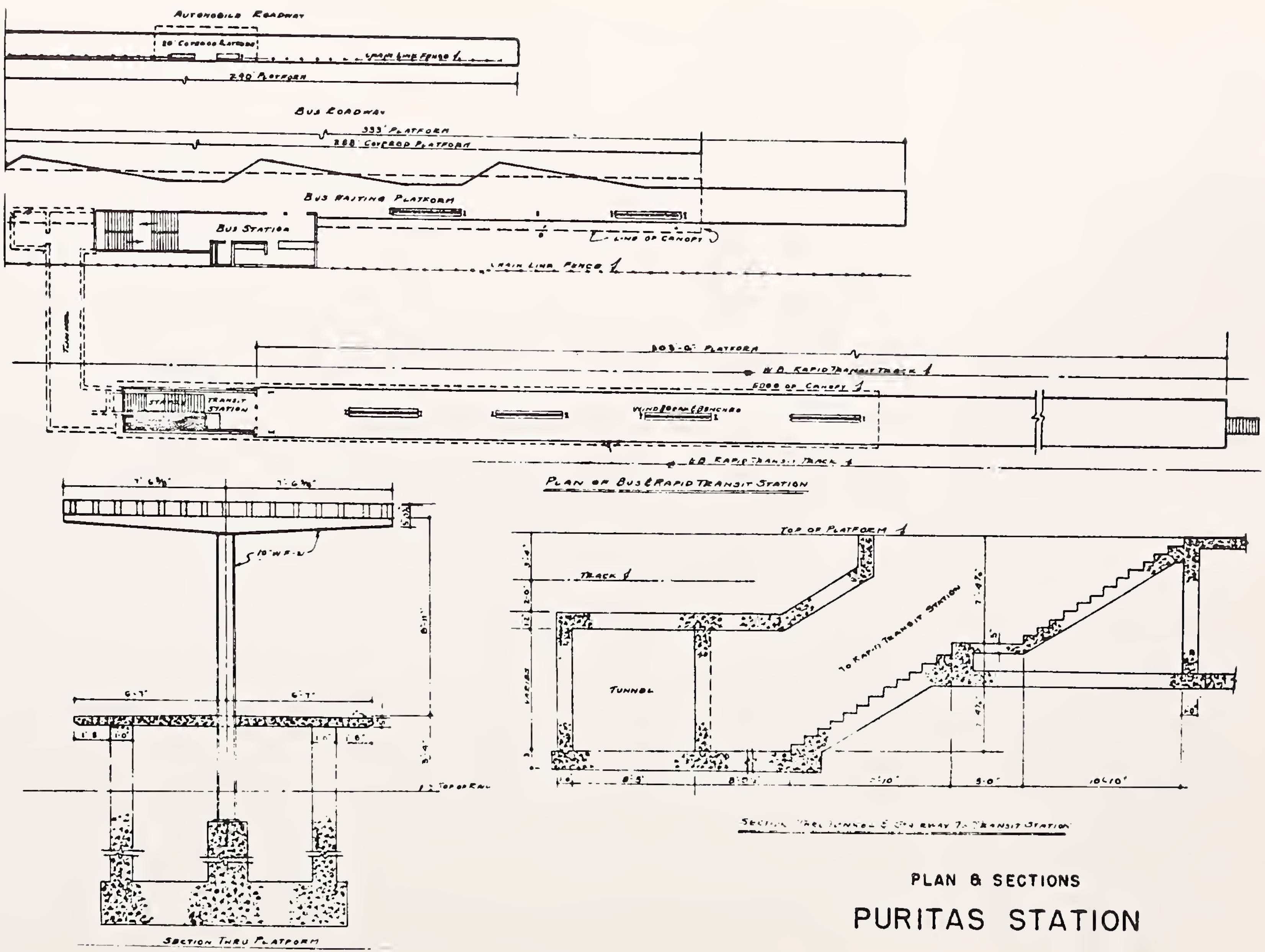


FIGURE 5.4. TYPICAL CENTER PLATFORM STATION

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 5.5 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 5.5. 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) of 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 CTS were conducted at three locations: near Windermere, West Park, and West 98th St. Stations.

Windermere was chosen on the basis of its location on elevated embankment, proximity to commercial, business, and residential locations, as well as being one of the few above-ground locations nearby to a site where wheel squeal is occasionally heard (approach tracks to terminals). From three to six train noise events were recorded at three distances from the tracks in the direction of maximum sound intensity along with normal community background noises.

A second noise survey was near the West 98th-Detroit Station at Landon Street. The roadbed is located in a cut near an industrial/residential area. Background noise is moderate. Running parallel to the transit tracks in the same cutting is the Norfolk and Western Railroad which also contributes to the noise environment.

The third community noise survey location was near the West Park Station. This track section is located at-grade in a low background noise, residential neighborhood. This last area is typical of the transit line community environment for on-grade operation from Brookpark to West 117th Street and University Circle to Superior.

WINDERMERE WAYSIDE

Site Description (see Figure 5.5)

Measurements were taken on Elsinore Avenue, approximately two blocks west of Windermere Station in East Cleveland in a residential neighborhood. The area is comprised primarily of single family 2 and 3 story dwellings located on a street which underpasses the railroad. The railroad bridge carries the Norfolk and Western main line as well as the Airport Rapid over Elsinore Avenue. The speed of the transit cars is generally below 20 mph in this area, since trains are approaching and leaving Windermere Station. Track and roadbed is on elevated embankment in this region.

Noise Climate (see Table 5.6, Figures 5.6 - 5.11)

Noise levels at the site arise from vehicle traffic on Elsinore Avenue and Euclid Avenue (a major artery for vehicular traffic in East Cleveland), the transit line, the Norfolk and Western Railroad, and other community noises, such as children at play, barking dogs, sirens, etc. High-speed Norfolk and Western trains frequently mask the noise of the Rapid.

The night time data sample included a passby of one CTS Rapid car and a Norfolk and Western Freight train.

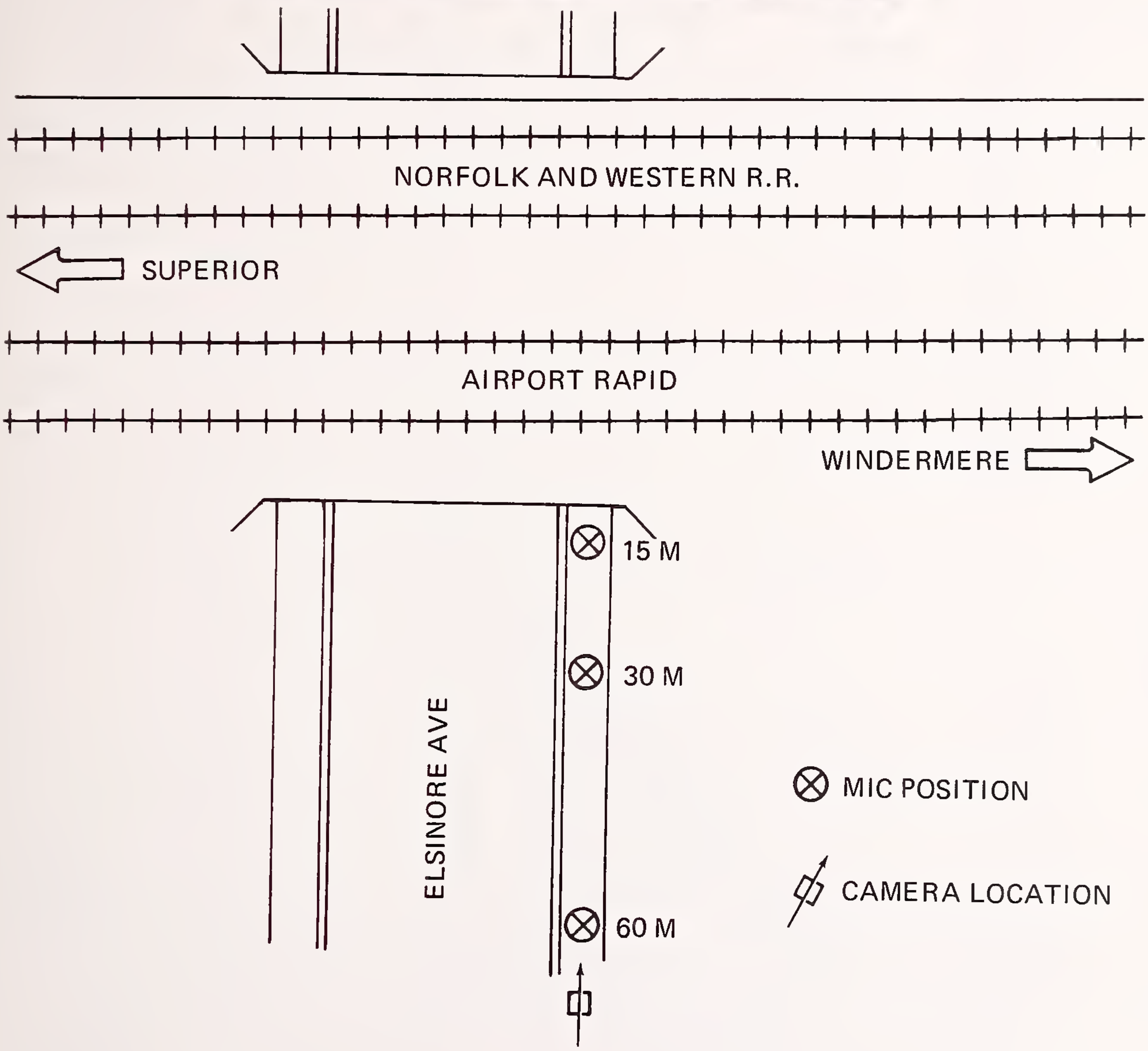


FIGURE 5.5. WAYSIDE MEASUREMENT LOCATION, WINDERMERE

TABLE 5.6. SUMMARY OF MEASUREMENT RESULTS FOR ELSINORE STREET
WINDERMERE COMMUNITY

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	a) WEST	a) EAST	a) WEST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	15m	30 min.	Pass-by	b) N	5-1	5-1	5-1	5-1						
				dBA	72	84	79	89	61	61	62	63	74	64
				c) S	0.57	3.38	0.98	2.70						
Rush	15m	30 min.	Pass-by	dBA					71	72	74	83	95	82
Evening	15m	30 min.	Pass-by	dBA					62	63	64	70	85	72
Night	15m	30 min.	Pass-by	dBA					66	66	67	68	74	68
Day	30m	15 min.	Pass-by	dBA					61	61	62	66	77	66
	60m	15 min.	Pass-by	dBA					61	61	62	66	78	66

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

$L_{dn} = 80$

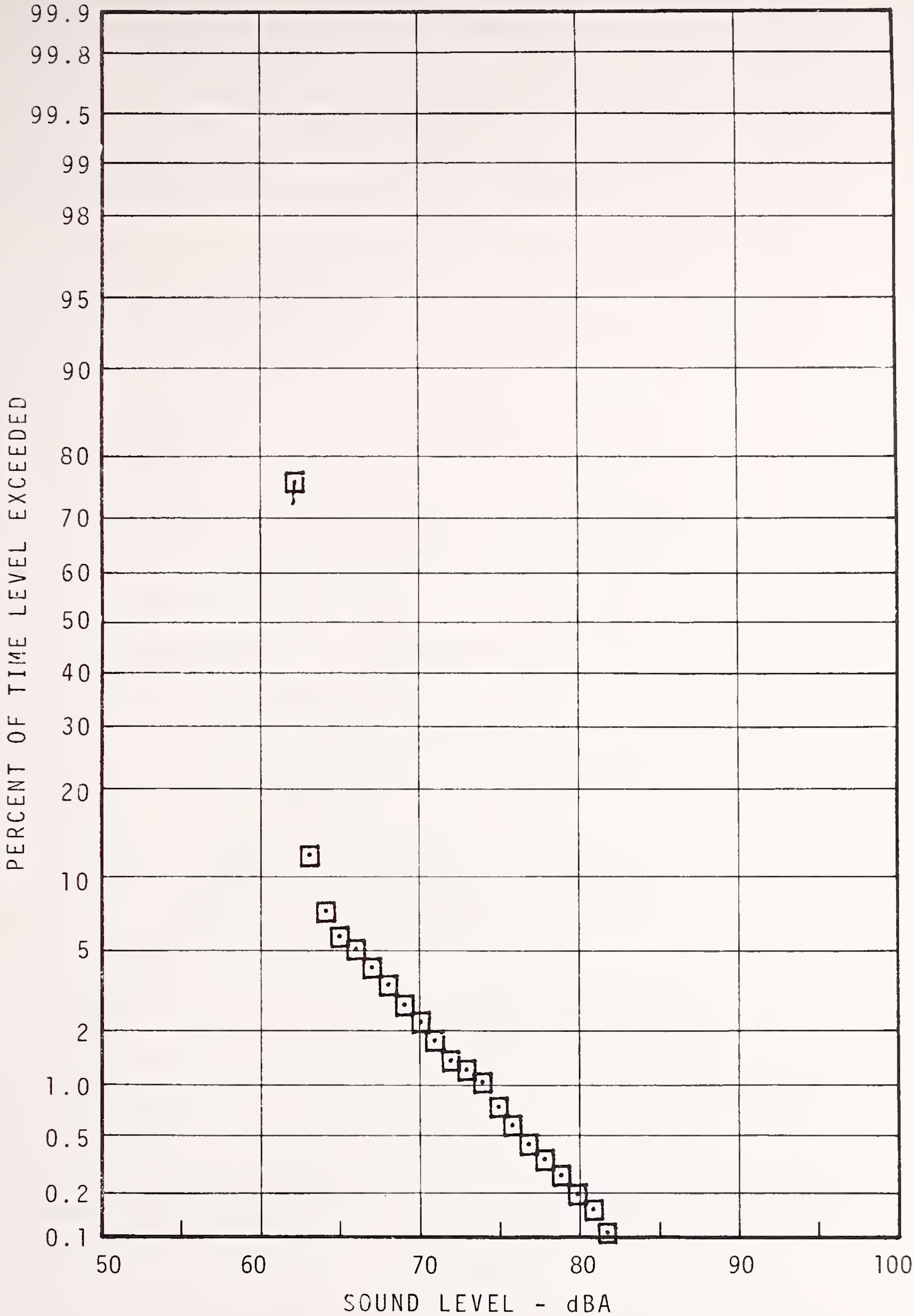


FIGURE 5.6. WINDERMERE COMMUNITY STATISTICAL DISTRIBUTION - 15M - DAYTIME

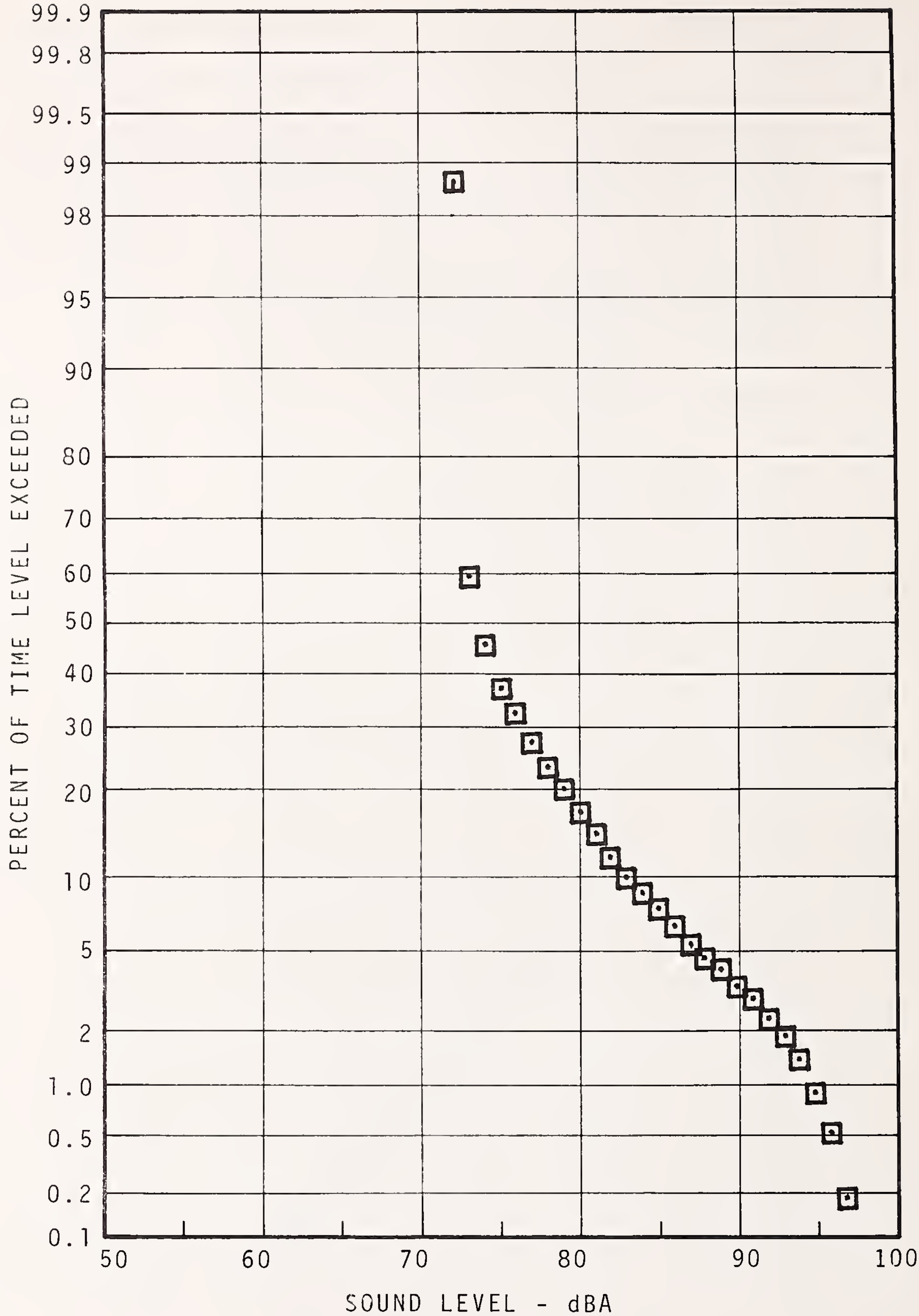


FIGURE 5.7. WINDERMERE COMMUNITY STATISTICAL DISTRIBUTION - 15M - RUSH HOUR

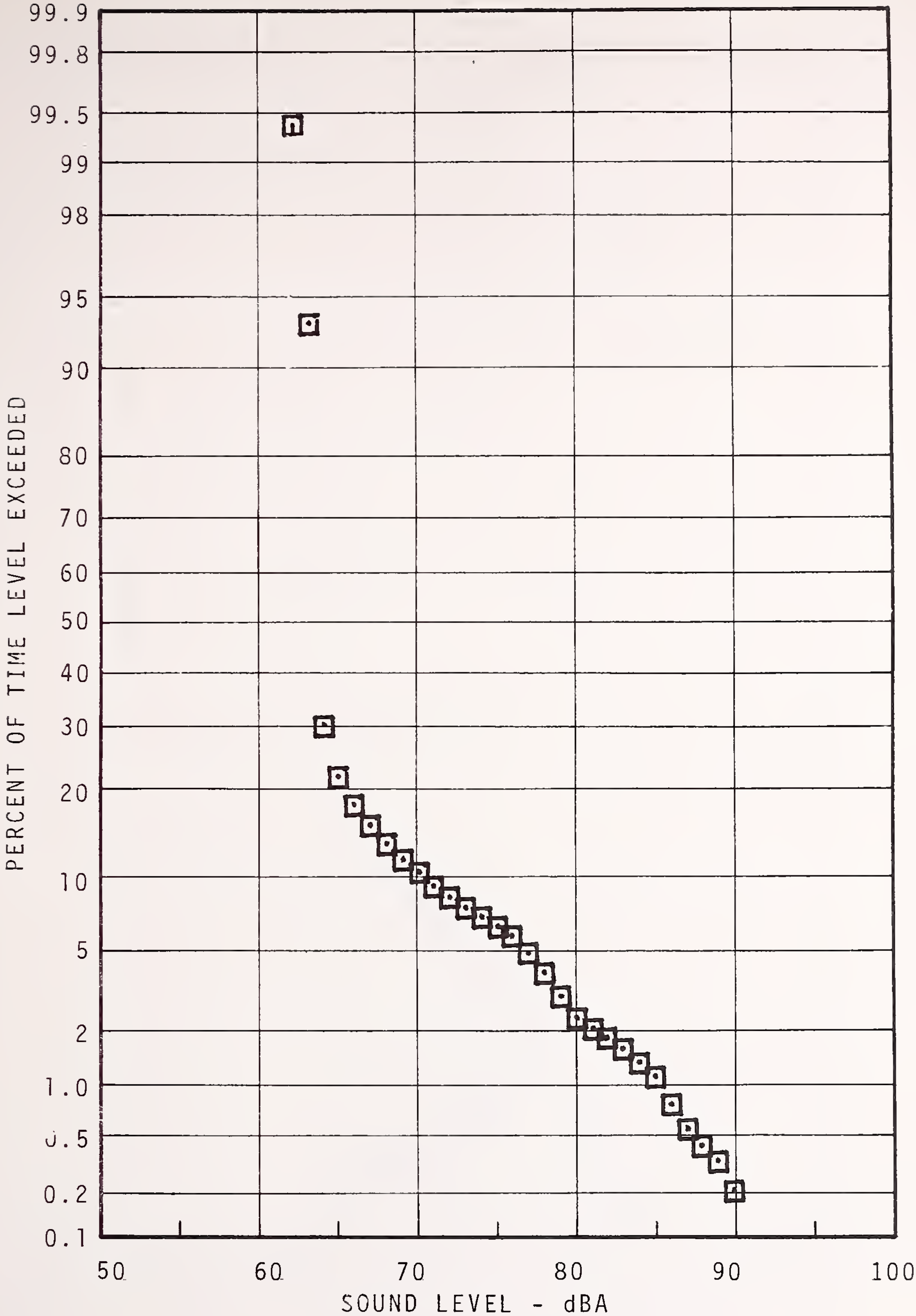


FIGURE 5.8. WINDERMERE COMMUNITY STATISTICAL DISTRIBUTION - 15M - EVENING

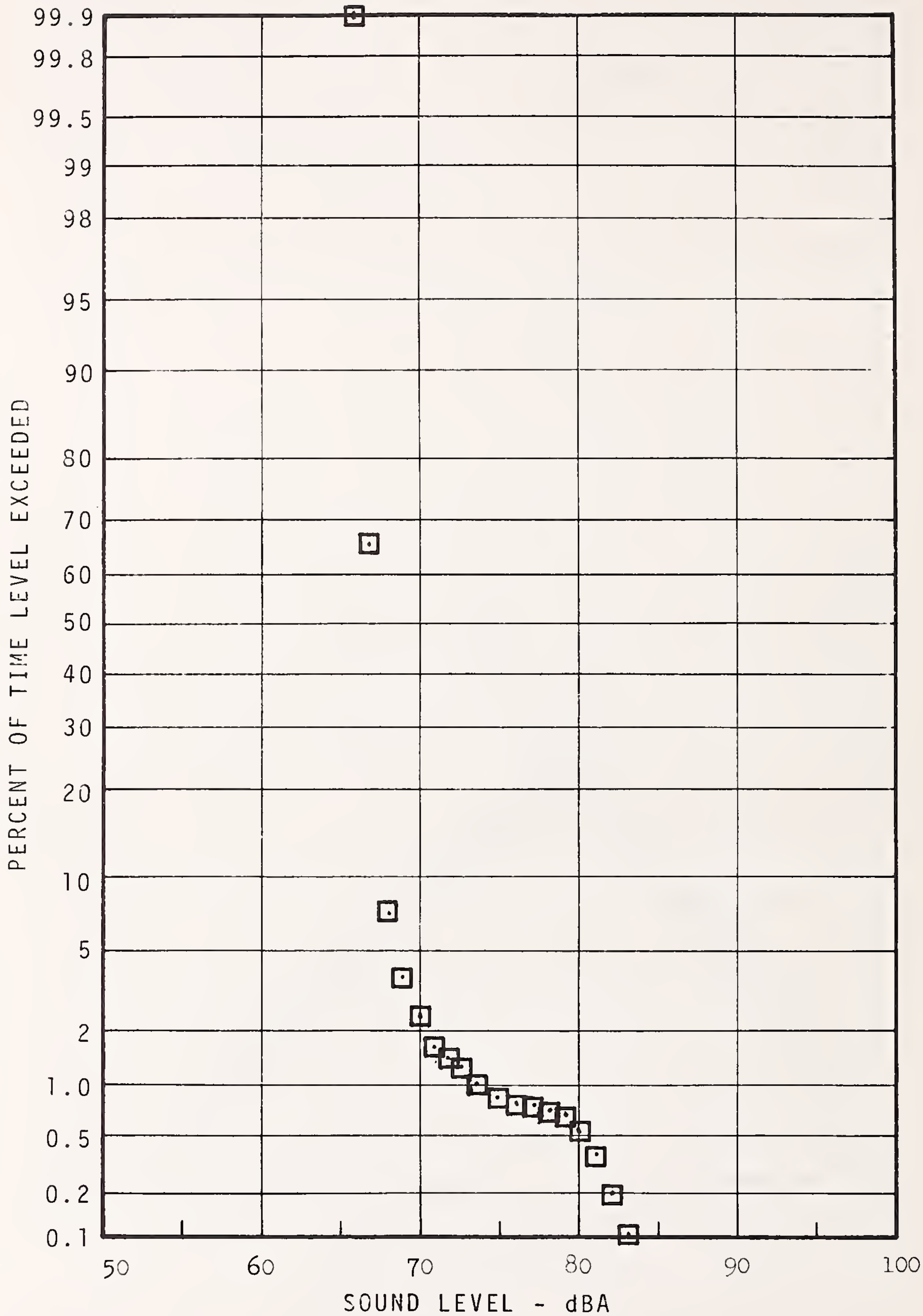


Figure 5.9 WINDERMERE COMMUNITY STATISTICAL DISTRIBUTION

15M - NIGHT

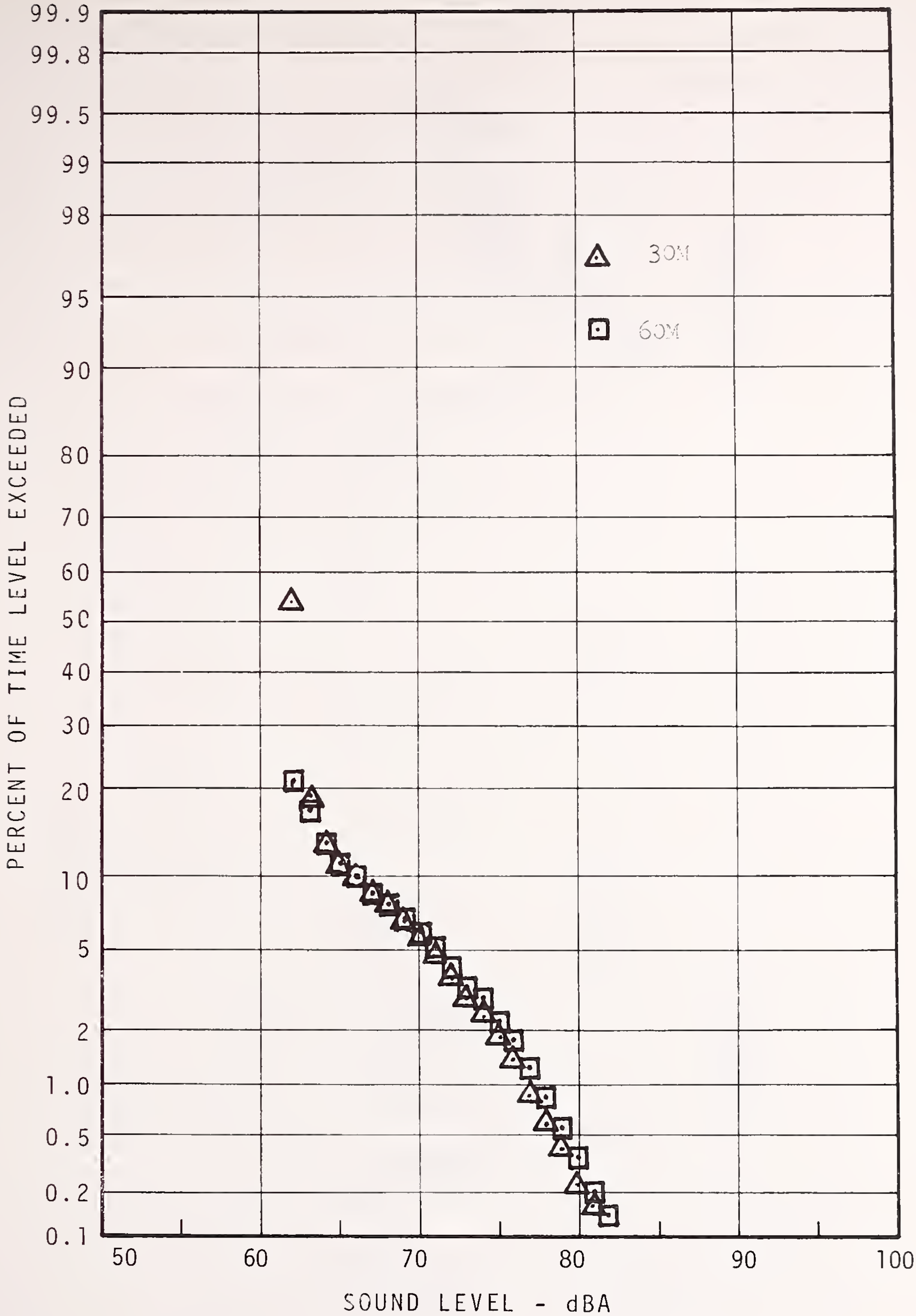


FIGURE 5.10. WINDERMERE COMMUNITY STATISTICAL DISTRIBUTION
30M AND 60M - DAYTIME

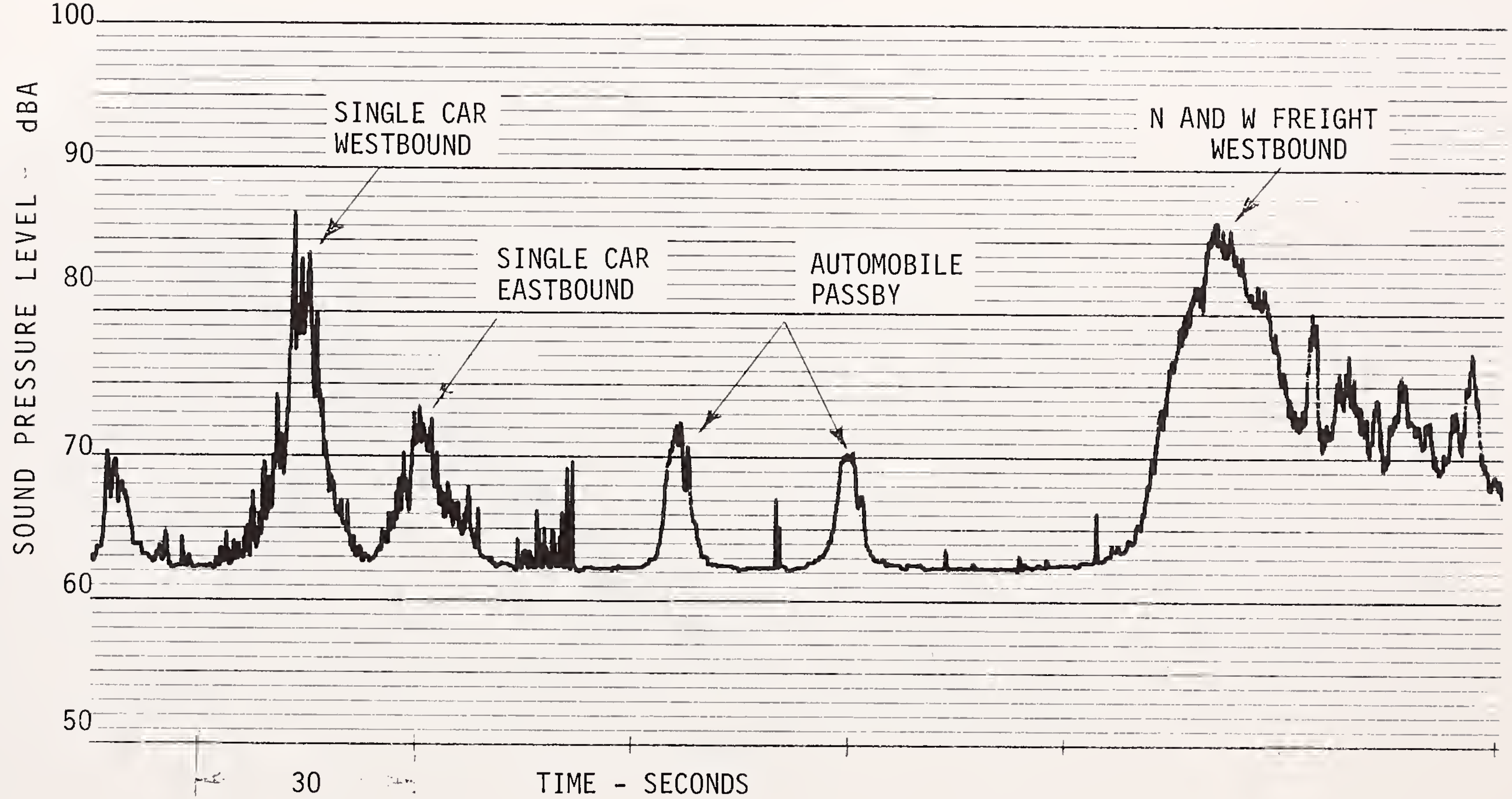


FIGURE 5.11. TYPICAL TIME HISTORY, WINDERMERE COMMUNITY, 15m, DAYTIME

WEST PARK WAYSIDE

Site Description (see Figure 5.12)

Measurements were made in a residential area in West Park along a section of right-of-way where the Rapid operates at a normal high speed. The site was on Tuckahoe Street, and the 15m and 30m locations were in the back and front yard, respectively, of a private residence. A playground of approximately 1 acre was located across the street from the houses which join the transit right-of-way. The Penn Central tracks are on the far side of the transit line. The transit line is on-grade in this area.

Noise Climate (see Table 5.7, Figures 5.13 - 5.19)

Specific event noise levels at this site are generated by nearby vehicle traffic on Tuckahoe Street, the Airport Rapid Transit and the Penn Central. Other distinguishable sources are the occasional barking of dogs, distant truck traffic and aircraft. Transit system noise is occasionally masked by Penn Central freight trains.

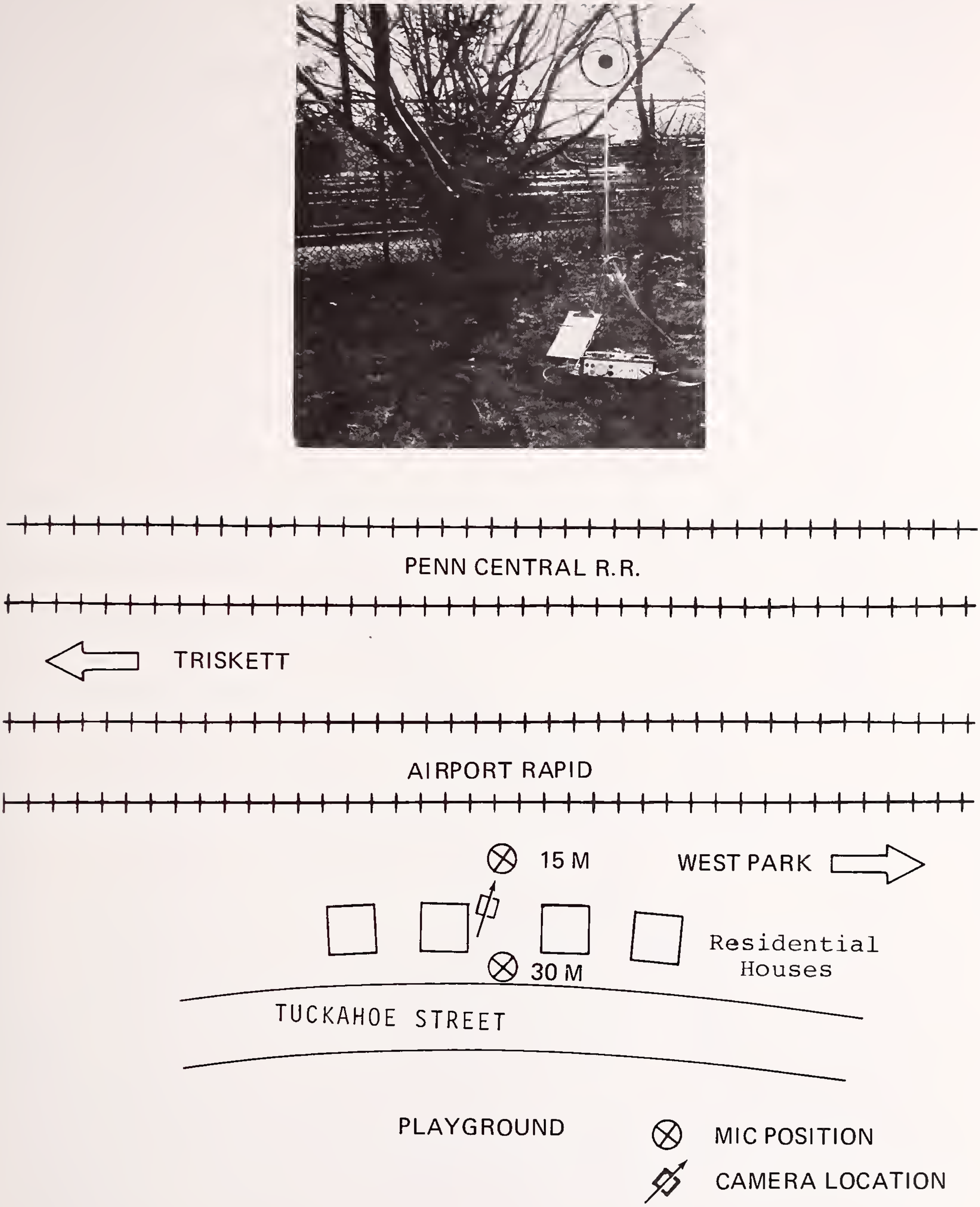


FIGURE 5.12. WAYSIDE MEASUREMENT LOCATION, WEST PARK

TABLE 5.7. SUMMARY OF MEASUREMENT RESULTS FOR TUCKAHOE STREET, WEST PARK COMMUNITY

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	15m	30 min.	Pass-by	b) N	6-1	6-1	6-1	6-1	56	58	61	75	85	72
				dBA	99	96	100	102						
				c) S	6.41	1.36	5.96	1.86						
Rush	15m	30 min.	Pass-by	dBA					56	56	59	77	89	76
Evening	15m	30 min.	Pass-by	dBA					54	56	58	77	89	74
Night	15m	10 min.	Pass-by	dBA					69	69	70	71	77	72
Day	30m	15 min.		dBA					70	70	71	79	85	75

