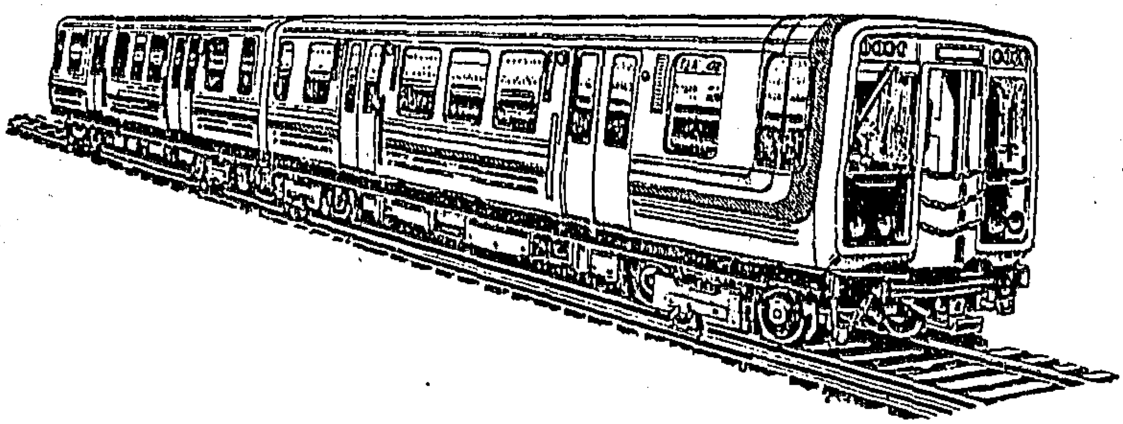
O'HARE EXTENSION PROJECT

NOISE & VIBRATION STUDY FINAL REPORT



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NOISE AND VIBRATION STUDY FOR THE O'HARE EXTENSION

SUBMITTED TO:
CITY OF CHICAGO
DEPARTMENT OF PUBLIC WORKS

DPW PROJECT NO. D-7-002-205
FINAL REPORT
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PREFACE

This final report "Noise and Vibration Study for the O'Hare Extension" is composed of three separate reports, I. Noise and Vibration Survey Report, II. Design Recommendations and Evaluations Report, and III. Noise and Vibration Control Design Criteria Report.

Section I, Noise and Vibration Survey, includes the results of the environmental noise and vibration survey, noise and vibration levels from existing CTA operations, identification of noise impact, and recommended noise and vibration control measures for wayside noise, station platform noise and ground-borne noise at the O'Hare Airport.

Section II, Design Recommendations and Evaluations, includes recommendations on track systems, station acoustics, ancillary transit facilities, noise and air pressure control associated with fan shafts, vent shafts and portals, acoustical barriers and construction noise.

Section III, Noise and Vibration Control Design Criteria, presents an outline of noise and vibration control requirements and procedures for use in facility design.

The preparation of this report has been financed in part through a grant from the U.S. Department of Transportation, Urban Mass Transportation Administration, under the Urban Mass Transportation Act of 1964, as amended.

The subject of this report has been financed in part through a grant from the Illinois Department of Transportation, Division of Public Transportation, under the Provision of Illinois Revised Statutes [1973] Section 49.19 and Sections 701-711.

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I. NOISE AND VIBRATION SURVEY

INTRODUCTION

This report presents a study of the noise and ground-borne vibration characteristics existing at the present time and expected at the time of implementation of Chicago Transit Authority [CTA] rapid transit service along the O'Hare Extension alignment [from Jefferson Park to O'Hare International Airport].

Noise and vibration measurements were made inside and outside representative buildings and in representative areas along the Kennedy Expressway where the alignment will be located to provide information and documentation on the existing levels and to provide assistance in determining the acceptable or appropriate noise and vibration levels in nearby buildings. The data and criteria provide a basis for determining those areas [if any] where special design features are needed to reduce the transit train noise and vibration to acceptable levels.

This noise and vibration survey report discusses the survey locations and procedure, presents background information on noise measurements and noise descriptors, presents the results of the acoustical and vibration measurements, and identifies the individual critical structures along the alignment requiring particular attention to assure acceptable noise levels.

SURVEY PROCEDURE AND BACKGROUND INFORMATION

Establishing the existing noise level or noise environment in a community requires measuring the noise at a large number of locations at several different times of day and, preferably, on several different days and times of the year. Community noise is a continually fluctuating entity dependent on many factors. Because the noise level does fluctuate over a relatively wide range, it is necessary to make measurements which are statistically significant and which can be analyzed on a statistical basis.

The O'Hare Extension alignment is in the median of the Kennedy Expressway through both commercial areas consisting of office buildings and retail stores, and residential areas consisting of single family residences and some apartments. For the commercial areas, with principally daytime occupancy, the possibility of intrusion from transit train operations is primarily a daytime consideration. In residential areas, the community ambient or background noise level is generally the lowest during the evening and nighttime hours and the possibility of intrusion from transit train operations is greatest during this time period. Thus, in the commercial areas, the environmental measurements are accomplished mainly in the daytime and the transit system design criteria are based primarily on daytime operations and noise levels. In the residential areas the measurements are performed at several different times of the day and the transit system design criteria are based primarily on evening and nighttime operations and noise levels.

Although community noise data for the daytime in commercial areas and noise data for the evening and nighttime in residential areas are sufficient to establish the design criteria and evaluate the potential impact of the transit system, such measurements are not sufficient for a complete assessment of the community area. Therefore, noise measurements are made to give data on the existing noise levels for several different times of day. For some types of studies, complete 24-hour surveys of the noise level have been performed in order to obtain a complete statistical representation of the daily noise exposure in a community area. It has been found, however, that the noise in communities can be characterized adequately by making spot-check surveys during at least four characteristic times of day. Because of the purpose of the noise measurements reported herein, the spot-check type of survey was performed during appropriate characteristic times of day along the O'Hare Extension alignment.

A total of twelve exterior and four building interior locations were chosen as representative of areas along the O'Hare Extension alignment. Additional measurements were made at an exterior location along the existing Kennedy Rapid Transit Line to provide data for use in determining the expected noise and vibration produced by the extension, and on the Addison Station platform and Jefferson Park Station platform to determine transit patron exposure to highway traffic noise. The locations of the measurement sites are indicated in Figure 1 showing the O'Hare Extension alignment. Figures 25 through 35 are a series of drawings indicating the locations of the measurement points in greater detail. A brief description of each exterior and interior measurement location is given in Table I. To help distinguish between exterior and interior measurement sites, each site is identified with the location number and an "e" for an exterior location or an "i" for an interior location. Hence, "4i" is an interior measurement location.

The sound level data were taken at the selected locations April 10 through 14, 1978. Results of the noise survey are presented in the section, Existing Noise Levels.

For the purpose of this study the day was divided into four characteristic periods. To obtain clearly characteristic noise measurements the observation periods were defined as:

Daytime:	10:00 a.m. to 2:00 p.m.
Rush Hour:	4:00 p.m. to 6:00 p.m.
Evening:	7:00 p.m. to 10:00 p.m.
Nighttime:	11:00 p.m. to 2:00 a.m.

No data were taken during the morning rush hour because it is generally found that the noise level results are essentially the same as for the evening rush hour. Each measurement consisted of a ten minute long continuous sample of noise at the site, recorded by means of a calibrated multi-channel precision magnetic tape recorder equipped with a laboratory quality microphone. The recordings obtained were later analyzed to obtain the statistical distribution and other descriptors of the noise levels. The tape recordings can be used in the future to obtain spectral analysis of the noise at the sites [such as octave band analyses] and are permanently retained as a record of the noise environment existing at the time of the measurements.

The results of the noise measurements and the description of the noise environments prevailing at each of the measurement locations in the community are based on a statistical analysis of the observed noise levels in decibels. The factors derived from the analysis are the levels exceeded 99% of the time, 90%

of the time, 50% of the time, 10% of the time, and 1% of the time designated L_{99}, L_{90}, L_{50}, L_{10}, and L_1, respectively.

L_{99} and L_{90} are descriptors of the typical minimum or "residual" background noise level observed during a measurement period, normally made up of the summation of a large number of sound sources distant from the measurement position and not usually recognizable as individual sound sources. The most prevalent source of this residual noise is distant street and highway traffic, but L_{99} and L_{90} are not strongly influenced by occasional local motor vehicle passbys. However, they can be influenced by stationary sources such as air conditioning equipment.

L_{50} represents a long-term statistical average or median sound level over the measurement period and does reveal the long-term influence of local traffic. If the instantaneous sound level is sampled over a measurement period, the sound level will be above L_{50} 50% of the time and below L_{50} 50% of the time.