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

$L_{dn} = 80$

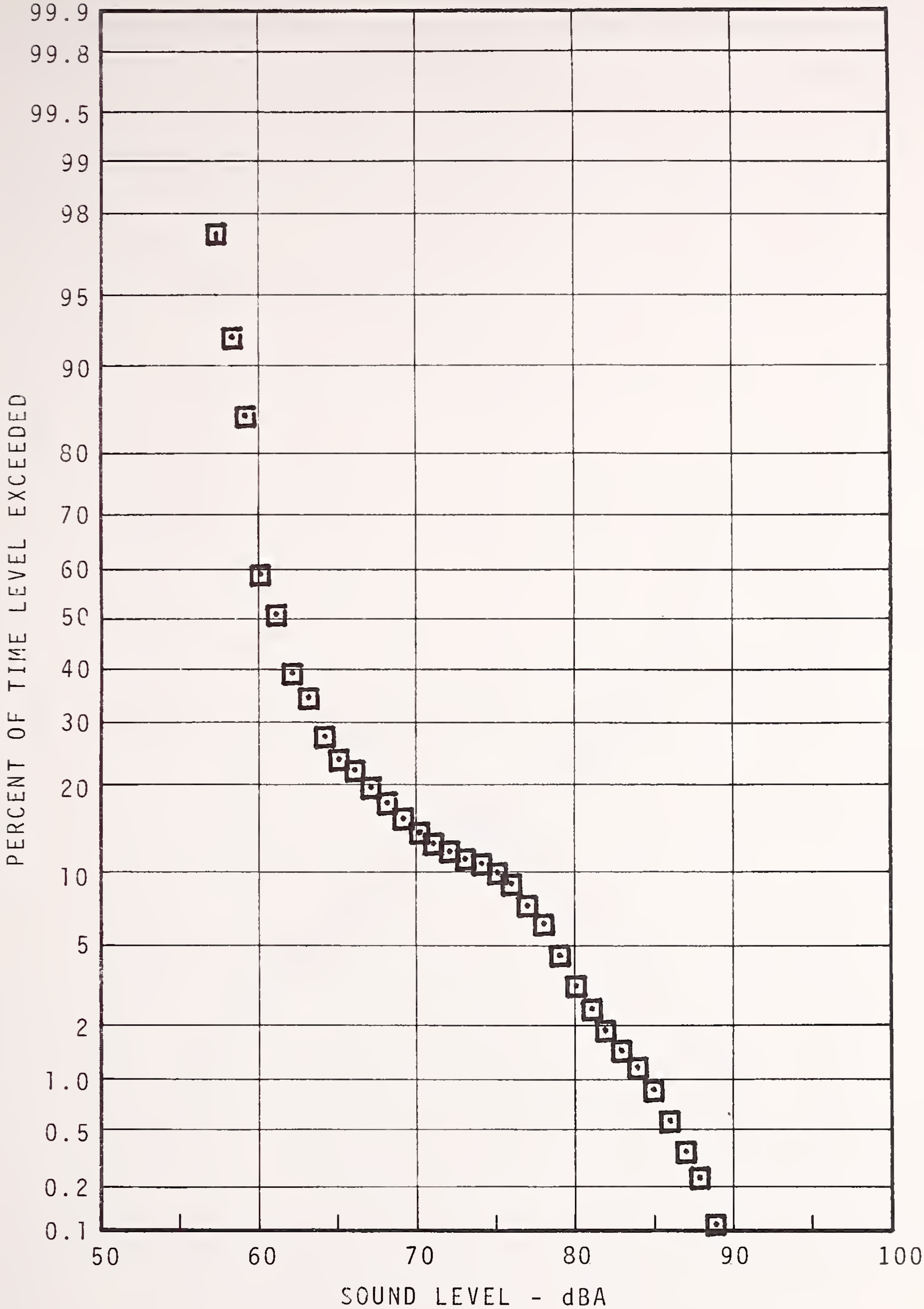


FIGURE 5.13. WEST PARK COMMUNITY STATISTICAL DISTRIBUTION - 15M - DAYTIME

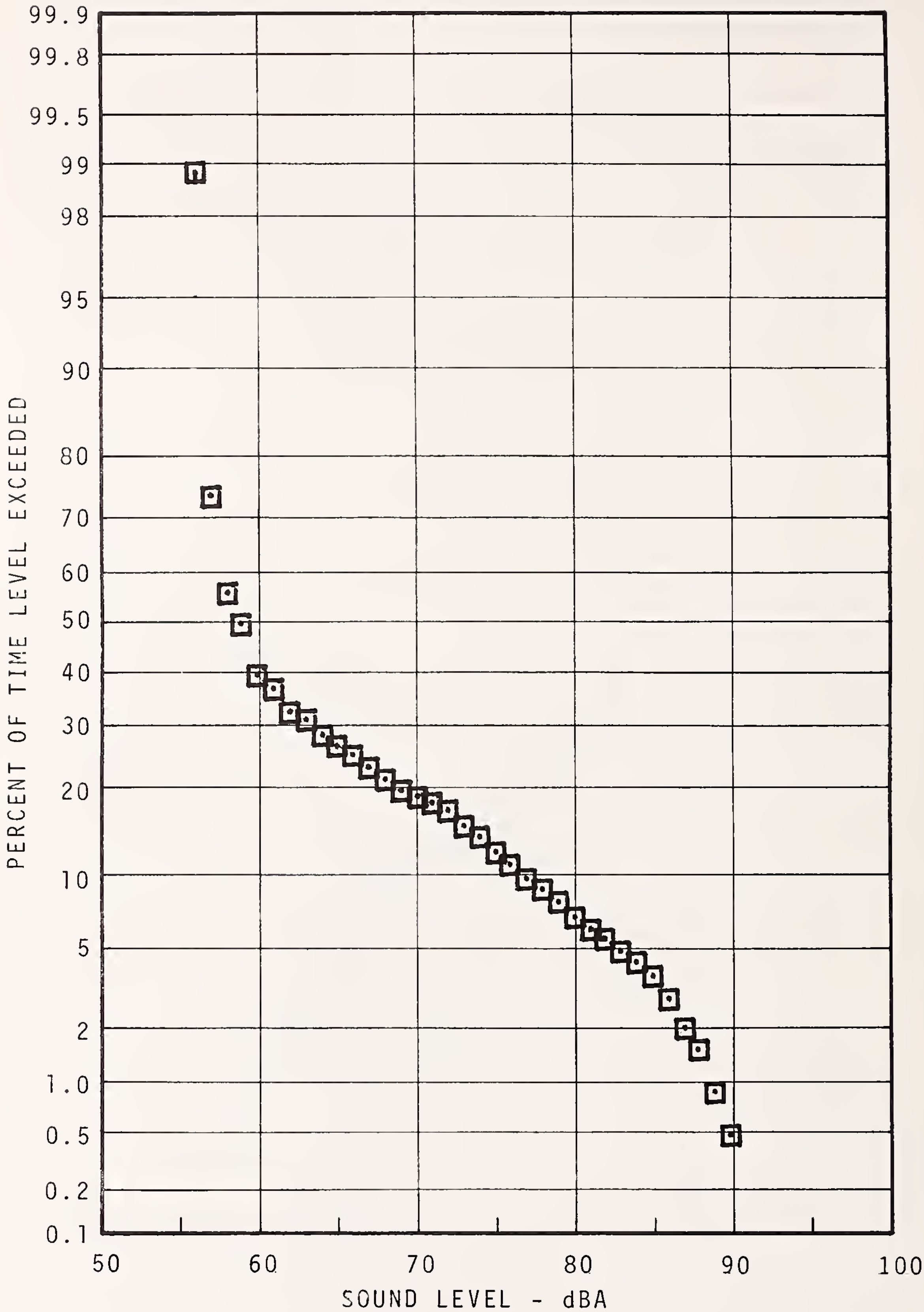


FIGURE 5.14. WEST PARK COMMUNITY STATISTICAL DISTRIBUTION - 15M - RUSH HOUR

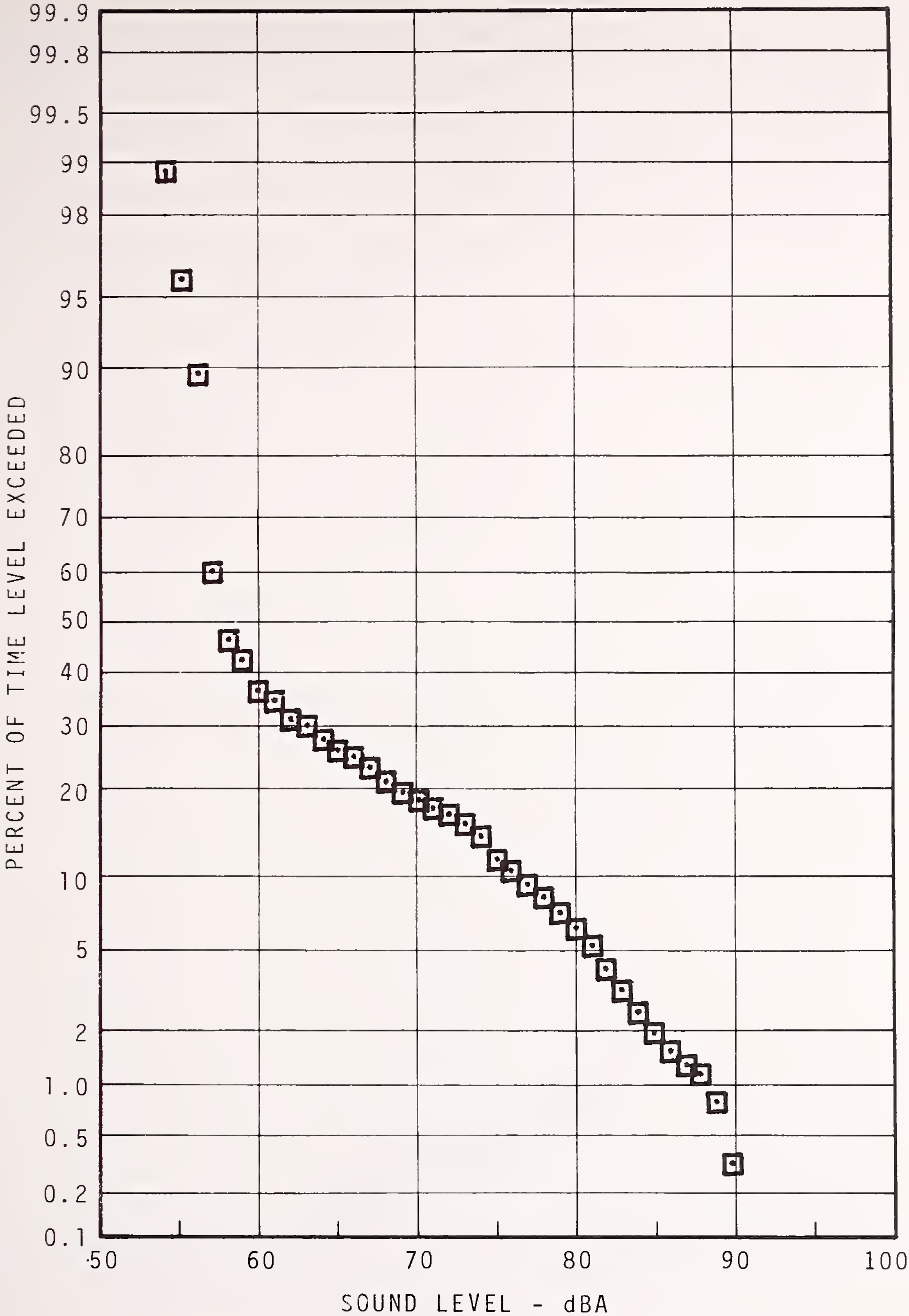


FIGURE 5.15. WEST PARK COMMUNITY STATISTICAL DISTRIBUTION - 15M - EVENING

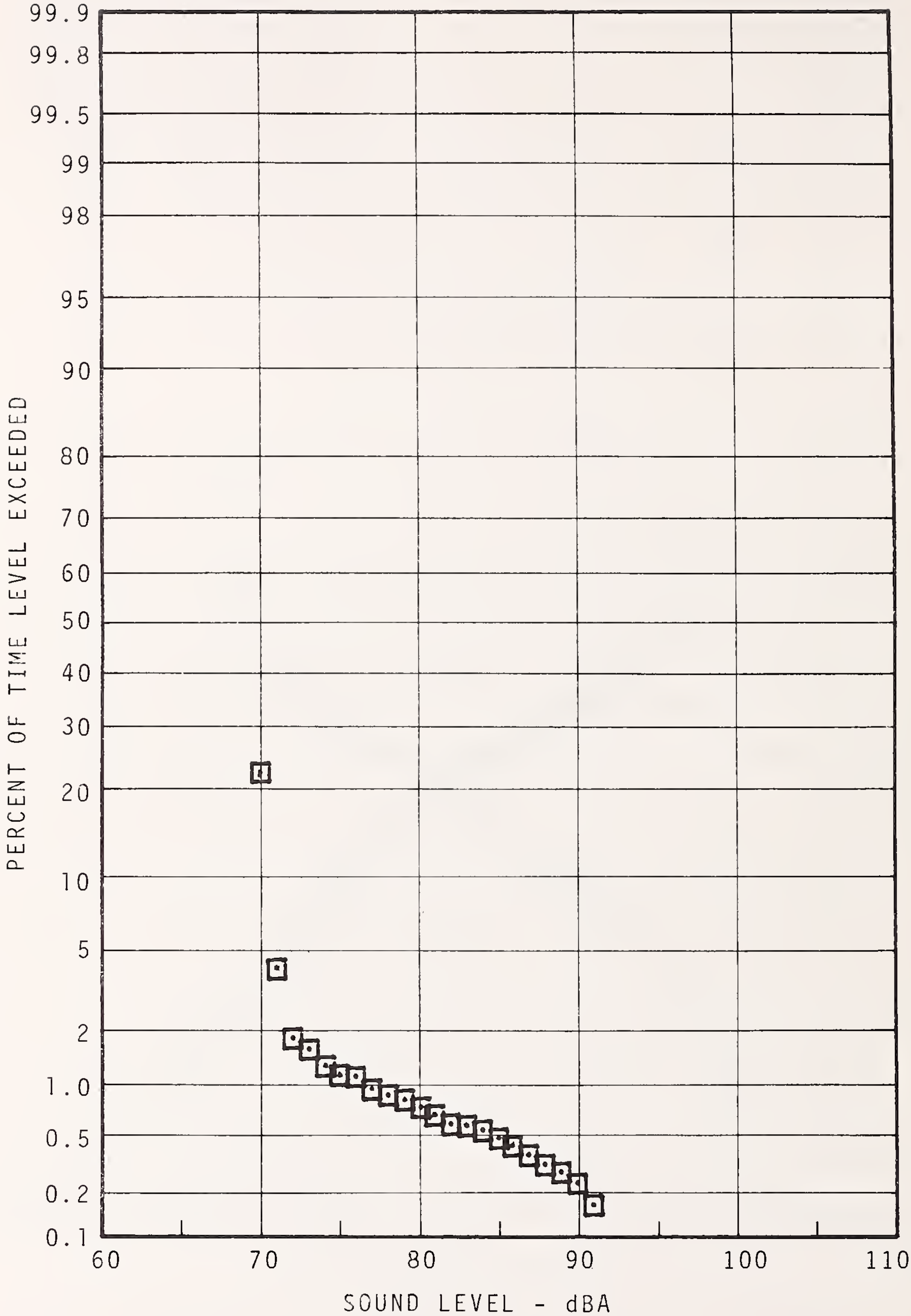


FIGURE 5.16. WEST PARK COMMUNITY STATISTICAL DISTRIBUTION - 15M - NIGHT

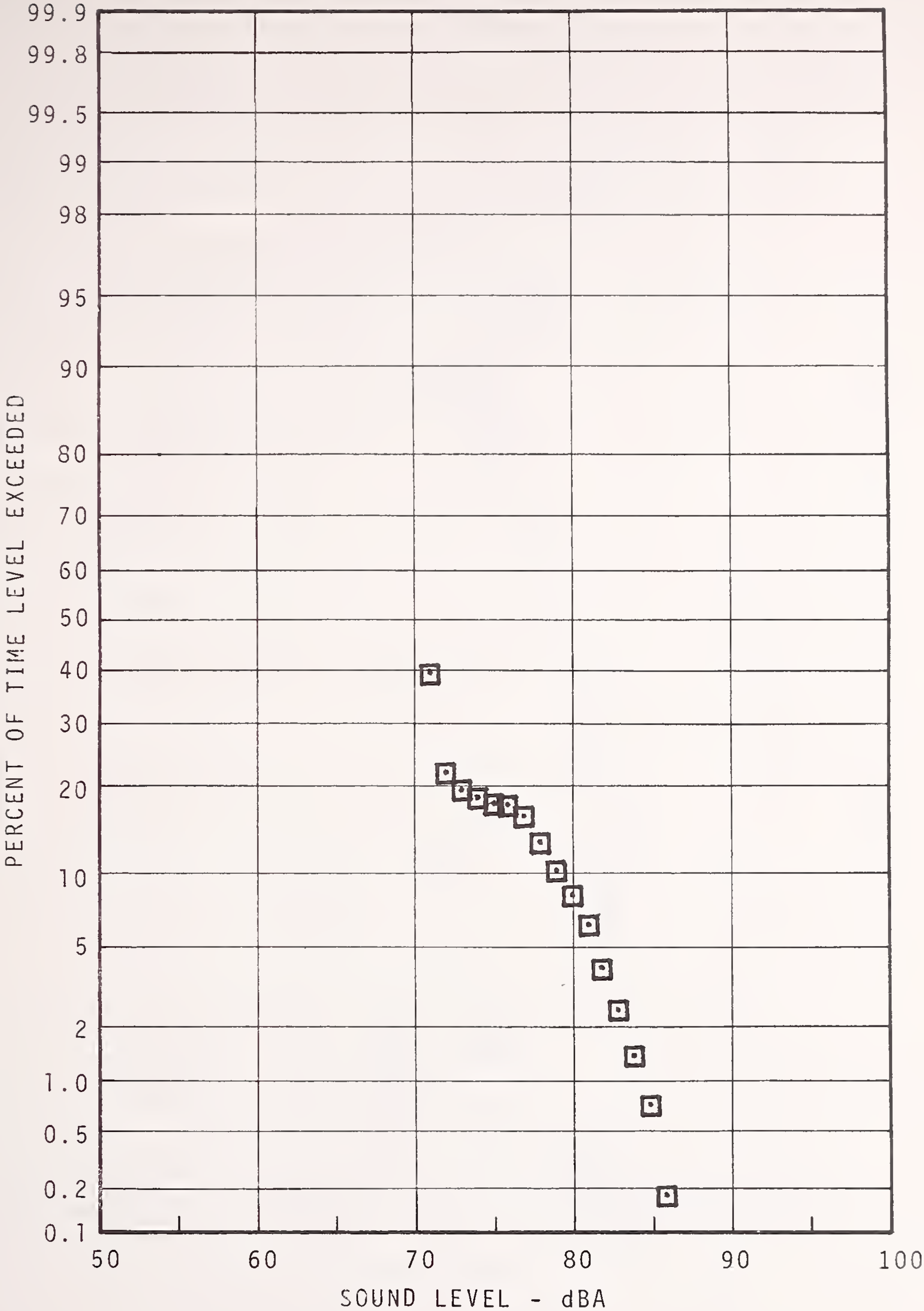


FIGURE 5.17. WEST PARK COMMUNITY STATISTICAL DISTRIBUTION - 30M - DAYTIME

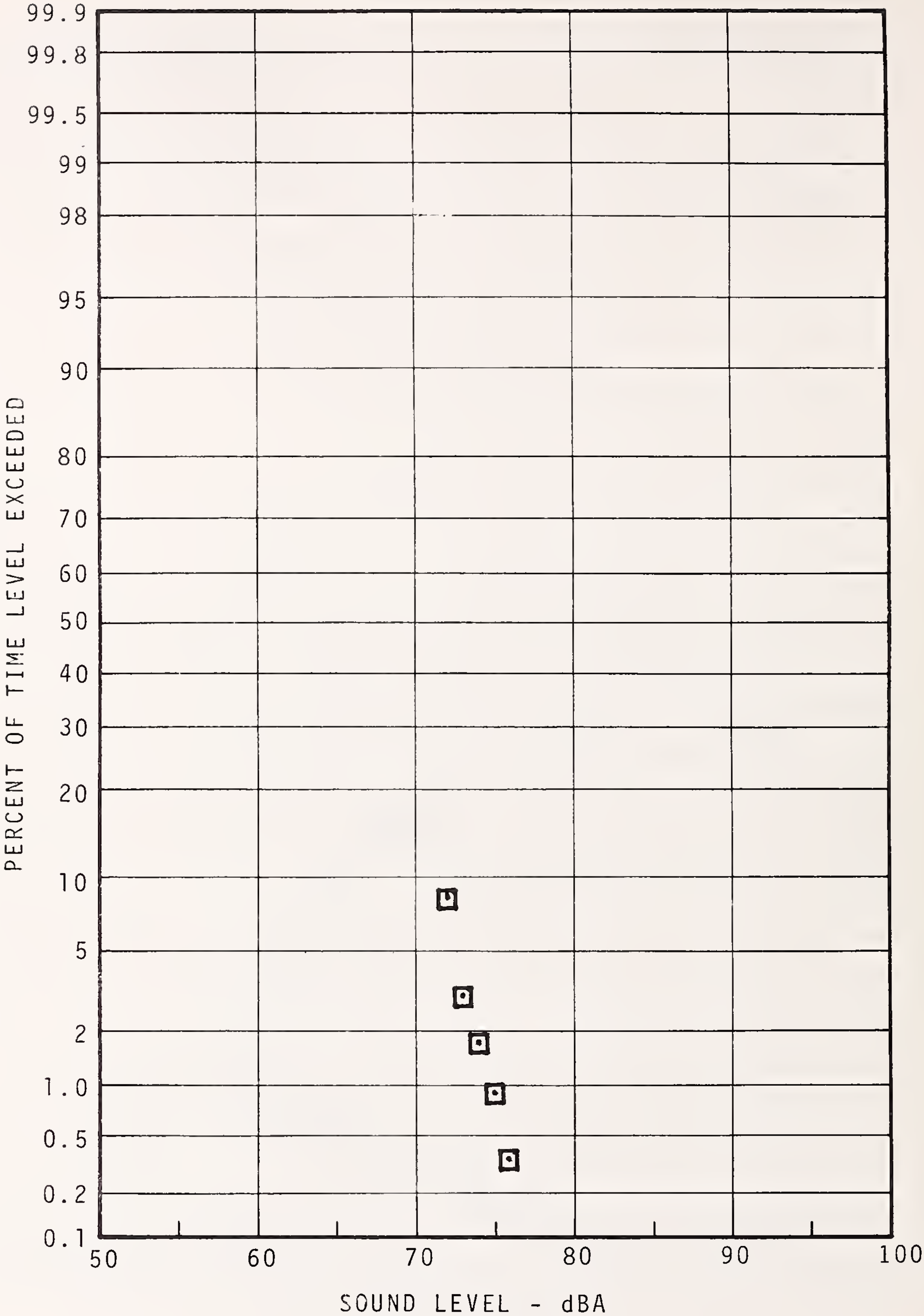


FIGURE 5.18. WEST PARK COMMUNITY STATISTICAL DISTRIBUTION - 60M - DAYTIME

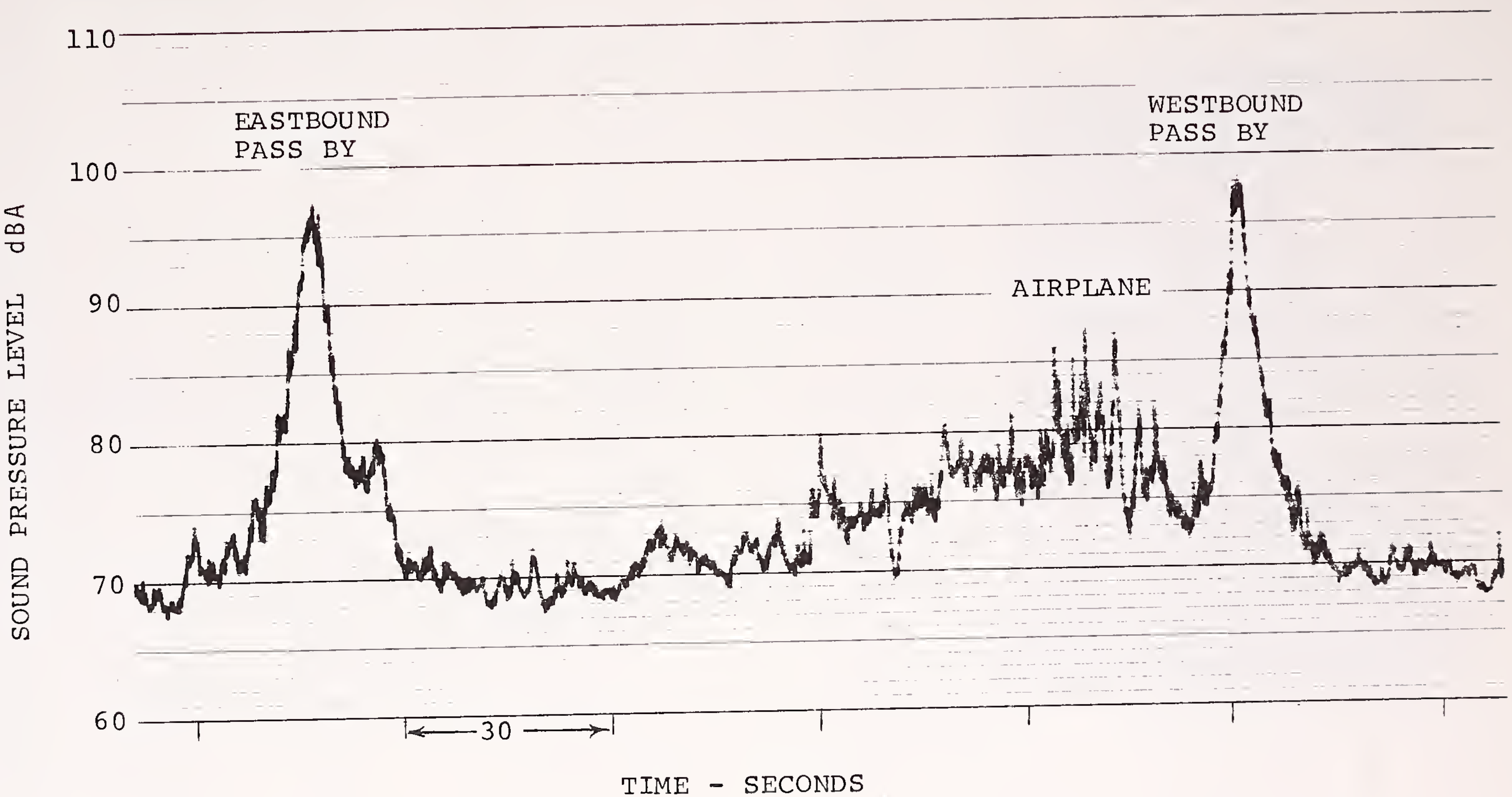


FIGURE 5.19. TYPICAL TIME HISTORY, WEST PARK WAYSIDE

WEST 98TH AND LANDON WAYSIDE

Site Description (see Figure 5.20)

The transit system is located in a cut in this neighborhood which is composed of business/commercial and apartments on the north side of the track and commercial and residential homes on the south side. The Norfolk and Western Railroad is also located in the cut on the far side of the transit line from where noise measurements were made. A small park and an elementary school are situated nearby the measurement site.

Noise Climate (see Table 5.8, Figures 5.21 - 5.27)

The predominant single event source of noise at this site is the passage of freight trains at moderate speeds. The transit cars are normally audible at the 15m and 30m locations, but less at the 60m location due to depression in the cut. Traffic on Detroit Avenue on the far side of the cut, on Landon Avenue, aircraft overflights and children at play at the elementary school are also sources of noise in this locale.

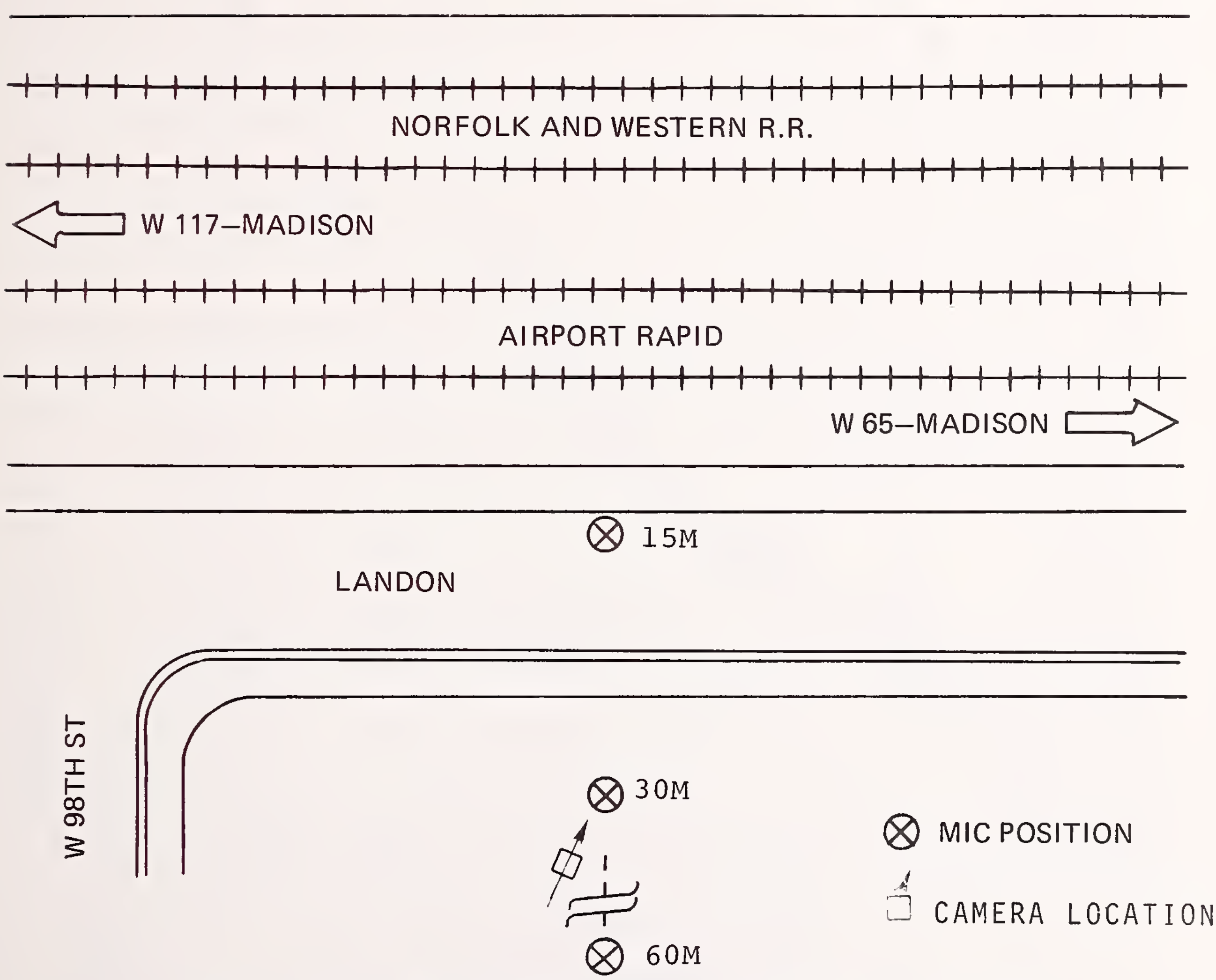


FIGURE 5.20. WAYSIDE MEASUREMENT LOCATION, W. 98TH AND LANDON - IN CUT

TABLE 5.8. SUMMARY OF MEASUREMENT RESULTS FOR W. 98TH AND LANDON STREETS

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	FAR	NEAR	FAR						
					EAST	WEST	EAST	WEST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	15m	30 min	Pass-by	b) N	6-1	6-1	6-1	6-1	62	62	63	69	88	68
				dBA	91	93	96	97						
				c) S	2.67	2.44	2.77	1.61						
Rush	15m	30 min	Pass-by	dBA					67	67	69	78	91	78
Evening	15m	30 min	Pass-by	dBA					61	61	62	77	87	74
Night	15m	10 min	Pass-by	dBA					59	60	62	68	73	65
Day	30m	5 min	Pass-by	dBA					61	62	64	68	73	65
Day	60m	9 min	Pass-by	dBA					62	63	64	69	73	66

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

$L_{dn} = 78$

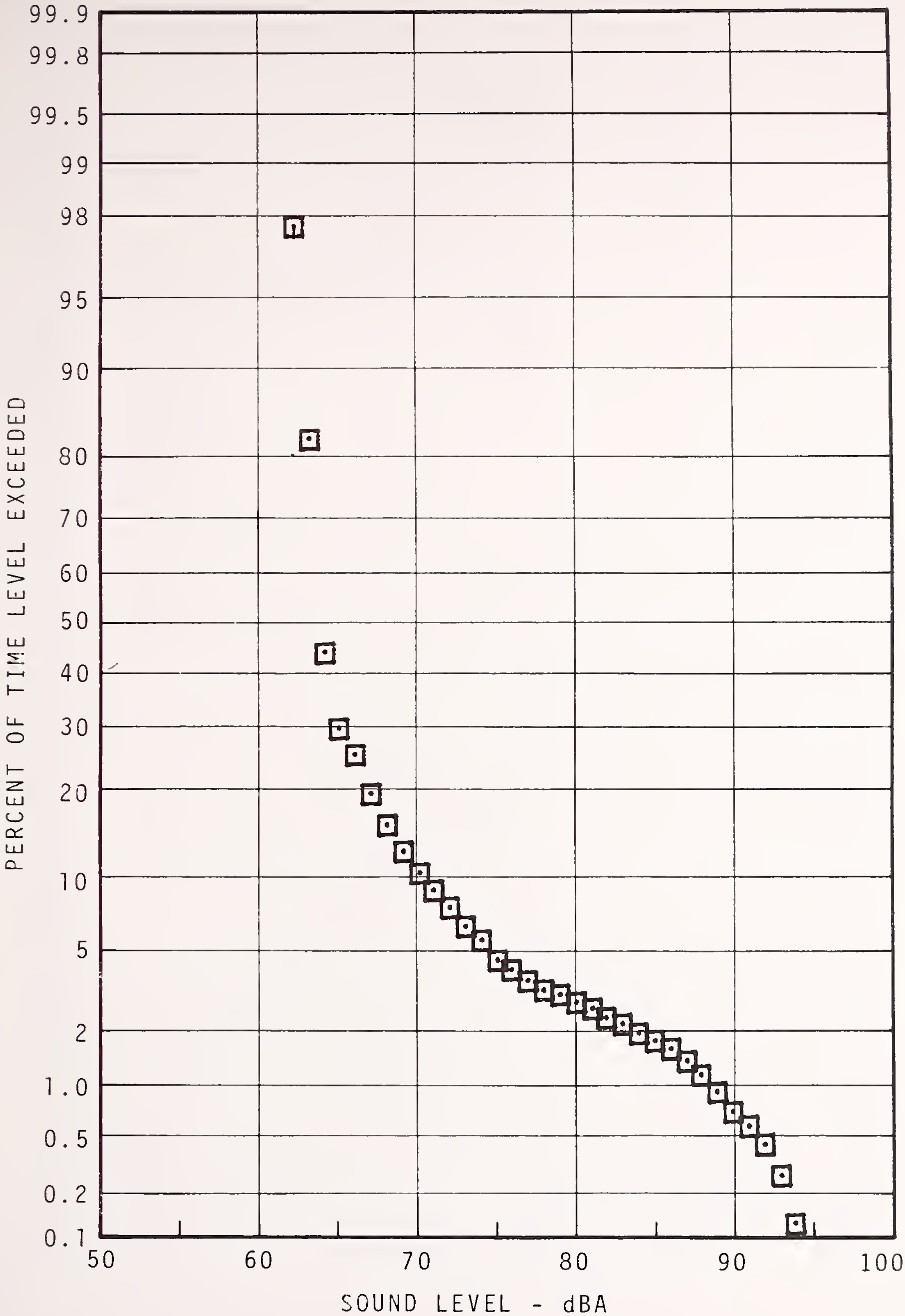


FIGURE 5.21. W. 98TH-LANDON COMMUNITY STATISTICAL DISTRIBUTION - 15M - DAYTIME

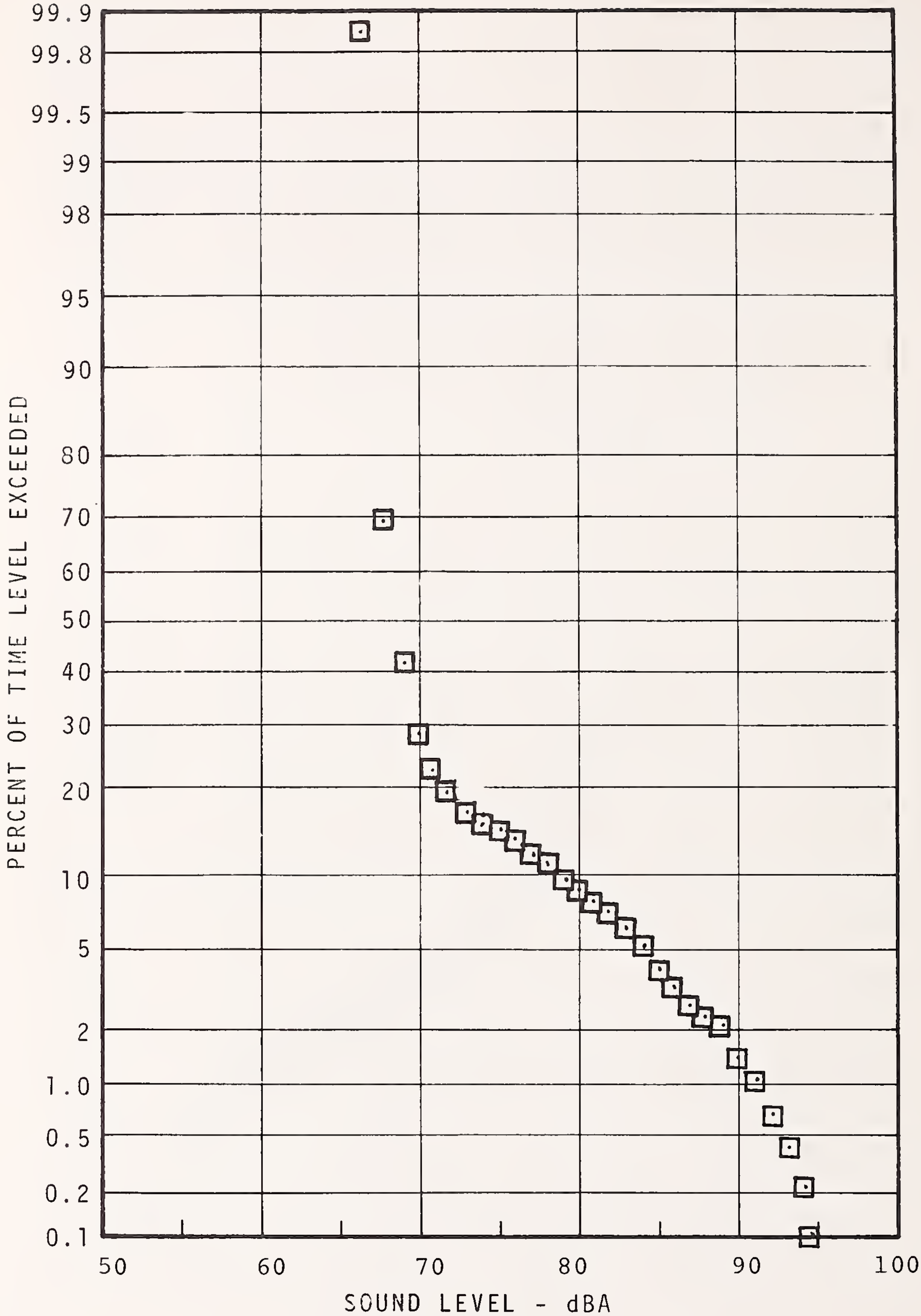


FIGURE 5.22. W. 98TH-LANDON COMMUNITY STATISTICAL DISTRIBUTION - 15M - RUSH

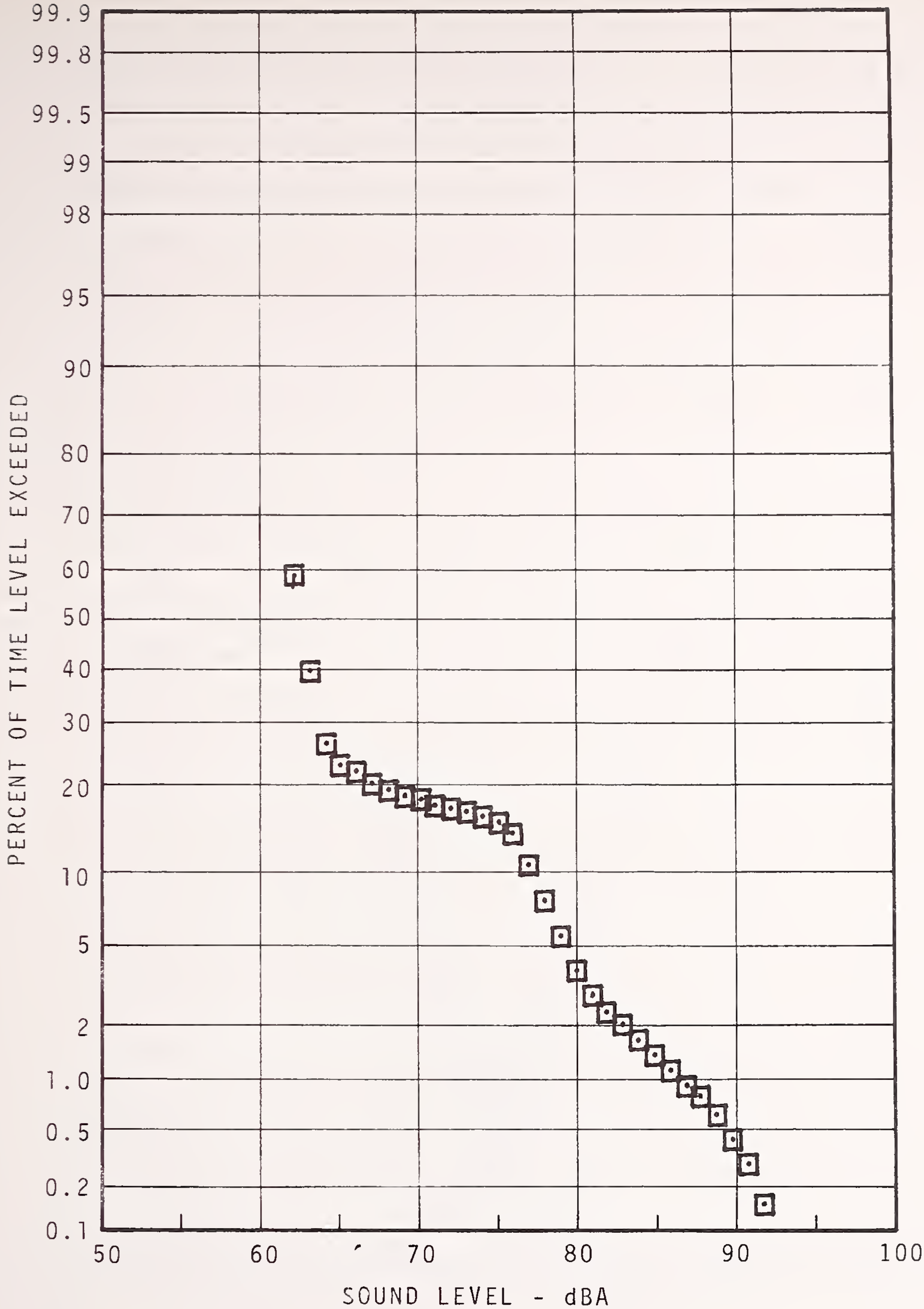


FIGURE 5.23. W. 98TH-LANDON COMMUNITY STATISTICAL DISTRIBUTION - 15M - EVENING

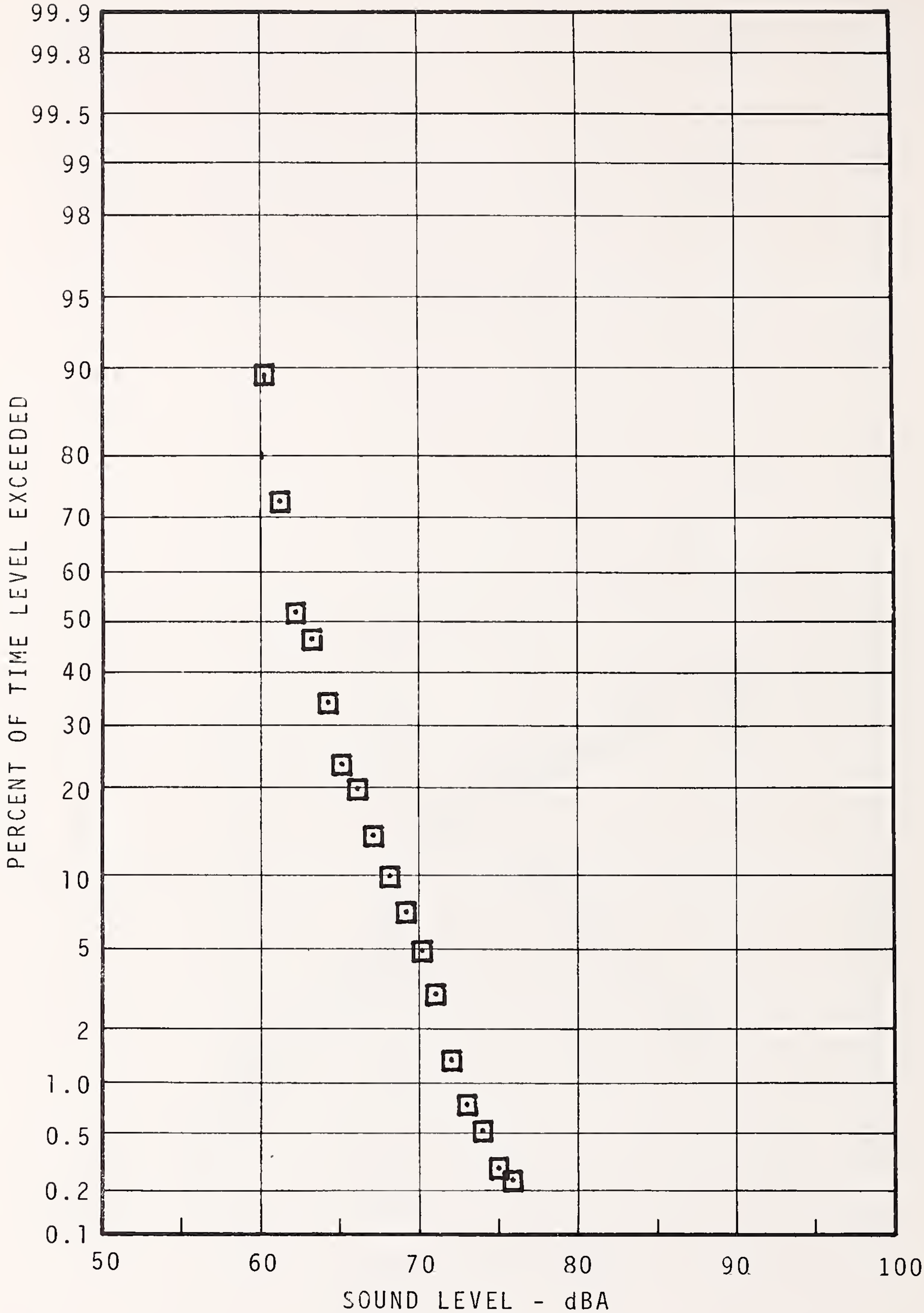


FIGURE 5.24. W. 98TH-LANDON COMMUNITY STATISTICAL DISTRIBUTION - 15M - NIGHT

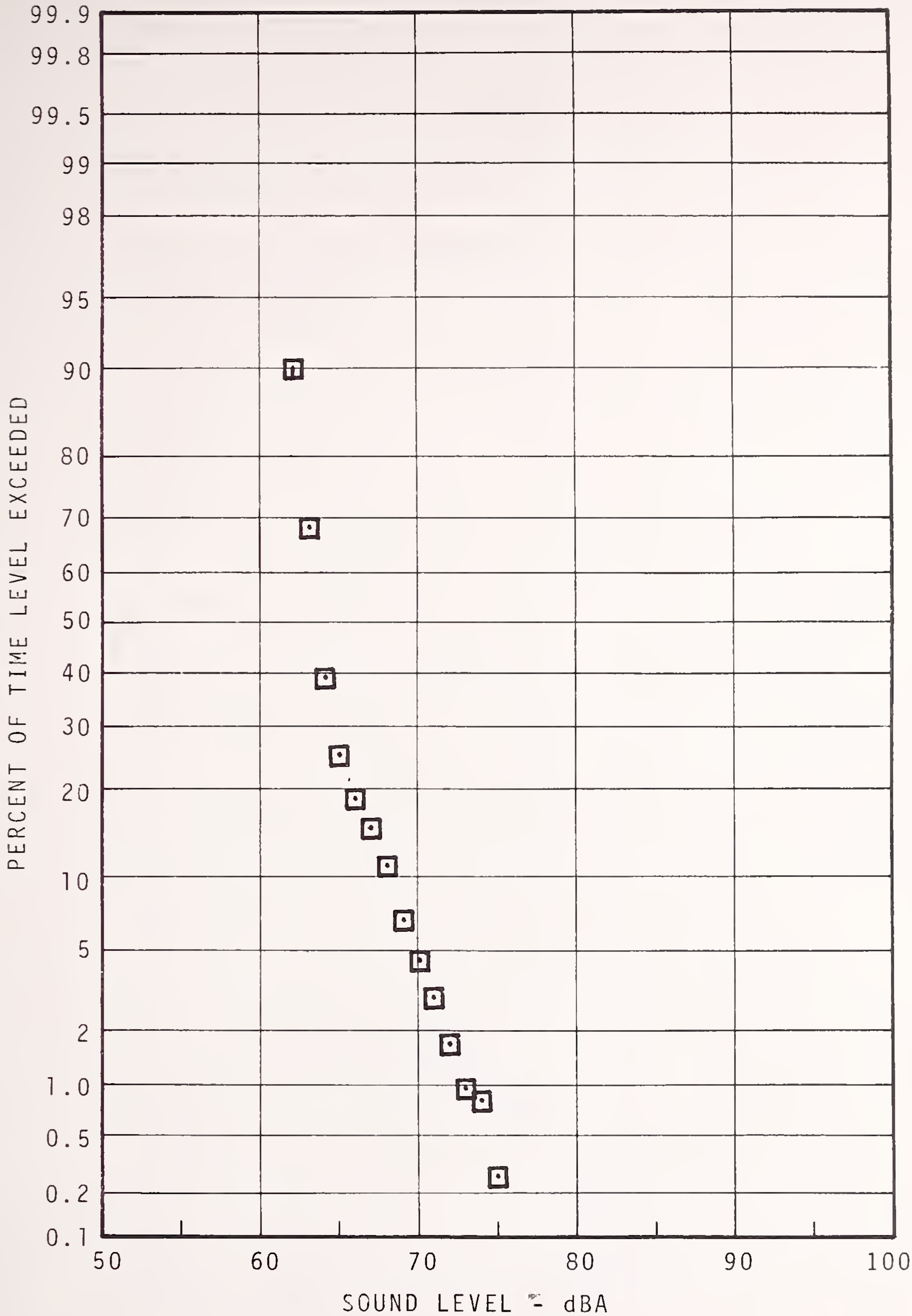


FIGURE 5.25. W. 98TH-LANDON COMMUNITY STATISTICAL DISTRIBUTION - 30M - DAYTIME

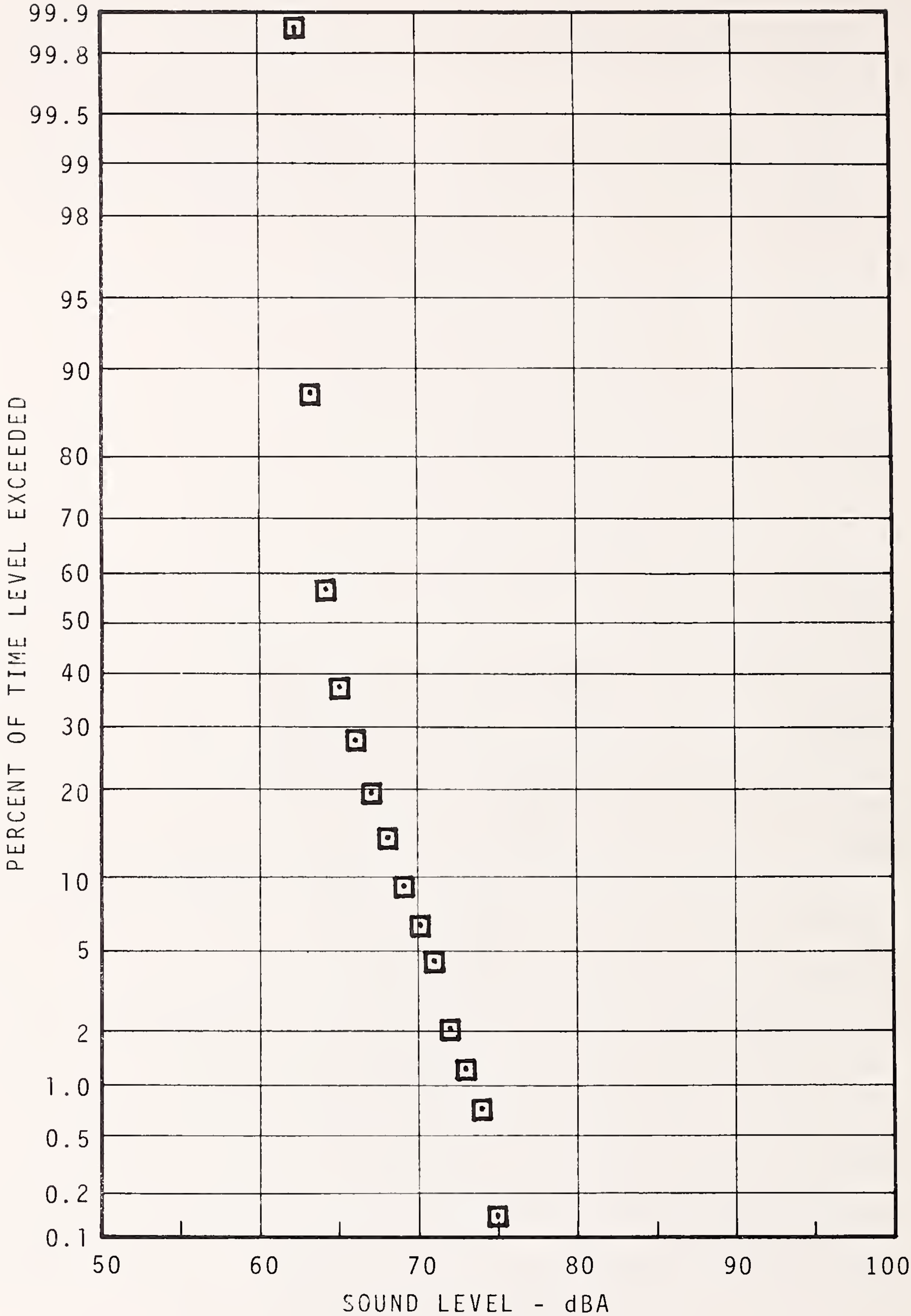


FIGURE 5.26. W. 98TH-LANDON COMMUNITY STATISTICAL DISTRIBUTION - 60M - DAYTIME

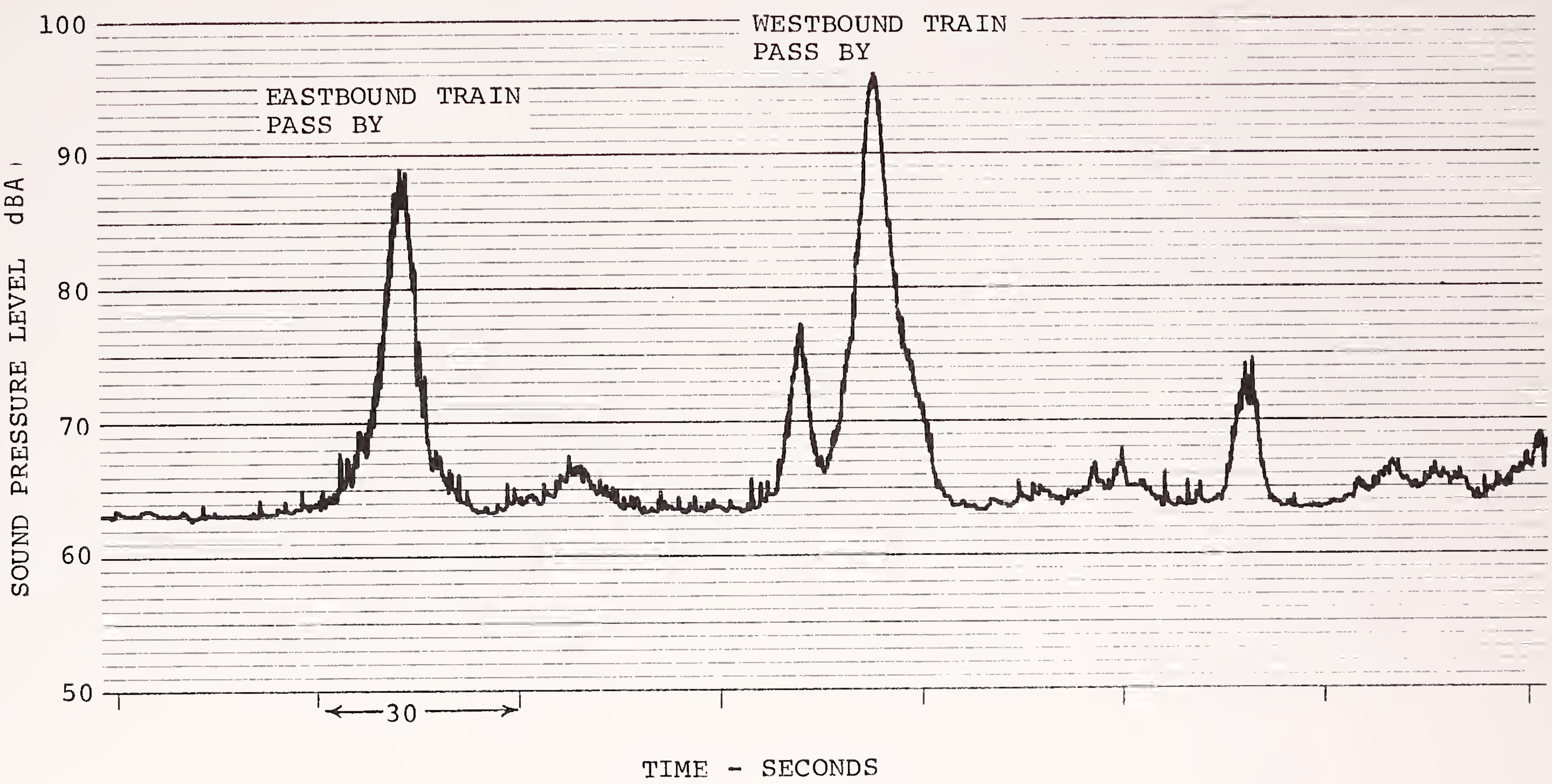


FIGURE 5.27. TYPICAL TIME HISTORY W. 98TH ST., COMMUNITY

5.2.2 Station Platform

The acoustical environment of transit line patrons of six station platforms was surveyed. These stations were selected because of either their unique or typical configuration.

1. Windermere - Center platform, on elevated embankment; patrons occasionally exposed to wheel squeal from yard approach tracks. The waiting room area one level below the platform was also surveyed. (Unique)

2. East 55th - A side platform station sharing common tracks with the Shaker Heights Rapid Transit, located in a cut. (Unique)

3. Public Square - An underground station which is also exposed to noise from other lines. Three tracks separated by two island platforms. (Unique)

4. West 65th-Madison - Center platform in cut; similar to many stations on the line. Wheel squeal audible. (Typical)

5. Triskett - A typical at-grade center platform, station, parallel to Penn Central Railroad, on-grade. (Typical)

6. Airport - Center platform underground; ventilation noise and wheel squeal audible. (Unique)

Although no trains are scheduled during nighttime hours, a 5 minute noise survey was made at each station in this time period. This data may be used for comparison with data taken at a future date if nighttime operations are initiated. Station day-night levels may also be calculated utilizing this information.

WINDERMERE STATION

Station Description

Windermere terminal station platform, Figure 5.28, is elevated above a ground level waiting room which is also used as a terminal for bus patrons. The cashier's booth is located on the lower level (Figure 5.33). The yard and shops are located on the northwest side of the station and a parking lot and bus plaza on the southeast side. A short radius curve leads from the station to the yards.

Measurements were also taken at ground level in the area below the station tracks near the cashier's booth.

Noise Climate (see Tables 5.9, 5.10; Figures 5.29-5.32, 5.34)

The noise of undercar equipment on the standing cars is a significant contributor to the total environment, particularly air-conditioned cars in the summertime months. Screech is heard when cars are brought on-line or off-line over the approach tracks to the shops. Automobile traffic noise is also quite prevalent.

Although no trains were operating during nighttime hours, the data sample for this time period includes the noise of cars standing in the station with undercar blowers running continuously.

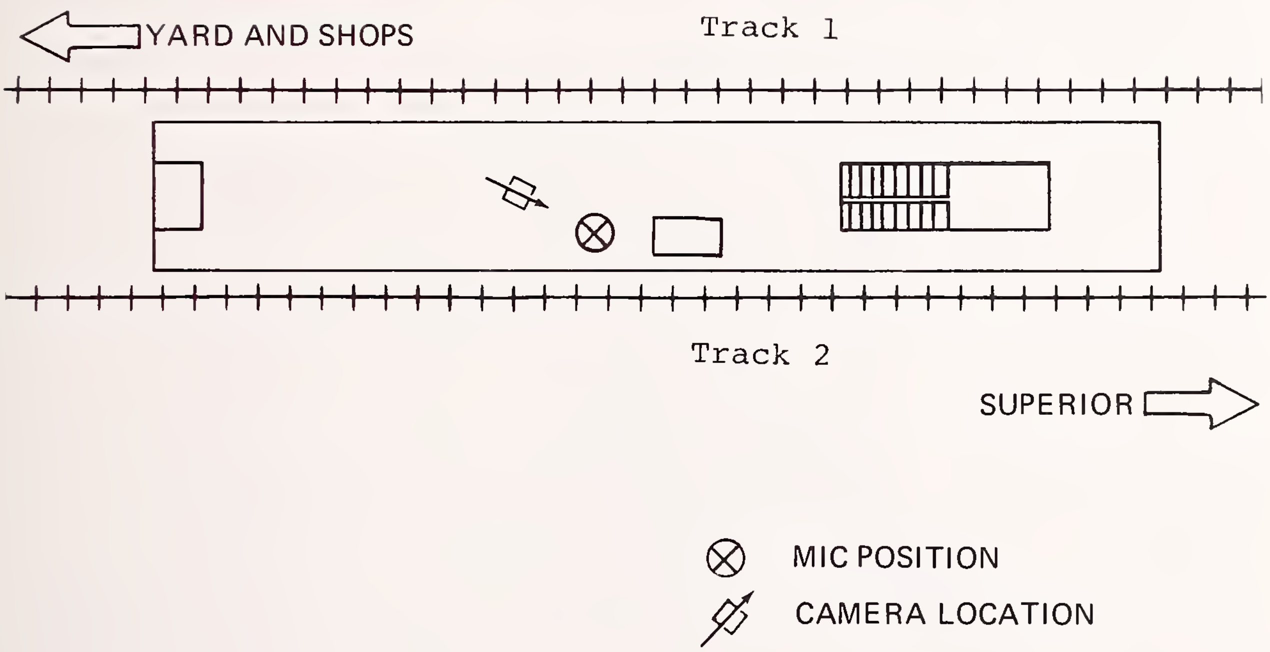


FIGURE 5.28. WINDERMERE TERMINAL STATION PLATFORM
ELEVATED EMBANKMENT

TABLE 5.9. SUMMARY OF MEASUREMENT RESULTS FOR WINDERMERE STATION

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)	2	1	2	1						
Day	Center	30 min.	Arrival	b) N	3-1	2-1	2-1	-	67	70	72	75	83	74
				dBA	77	74	86	-						
				c) S	2.89	1.77	5.94	-						
			Departure	N	3-1	3-1	2-1	1-1						
				dBA	78	78	89	85						
				S	5.58	3.06	4.88	0						
Rush	Center	30 min.	Arrival and Departure	dBA					64	66	70	73	84	73
Evening	Center	30 min.		dBA					71	71	74	78	87	77
Night	Center	5 min.	No sched. Trains	dBA					71	72	73	74	76	73

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

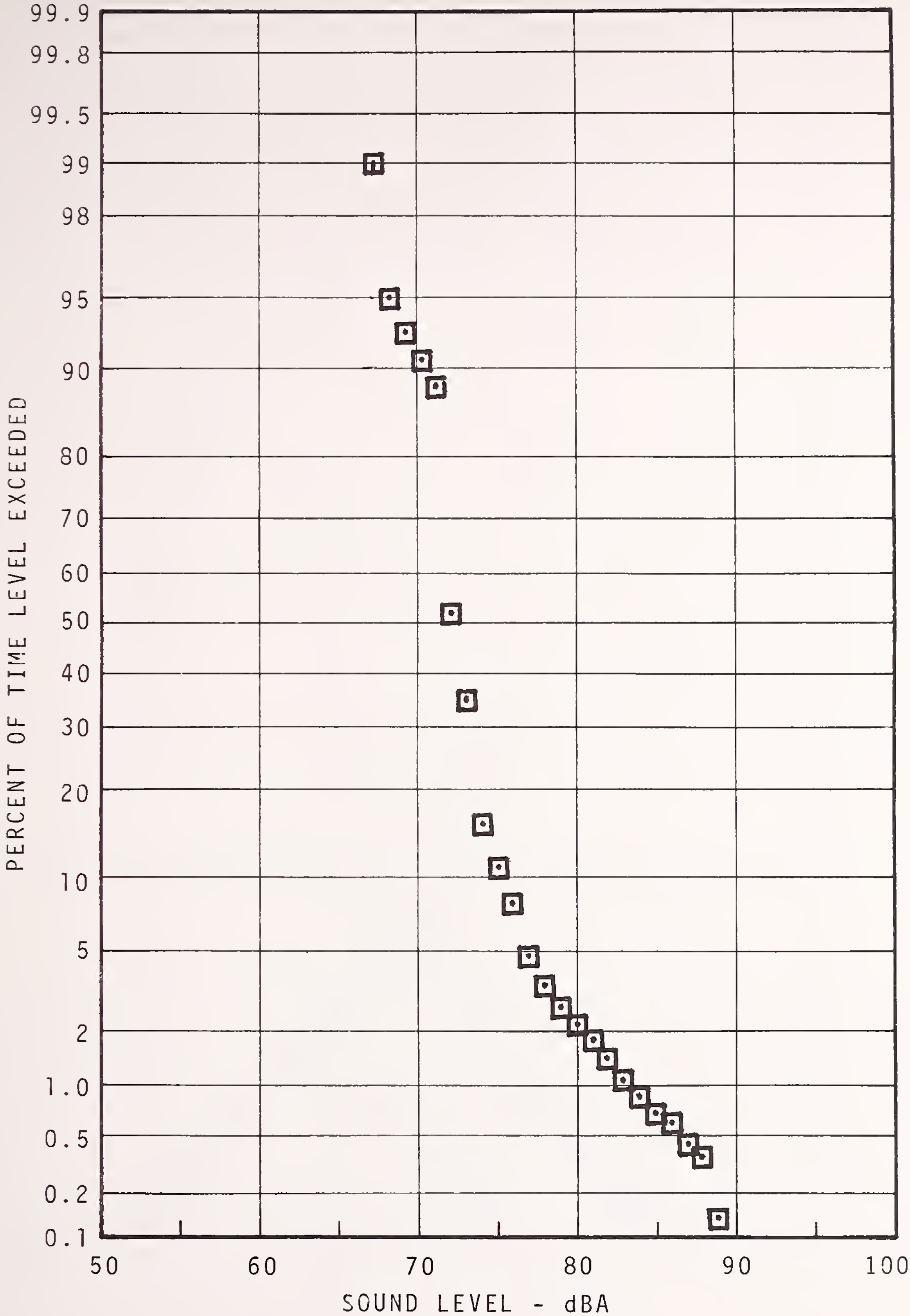


FIGURE 5.29 WINDERMERE STATION PLATFORM STATISTICAL DISTRIBUTION - DAYTIME

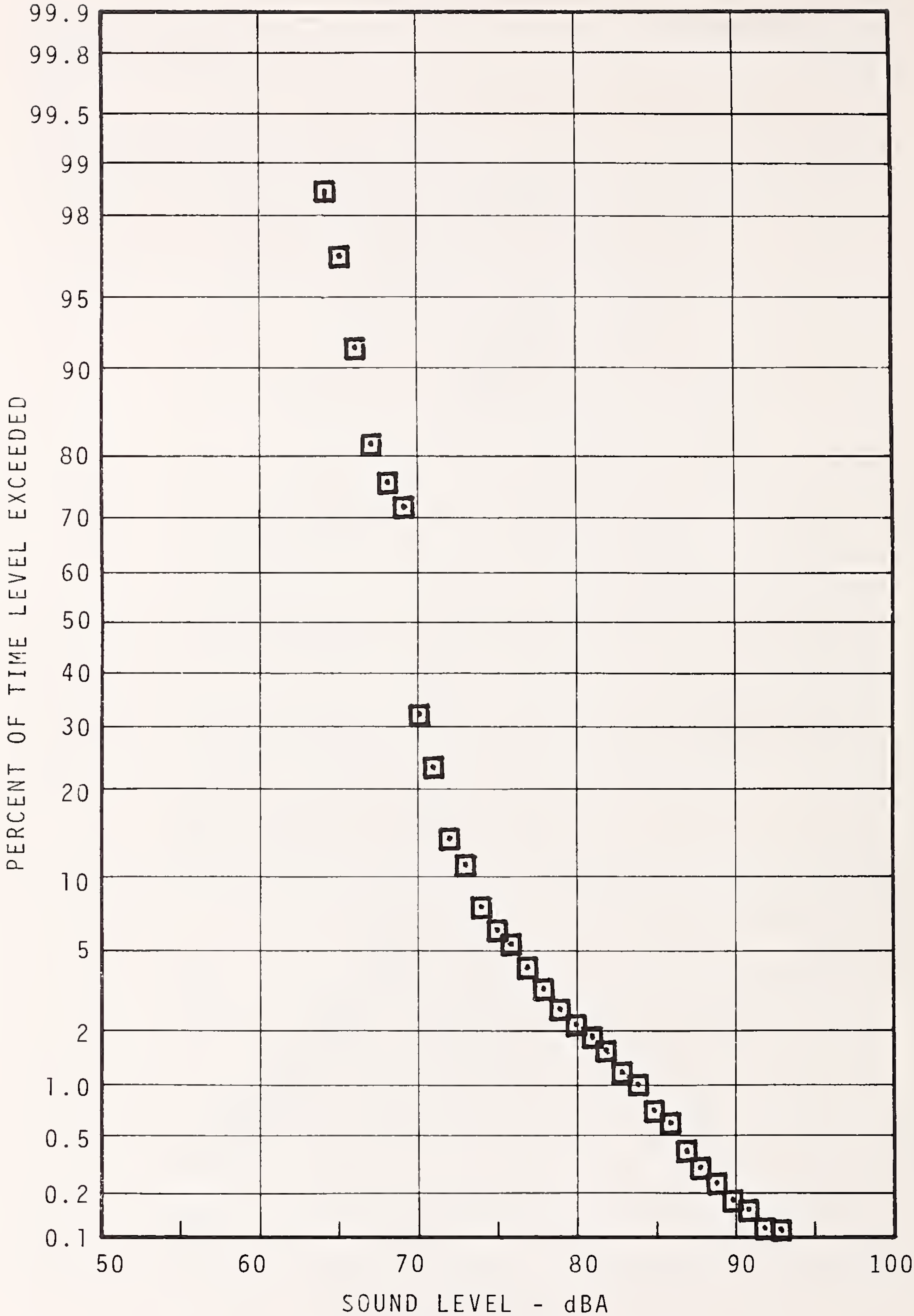


FIGURE 5.30 WINDERMERE STATION PLATFORM STATISTICAL DISTRIBUTION - RUSH HOUR

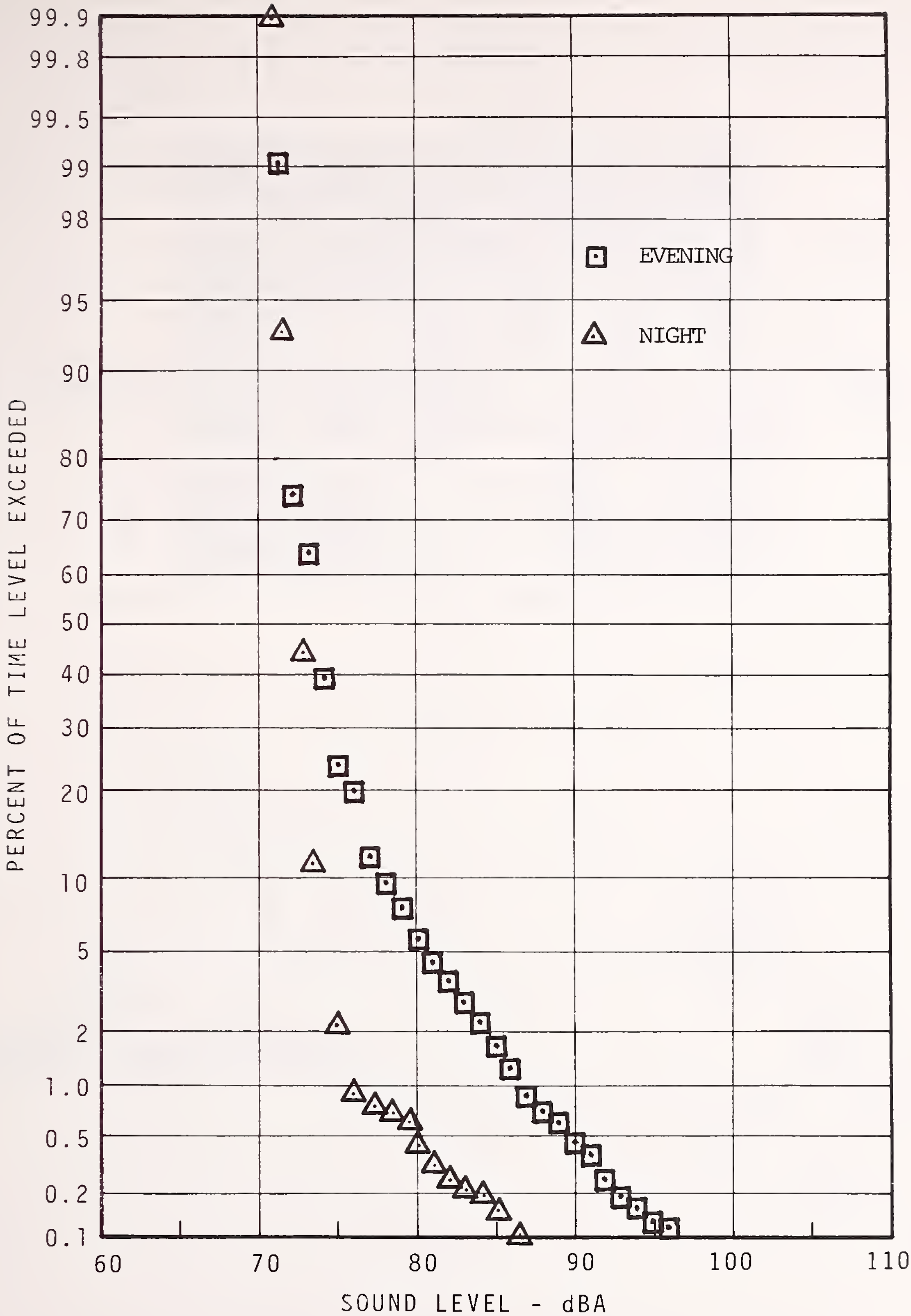
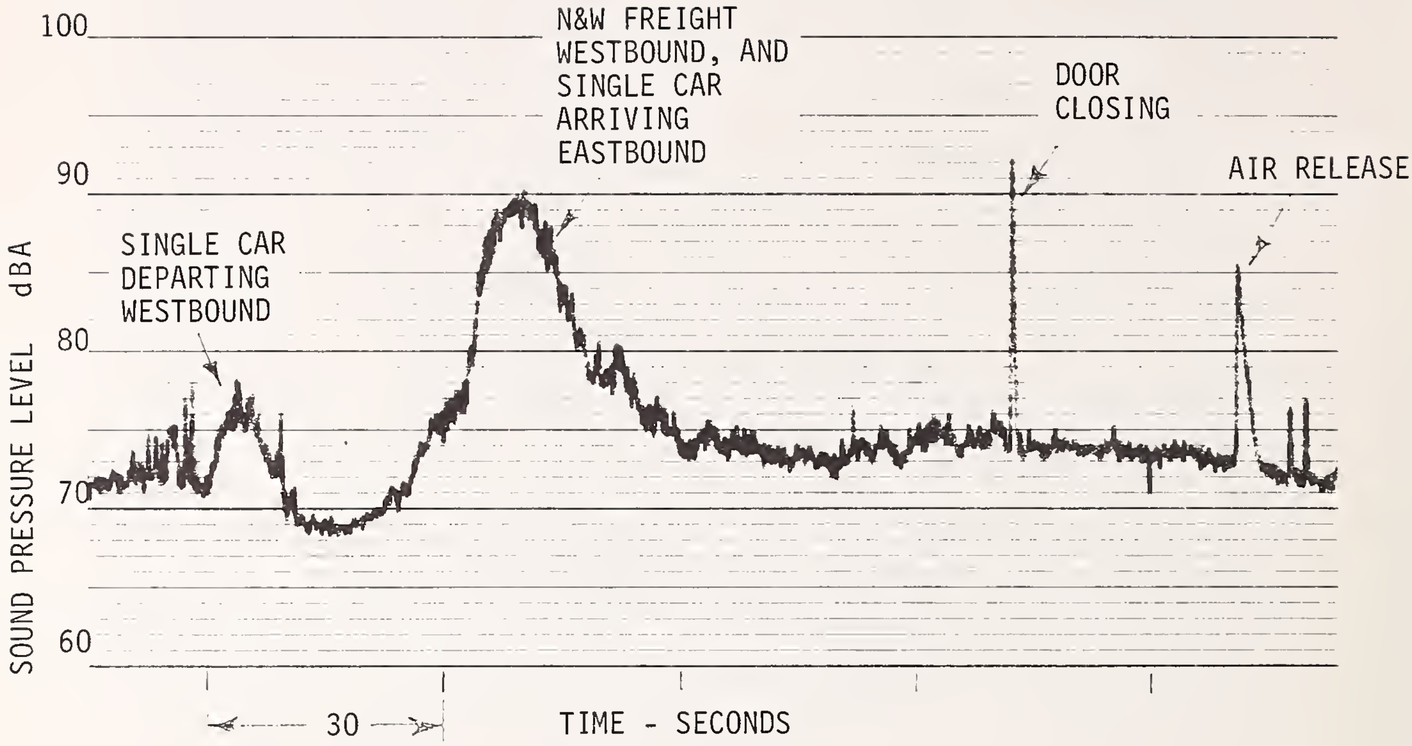


FIGURE 5.31. WINDERMERE STATION PLATFORM STATISTICAL DISTRIBUTION - EVENING AND NIGHT



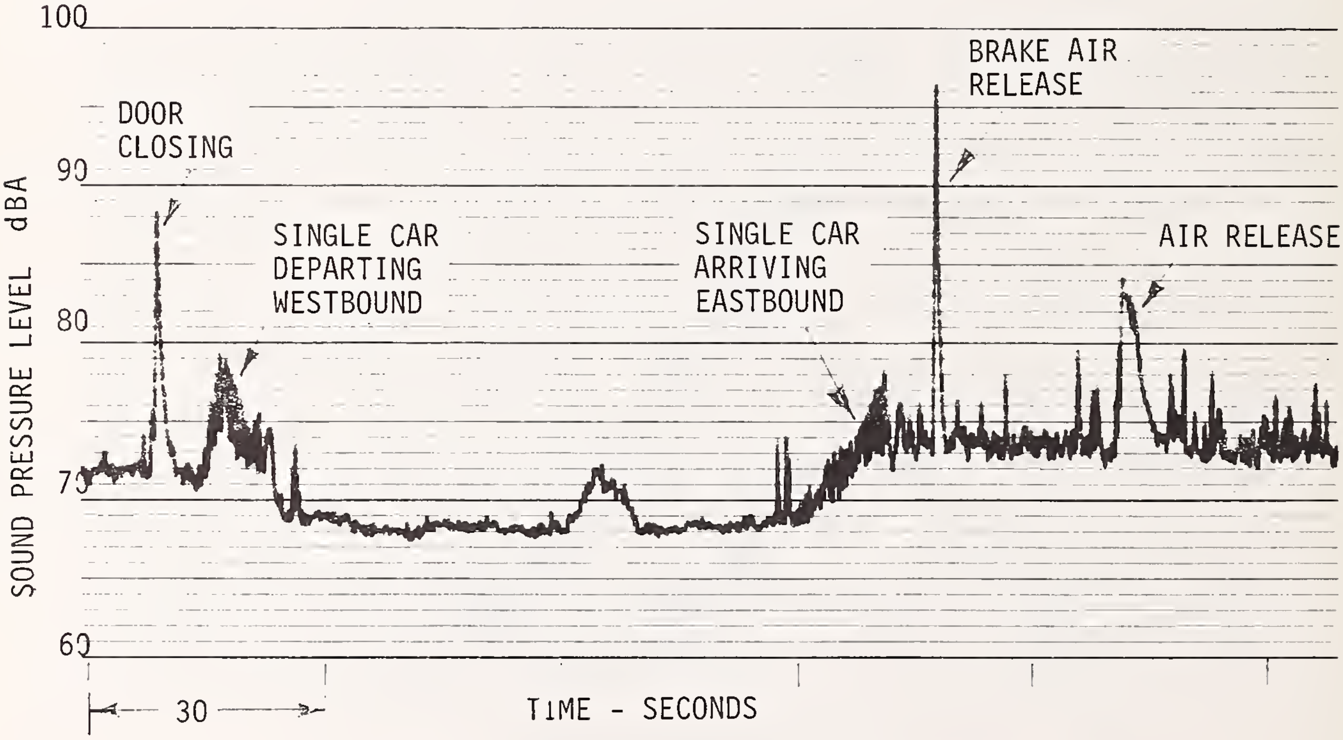


FIGURE 5.32. TYPICAL TIME HISTORY, WINDEREMERE STATION PLATFORM, DAYTIME

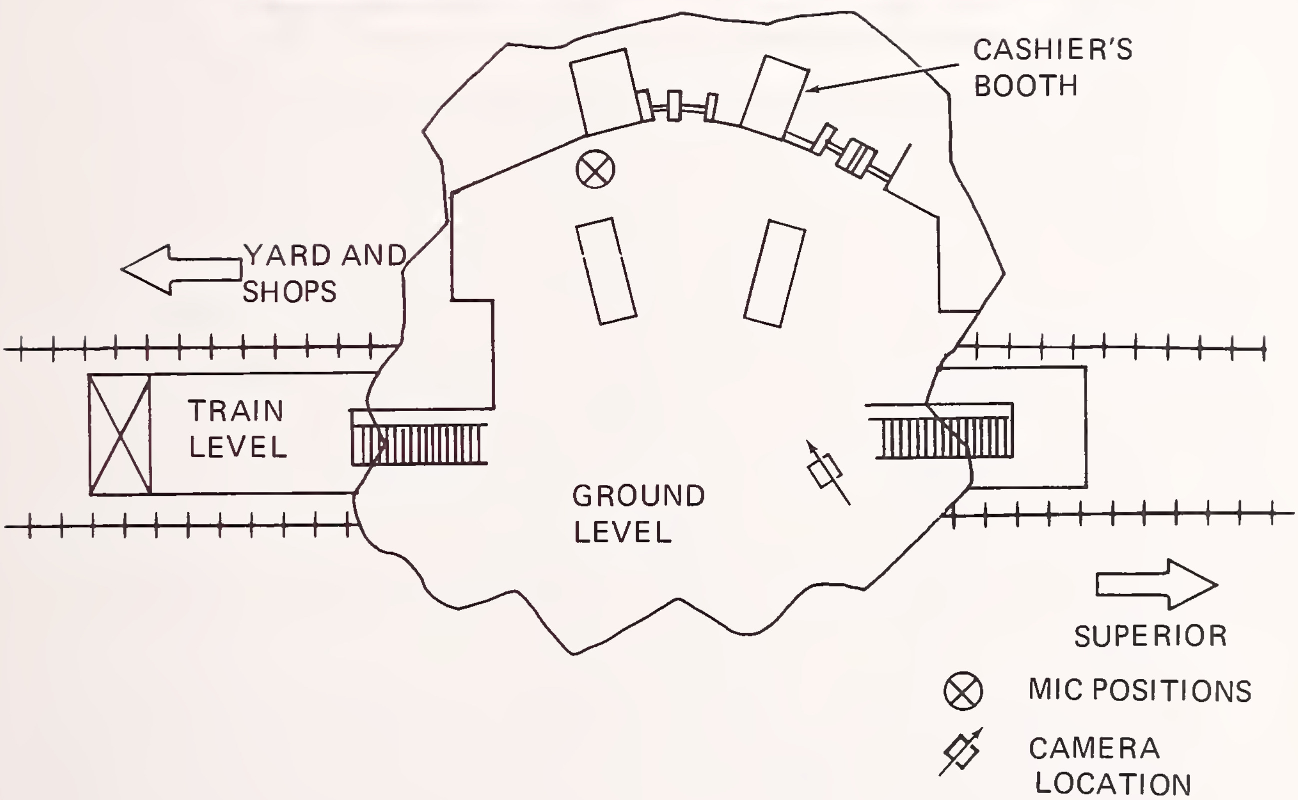


FIGURE 5.33. WINDERMERE STATION WAITING ROOM MEASUREMENT SITE

TABLE 5.10. SUMMARY OF MEASUREMENT RESULTS FOR WINDERMERE STATION WAITING ROOM.

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	
Day	Near Cashier's Booth	15 min	Arrival and Departure	dBA					68	69	71	73	78	72

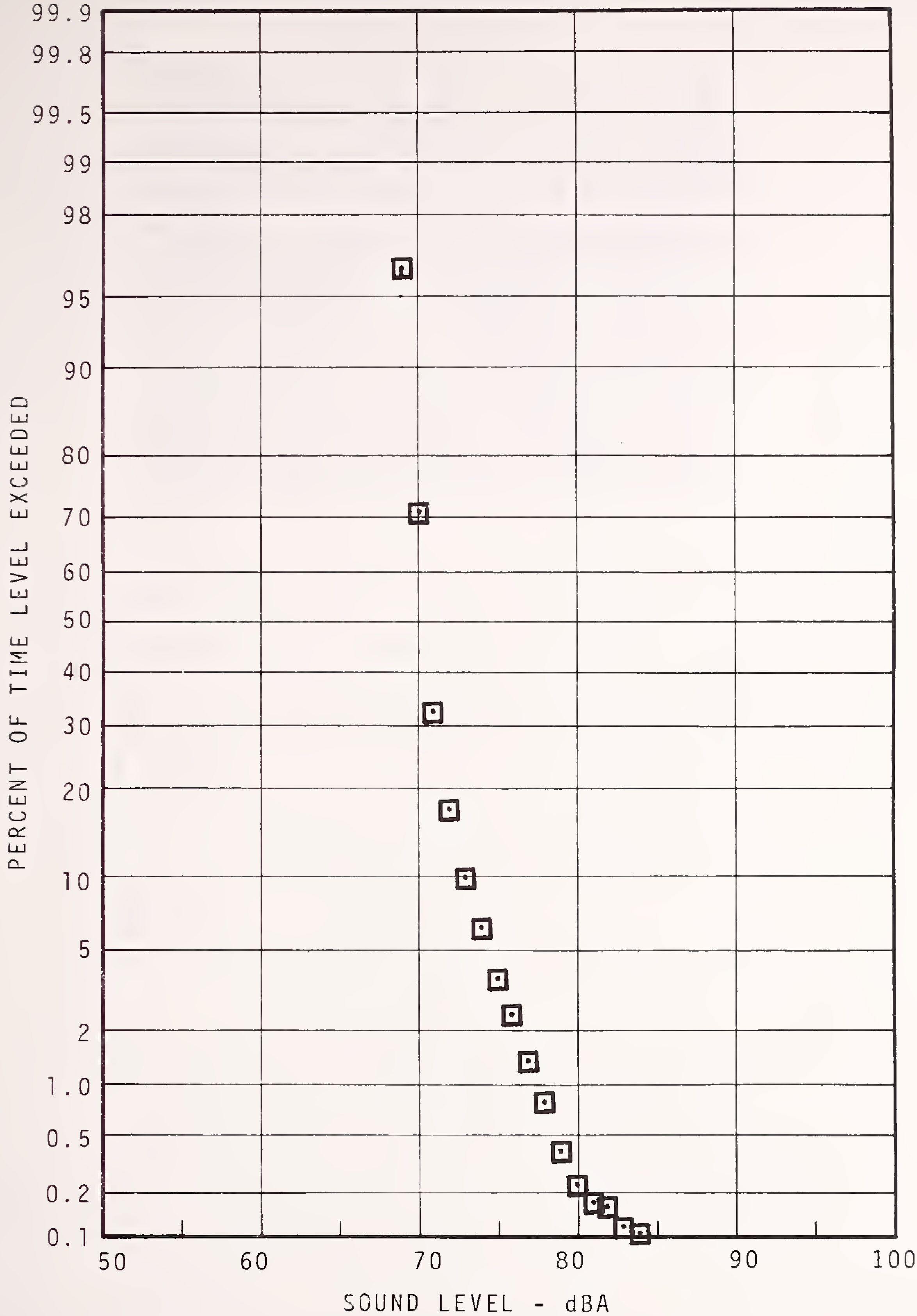


FIGURE 5.34. WINDERMERE STATION WAITING ROOM
STATISTICAL DISTRIBUTION - DAYTIME

EAST 55TH STATION

Station Description (see Figure 5.35)

East 55th is a side platform station and an interchange with the Shaker Heights Rapid Transit (light rail). Patrons on the Shaker Rapid enter and exit between tracks at ground level, while Airport Rapid patrons use the side platforms. There is an exit to East 55th Street, which carries vehicular traffic over the Rapid as well as the Norfolk and Western tracks at the east end of the platform. South of the right-of-way an embankment leads to an upper grade level while the north side is at-grade with the Rapid right-of-way. The Norfolk and Western has a make-up yard in this area. The region is industrial north of the right-of-way and mixed commercial/residential on the south side.