L_{10} describes the average peak or maximum sound level occurring, for example, during nearby passbys of trucks, buses, automobiles, trains, or airplanes. Thus, while L_{10} does not describe the long-term noise prevailing it does describe the typical maximum noise levels observed at a point and is strongly influenced by the momentary maximum sound level occurring during vehicle passbys.

L_1, the sound level exceeded 1% of the time, is representative of the occasional maximum or peak sound level which occurs in an area.

Because of some inherent deficiencies of the simple percentile measures described above in evaluating the noise exposure effects of short duration, high level sound [such as truck or bus passbys], the Energy Equivalent Level, L_{EQ}, has been developed and is widely used as a valid single-number descriptor of environmental noise. Because it is an energy integral over time, L_{EQ} represents the constant or steady sound level which would give the same *energy level* as the fluctuating value integrated over the total time period. Thus L_{EQ} places more emphasis on high noise level periods than does L_{50} or a straight arithmetic average of noise level over time. Some consider L_{EQ} a more useful measure than L_{50} for the average or typical noise exposure in an area and most new evaluation systems such as CNEL [Community Noise Equivalent Level] or L_{DN} [Day/Night Average Level] use the energy equivalent concept.

The interior noise environment is also described in terms of L_{99}, L_{90}, L_{50}, L_{10}, L_1, and L_{EQ}. Although these designations still describe the sound level exceeded a certain percentage of the time, the interior noise levels, besides being much lower, generally do not have as wide a range, i.e., L_{90} and L_{10} are much closer together than at a nearby exterior location. This is due to the averaging effects of reverberation inside buildings and because the interiors of most buildings have relatively steady noise sources while the dominant exterior noise sources, which strongly affect L_{10}, L_1 and L_{EQ}, are reduced in level.

TABLE I LOCATIONS USED FOR EVALUATION OF THE NOISE AND VIBRATION ENVIRONMENT ALONG THE PROPOSED O'HARE EXTENSION ALIGNMENT

Location Number	Description
1i	Inside stairwell area at basement level of O'Hare Airport parking garage.
2e	At dead-end of Ruby Street west of the Tri-State Tollway and north of the Kennedy Expressway.
3e	At intersection of L Street of mobile home park and Bryn Mawr Avenue, south of the Kennedy Expressway.
4e	In the south parking lot of the Chicago Marriott O'Hare, 8535 West Higgins Avenue, approximately 200 ft north of edge of Kennedy Expressway.
4i	Inside Room 2163 of the Chicago Marriott O'Hare, 8535 West Higgins Avenue, approximately 200 ft from edge of Kennedy Expressway.
5e	In parking lot approximately 100 ft east of Holy Resurrection Serbian Orthodox Church on Redwood Street, approximately 200 ft south of edge of Kennedy Expressway.
5i	Inside sanctuary of Holy Resurrection Serbian Orthodox Church.
6e	On sidewalk outside Norwood Medical Center, 7742 West Higgins Avenue, near Canfield Avenue, on north side of Kennedy Expressway.
6i	Inside unused office of Norwood Medical Center, 7742 West Higgins Avenue.
7e	On sidewalk approximately 50 ft east of the intersection of West Higgins and West Bryn Mawr Avenues, on south side of Kennedy Expressway.
8e	On sidewalk approximately 50 ft west of the intersection of West Gregory Street and North New England Avenue, on south side of Kennedy Expressway.

TABLE I [CONT.]

Location Number	Description
9e	On walkway in front of Taft High School Gymnasium, off North Natoma Avenue, on north side of Kennedy Expressway.
10e	On sidewalk of Avondale Street, approximately 80 ft west of North Moody Avenue, approximately 120 ft from south edge of Kennedy Expressway.
11e	At dead-end of North Austin Avenue, south of the North Northwest Highway and north of the C&NW Railroad tracks and Kennedy Expressway.
12e	On sidewalk at the intersection of West Carmen and North Parkside Avenues, on south side of Kennedy Expressway.
13e	On sidewalk near intersection of West Argyle Street and North Long Avenue, near Jefferson Park CTA Station, on north side of Kennedy Expressway.
14e	On sidewalk of West Leland Avenue between North Lawler and North Lavergne Avenues, north of Kennedy Expressway approximately 100 ft from the CTA alignment in the Expressway median.