Noise Climate (see Table 5.11, Figures 5.36 - 5.40)

The noise environment of East 55th primarily stems from the industry in the vicinity. Train make-up constitutes a large part of this, particularly at night. Traffic noise on the East 55th span over the area also contributes to the total. As with all stations above ground, the transit patron is exposed to many sources of noise other than the transit vehicle. At this interchange station, transit noise is composed of both the airport and Shaker Heights Rapid rail vehicles.

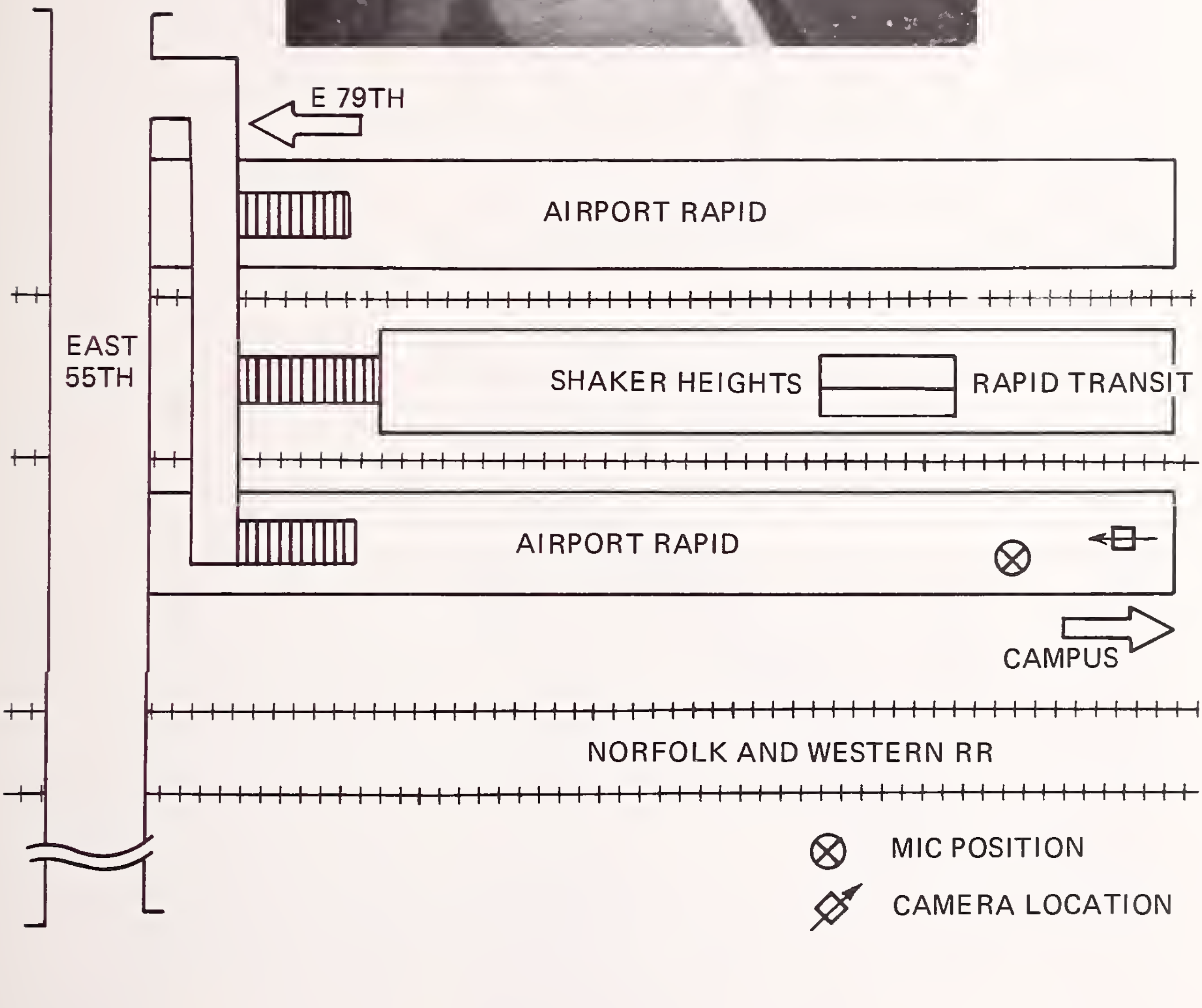


FIGURE 5.35. E. 55TH STATION PLATFORM - IN CUT

TABLE 5.11. SUMMARY OF MEASUREMENT RESULTS FOR E. 55TH STATION

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL a) NEAR 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	Center	30 min.	Arrival	b) N	2-1	2-1	2-1	1-1	63	64	66	70	85	72
				dBA	82	77	89	86						
				c) S	1.06	9.9	0.42	-						
			Departure	N	2-1	2-1	2-1	2-1						
				dBA	76	78	81	86						
				S	2.12	6.72	1.13	4.03						
			Pass-Thru	N	4-1	3-1	4-1	3-1						
				dBA	85	85	93	91						
				S	3.74	5.39	3.88	5.92						
Rush	Center	30 min.	Arrival and Departure	dBA					63	63	65	76	85	73
Evening	Center	30 min.		dBA					66	66	71	74	86	76
Night	Center	5 min.	No Sched. Trains	dBA					62	63	64	67	69	65

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

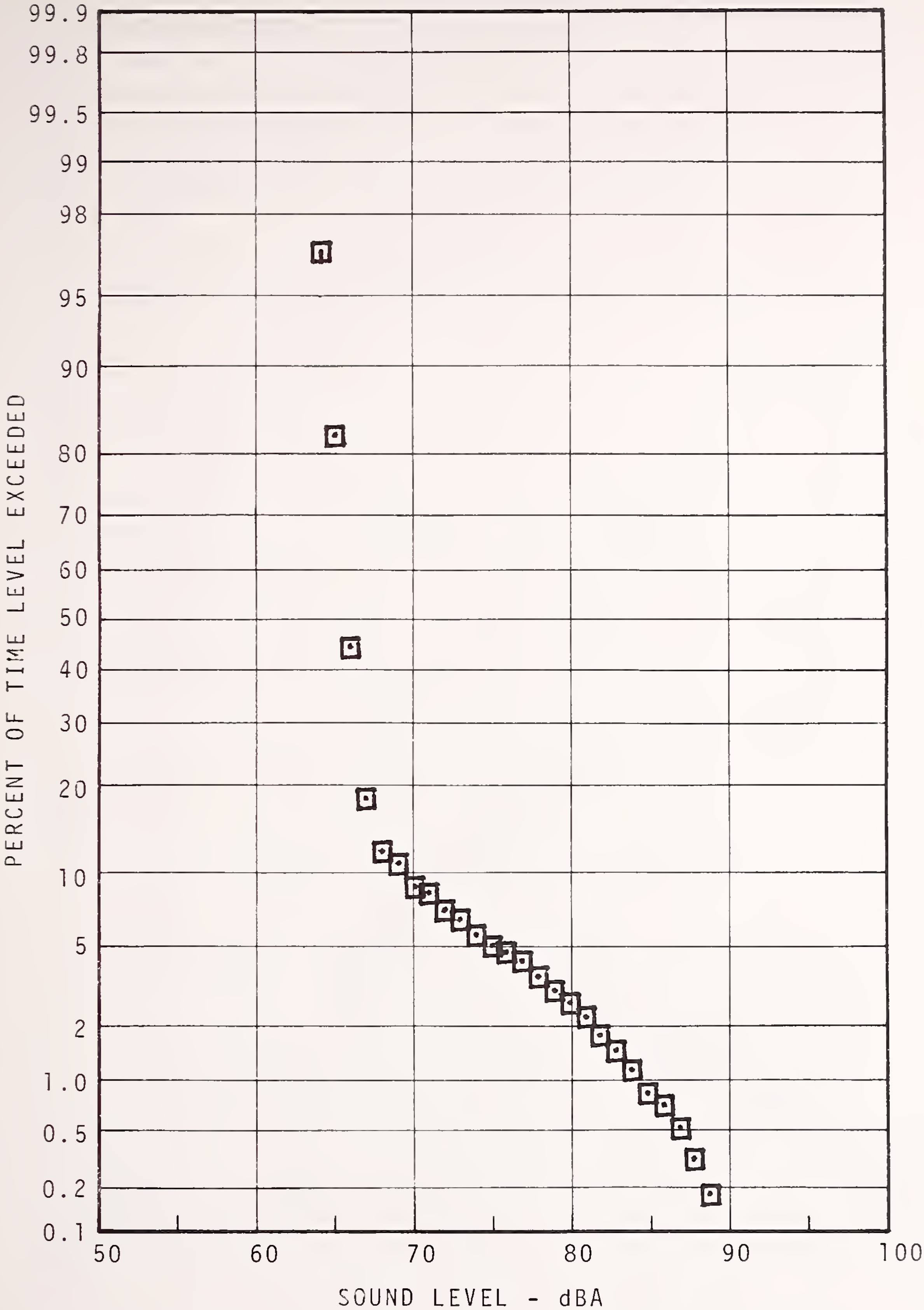


FIGURE 5.36. E. 55TH STATION PLATFORM STATISTICAL DISTRIBUTION - DAYTIME

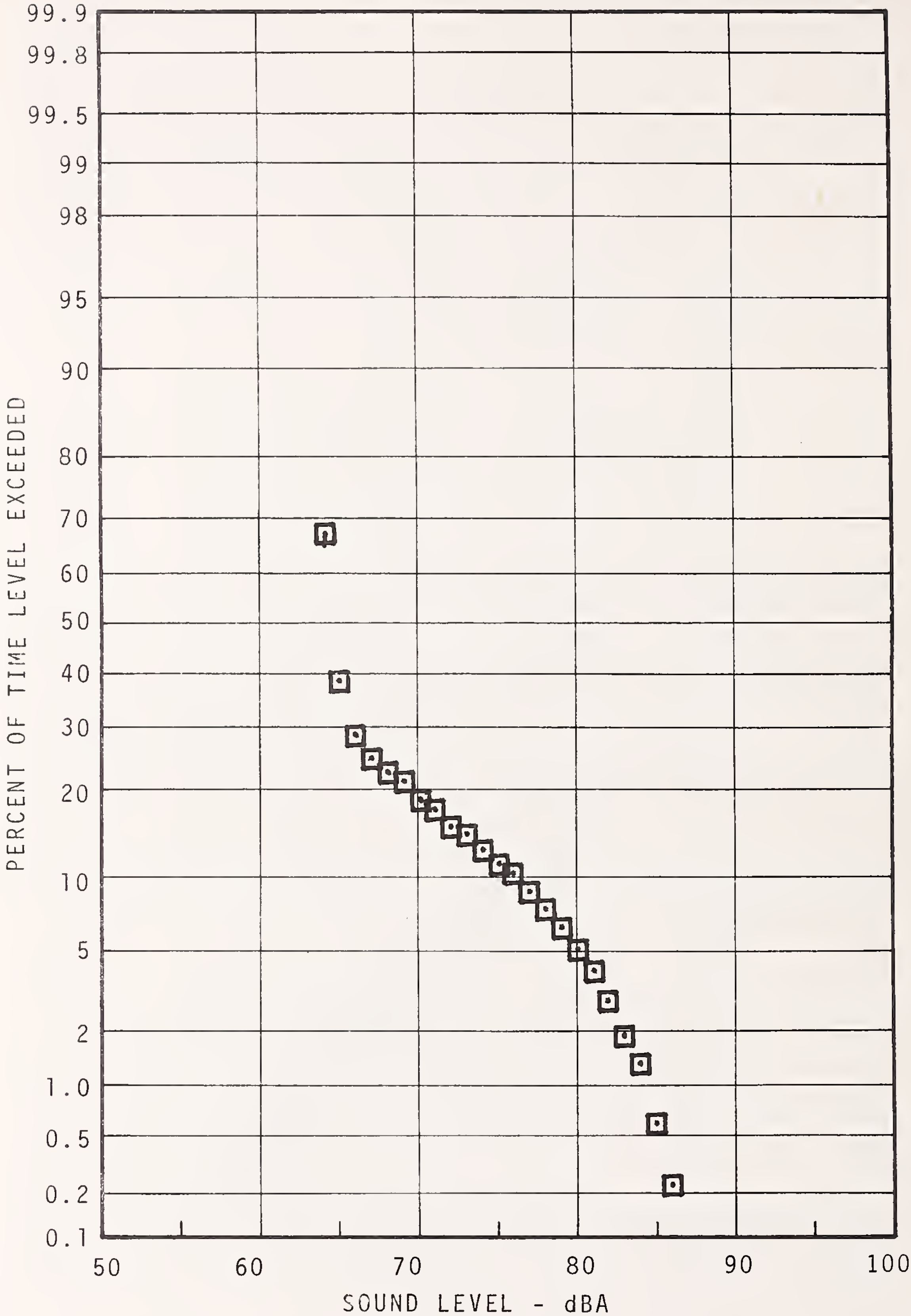


FIGURE 5.37. E. 55TH STATION PLATFORM STATISTICAL DISTRIBUTION - RUSH HOUR

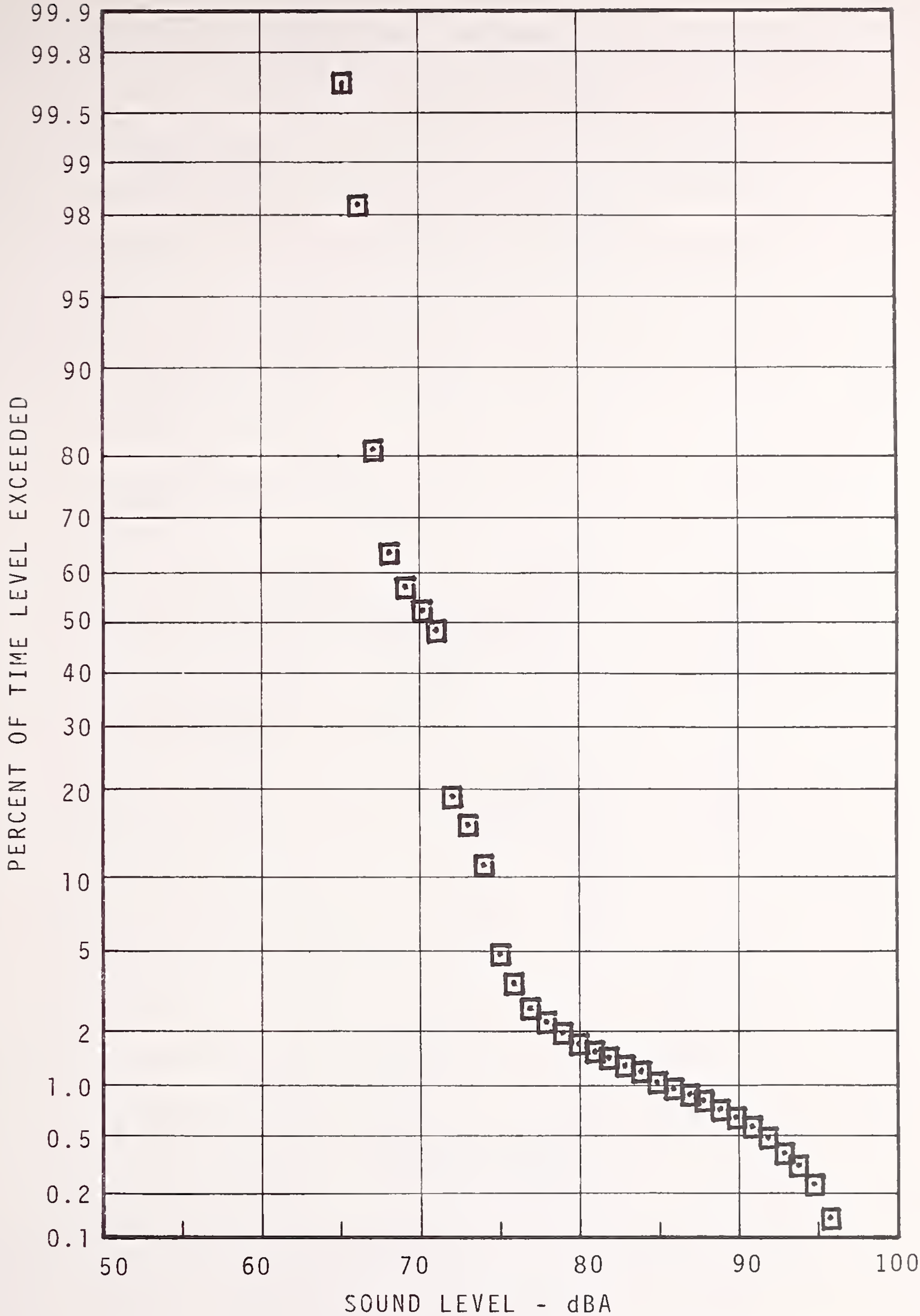


FIGURE 5.38. E. 55TH STATION PLATFORM STATISTICAL DISTRIBUTION - EVENING

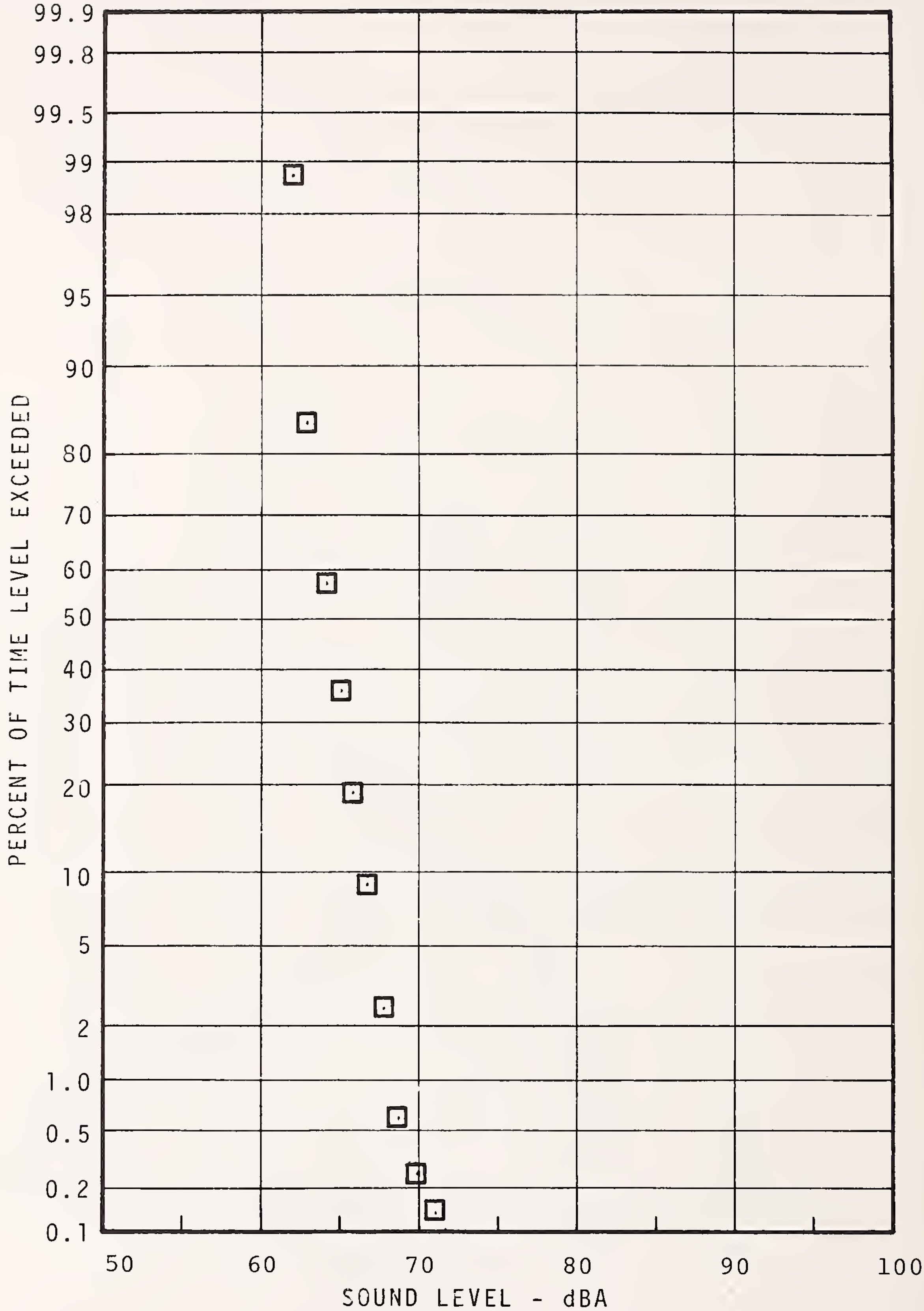


FIGURE 5.39 - E. 55TH STATION PLATFORM STATISTICAL DISTRIBUTION - NIGHT

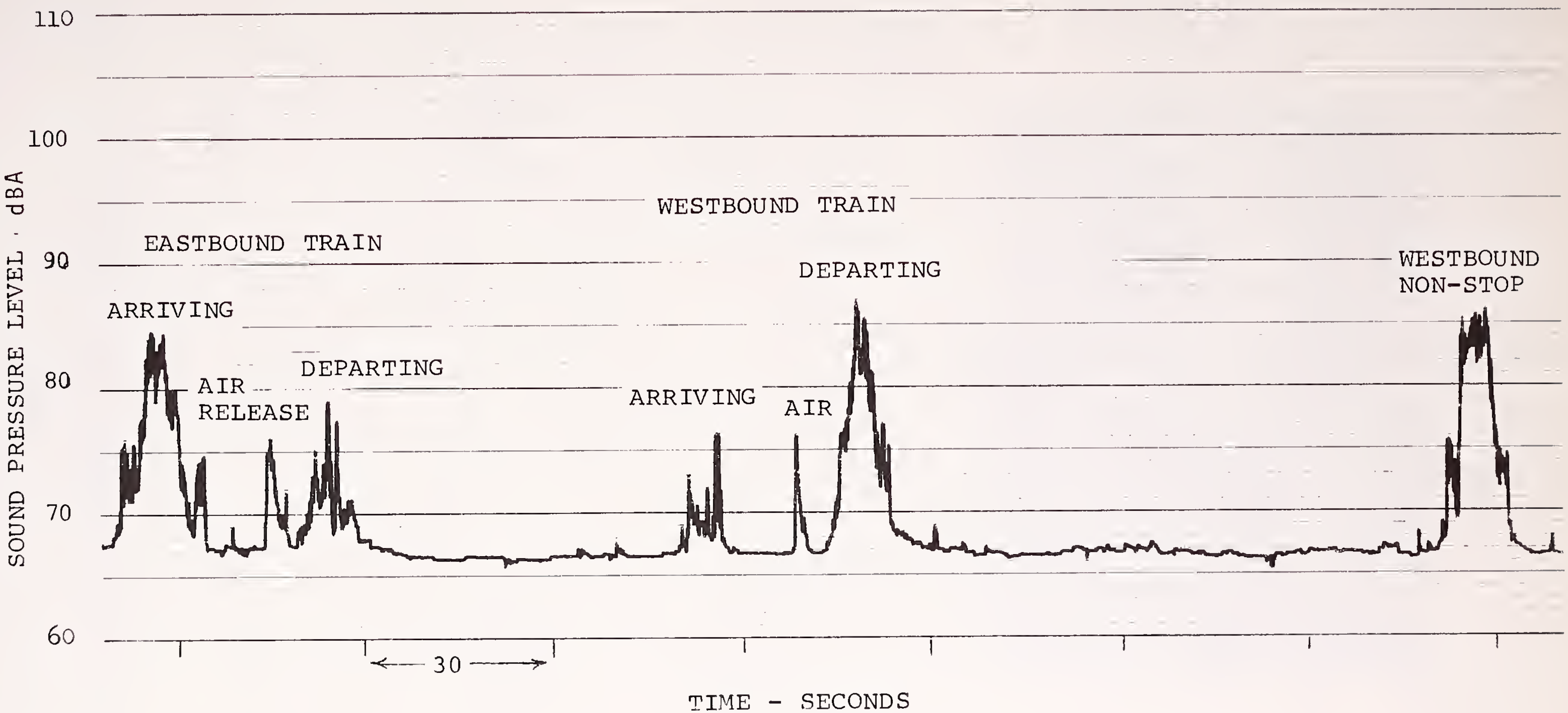


FIGURE 5.40. TYPICAL TIME HISTORY, E. 55TH STREET, STATION

CLEVELAND UNION TERMINAL

(Public Square)

Station Description (see Figure 5.41)

Public Square Station is located in the Cleveland Union Terminal, formerly a major railroad center in Cleveland. It is the major station for downtown Cleveland and is the primary station for commuters to and from the business/commercial district. There are three tracks for the transit system and two island platforms at this underground station. Construction of the station is primarily concrete, and acoustic absorption is low. The wide concrete platforms are open below each island.

Noise Climate (see Table 5.12, Figures 5.42 - 5.46)

As with most underground stations, there is a strong reverberant field noticeable during the passage of rail vehicles. As a train enters, some wheel screech is audible. Cars, while loading and unloading, display a noise signature composed mainly of the equipment cooling fan and release of brake air. Also, squeal is audible as brakes are released and gearbox noise can be heard as the cars accelerate out of the station. When rail vehicles are not present, the noise floor stems generally from waiting patrons and above-ground sources.

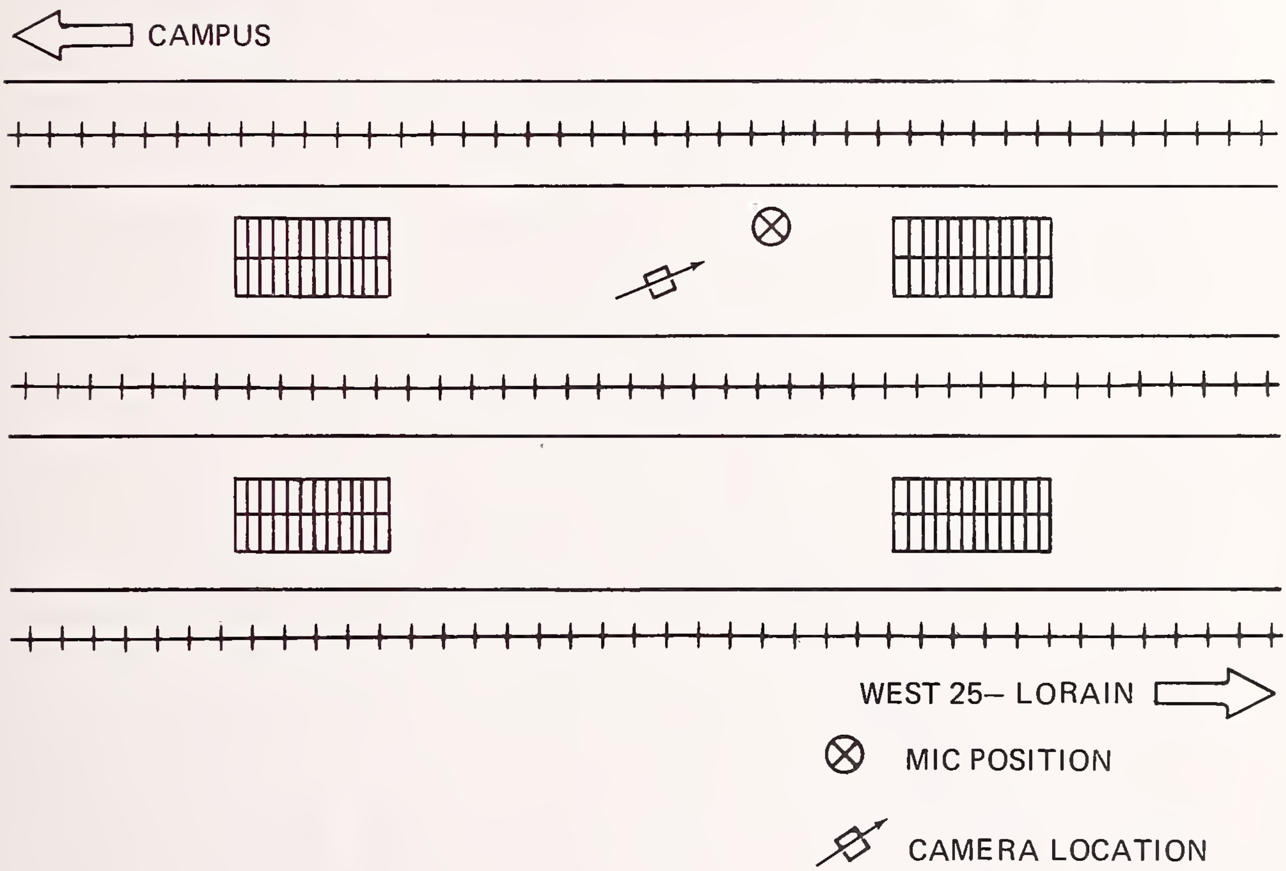


FIGURE 5.41 CLEVELAND UNION TERMINAL (PUBLIC SQUARE) STATION PLATFORM - UNDERGROUND

TABLE 5.12. SUMMARY OF MEASUREMENT RESULTS FOR PUBLIC SQUARE STATION

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL			AVG L_R			CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR	OPP.	FAR	NEAR	OPP.	FAR						
					a) 10	9	8	10	9	8	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	Center	30 min.	Pullman Arrival	b) N			1-2				64	65	70	77	84	74
				dBA			76									
				c) S			-									
			St. Louis Pass-Thru	N			1-6			1-6						
				dBA			83			95						
				S			-			-						
			Pullman Departure	N		1-1			1-1							
				dBA		82			90							
				S		-			-							
			Pullman Arrival	N	4-1		5-1	3-1		3-1						
				dBA	80		80	91		89						
				S	2.89		1.79	2.26		2.08						
			Pullman Departure	N	5-1		4-1	3-1		4-1						
				dBA	78		82	88		89						
				S	4.05		2.45	1.35		2.17						
Rush	Center	30 min.	Arrival and Departure	dBA							66	67	71	79	87	76
Evening	Center	30 min.		dBA							65	66	67	69	82	70
Night	Center	5 min.	No sched. Trains	dBA							51	53	55	57	58	55

Notes: a - Track
b - Number of Trains
c - Standard Deviation of Level

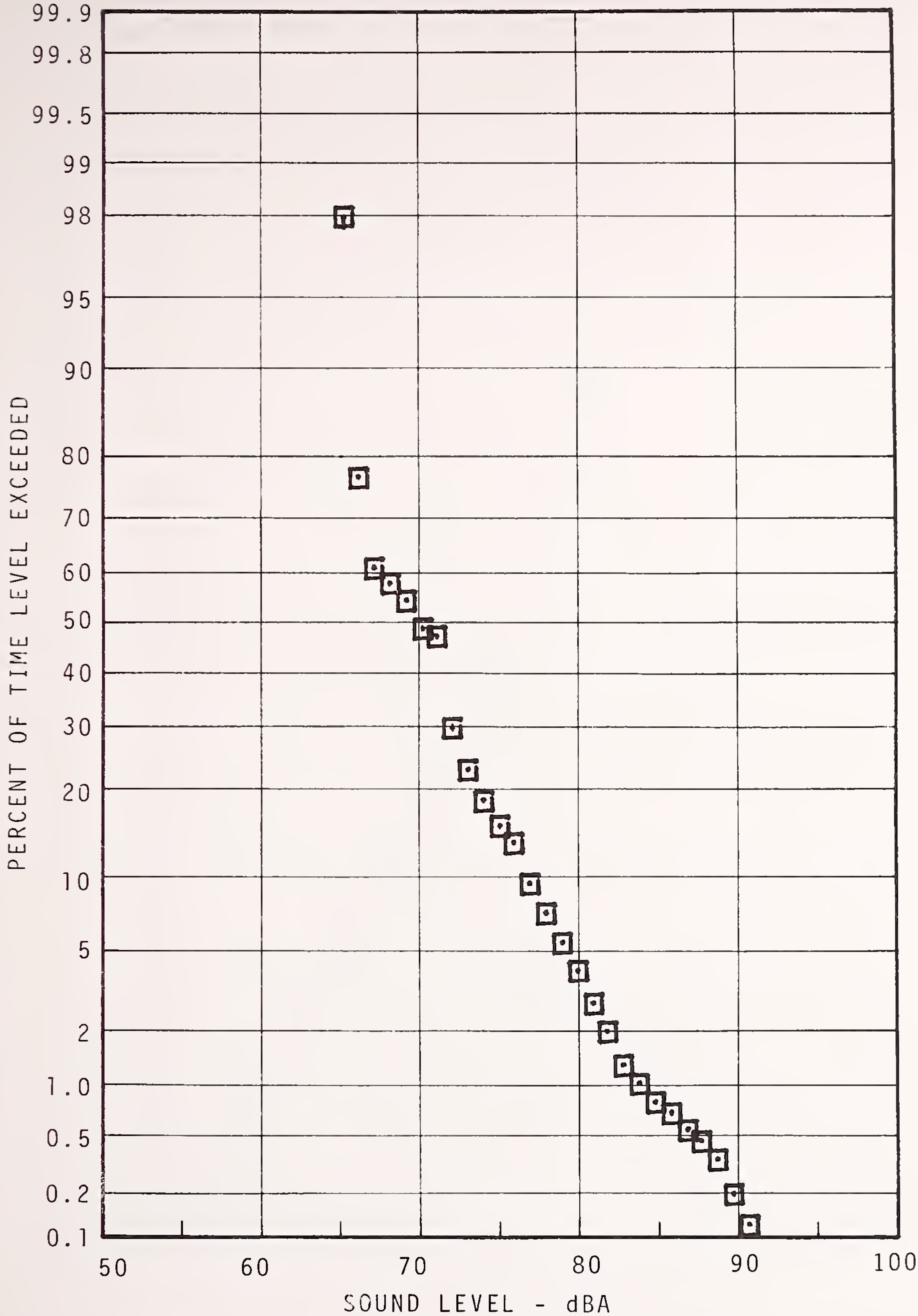


FIGURE 5.42. PUBLIC SQUARE STATION PLATFORM STATISTICAL DISTRIBUTION - DAYTIME

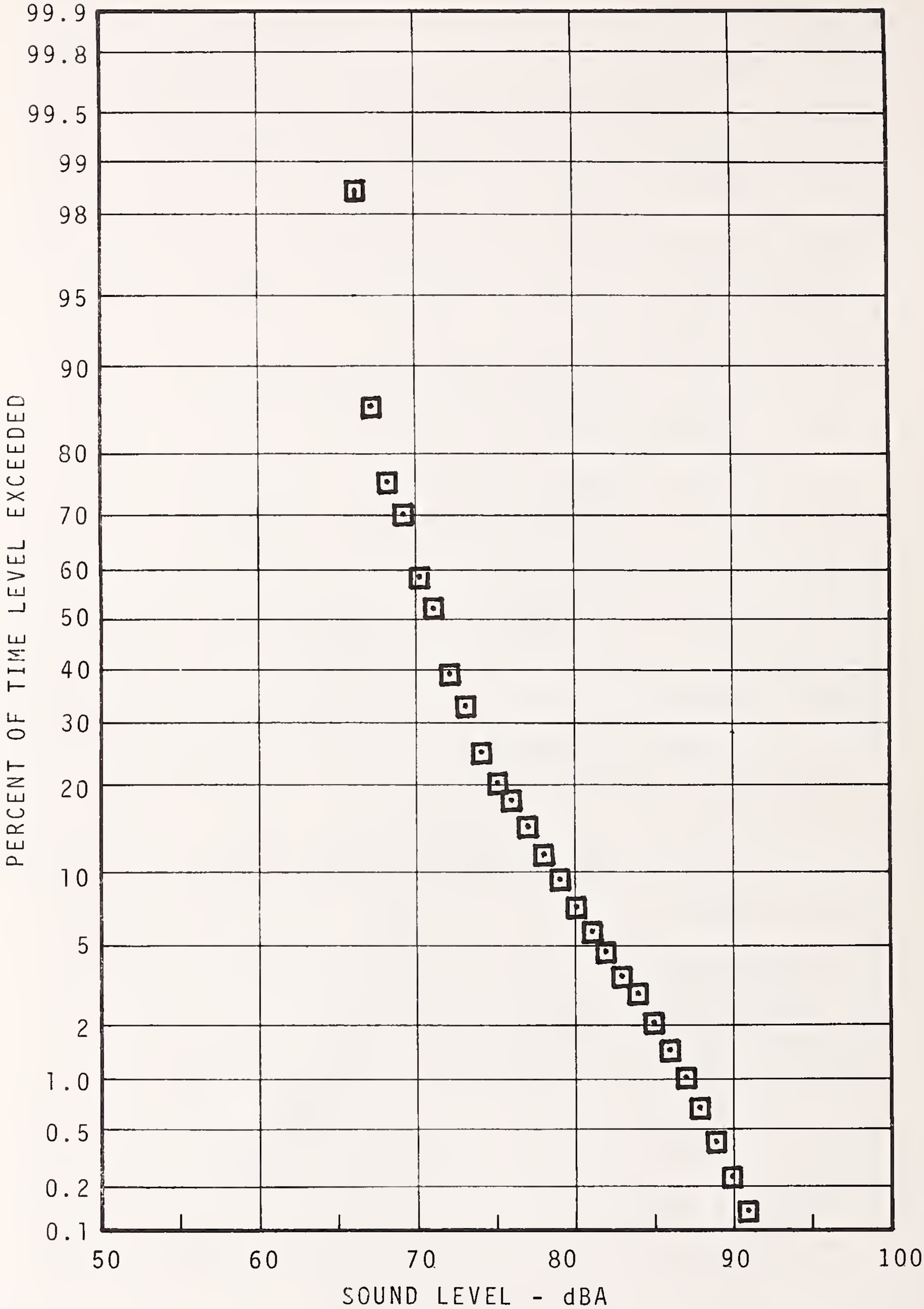


FIGURE 5.43. PUBLIC SQUARE STATION PLATFORM
STATISTICAL DISTRIBUTION - RUSH HOUR

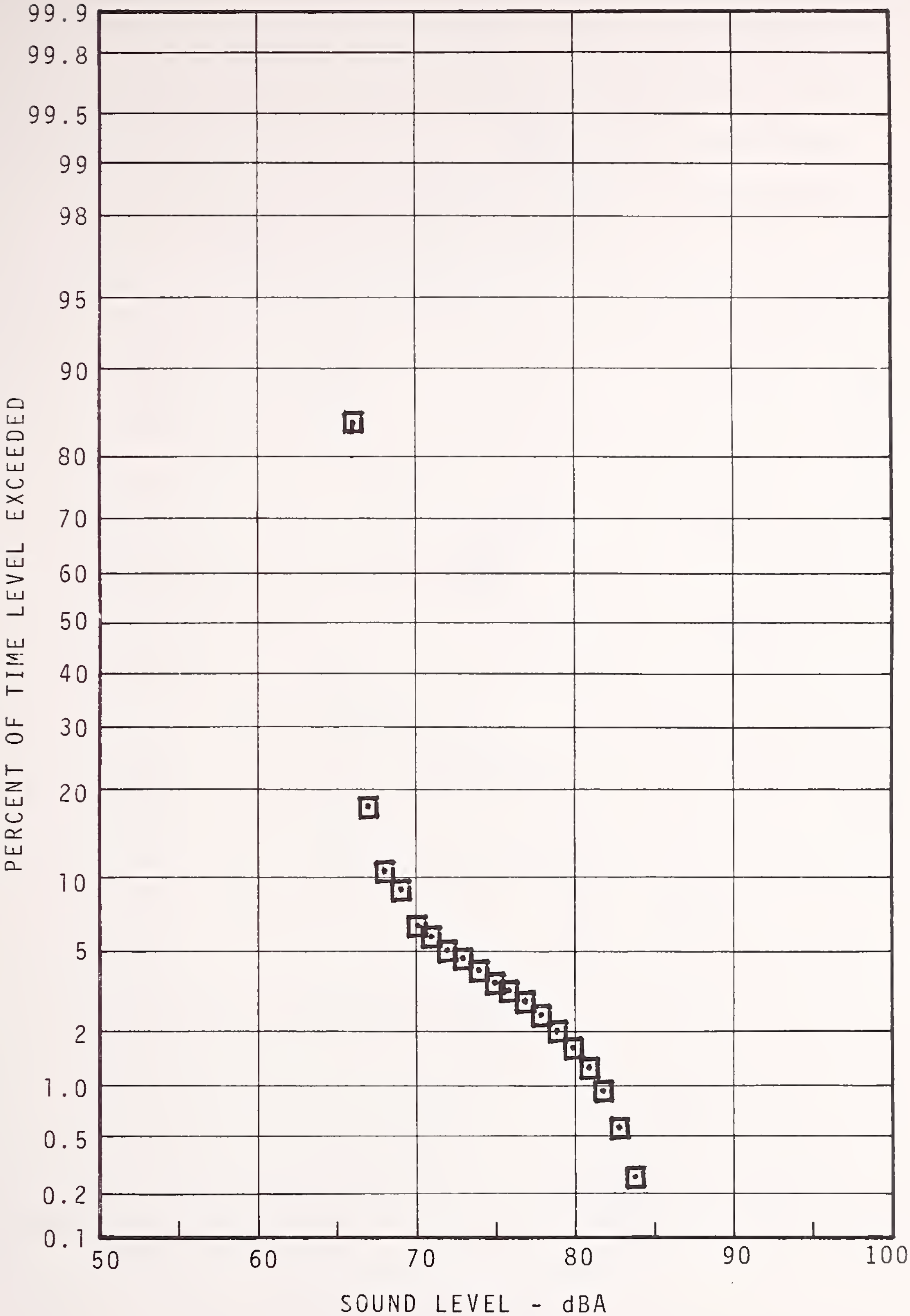


FIGURE 5.44. PUBLIC SQUARE STATION PLATFORM
STATISTICAL DISTRIBUTION - EVENING

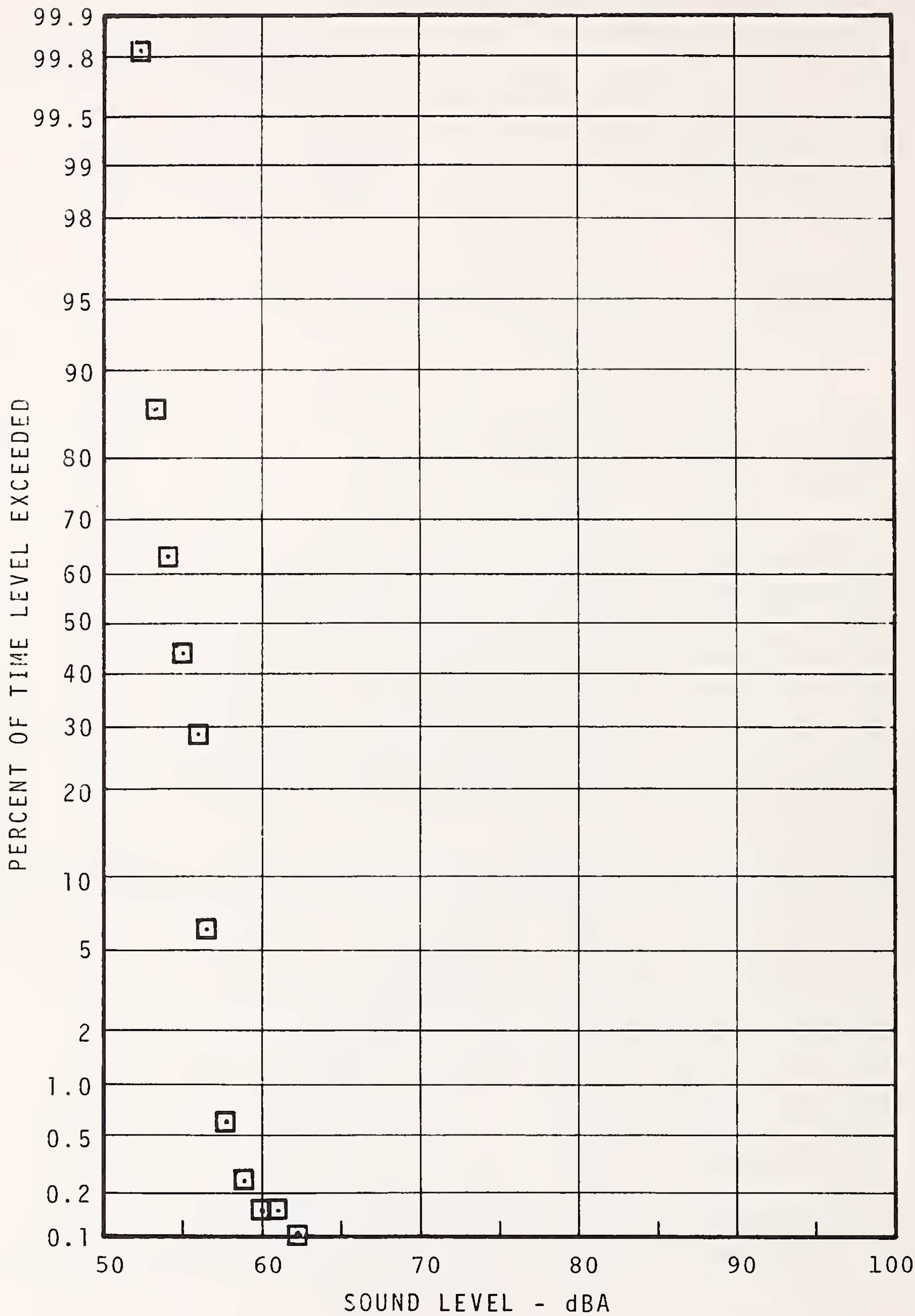


FIGURE 5.45 - PUBLIC SQUARE STATION PLATFORM STATISTICAL DISTRIBUTION - NIGHT (NO TRAINS)