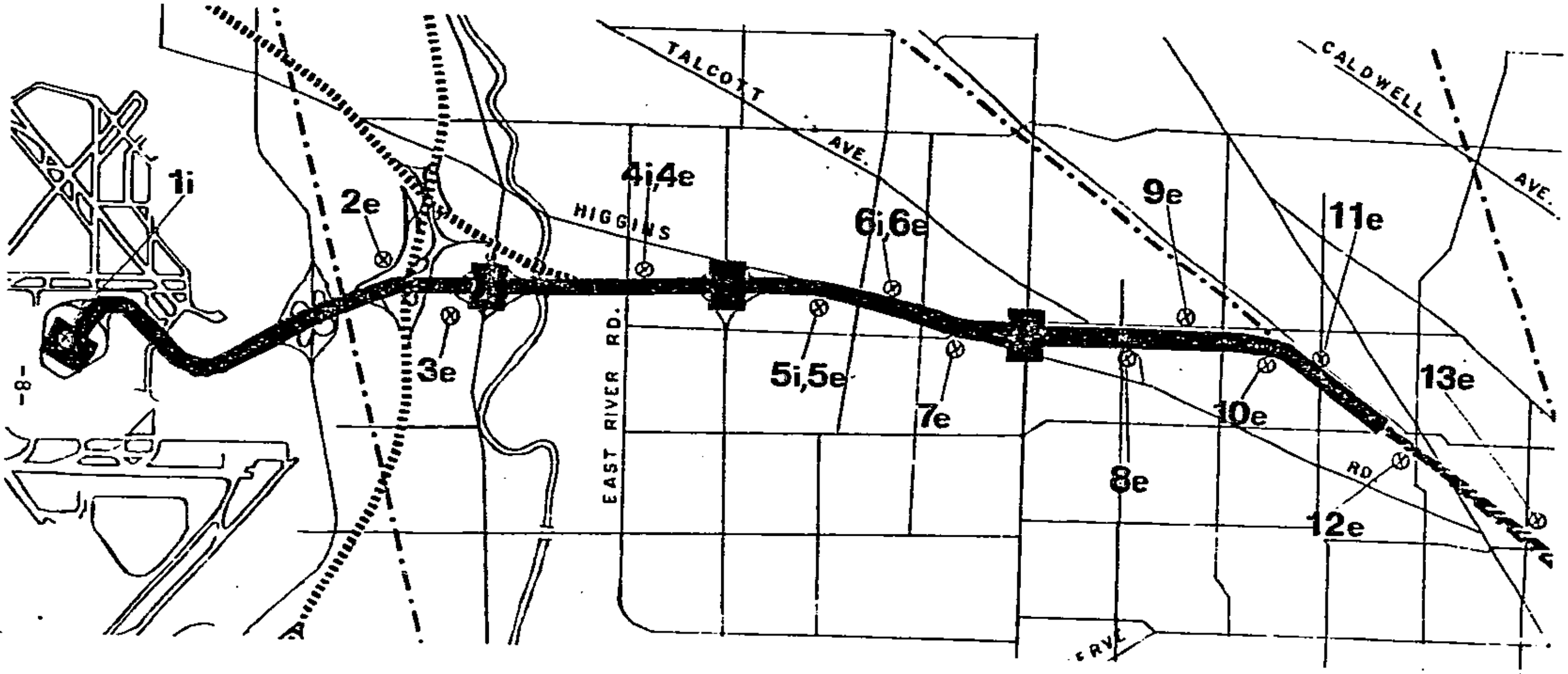

FIGURE 1 MAP SHOWING THE O'HARE EXTENSION ALIGNMENT AND THE LOCATIONS OF THE NOISE AND VIBRATION MEASUREMENTS

EXISTING NOISE LEVELS

Table II presents a tabulation of the statistical analysis of the exterior noise observed at each measurement site. Review of the sound level data indicates that the residual background noise levels, L_{99} and L_{90}, range from 57 to 70 dBA during the rush hour and day, and 51 to 67 dBA during the evening and nighttime hours. During the evening and nighttime hours, the noise levels do not drop appreciably when compared to the rush hour and daytime noise levels. This is due principally to the continual steady traffic on the Kennedy Expressway during all of the times of day when measurements were made.

The median or L_{50} noise level for the different sites ranges from 62 to 71 dBA during the rush hour, 64 to 74 dBA during the day, 54 to 71 dBA during the evening, and 56 to 69 dBA during the night. As with the residual background noise levels, the L_{50} noise level does not drop appreciably during the evening and nighttime hours. Part of the reason for the relatively constant noise level is the steady traffic on the Kennedy Expressway, and part is the high noise levels produced by jet aircraft landing at O'Hare International Airport. Location 3e, which is somewhat removed from the freeway, did show a significant decrease in noise level during the evening after 10:00 p.m. when the number of jet aircraft landings decreased significantly.