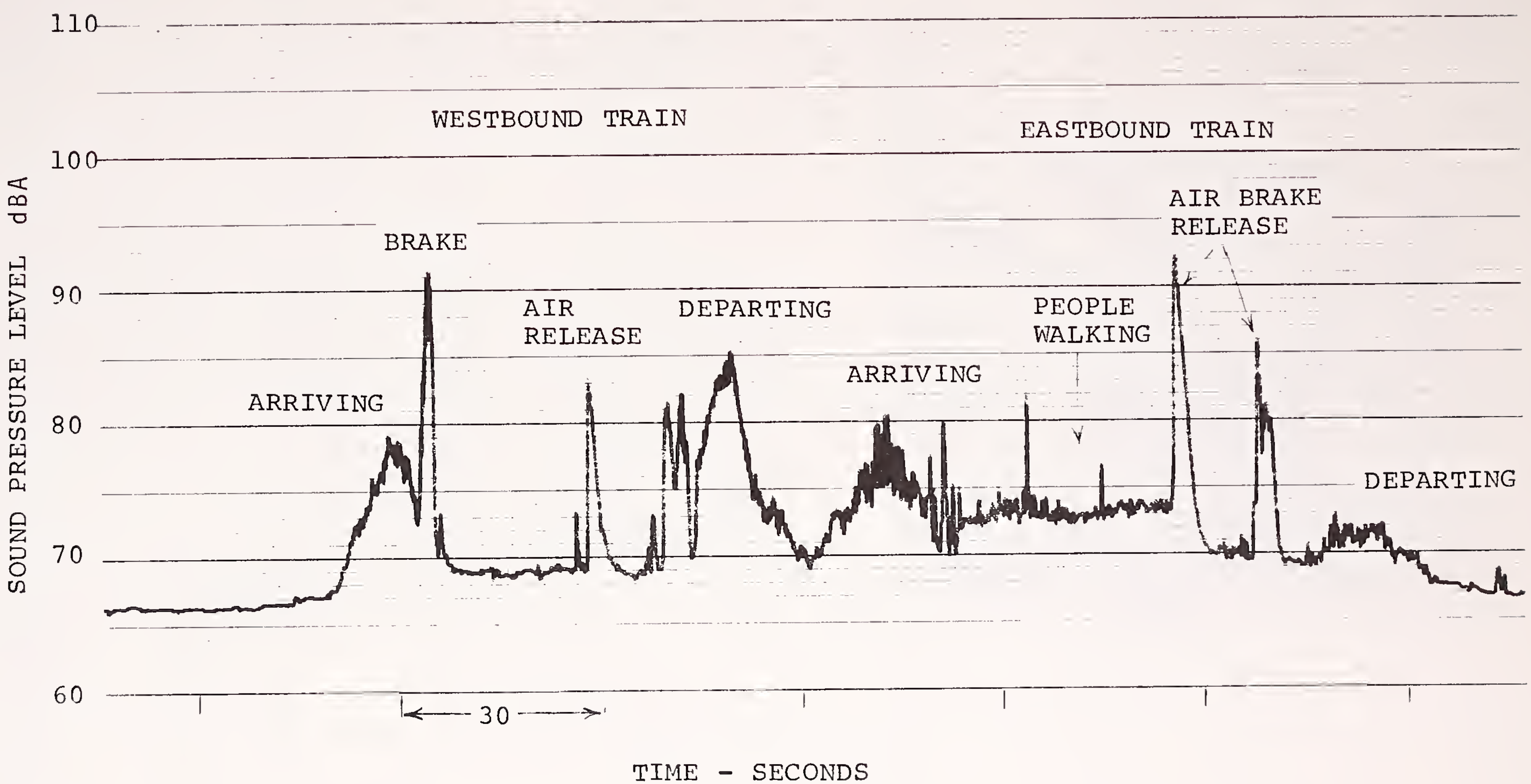


FIGURE 5.46. TYPICAL TIME HISTORY, PUBLIC SQUARE STATION

WEST 65TH - MADISON STATION

Station Description (see Figure 5.47)

West 65th and Madison is an island platform station located in a cut in a residential area. The east end of the platform is wood planked and covered with a "T" shelter. An exit at this end leads to an overhead pedestrian walk-way and street level. West of the sheltered area, the concrete platform loads to West 65th St. and an exit to street level. The Norfolk and Western Railroad parallels the Rapid in this location. The dwellings in this area are 1-1/2 - 2 story frame structures. The closest residence is approximately 200 feet from the Rapid adjoining the Norfolk and Western tracks.

Noise Climate (see Table 5.13, Figures 5.48 - 5.52)

The railroad, transit line and vehicular traffic are the predominant noise sources in the area. When these sources of noise are not present, the background level is approximately 65 dBA.

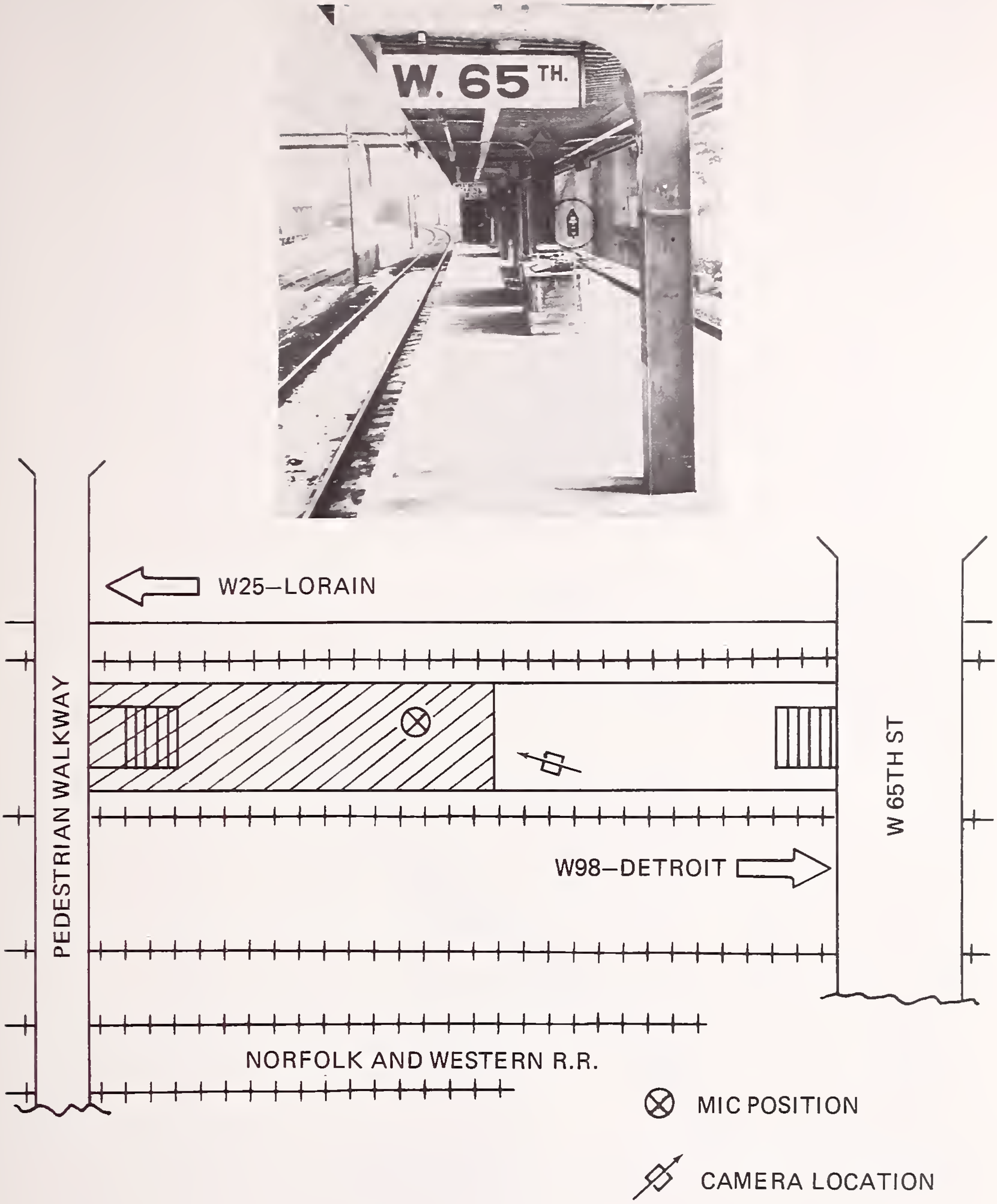


FIGURE 5.47. W. 65TH-MADISON STATION PLATFORM-IN CUT.

TABLE 5.13. SUMMARY OF MEASUREMENT RESULTS FOR W. 65TH-MADISON STATION

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL		AVG L_R		CUMULATIVE AMPLITUDE DISTRIBUTION					L_{eq}
					NEAR a) EAST	FAR WEST	NEAR EAST	FAR WEST	L_{99}	L_{90}	L_{50}	L_{10}	L_1	
Day	Center	30min.	Arrival	N	5-1	4-1	5-1	4-1	64	64	65	73	88	75
				dBA	83	77	90	85						
				c) S	5.28	3.01	3.58	4.77						
			Departure	N	5-1	4-1	5-1	4-1						
				dBA	78	91	86	95						
				S	3.46	4.77	2.97	5.83						
			Pass-Thru	N		1-1		1-1						
				dBA		96		102						
				S		-		-						
Rush	Center	30 min.	Arrival and Departure	dBA					65	65	66	75	89	76
Evening	Center	30 min.		dBA					63	64	65	73	86	74
Night	Center	10 min.		dBA					69	69	70	70	77	70

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

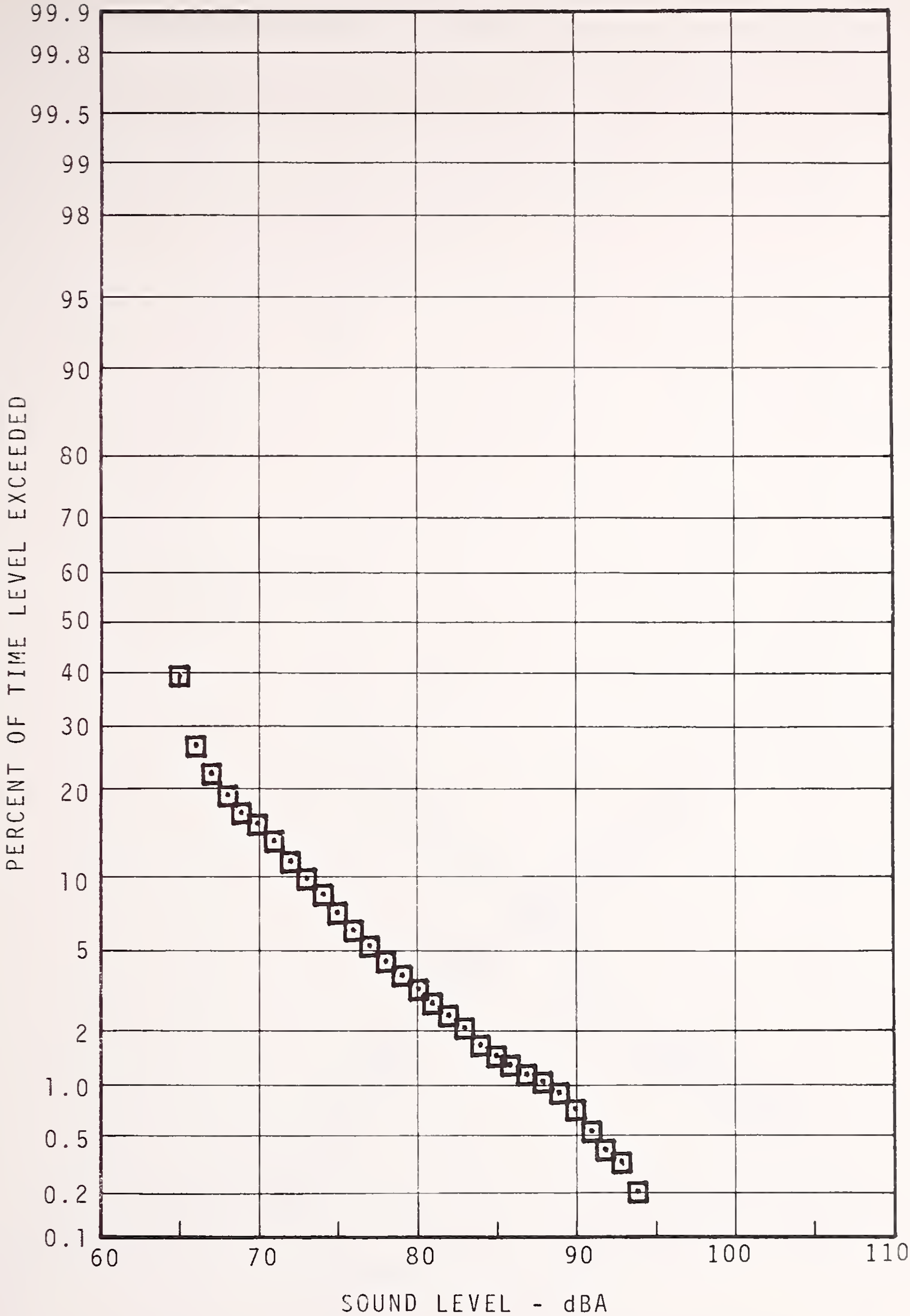


FIGURE 5.48. W. 65TH-MADISON STATION PLATFORM
STATISTICAL DISTRIBUTION - DAYTIME

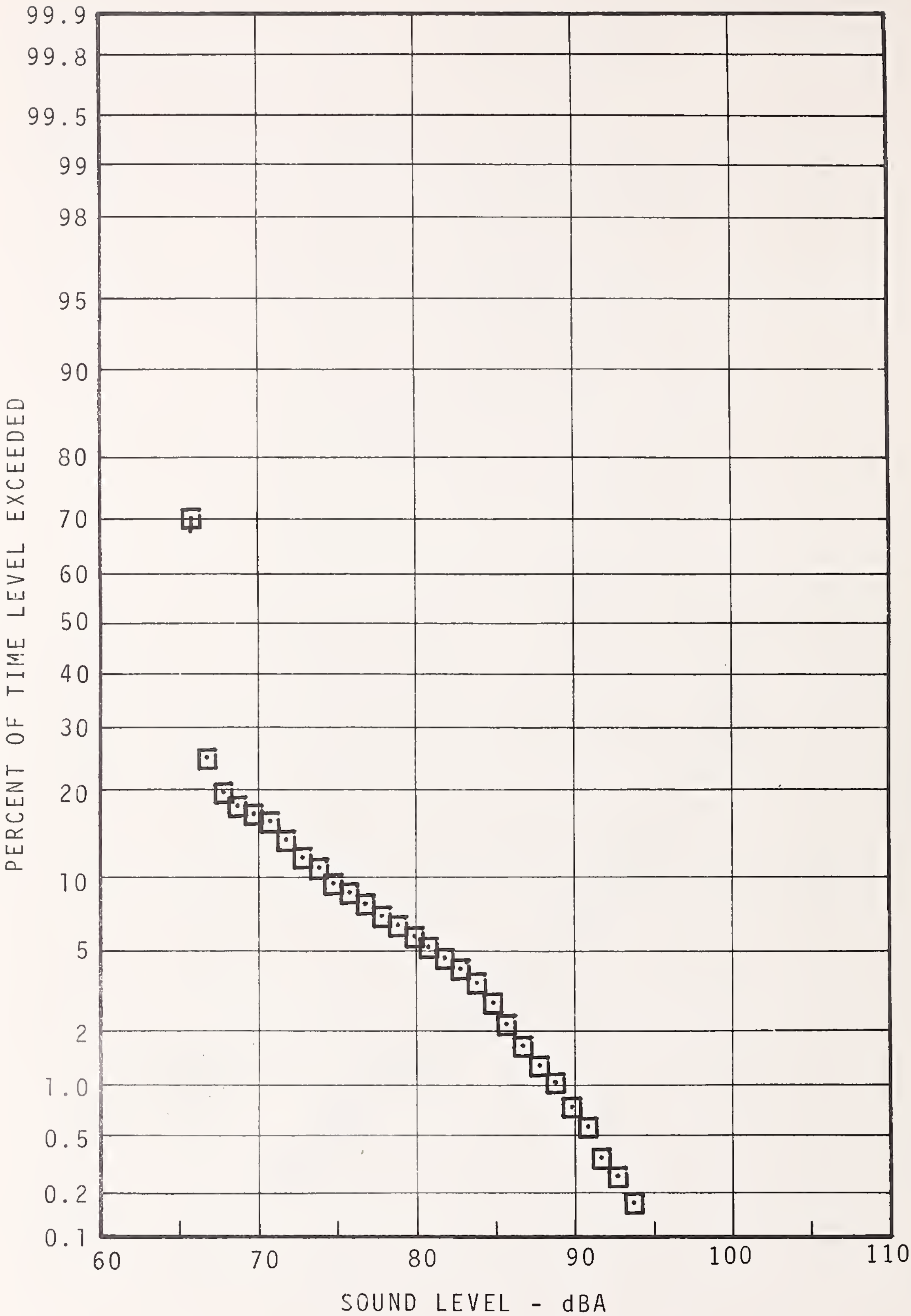


FIGURE 5.49. W. 65TH-MADISON STATION PLATFORM STATISTICAL DISTRIBUTION - RUSH HOUR

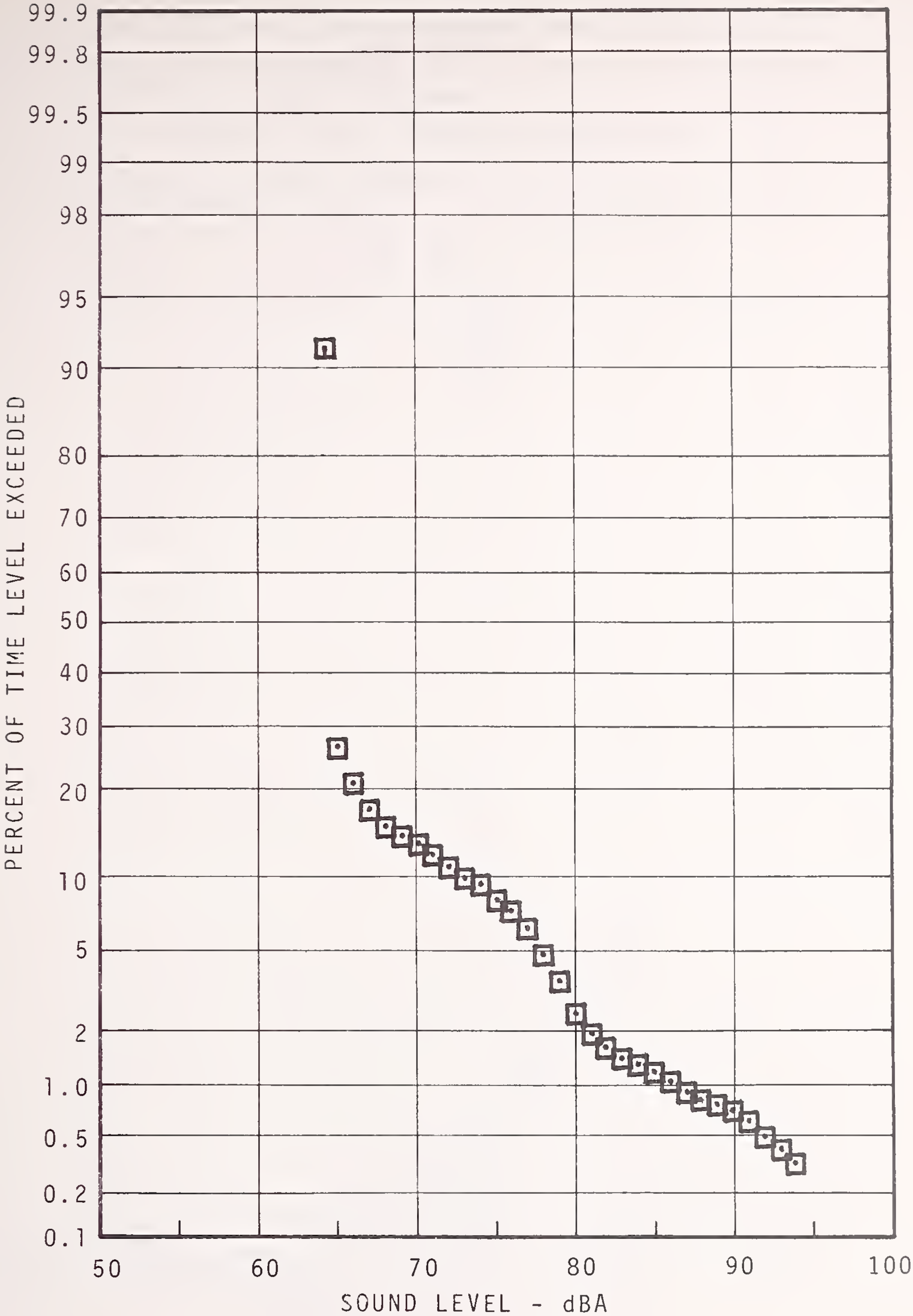


FIGURE 5.50. W. 65TH-MADISON STATION PLATFORM STATISTICAL DISTRIBUTION - EVENING

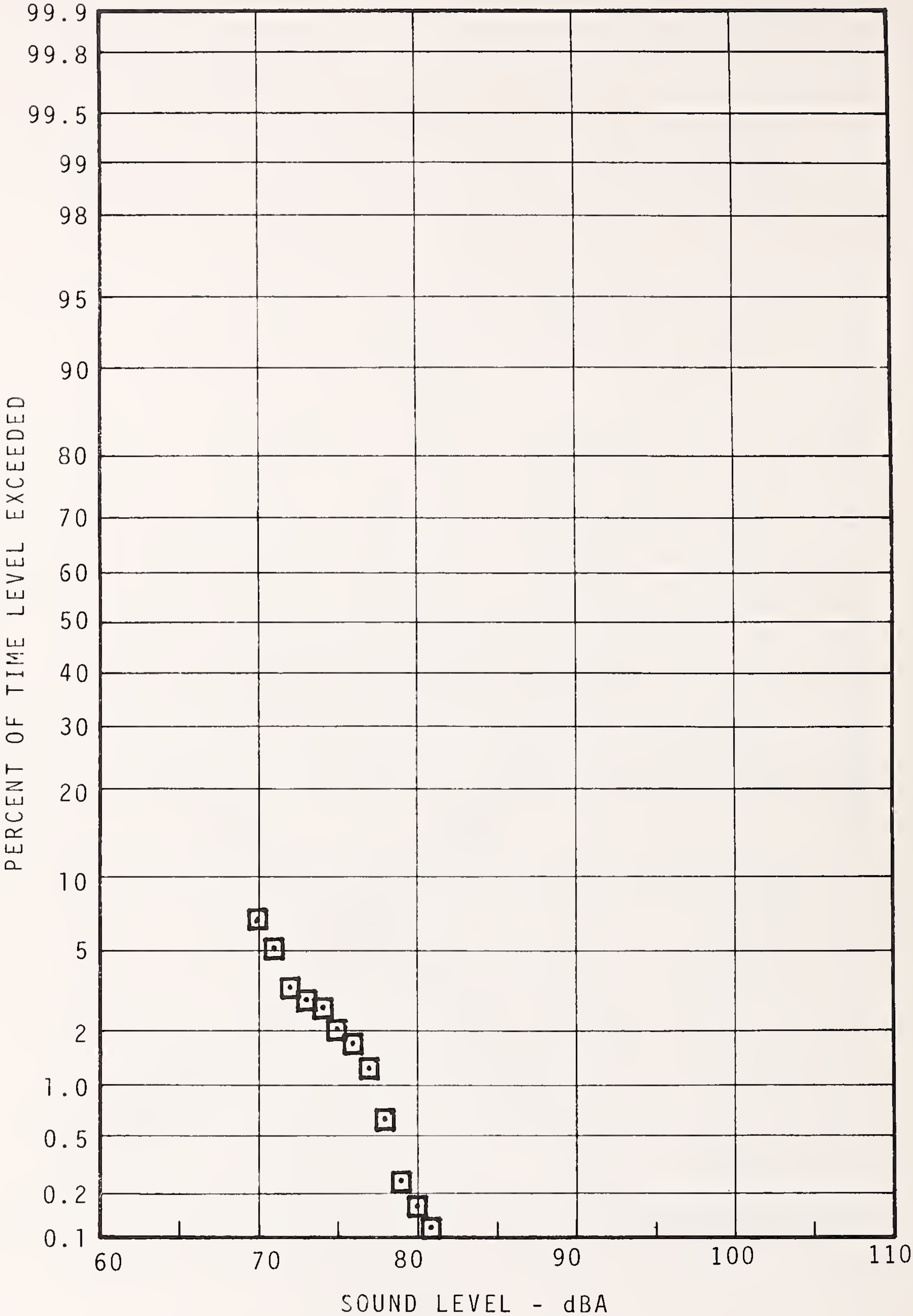


FIGURE 5.51. W. 65TH-MADISON STATION PLATFORM STATISTICAL DISTRIBUTION - NIGHT

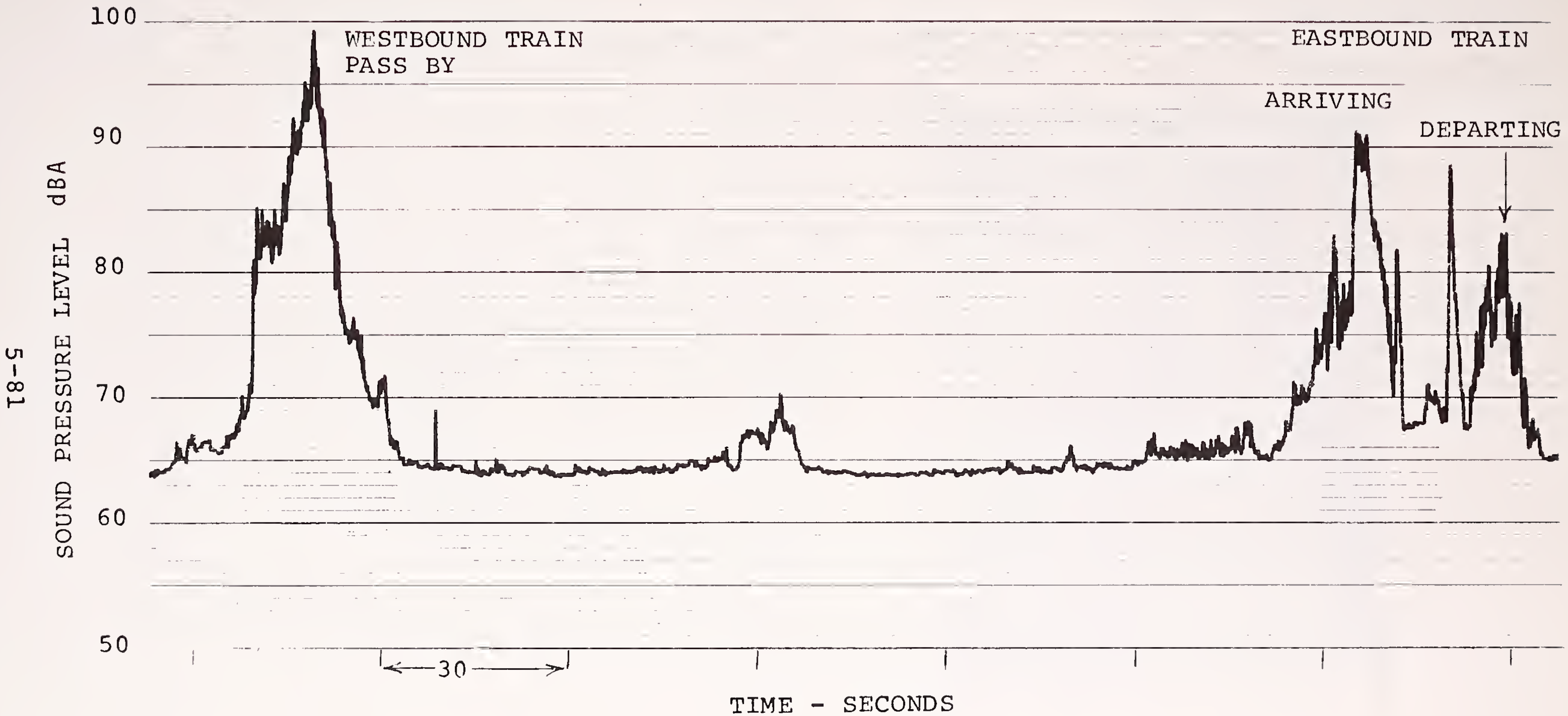


FIGURE 5.52. TYPICAL TIME HISTORY, W. 65TH ST. STATION

TRISKETT STATION

Station Description (see Figure 5.53)

Triskett is an island platform station on-grade adjacent to the Penn Central Railroad. A large auto park for the transit line is located on the northwest side of the right-of-way with an industrial region adjoining the southeast side. Patrons on the Rapid enter and exit through a passageway under the tracks connecting with stairs and an escalator at the west end of the platform. A canopy and four windbreaks are provided at the west end. North and east of Triskett, and within 30 feet of the right-of-way, there are a number of houses.

Noise Climate (see Table 5.14, Figures 5.54 - 5.58)

The background noise in the area is set by the industry along the right-of-way, particularly that of a nearby punching or shearing operation, which is impulsive. Frequently, Penn Central trains pass by, some at high speed. When present, the noise from these trains masks the arrival and departure of the Airport Rapid cars.

Data taken during the night sample includes an eastbound Penn Central freight train. The L_{eq} for this 10 min sample would be lower if taken over a period of 30 minutes, since the lower levels with no freight trains present would reduce the mean value of noise.

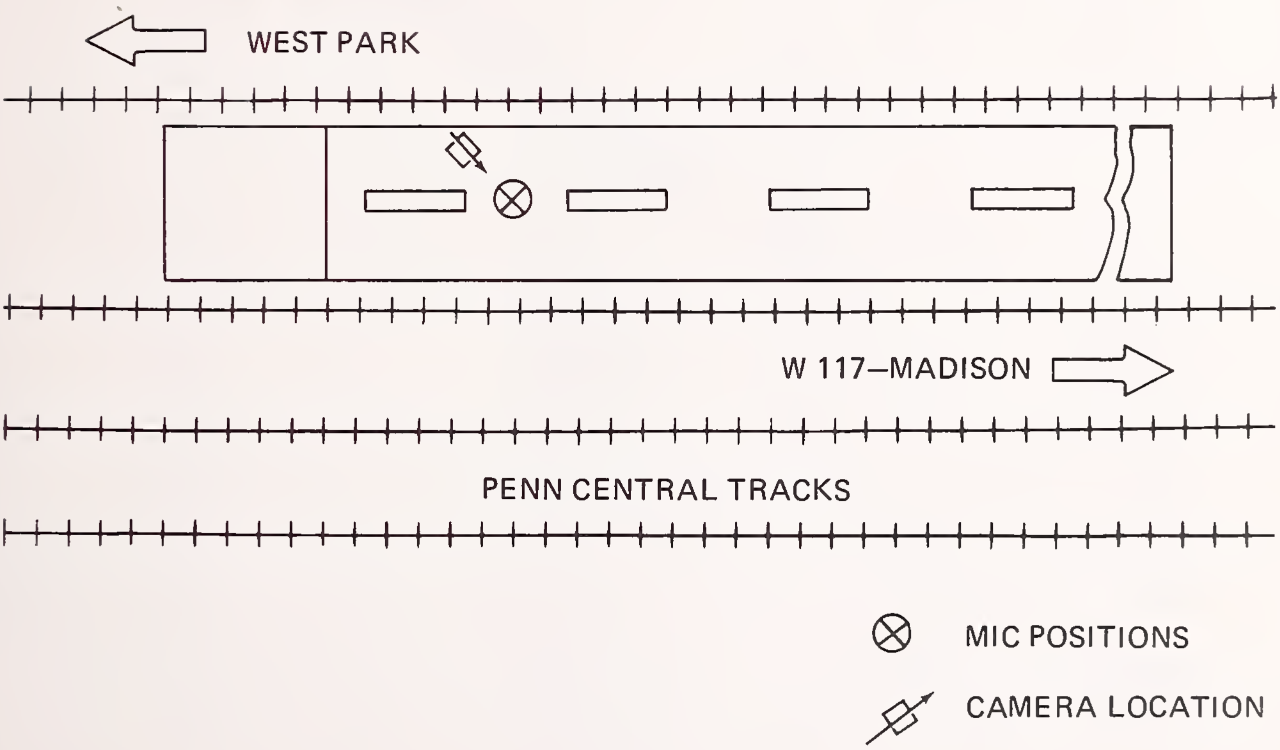


FIGURE 5.53. TRISKETT STATION PLATFORM - AT GRADE

TABLE 5.14. SUMMARY OF MEASUREMENT RESULTS FOR TRISKETT STATION

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	Center	30 min.	Arrival	b) N	4-1	6-1	3-1	6-1	65	67	69	93	97	86
				dBA	79	83	90	92						
				c) S	8.31	2.73	5.92	2.31						
			Departure	N	3-1	5-1	3-1	5-1						
				dBA	86	82	93	91						
				S	6.54	3.38	5.88	2.69						
Rush	Center	30 min.	Arrival and Departure	dBA					63	63	65	83	92	79
Evening	Center	30 min.		dBA					65	66	67	69	83	71
Night	Center	10 min.	No sched. Trains	dBA					69	69	70	71	94	79

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

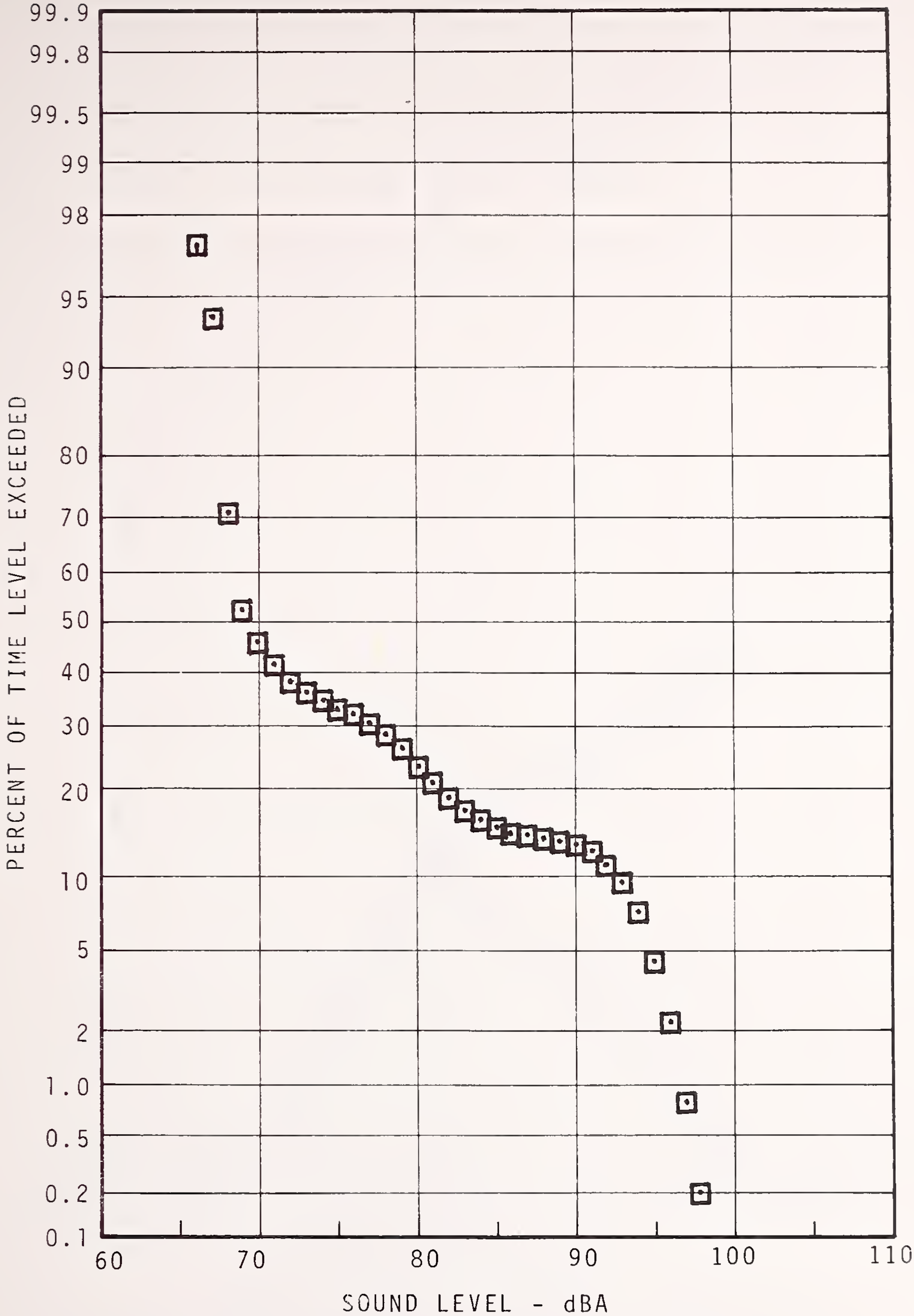


FIGURE 5.54. TRISKETT STATION PLATFORM
STATISTICAL DISTRIBUTION - DAYTIME

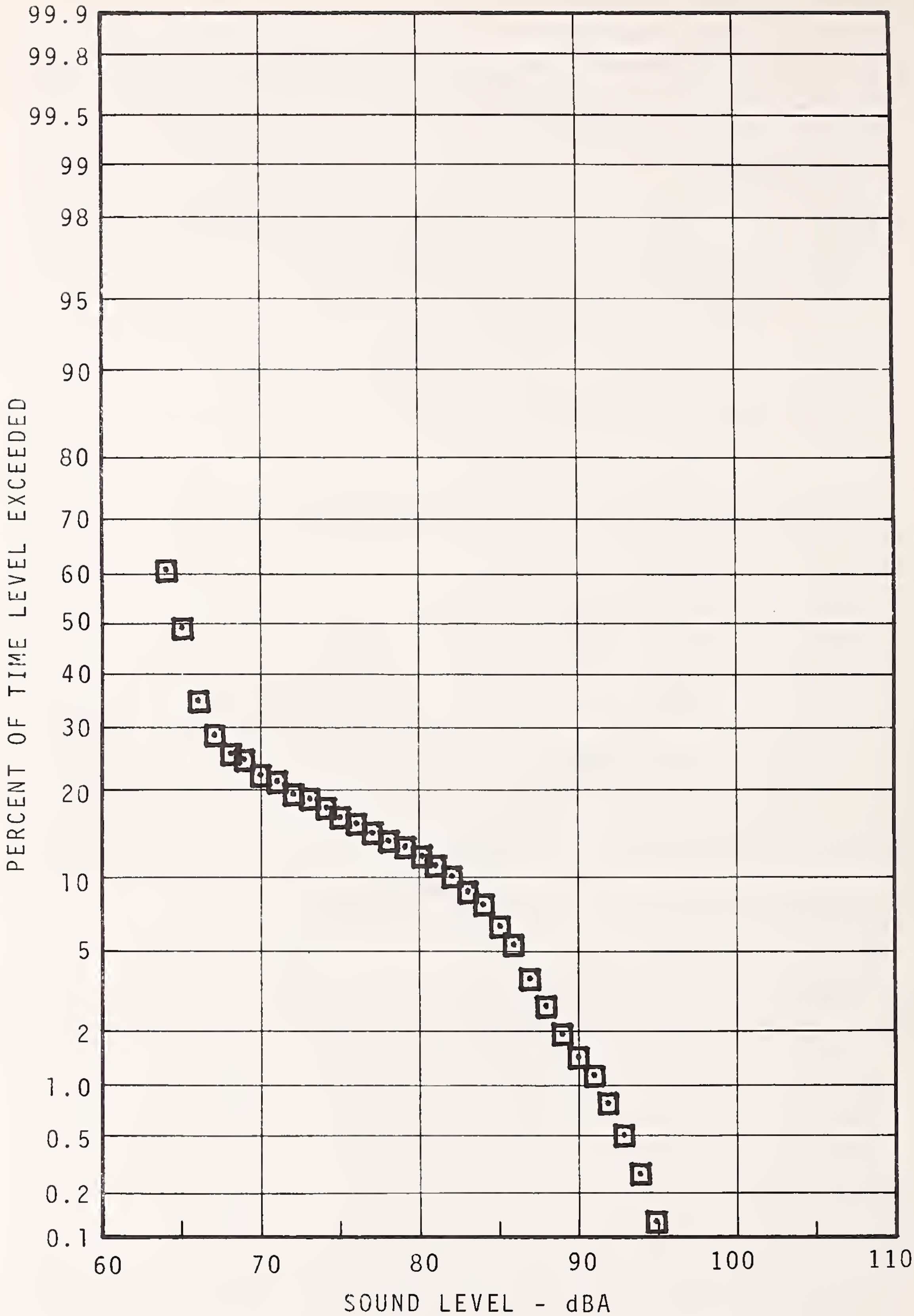


FIGURE 5.55. TRISKETT STATION PLATFORM STATISTICAL DISTRIBUTION - RUSH HOUR

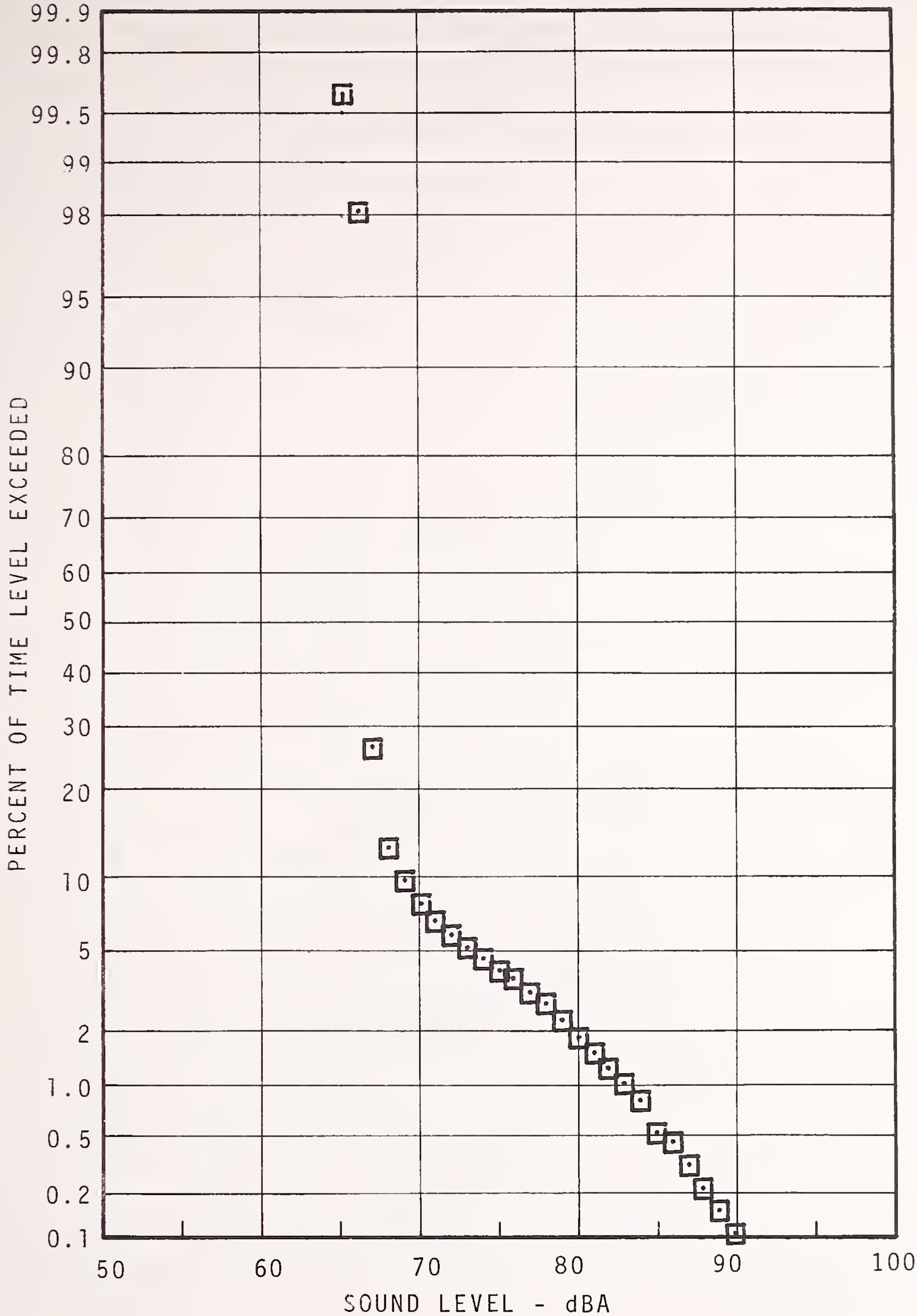


FIGURE 5.56. TRISKETT STATION PLATFORM
STATISTICAL DISTRIBUTION - EVENING

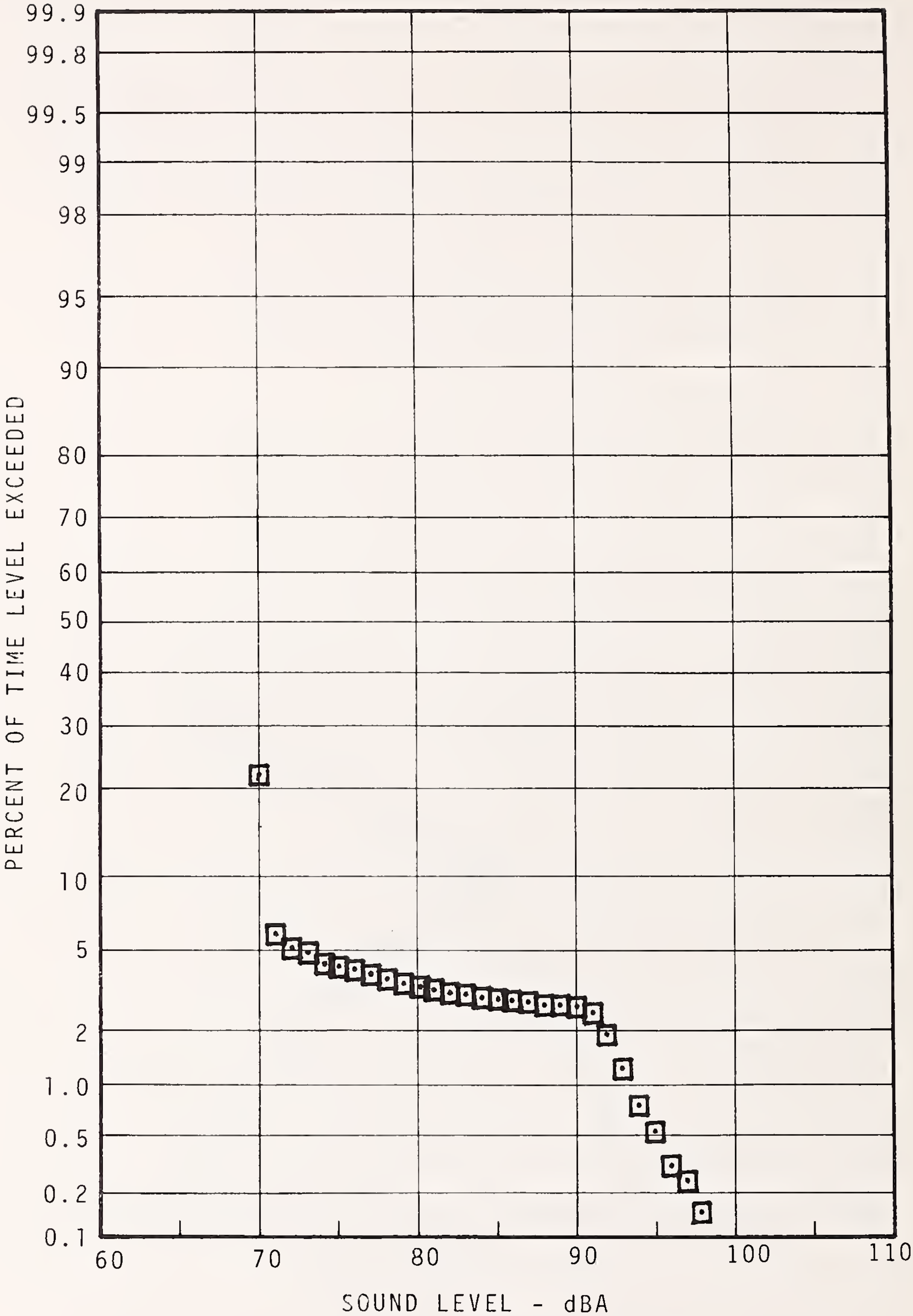


FIGURE 5.57. TRISKETT STATION PLATFORM
STATISTICAL DISTRIBUTION - NIGHT

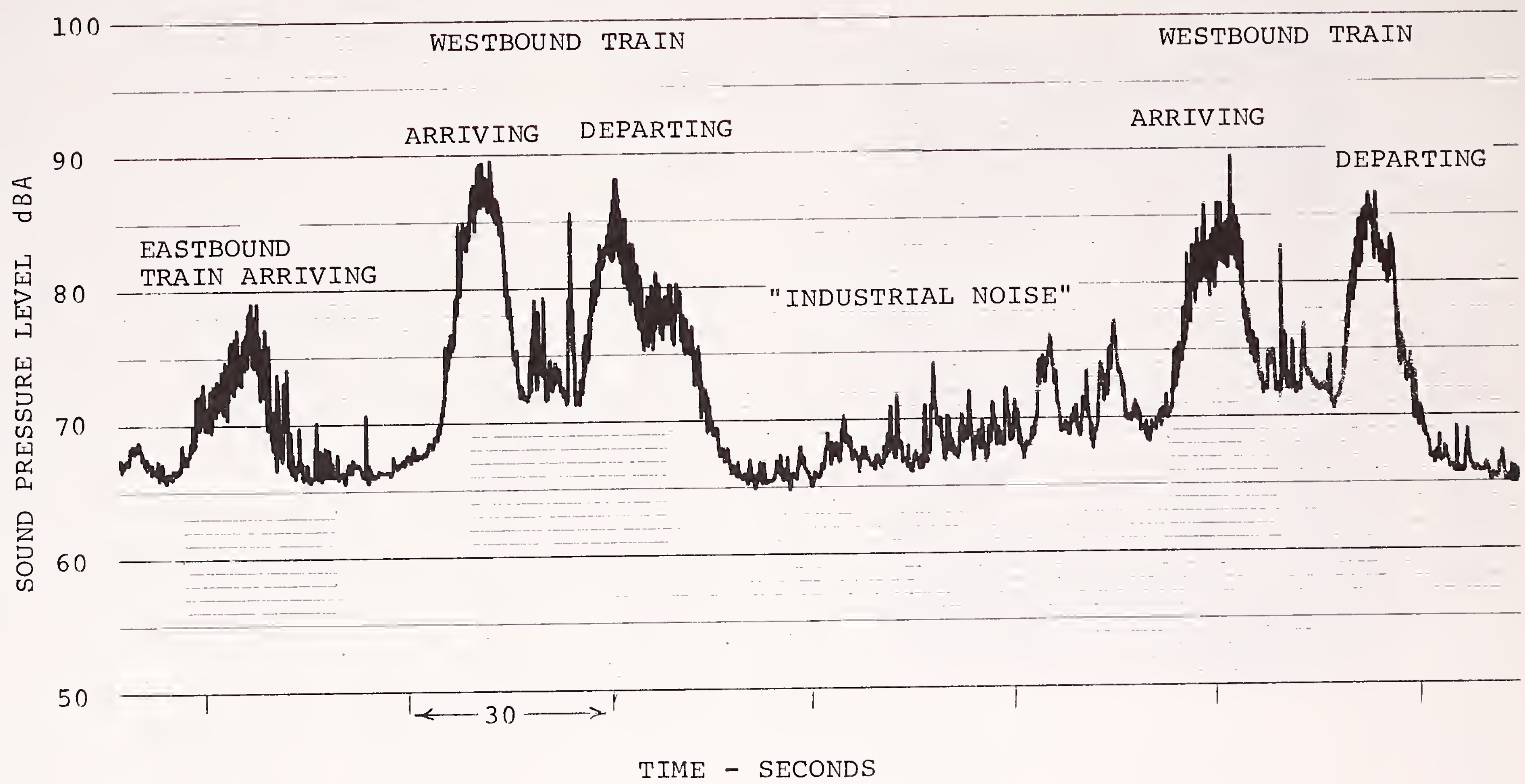


FIGURE 5.58. TYPICAL TIME HISTORY TRISKETT STATION

AIRPORT TERMINAL

Station Description (see Figure 5.59)

The Airport Station is an underground, two track, center platform station. The system ends at this terminal, and vehicle operation is from the opposite end of the car on the run to Windermere. Brookpark yard is used to make up trains at this end of the line. Station construction is mostly concrete, with ceramic tile walls. Patrons enter and exit at the west end of the platform, through doors leading to an escalator to the airport terminal. The track has a macadam layer from rail to rail with no ballast or ties visible.

Noise Climate (see Table 5.15, Figures 5.60 - 5.64)

The station is in a reverberant field. Wheel squeal is audible as trains enter and leave a curved tunnel section east of the station. When standing trains at the station are powered, the noise of the undercar fans become the predominant noise source in the station. This is especially notable during the night hours when a Pullman car is normally sitting in the station. In the summer months, air-conditioner noise prevails over the level of the equipment blowers.

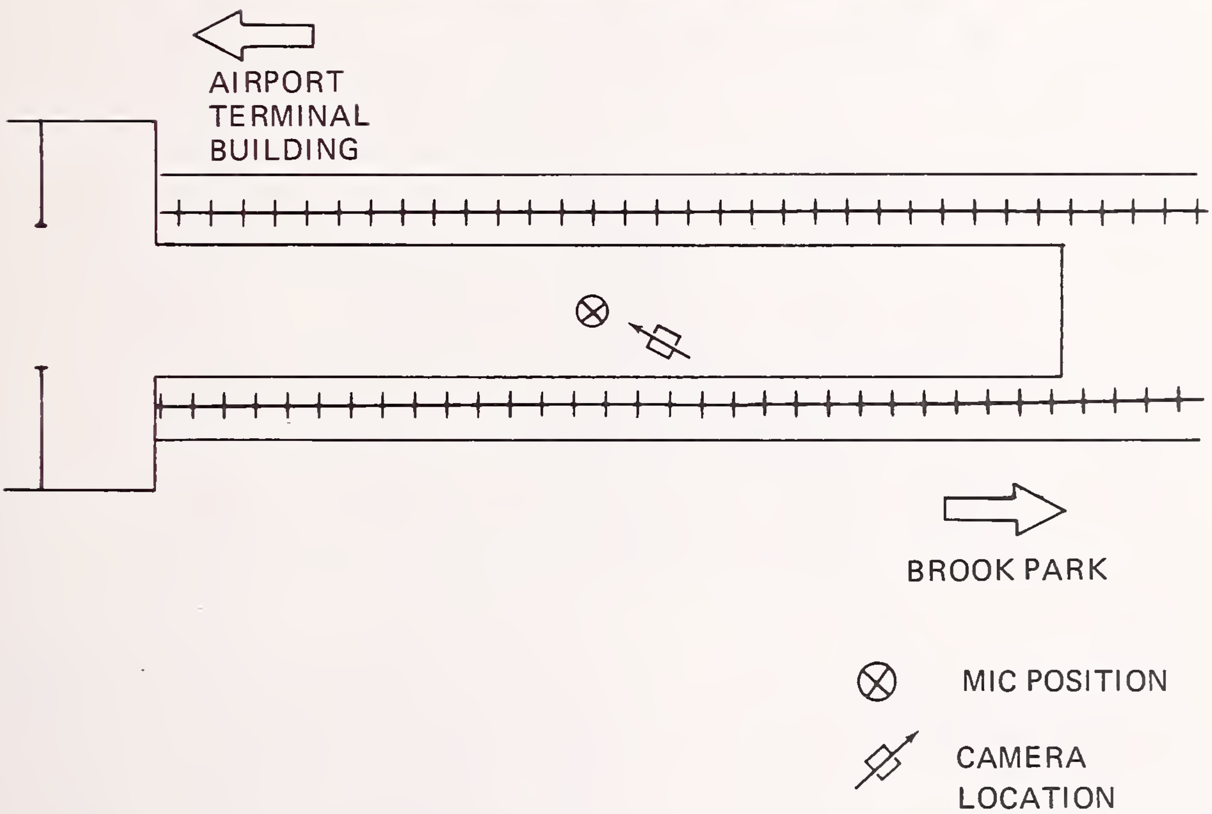


FIGURE 5.59. AIRPORT TERMINAL STATION PLATFORM-UNDERGROUND

TABLE 5.15. SUMMARY OF MEASUREMENT RESULTS FOR AIRPORT STATION, MIXED CARS

TIME	MIC POSITION	SAMPLE TIME	TRAIN CONDITIONS	UNITS	AVG MAX LEVEL a) NEAR 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	Center	30 min	Pullman arrival	b) N	4—1	3—1	4—1	3—1	65	67	75	82	92	80
				dBA	91	84	98	93						
				c) S	1.65	4.86	1.70	3.91						
			Pullman departure	N	3—1	2—1	3—1	2—1						
				dBA	91	82	100	92						
				S	3.04	1.41	2.99	1.06						
			St. Louis arrival	N	-	1—6	-	1—6						
				dBA		81		89						
				S		-		-						
			St. Louis departure	N	-	2—6	-	2—6						
				dBA		87		97						
				S		1.77		1.91						
Rush		30 min	Arrival	dBA					67	68	69	75	85	73
Evening	Center	30 min	and	dBA					63	64	77	78	85	78
Night		10 min	Departure	dBA					69	72	74	77	95	80

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

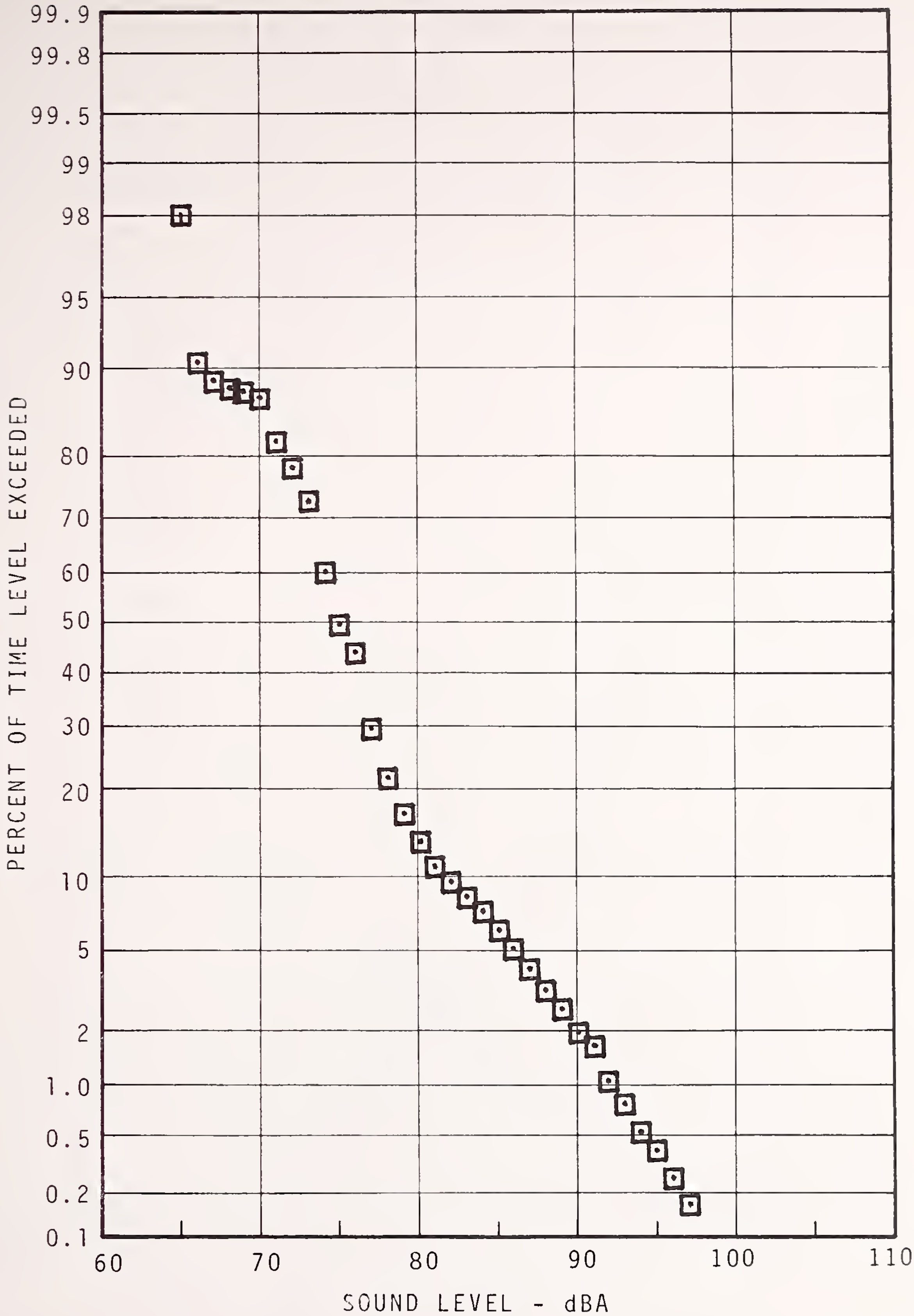


FIGURE 5.60. AIRPORT STATION PLATFORM STATISTICAL DISTRIBUTION - DAYTIME

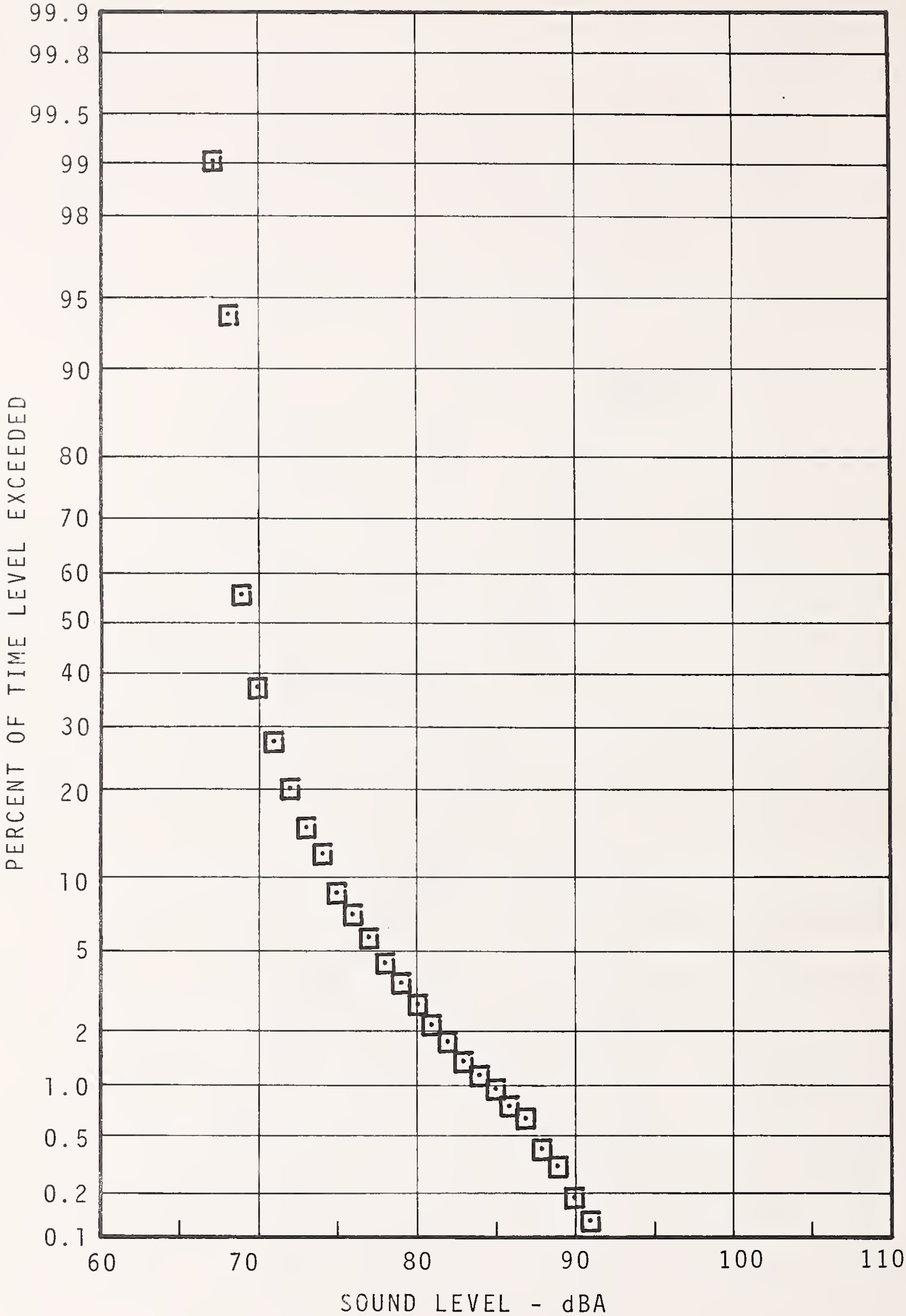


FIGURE 5.61. AIRPORT STATION PLATFORM STATISTICAL DISTRIBUTION - RUSH HOUR

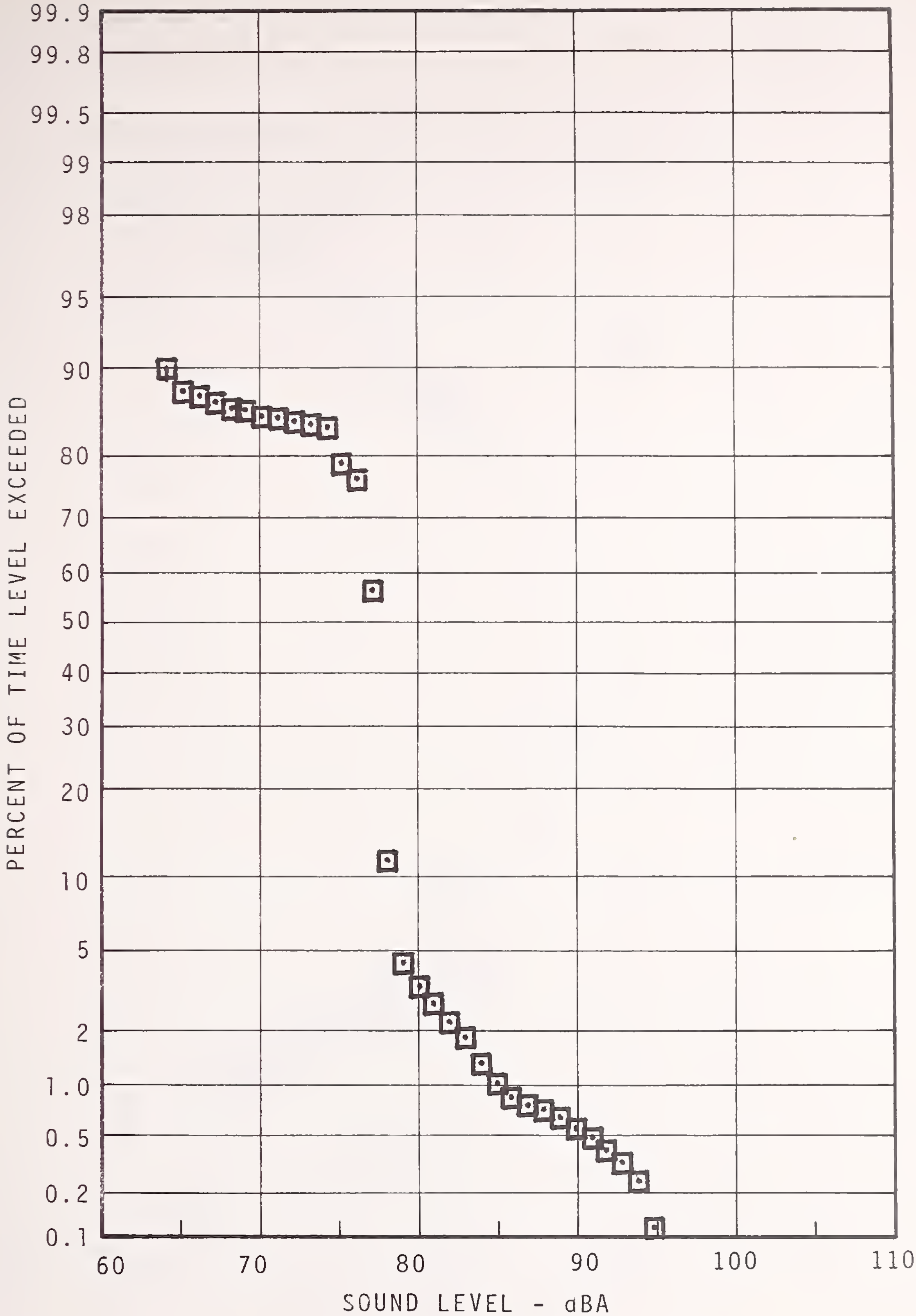


FIGURE 5.62. AIRPORT STATION PLATFORM STATISTICAL DISTRIBUTION - EVENING

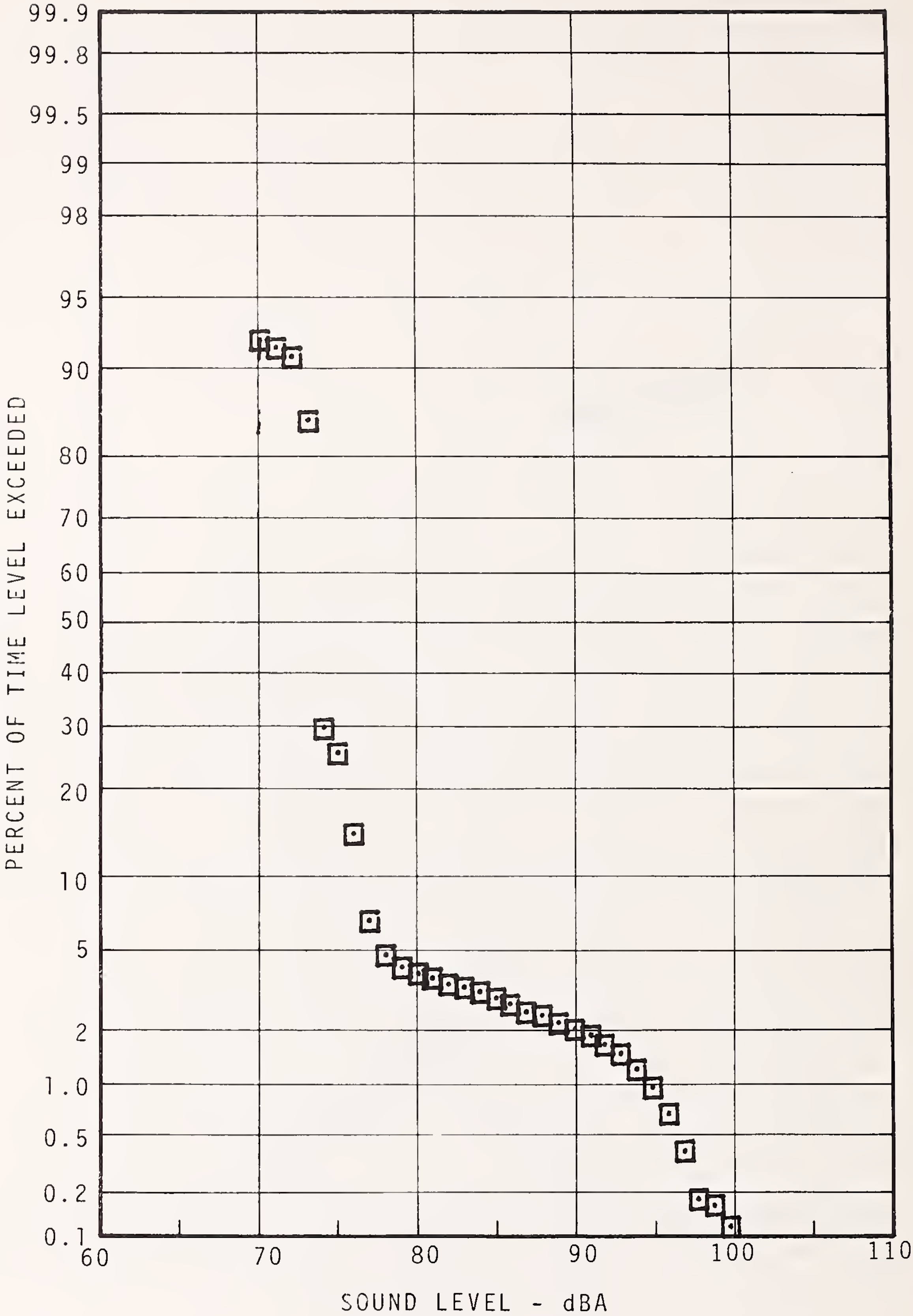


FIGURE 5.63. AIRPORT STATION PLATFORM STATISTICAL DISTRIBUTION - NIGHT

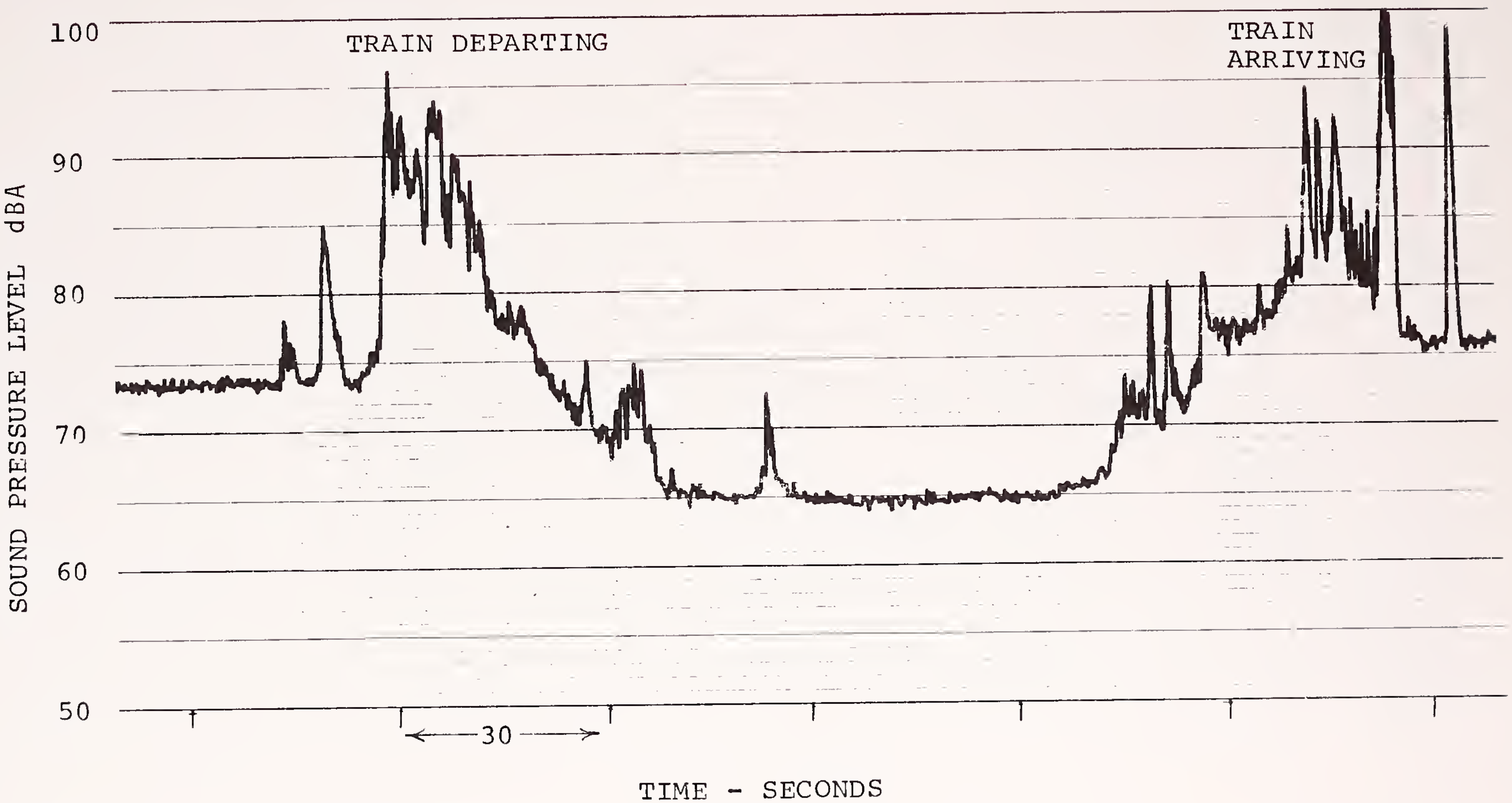


FIGURE 5.64. TYPICAL TIME HISTORY, AIRPORT STATION

5.2.3 Vehicle Interior

Both the St. Louis and Pullman cars were surveyed. One round trip was made on each type car to survey typical patron and operator noise exposure at seated ear level heights. Voice annotations on a separate recording track were used to document site specific car sources.

PULLMAN CAR INTERIOR

Car Description (see Figure 5.65)

Measurements of noise were made in the second car (No. 163) of a three-car train during morning rush hours for the trip from Airport to Windermere. The data was taken during winter months and the heater and blowers were operating. Beginning at the Airport station, the only occupants of the car were the two noise control engineers recording data. At Brookpark approximately 10 patrons boarded and at succeeding stations increasing numbers of patrons boarded until at West 117th-Madison the car was at a crush load and continued so until Public Square, where all but approximately 15 patrons left the car. On the continuation to Windermere, the car was never more than one-quarter full at any time. On the return trip from Windermere, data was recorded in car No. 173. The returning train departed from Windermere past the rush hour, and the cars were less than one-half full at all times.

Noise Climate (see Table 5.16, Figures 5.66 - 5.70)

A primary source of steady-state noise inside the car is the air comfort blower. Wheel flats are also noticeable on many CTS cars, and wheel flange "singing" was almost continuously noted. This noise is not the normal wheel squeal heard on short radius curves, but appears to be a rubbing or scraping of the flange on the rail. Inspection of the wheel contour on several cars shows a very sharp radius between the wheel tread and the flange - much greater than noted on other systems. Track gauge is also tighter than noted elsewhere - 4 feet, 8-1/4 inches on tangent track, and 4 feet, 8-1/2 inches on curves. Wheel gauge is the same as for cars running on 4 feet, 8-1/2 inch gauge tangent track.

Occasionally, a passing freight train which operates on track parallel to the rapid is heard. Wheel squeal is noticeable eastbound approaching West 98th - Detroit Public Square and Windermere as the car negotiates an "S" curve near these stations. Impact noise over special trackwork predominates when it is encountered. During acceleration and deceleration, gearbox noise is quite noticeable and the brake air compressor is audible when it cycles.

Plateau levels between stations at the car center are 4 dBA higher than the operators booth which is enclosed from noise sources such as fans and trucks. The modified car displays a signature at the car center which is 4.5 dBA lower than the standard configuration (See Table 5.17).

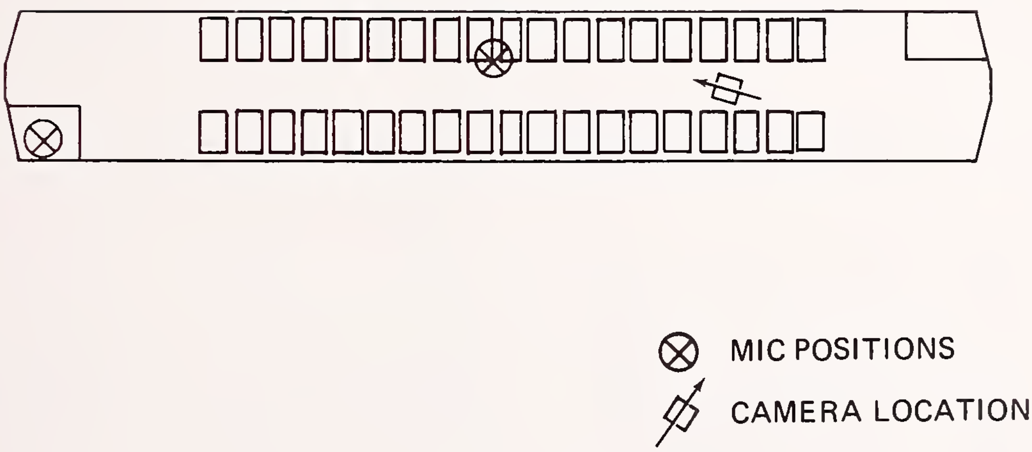


FIGURE 5.65. IN-CAR MEASUREMENT LOCATIONS, CTS PULLMAN CAR

TABLE 5.16. SUMMARY OF MEASUREMENT RESULTS FOR STANDARD PULLMAN AND MODIFIED PULLMAN CARS - INTERIOR NOISE LEVEL

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	
Pullman (Std. Config)	Center	39.5 min	East	dBA					71	73	81	86	90	83
	Center	38.7 min	West	dBA					72	74	81	86	89	83
	Oper. Booth	40 min	West	dBA					73	74	79	83	85	80
		41 min	East	dBA					73	74	78	82	85	79
	Center	37 min	West	dBA					73	74	79	82	84	

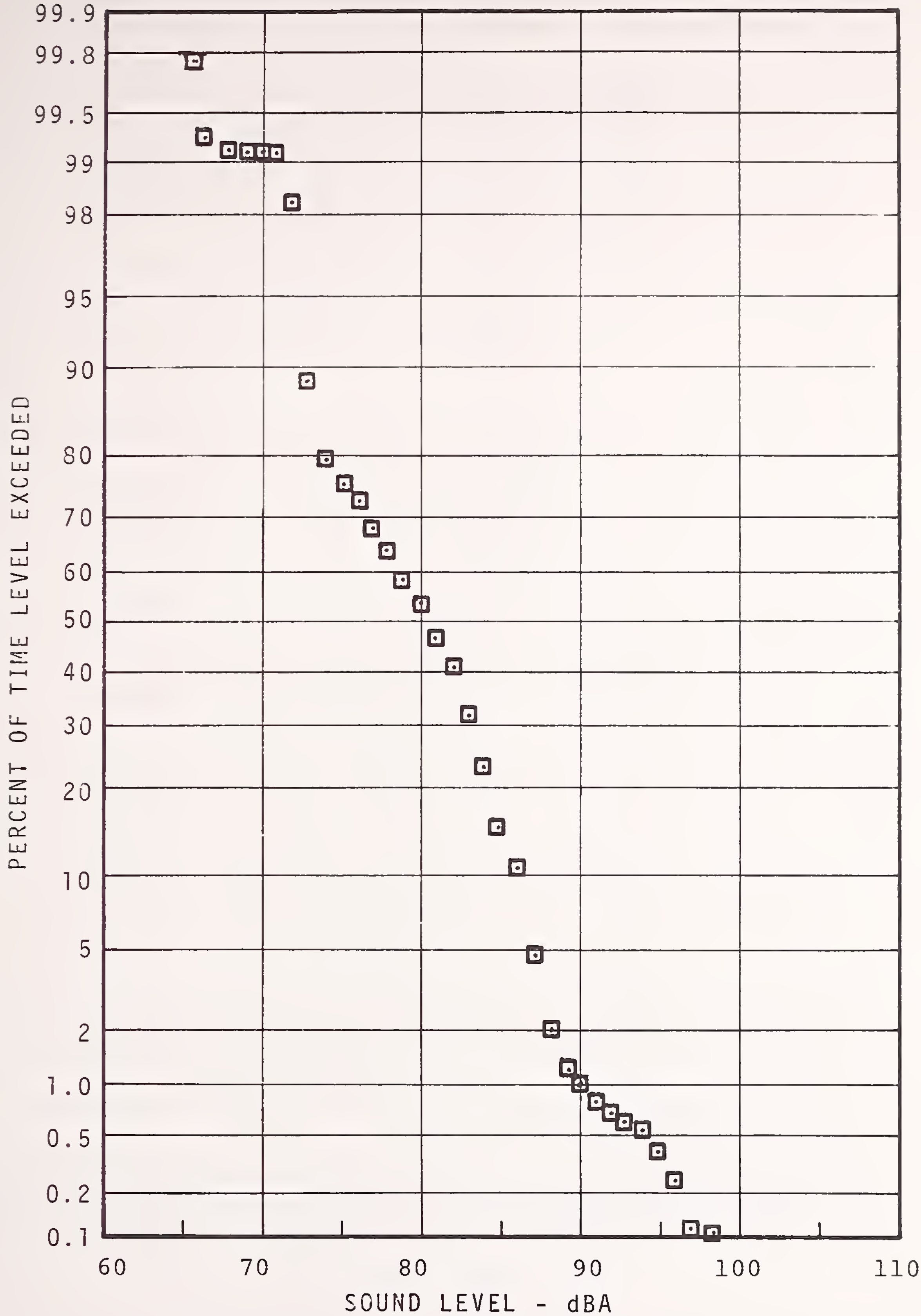


FIGURE 5.66 - PULLMAN IN-CAR STATISTICAL DISTRIBUTION - AIRPORT-TO-WINDERMERE, CENTER

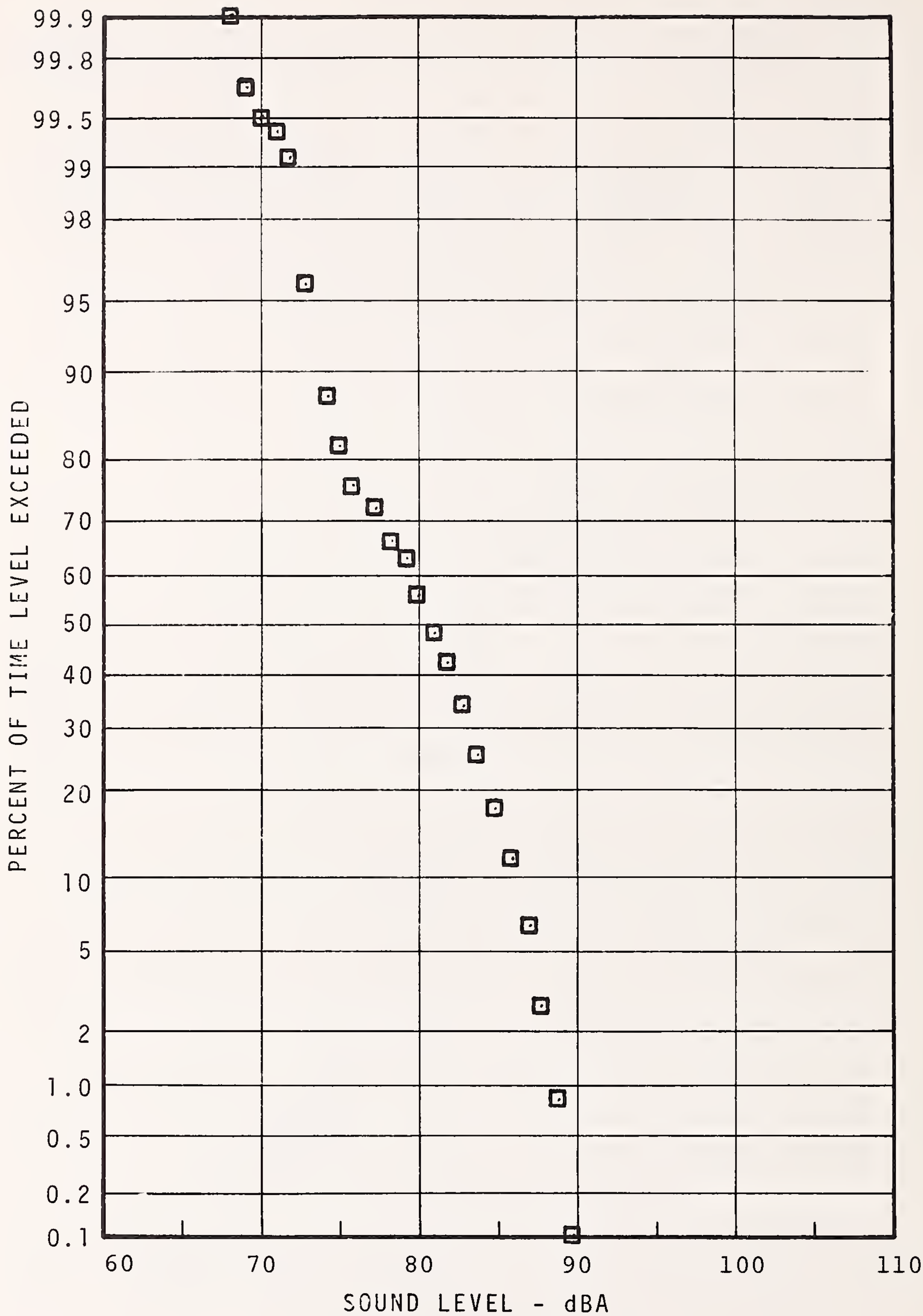


FIGURE 5.67 - PULLMAN IN-CAR STATISTICAL DISTRIBUTION, WINDERMERE-TO-AIRPORT, CENTER

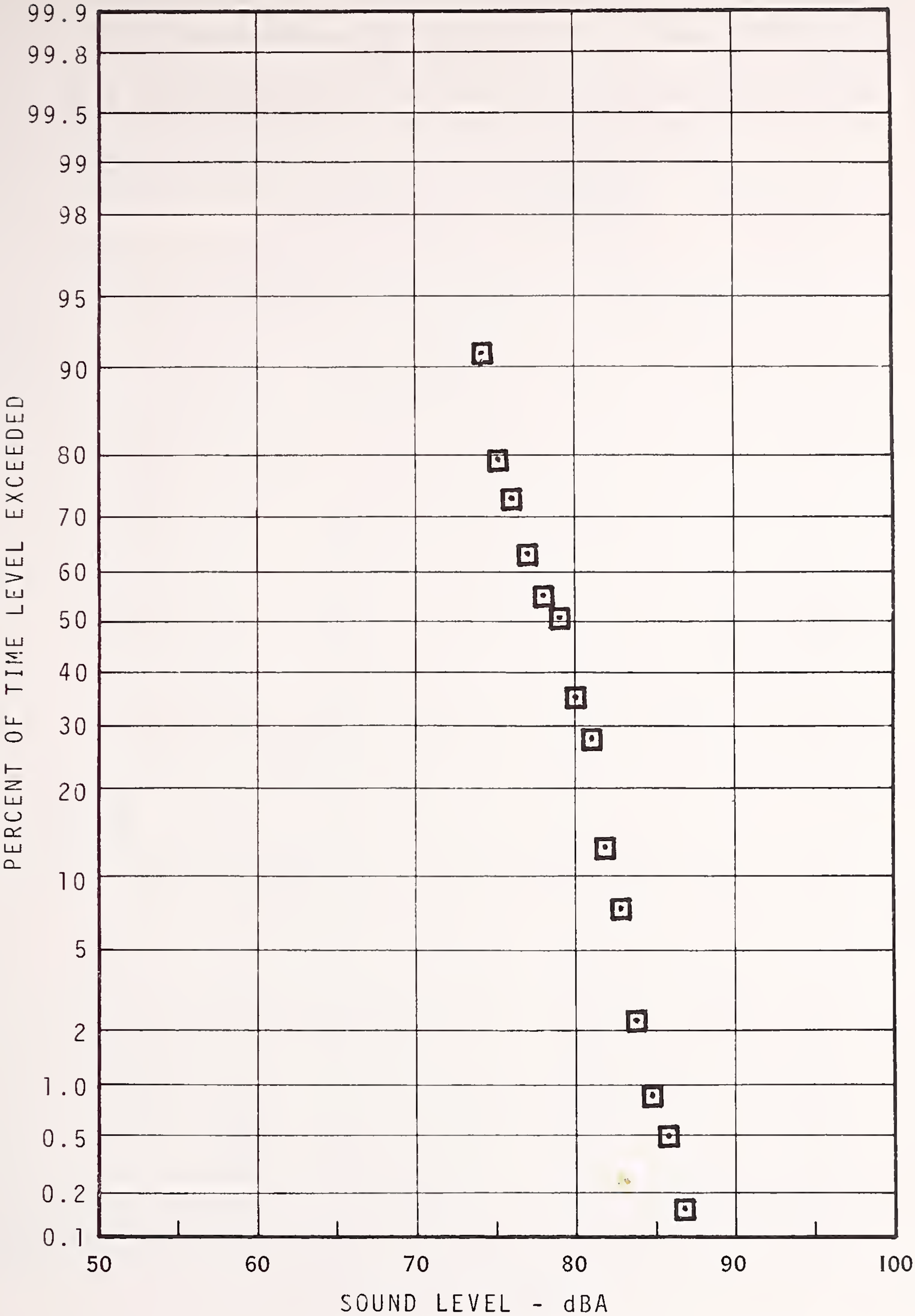


FIGURE 5.68. PULLMAN IN-CAR STATISTICAL DISTRIBUTION, AIRPORT-TO-WINDERMERE, OPERATOR BOOTH.

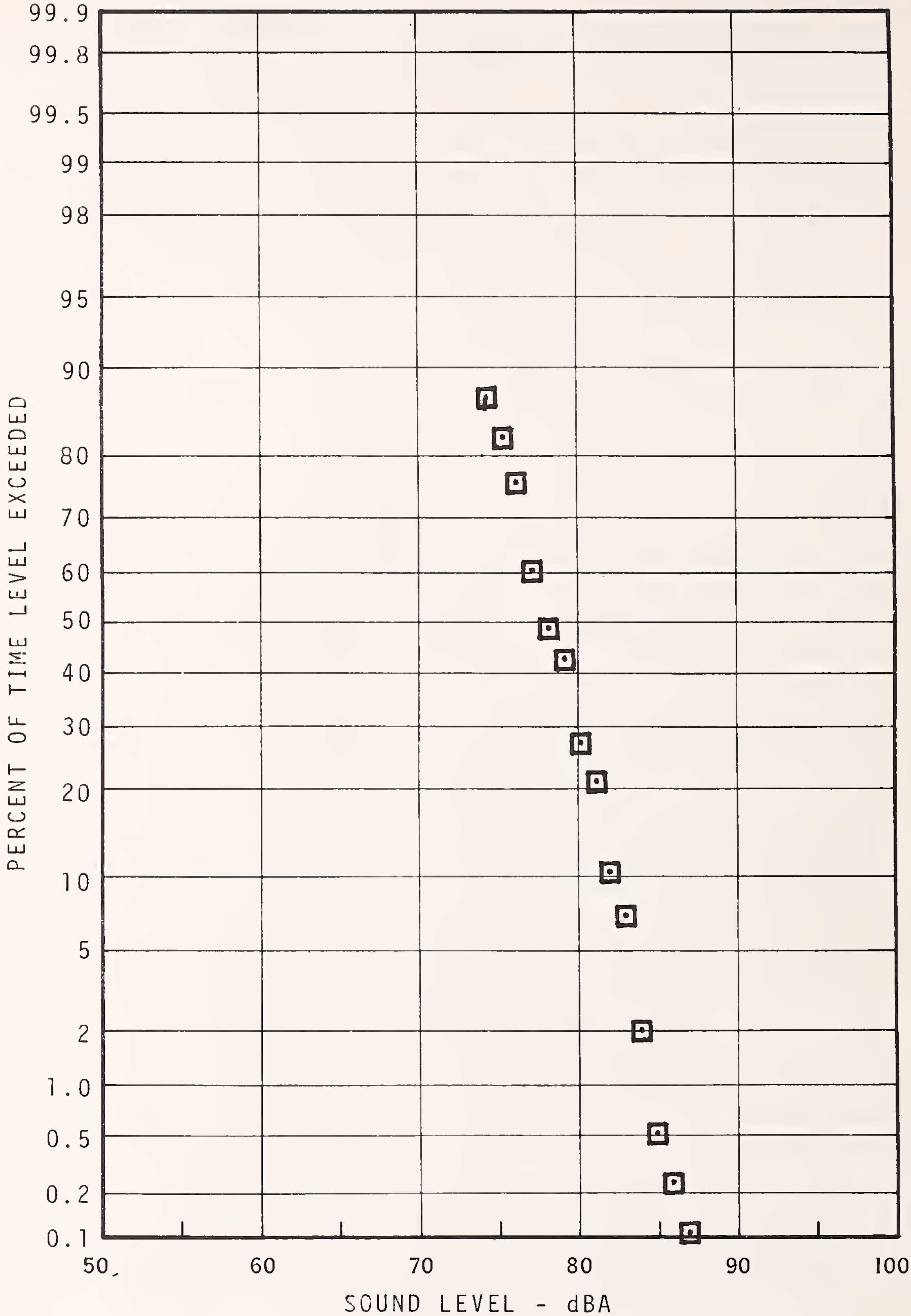


FIGURE 5.69. PULLMAN IN-CAR STATISTICAL DISTRIBUTION, WINDERMERE-TO-AIRPORT, OPERATOR BOOTH.

TABLE 5.17. CLEVELAND TRANSIT SYSTEM IN-CAR NOISE PLATEAU LEVELS

STATION	EASTBOUND PULLMAN CENTER L_A(Max) (dBA)	EASTBOUND PULLMAN OPER. BOOTH L_A(Max) (dBA)	WESTBOUND (MOD) PULLMAN L_A(Max) (dBA)
AIRPORT			
	87.5	82	81
BROOKPARK			
	88	82	82.5
PURITAS			
	85.5	82	81.5
WEST PARK			
	84.5	81.5	81.5
TRISKETT			
	84.5	81.5	81
W117			
	83	80	80.5
W98			
	84	82.5	82
W65			
	84	80.5	82.5
W25			
	84	82	81
PUBLIC SQUARE			
	88	84	83
CAMPUS			
	87	83	80.5
E55			
	85	80.5	79
E79			
	87	81.5	82.5
E105			
	85	81	82.5
UNIVERSITY CIRCLE			
	88	82	82.5
EUCLID			
	88	82.5	81
SUPERIOR			
	86	81	80
WINDERMERE			
	$\bar{x}$ = 86	$\bar{x}$ = 82	$\bar{x}$ = 81.5
	σ = 1.8	σ = 1.0	σ = 1.1

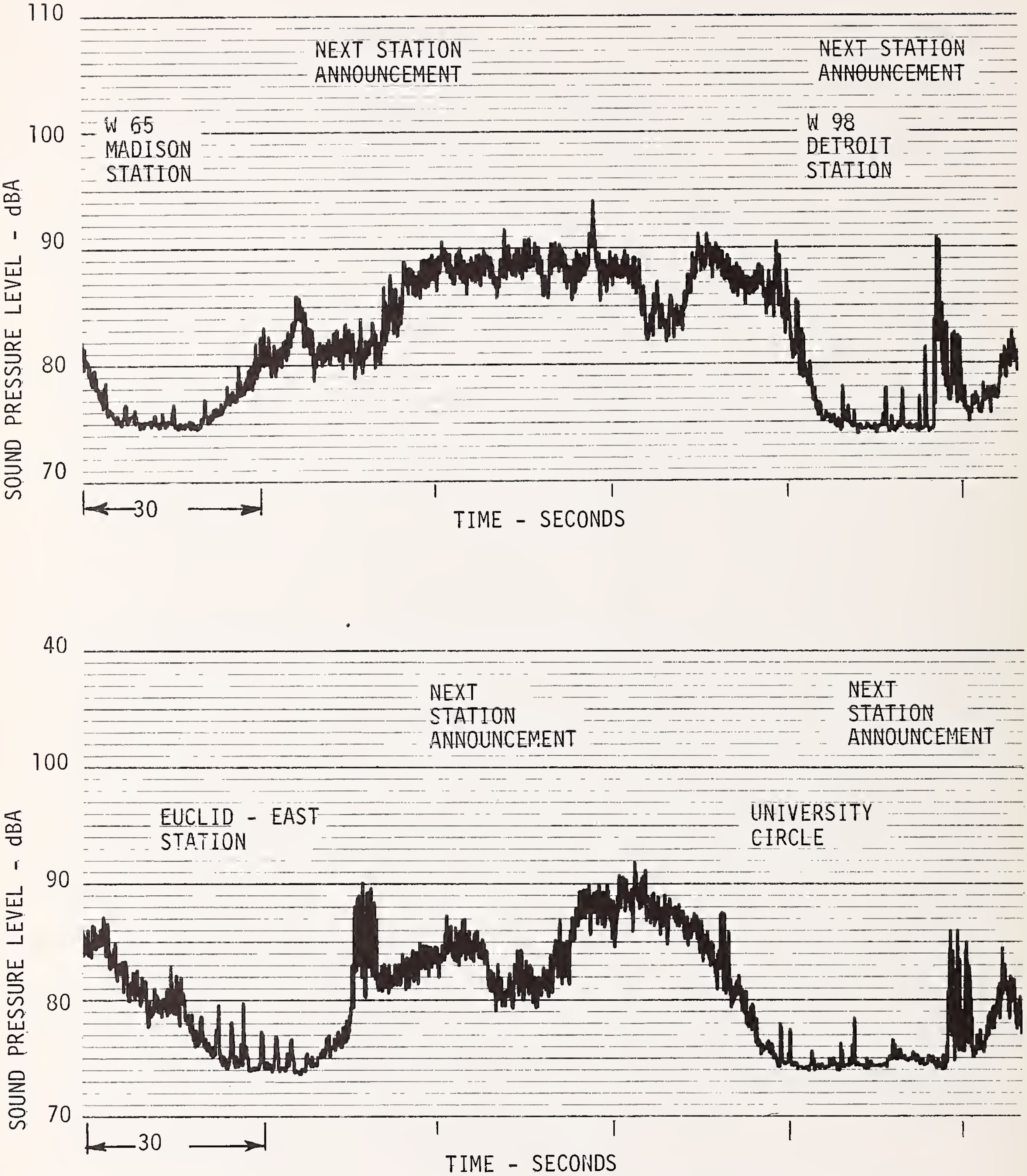


FIGURE 5.70 - TYPICAL TIME HISTORY PULLMAN STANDARD INTERIOR CAR, WINDERMERE-TO-AIRPORT

PULLMAN CAR INTERIOR

(Experimental Configuration)

Car Description

Three Pullman cars (Numbers 151, 152 and 153) at CTS are in an experimental configuration consisting of individually contoured seats covered with fabric instead of the standard bench seats and vinyl upholstery. The floor of the experimental cars is carpeted and this extends partially up the sidewall as a kick-pad. Instead of a bench seat adjacent to the operator's booth there is a baggage rack. The passenger seat covering and carpeting provide additional acoustical absorption compared with standard configuration, although no absorption measurements were made. Aside from the changes noted, the experimental Pullman cars are similar to the standard configuration.

Noise Climate (see Figures 5.71 - 5.72)

An end-to-end line survey was conducted on an experimental Pullman car (No. 153) in a single-car train configuration westbound from Windermere to the Airport. This car type is noticeably quieter than the regular Pullman cars and quite a bit quieter than the St. Louis car types. This can probably be attributed to the increased acoustical absorption provided on the floor and passenger seats. In most other respects, the acoustical environment on-board this configuration is similar to that of the standard Pullman car at CTS.

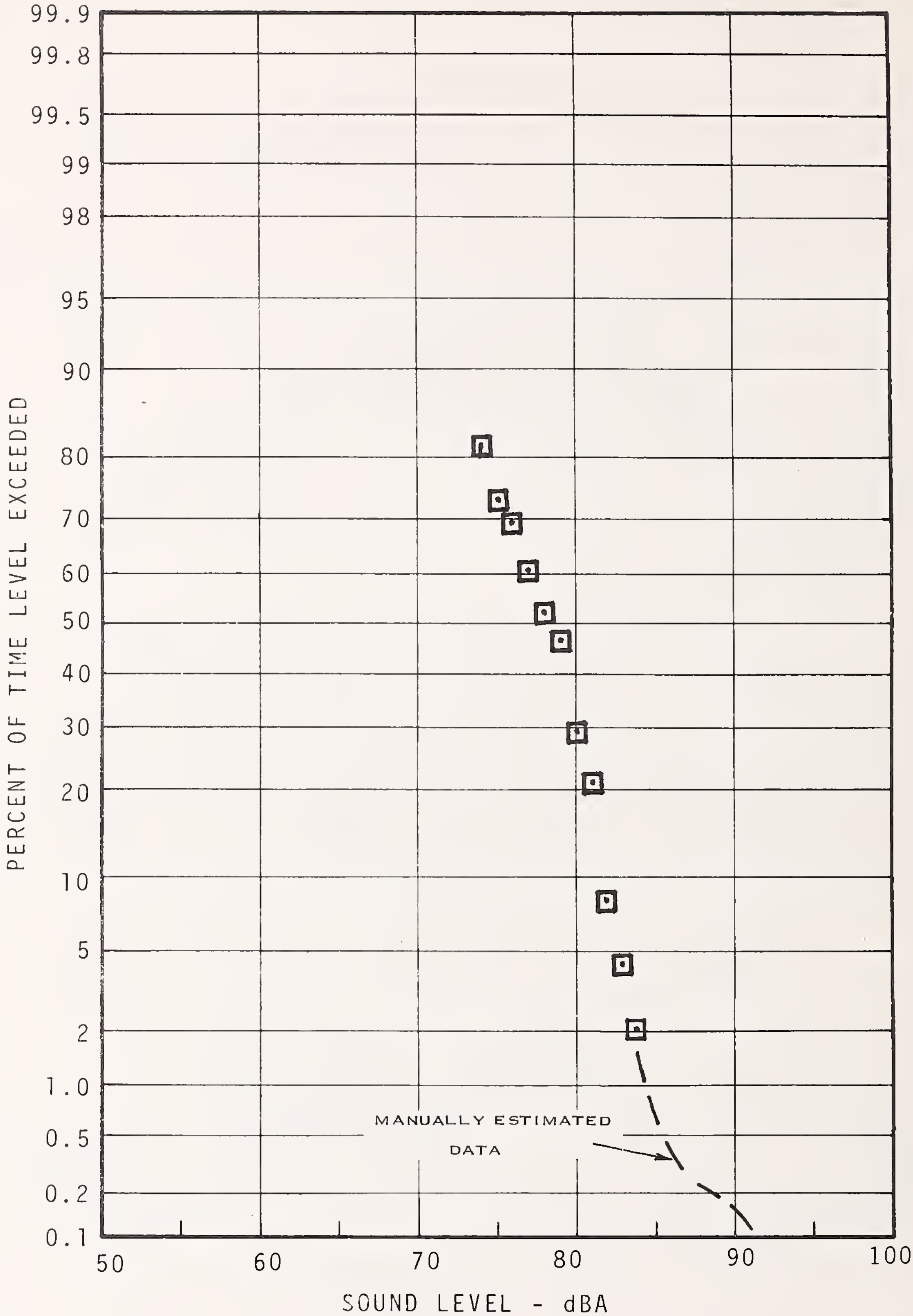
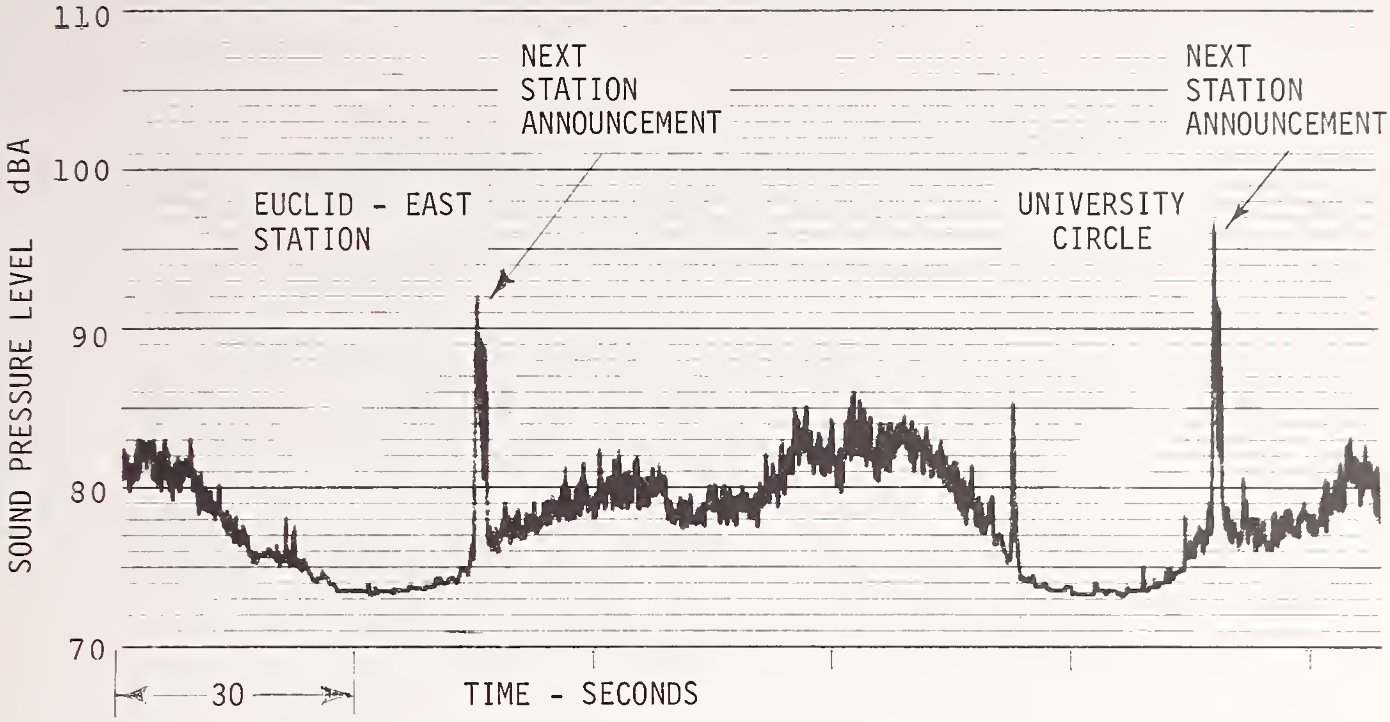


FIGURE 5.71. MODIFIED PULLMAN IN-CAR STATISTICAL DISTRIBUTION, WINDERMERE-TO-AIRPORT, CENTER.



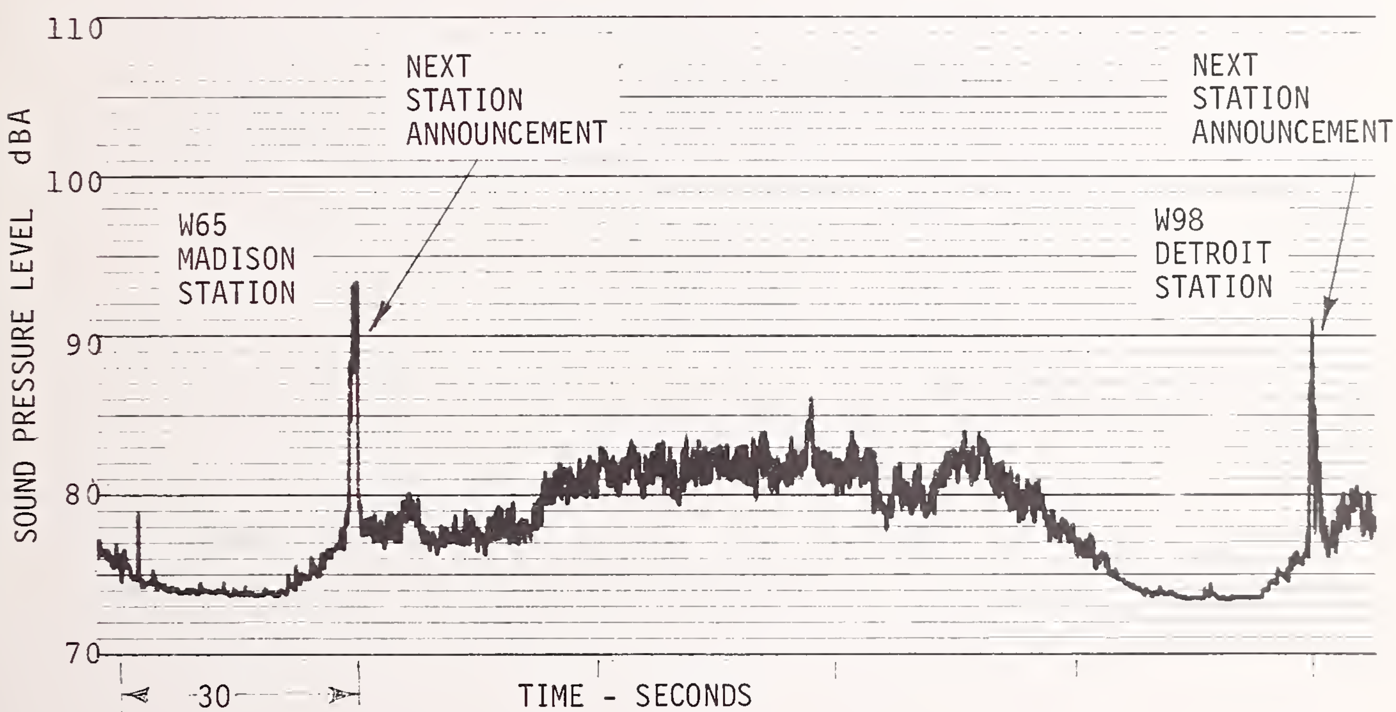


FIGURE 5.72. TYPICAL TIME HISTORY, PULLMAN MODIFIED INTERIOR CAR, WINDERMERE-TO-AIRPORT

ST. LOUIS CAR INTERIOR

Car Description (see Figure 5.73)

Measurements of noise were made in car No. 112 during morning rush hour for the trip from Airport to Windermere. Data was taken during winter months and the car heating system was operating and all windows were closed. On leaving the Airport Station, only the test engineers were on-board Car 112. At each station stop, the number of passengers increased until a crush load was reached at West 25th-Lorain. At Public Square, all but 20 passengers left the car and this number gradually decreased until only 10 patrons were on-board when the train arrived at Windermere. The return trip was made on Car No. 265 with 10 passengers, increasing to 25 at East 55th, and remaining essentially constant until reaching Public Square. On leaving Public Square, from six to 10 passengers were on board the car to Airport Station.

Noise Climate (see Tables 5.18, 5.19; Figures 5.74 - 5.76)

Noise levels in the St. Louis cars are low during periods when the car is stopped, since there are no auxillary systems which generate noise on these cars, other than the brake air compressor. When the car is in motion, the wheel/rail and propulsion system noise establishes the sound levels in the car. Wheel flats are frequently heard on CTS cars, although car Numbers 112 and 265 did not display any noticeable noise due to slid flats. Other comments regarding noise at specific locations on the system, such as squeal generation, are as noted for the standard Pullman car.

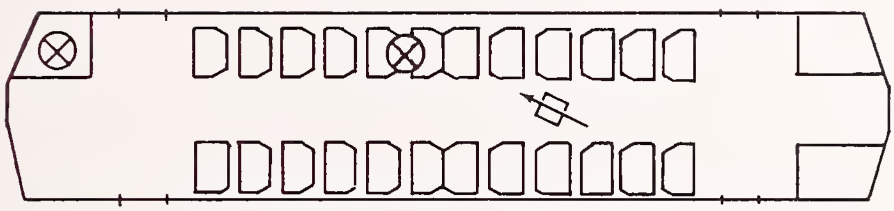


FIGURE 5.73. IN-CAR MEASUREMENT LOCATIONS, CTS
ST LOUIS CAR

TABLE 5.18. SUMMARY OF MEASUREMENT RESULTS FOR ST. LOUIS 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	
St.Louis Single	Center	46 min	East	dBA					76	77	81	86	90	83
		42 min	West	dBA					75	76	81	85	89	82

TABLE 5.19

CLEVELAND TRANSIT SYSTEM
IN-CAR NOISE PLATEAU LEVELS
ST. LOUIS CAR - MID-CAR

STATION	EASTBOUND SINGLE L_A(Max) (dBA)	WESTBOUND DOUBLE L_A(Max) (dBA)
AIRPORT		
	85	81.5
BROOKPARK		
	86.5	85.5
PURITAS		
	84.5	85
WEST PARK		
	83	84.5
TRISKETT		
	83	83.5
W117		
	85	85
W98		
	80.5	85
W65		
	79	86
W25		
	79	83
PUBLIC SQUARE		
	85	83
CAMPUS		
	86	83.5
E55		
	82	84.5
E79		
	84	84.5
E105		
	81	82.5
UNIVERSITY CIRCLE		
	85	83.5
EUCLID		
	85	82.5
SUPERIOR		
	85	81.5
WINDERMERE		
	$\bar{x}$ = 83	$\bar{x}$ = 84
	σ = 2.3	σ = 1.3

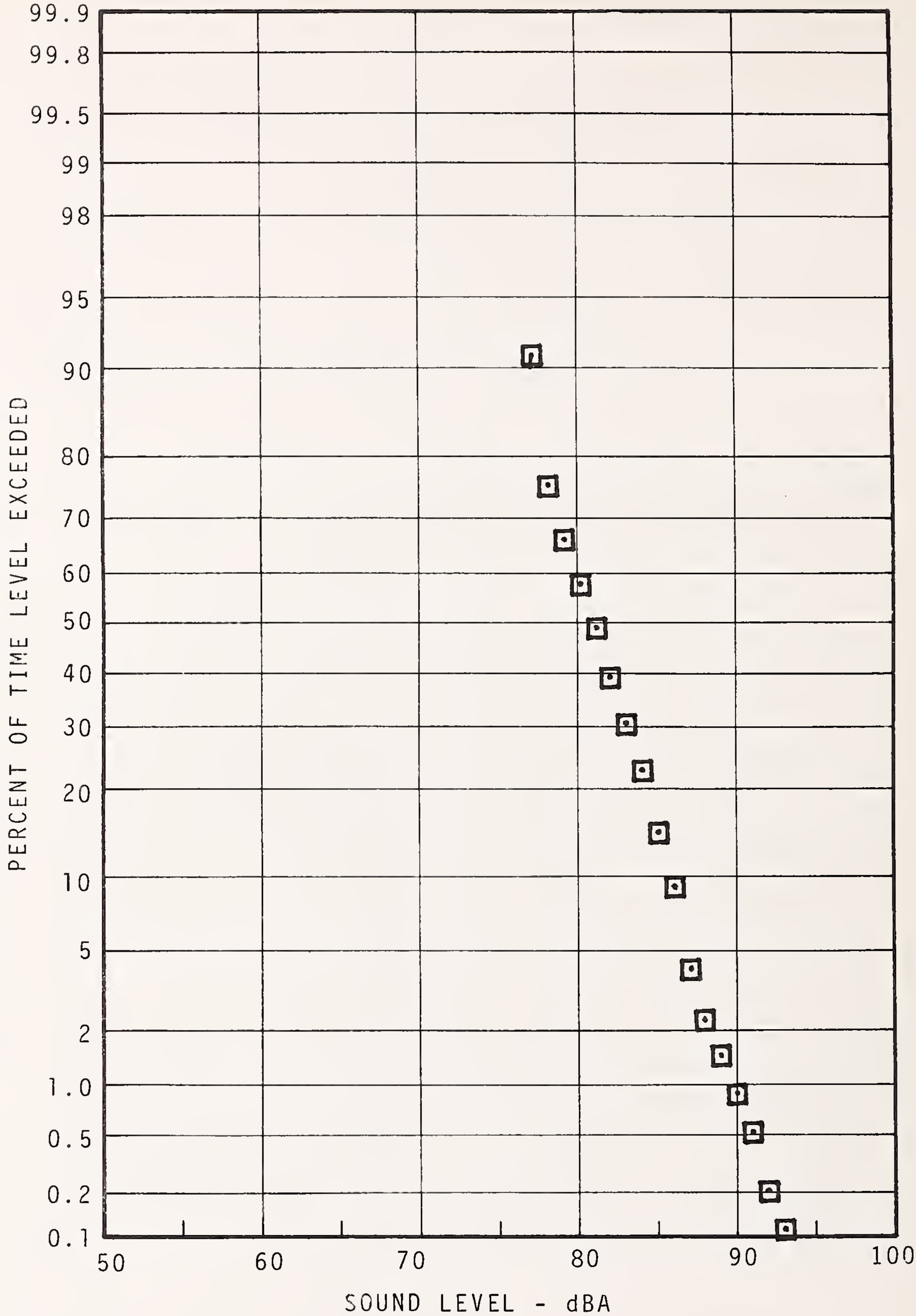


FIGURE 5.74. ST. LOUIS IN-CAR STATISTICAL DISTRIBUTION, AIRPORT TO WINDERMERE, SINGLE, CENTER

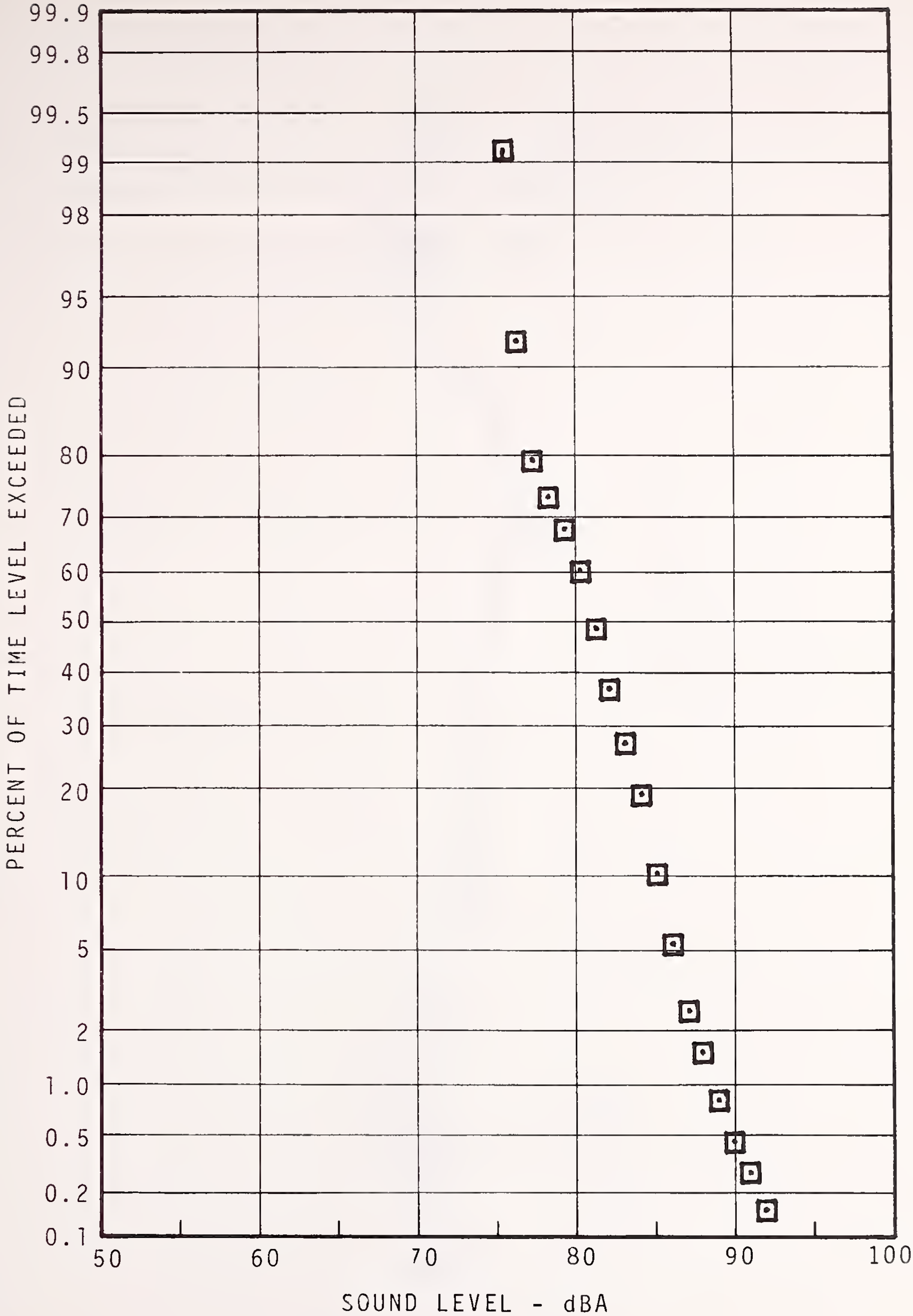


FIGURE 5.75. ST. LOUIS IN-CAR STATISTICAL DISTRIBUTION, WINDERMERE-TO-AIRPORT, SINGLE, CENTER

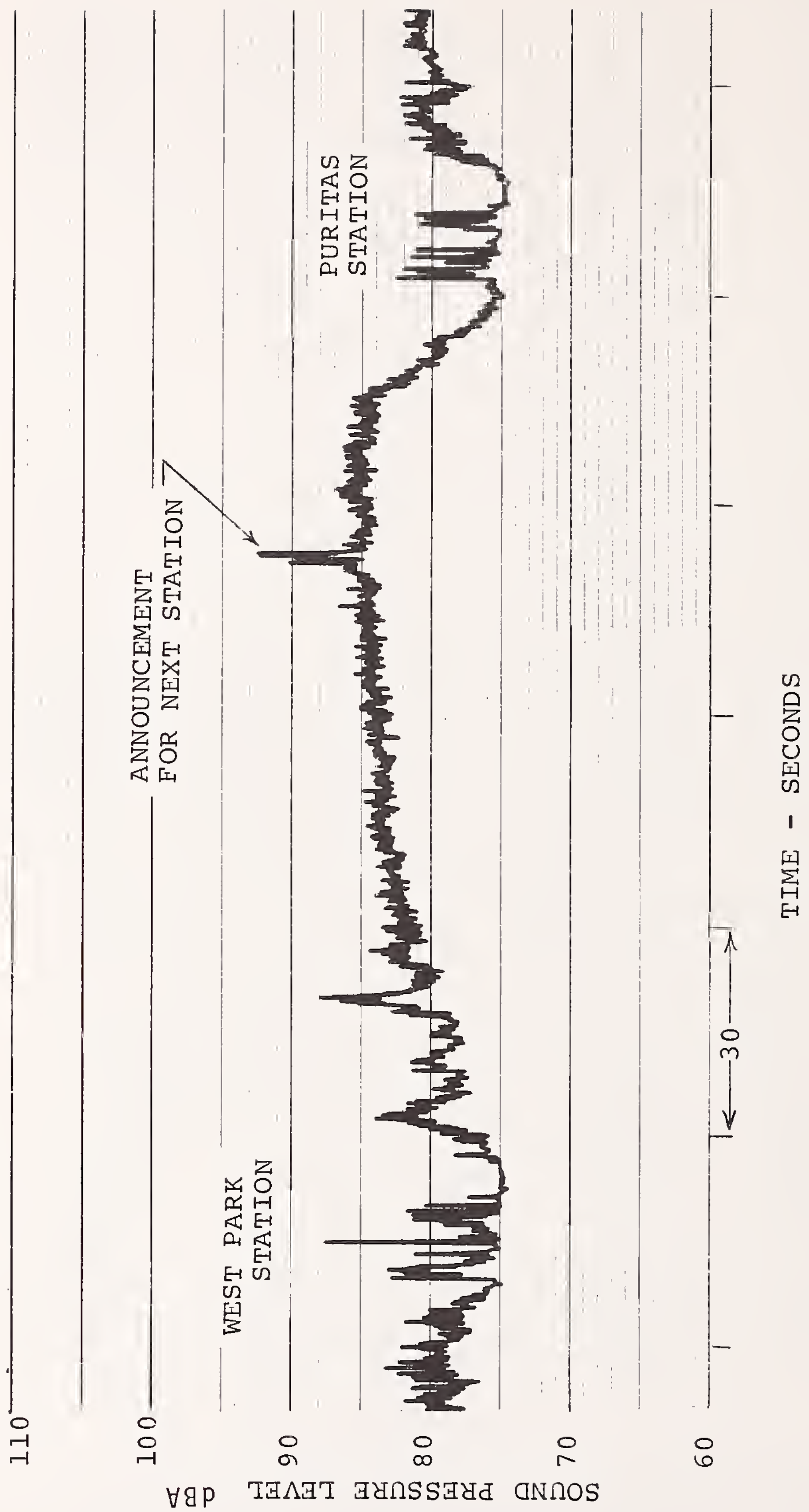


FIGURE 5.76. TYPICAL NOISE TIME HISTORY, IN CAR - CLEVELAND TRANSIT, WINDEMERE TO AIRPORT

5.2.4 Vehicle Exterior (see Figures 5.77 - 5.80)

In order to aid in the identification of the transit vehicle noise sources which contribute to wayside community and station platform environment, third-octave band frequency analyses were performed on individual undercar equipment sounds. These data were recorded at the Windermere yard loop with the car stationary at a distance of 15 feet (4.6m) from the microphone.

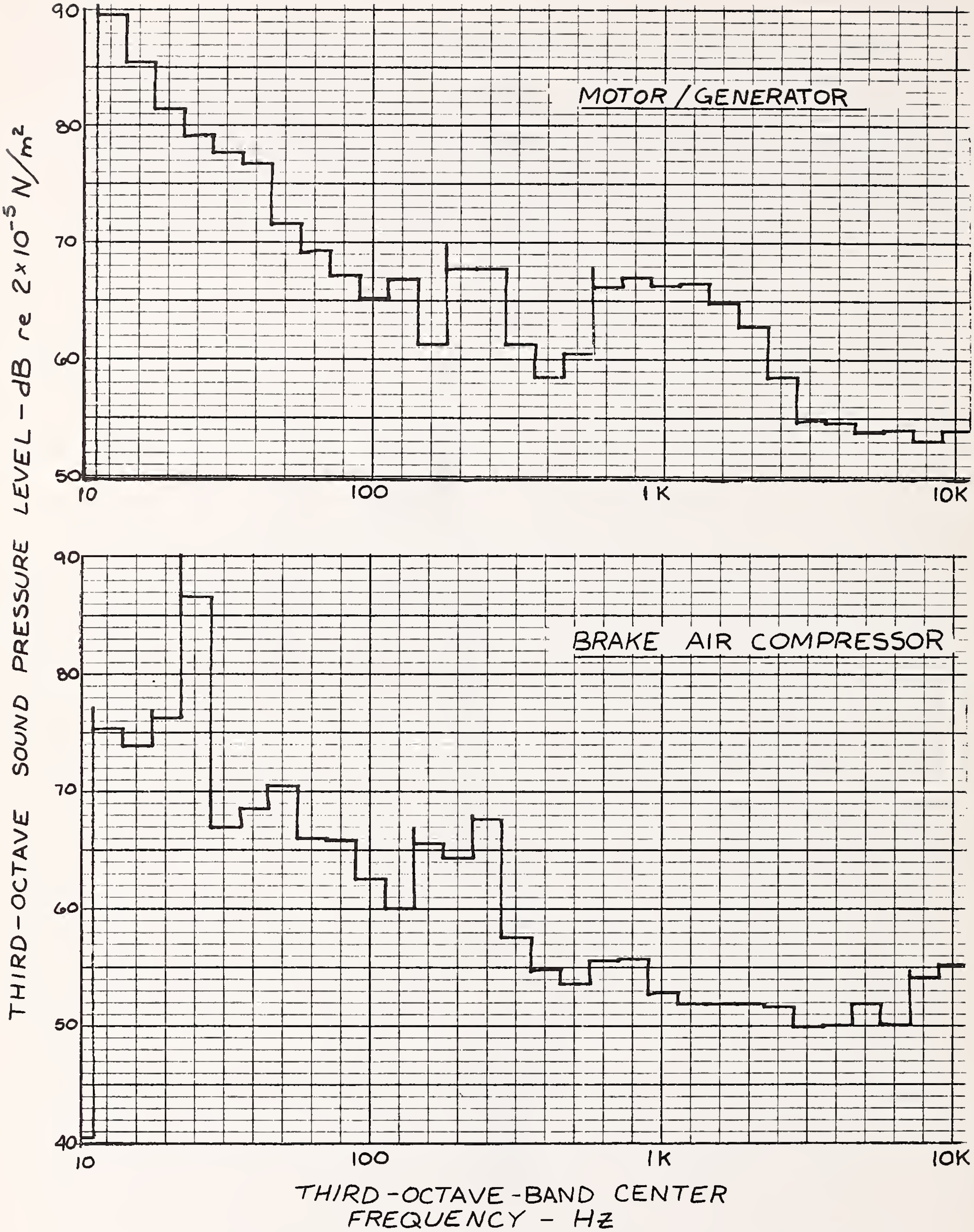


FIGURE 5.77. CTS EXTERIOR VEHICLE NOISE - PULLMAN CAR NO. 155 - INDIVIDUAL UNDERCAR EQUIPMENT - 0 MPH, 4.6 M

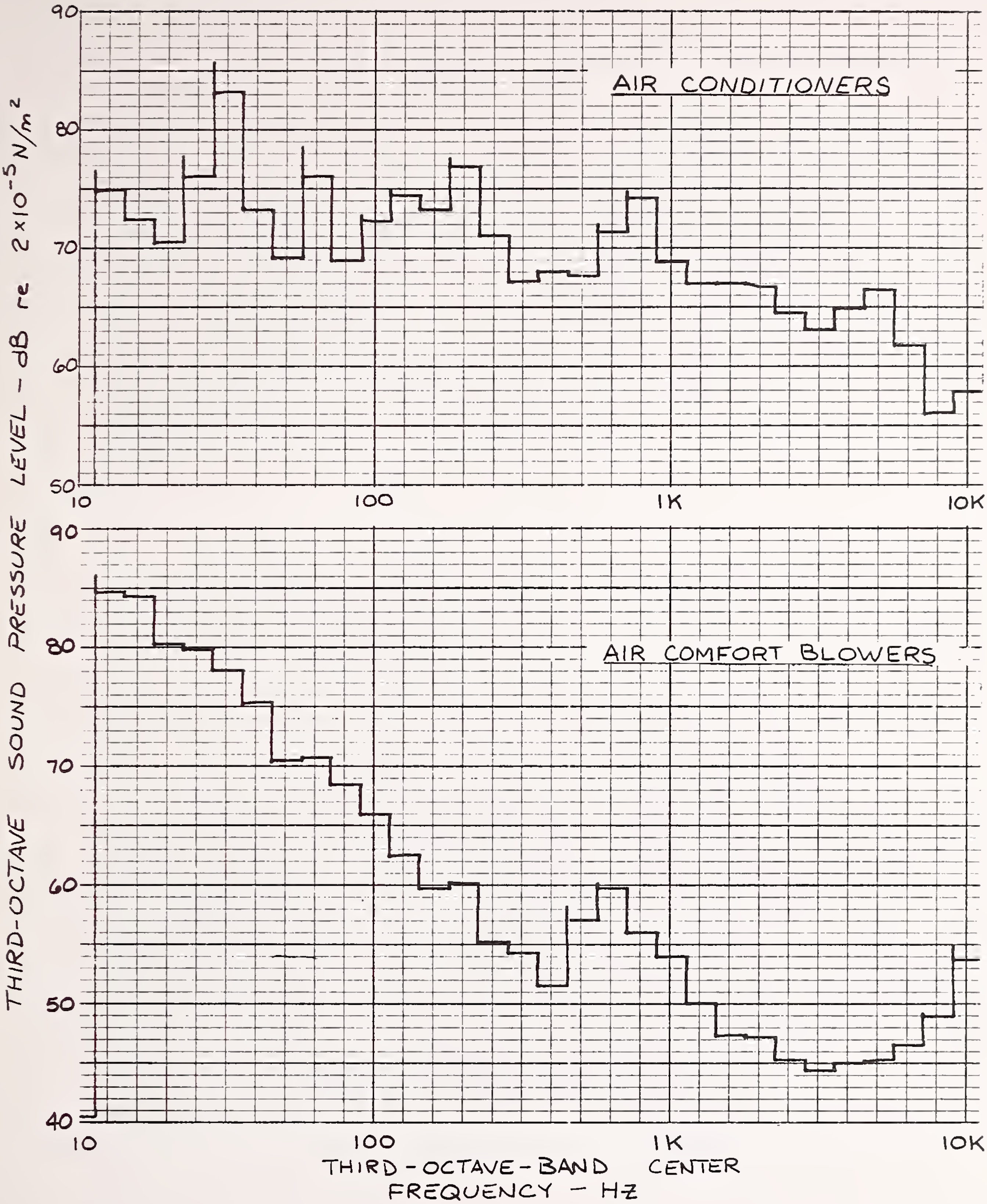


FIGURE 5.78. CTS EXTERIOR VEHICLE NOISE - PULLMAN CAR NO. 155 - INDIVIDUAL UNDERCAR EQUIPMENT - 0 MPH, 4.6 M

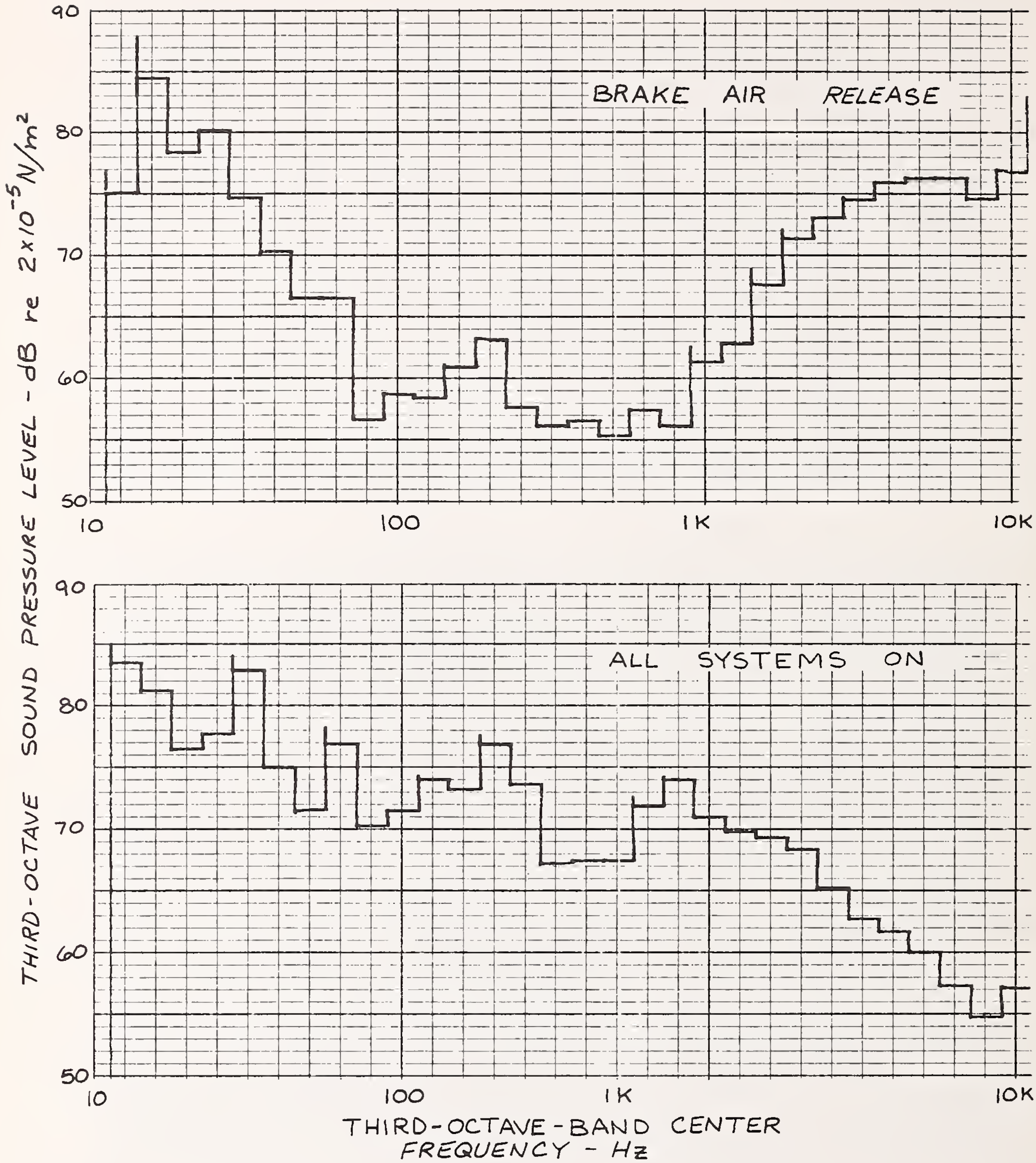


FIGURE 5.79. CTS EXTERIOR VEHICLE NOISE - PULLMAN CAR NO. 155 - INDIVIDUAL UNDERCAR EQUIPMENT - 0 MPH, 4.6 M

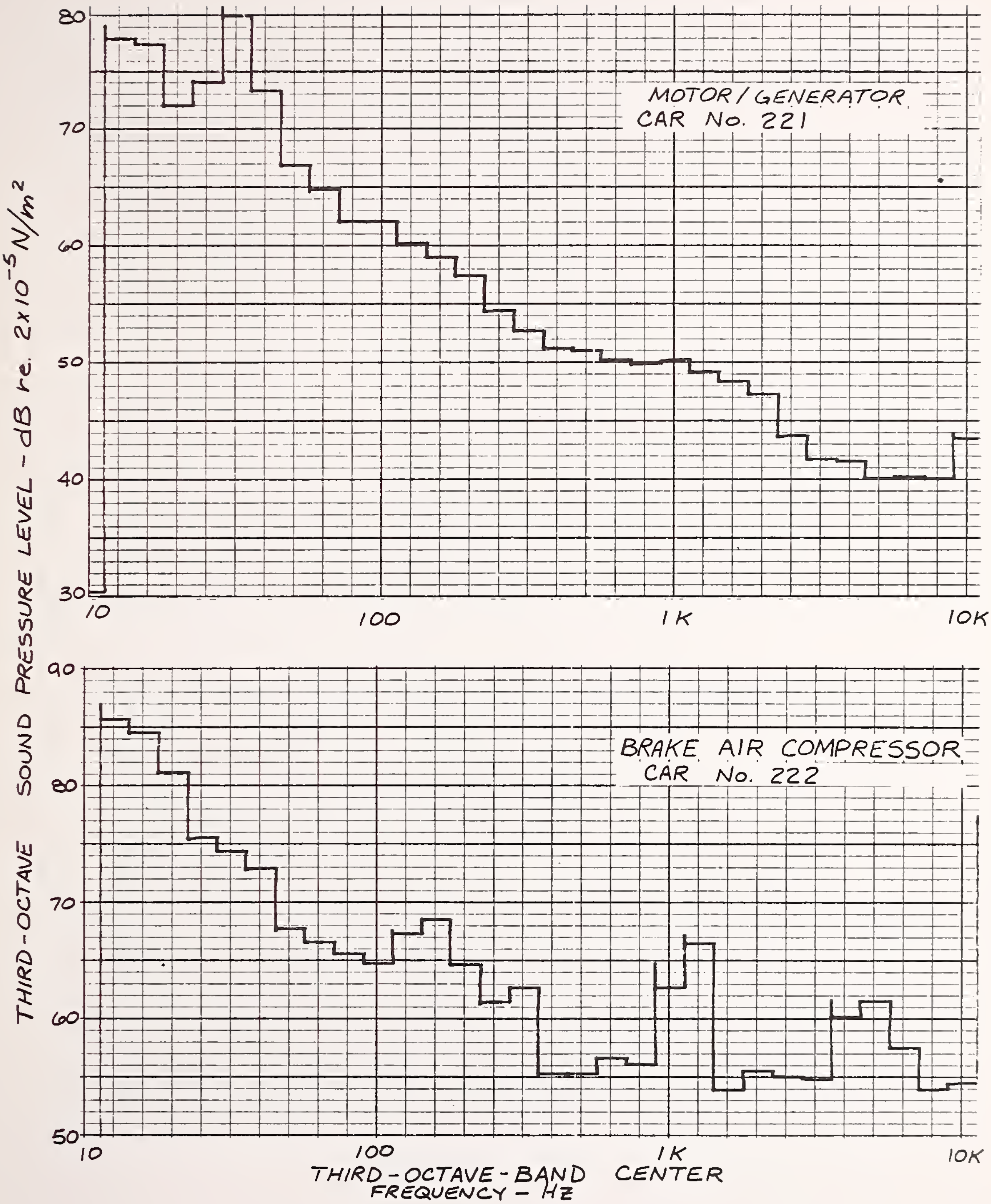


FIGURE 5.80. CTS EXTERIOR VEHICLE NOISE - ST. LOUIS CAR-
INDIVIDUAL UNDERCAR EQUIPMENT -
0 MPH, 4.6 M

6. TRANSIT SYSTEM LINE SUMMARY

6.1 General

Data reported in Section 5, recorded for representative community, station platform and in-car locations, is summarized for the entire rapid transit line in the following tables and illustrations. General information regarding systems operating factors (cars per train, headway, noise measurement periods, etc.) 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 (L_{dn}) have been based on daytime, rush hour, evening and nighttime measurements. Quantities used for calculating L_{dn} have also been identified in Table 6.1.

Tables summarizing noise recorded at each community and station location selected for measurement have been included in Section 5. This information has been further generalized to provide an overview of the noise climate of the rapid transit line and this data is presented in Table 6.2. Wayside noise levels shown represent the average of the passby maximum levels. This is presented for both the near and far tracks as noted in Section 4.

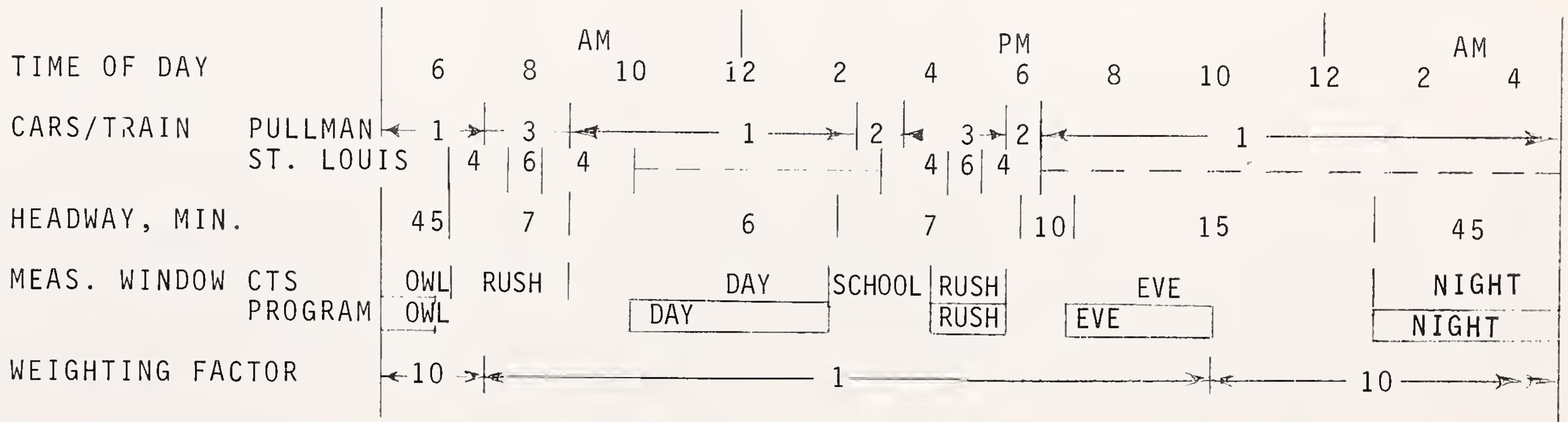
Station noise presented in Table 6.2 represents an average of the maximum levels (L_A(Max)) recorded for each train observed during the recorded interval. This maximum may occur either for the arrival or departure of the train. In-car data shown represents the plateau level between stations measured at a center car location.

A summary of track construction for the Cleveland Airport Line is presented in Figure 6.1.

6.2 Community Noise

Noise levels on the rapid transit line were measured at three community locations which were representative of roadbed on elevated embankment, in a cut and on-grade. At the elevated embankment site near Windermere, data was measured nearest the eastbound tracks. The levels shown for the eastbound direction are 12 dBA lower than for westbound and this results from the lower speeds of trains approaching the Windermere Terminal than those departing westbound. This site is also a location for wheel squeal generation, although levels reported in the table do not represent squeal-generated noise.

TABLE 6.1. GENERALIZED OPERATING SUMMARY AND INPUT FOR L_{dn} CALCULATION CLEVELAND TRANSIT SYSTEM



Period	Meas. L_{eq}	w_i	T (hrs)
5-6:30	NIGHT	10	1.5
6:30-7	RUSH	10	0.5
7-9:00	RUSH	1	2
9-4	DAY	1	7
4-6	RUSH	1	2
6-10	EVE	1	4
10-1	EVE	10	3
1-5	NIGHT	10	4

TABLE 6.2

NOISE MEASUREMENT SUMMARY
CLEVELAND TRANSIT SYSTEM
DAYTIME

Station	Inter Station Distance (Miles)	Average Time Between Stations (Min)	Type Roadbed	Track Constr.	No. Cars per Train (Pullman)	Pullman Wayside Noise 15M dB(A)		Pullman In-Station Noise dB(A)	In-Car Noise Mid Car dB(A)		
						E	W		St. Louis	Pullman[1]	Modified Pullman[3]
Windermere			El. Emb.	Welded Rail Wood Tie, Ballast	1	SLOW		77			
	0.67	1.5	El. Emb.			72	84		83	86	80
Superior											
	0.88	1.5	At Grade						84	88	81
Euclid											
	0.87	1.5	At Grade						84	88	82.5
University Circle											
	0.65	2.0	At Grade						82	85	82.5
E105											
	1.17	2.0	In Cut						84	87	82.5
E79											
	1.05	2.0	In Cut						83	85	79
E55								80[2]			
	0.86	2.0	In Cut						85	87	80.5
Campus											
	1.70	2.5	In Cut						84	88	83
Public Square			Underground					80			
	1.05	2.25	In Cut						81	84	81
W25											
	1.94	3.5	In Cut						83	84	82.5
W65								82			
	1.29	2.25	In Cut			91	93		83	84	82
W98											
	0.96	1.5	In Cut						85	83	80.5
W117											
	1.07	2.0	At Grade						83	84	81
Triskett								83			
	0.77	1.5	At Grade			96	99		84	84.5	81.5
West Park											
	1.26	2.5	At Grade						85	85.5	81.5
Puritas											
	1.72	2.5	At Grade						86	88	82.5
Brookpark											
	1.11	3.0	At Grade						83	87.5	81
Airport			Underground					88			

1. Recorded from Airport to Windermere
2. Side Platform Station - Near Track Data Only
3. Recorded from Windermere to Airport

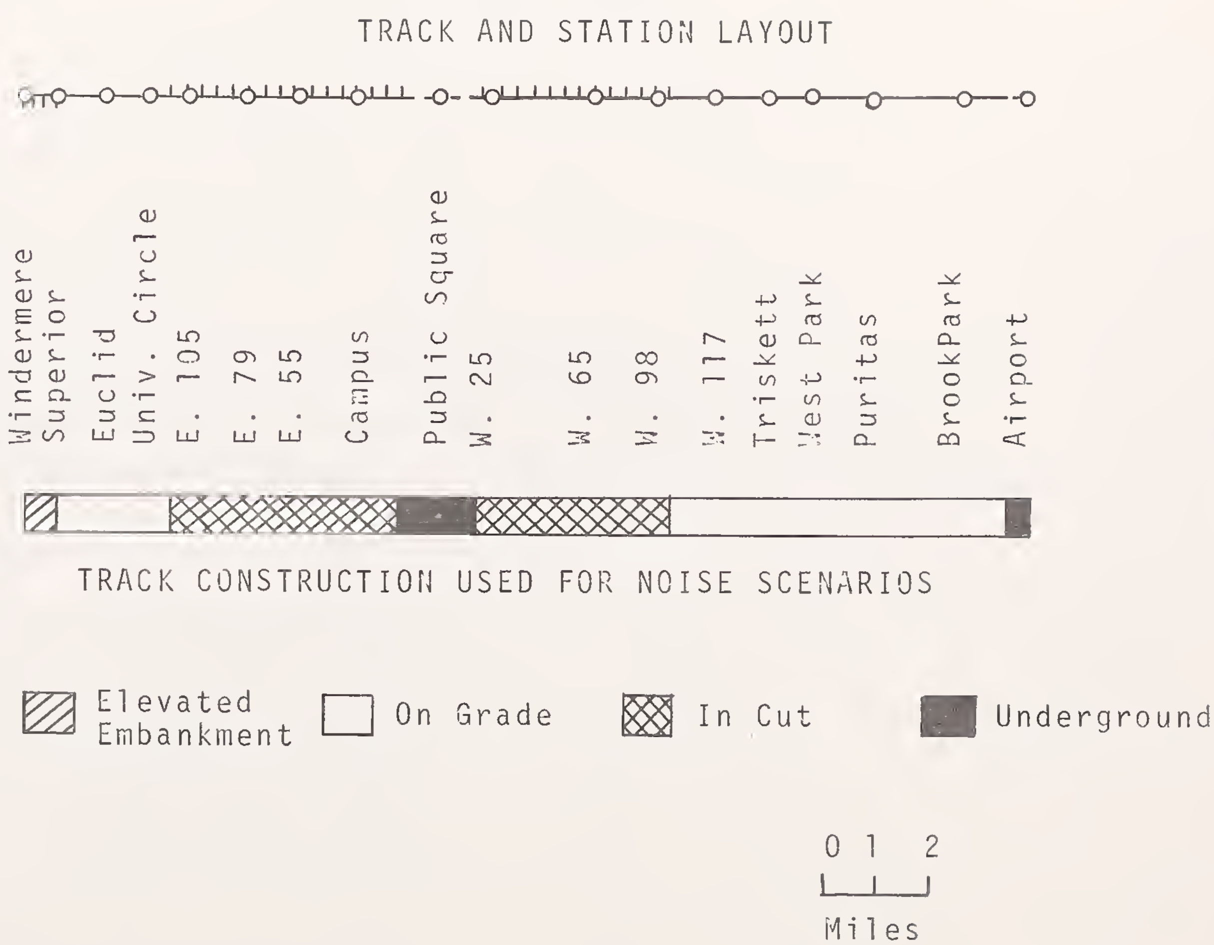


FIGURE 6-1. CTS RAPID TRANSIT - TRACK CONSTRUCTION SUMMARY

Data was also taken adjacent to a cut near the station at West 98th-Detroit, 15m from the eastbound track. Shielding of the cut afforded a 2 dBA reduction in noise compared with westbound trains. Speeds in this region were estimated to be approximately 45 mph.

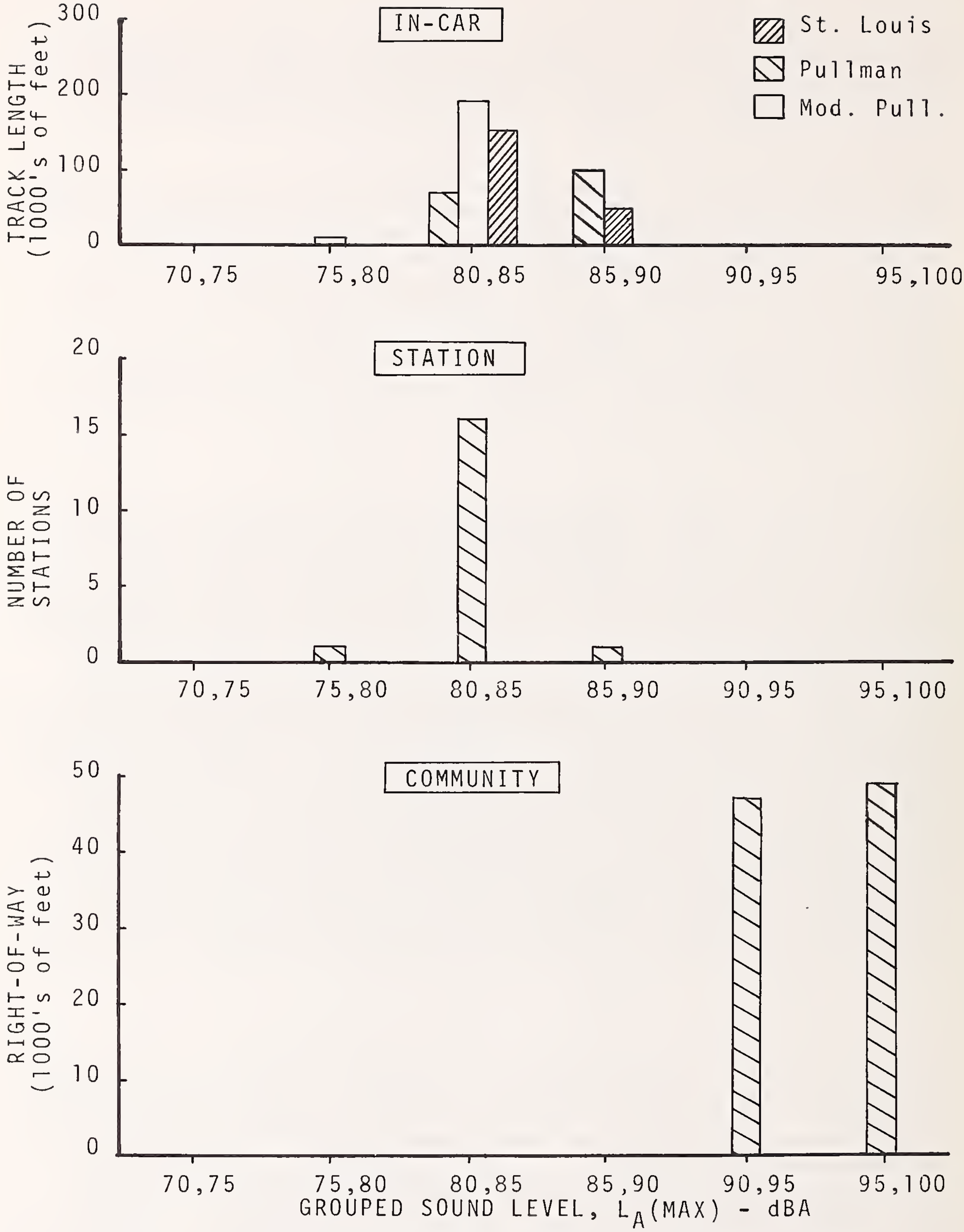
Measurements of the system noise where it is located on-grade were made between the Triskett and West Park Stations adjacent to the westbound track. Levels for eastbound trains are slightly higher than westbound since higher speeds for the accelerating eastbound trains compensated for the increased distance from the microphone. Speeds in this location were estimated to be 50 mph. Although measurement of community noise at the elevated embankment site near Windermere are substantially below those recorded at-grade, the difference is due to operating speed and not the elevation of the roadbed.

6.3 Station Noise

Station noise levels were measured at six stations on the rapid transit line. Windermere displayed the lowest noise levels of all stations measured, 75-80 dBA (Figure 6.2). This results primarily from the microphone being located at the center of a six-car train, and during the day only single cars are utilized. As the car enters the station area during daytime, it stops short of the microphone whose position was maintained for all measurement periods throughout the day. Thus lower levels were recorded than if the microphone position had been at the center of a stopped train, independent of the number of cars per train. Data at the other above ground stations was in the 80-85 dBA group. Airport, an underground station, had the highest noise levels, 88 dBA. Noise levels were considerably lower in Public Square Station at 80 dBA. Although Public Square is located under Union Terminal and the environment is semi-reverberant, car speeds are generally lower than normal, both approaching and departing the station platform as a result of curved track entering and leaving the station area.

6.4 In-Car Noise

Continuous records were taken in-car from terminal-to-terminal in three CTS car configurations: one St. Louis and two types of Pullman. One Pullman configuration had been modified with carpeting on the floor and individual fabric-covered seats. To determine the effect of these modifications on the noise environment, this configuration was also surveyed, although only three of these cars are currently in service. A comparison of the mean value for plateau levels between stations (17 data points) indicated that the standard Pullman car has



NOTE: Grouped sound level interval includes lower, but not upper end point.

FIGURE 6.2. SUMMARY OF CTS NOISE ENVIRONMENT

slightly higher levels of interior noise than the St. Louis car and that the modifications to the Pullman car result in a 4.5 dBA reduction in interior noise, which is significant.

For each type car, the highest plateau levels were recorded in the underground section between Public Square and Campus Stations. The standard deviations between plateau levels on any given car type is generally less than 2 dBA.

6.5 CTS Rapid Transit Noise Summary

A graphic summary of community, station and in-car noise on the rapid transit line is presented in Figure 6.2. Levels have been grouped into 5 dBA ranges: 75-80, 80-85, 85-90, 90-95, and 95-100 dBA. Wayside measurements were made at a distance of 15m from the near track, station noise recorded at the center of a stopped multi-car train, and in-car data was taken in the second car of a multi-car train for one round trip (modified Pullman car was one way only).

In-car noise presented represents steady-state plateau levels between stations. For all the cars surveyed, these levels are established by wheel/rail noise primarily, with propulsion system noise contributing at a second-order level. The cars surveyed in each case did not have any audible wheel flats, but these cars were judged to be generally unrepresentative of CTS wheels which typically have audible slid flats. Another source of wheel rail noise on the rapid transit line is rail/flange "sing". Wheel excitation at the flange mode is different from wheel squeal generated on curved track and the noise is heard on tangent track as well, particularly at higher speeds. Inspection of the wheel contour reveals that the wheels wear to a sharp radius at the flange-tread fillet. Indications are that the difference between rail gauge and wheel gauge may be less at CTS than on other systems, resulting in fillet wear as well as acoustic excitation of the flange.

Passengers riding the system end-to-end in a St. Louis car would experience plateau noise levels in the 80-85 dBA group 75% of the distance traveled and from 85-90 for 25% of the distance. Plateau noise levels in the Pullman cars are in the 80-84 dBA interval for 37% of the route mileage, and in the 85-89 dBA interval for the remainder. The modified Pullman cars have plateau levels in the 75-80 dBA grouping for 5% of route traveled.

The CTS rapid transit has many stations which are similar in construction and layout and the resulting noise exposure to patrons on the station platforms is rather uniform throughout the system. For example, 89% of the station noise environments due to train arrival and departure are in the 80-85 dBA interval with only two stations on the system displaying other noise levels. One of these is Airport (85-90), an underground station, and the other is Windermere (75-80). As noted in Section 6.3, however, the microphone at Windermere Terminal was placed at the center of a multicar train and this position was held constant for all measurement periods. During the day, only single cars are operated, and cars are positioned nearer the end of the station platform and thus do not pass by the microphone at any time. If the microphone position had been adjacent to the single car location, noise levels would have been in the 85-90 dBA interval.

Noise levels in approximately 49% of the wayside community were in the 90-95 dBA interval, and in 51% of the wayside in the 95-100 dBA interval. Where the system operates in a cut, levels are in the 90-95 dBA interval and where it is on-grade or at elevated embankment, levels are in the 95-100 dBA interval. Near the terminals, or other locations for low speed operation, noise levels are in the 80-85 dBA grouping. Wheel squeal is audible in the community near the Windermere Yard (there are few residences nearby) and near W. 98th-Detroit Station where the system is in a cut and "S" turns prior to the eastbound approach to the station. For the remainder of the system, noise levels are primarily established by wheel/rail sources.

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
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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.

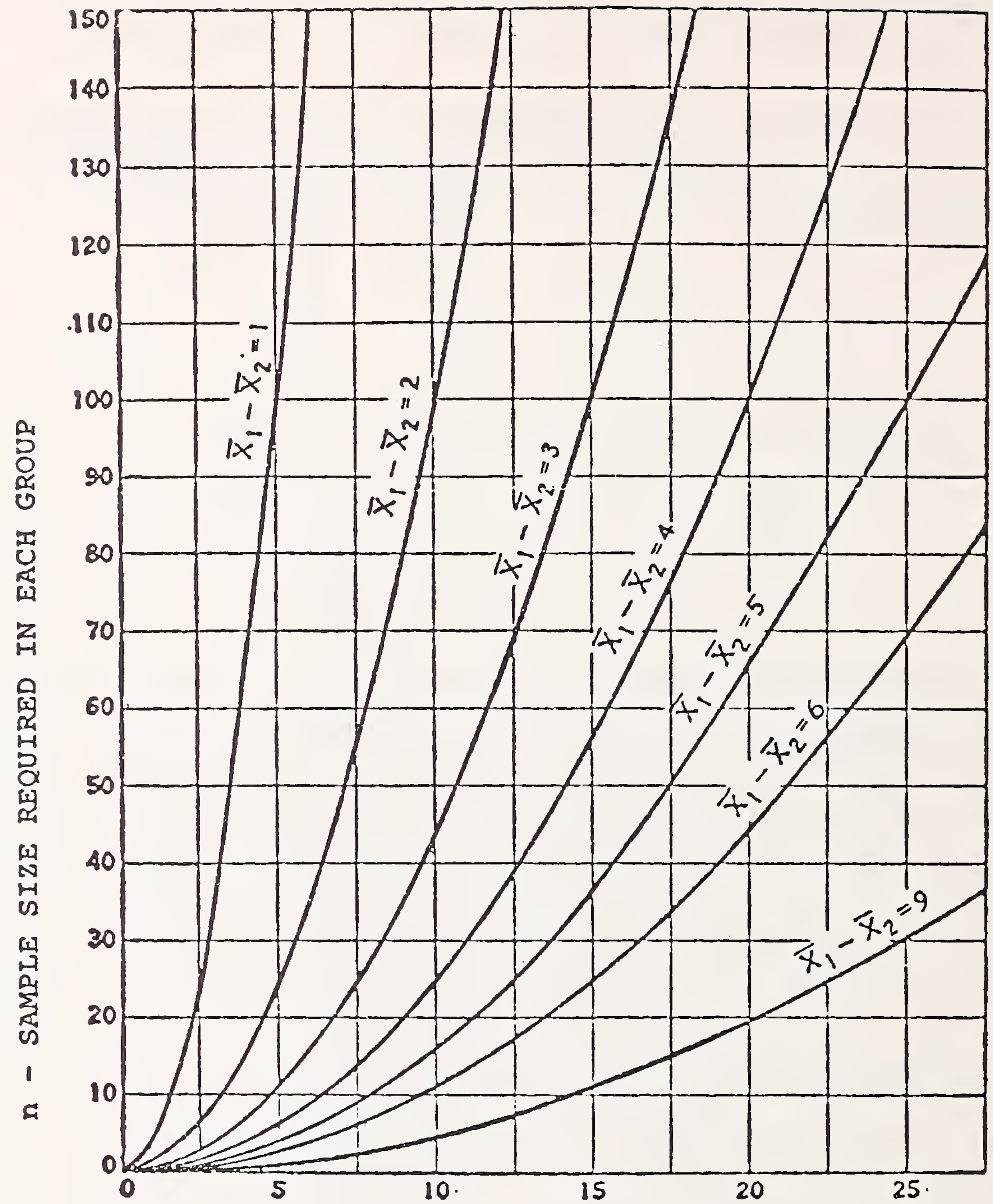
TABLE II

MEAN AND STANDARD DEVIATION OF PASSBY EVENTS

		ARRIVAL BASELINE	ARRIVAL HYPOTHESIZED	DEPARTURE BASELINE	DEPARTURE 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 $s_1 = 2.2$;



SUM OF STANDARD DEVIATIONS

$S_1 + S_2$

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 $\overline{x} - \overline{x}_2 > 5$ 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.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978 — A-1093/280

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