The data for L_{10} and L_1 show typical levels for vehicular traffic on an expressway for Locations 8e through 14e. For Locations 2e through 7e, the L_{10} and L_1 noise levels are strongly influenced by the jet aircraft landings. At several locations an L_1 noise level greater than 90 dBA was observed during the measurement period. This is an extremely high L_1 noise level to be encountered in an outdoor environment of a mixed land use developed area. At most of the remaining sites, an L_1 noise level of 80 dBA or greater was encountered which is high for commercial and residential developed areas. At some locations, depending on the distance to the Kennedy Expressway, this noise level was due to the jet aircraft landings or a combination of the jet aircraft landings and vehicular noise from the Kennedy Expressway. During the evening and nighttime hours, there were generally fewer high noise level events resulting in a decrease in the L_1 and L_{10} noise levels during these hours.

The Energy Equivalent Level, L_{EQ}, ranges from 68 to 79 dBA during the rush hour, 64 to 82 dBA for the daytime period, 58 to 80 dBA for the evening, and 60 to 75 dBA during the nighttime. As with the noise levels of the other statistical descriptors, these noise levels are high and are due primarily to vehicular traffic on the Kennedy Expressway and to jet aircraft landings at O'Hare International Airport.

Since very little of the noise impact is from local activities and local traffic, the areas with hotels, office buildings and retail stores have a similar noise environment to that in purely residential areas. In similar neighborhoods away from expressway traffic and airport flight paths, the noise levels would be 15 to 20 dBA lower, indicating a significantly quieter and more typical noise environment.

The use of digital analysis equipment to derive the statistics of the ambient noise level at each of the measurement locations permits calculation and plotting of continuous graphs or charts giving a complete graphical description of the noise level distribution for each measurement or group of measurements. Since this information is a supplement to the noise level information given in tabular form for the specific descriptors such as L_{90}, L_{50}, and L_{10}, a series of graphs of the statistical analyses has been prepared as part of the noise data analysis and are presented in Figures 2 through 10. These charts present data similar to that given on Tables II and III except that the complete distribution is shown with a resolution of 1 dBA.

Figures 2 through 4 show the detailed statistical distributions in terms of noise level exceedence in percentage of time for the exterior noise levels along the O'Hare Extension alignment for the daytime measurements. Figures 5 through 7 present statistical plots of the evening measurements, while Figures 8 through 10 present statistical plots for the nighttime measurements.

These charts provide a means of graphically comparing the noise distributions along different sections of the route. It is significant to note the decrease in the high sound level portion of the statistical distribution [the upper few percent versus sound level on the charts] at locations near the airport during the nighttime when compared with the evening. This high sound level portion of the statistical distribution charts is strongly affected by the jet aircraft landings, and thus when the number of landings is reduced after approximately 10:00 p.m., the high noise levels are reduced.

Table III presents a tabulation of the statistical analysis of the interior noise observed at each measurement location. The daytime and rush hour residual background [L_{99} or L_{90}] noise level was in the range of 29 to 40 dBA. The daytime and rush hour L_{50} ranged from 33 to 42 dBA and the L_{EQ} ranged from 34 to 44 dBA. The measurements indicate that the effect of the rush hour was negligible when compared with the daytime levels.

The interior noise measurements made during the evening and night do show a slight, although characteristic, decrease in noise level. The decrease during the night at Location 4i was due primarily to the decrease in jet aircraft landings at O'Hare International Airport. The general lack of overall change during the different time periods when the measurements was made is due to both a generally high exterior noise level which does not decrease appreciably during the evening and nighttime hours and due to the low level of interior activity at each of the interior measurement sites.

At Locations 4i and 5i, where the jet aircraft landings were perceivable inside the buildings, L_1 and at certain times L_{10} noise levels were significantly greater than L_{50}, since the jet aircraft did create a few large increases of short duration in the interior noise level.

It should be noted that the interior noise levels observed in these buildings are generally low, especially when the high exterior noise levels are considered. The buildings along the airport flight path have been designed to reduce the exterior noise level significantly. The exterior to interior noise level difference was typically observed to be 25 to 35 dBA.

Figures 11 and 12 are statistical distribution plots of the daytime interior noise levels observed and of the evening and nighttime interior noise levels observed where these data were taken. Although these interior noise plots are similar to the exterior noise plots, the noise level scale is 10 dBA lower than for the exterior noise plots in order to be able to plot the generally lower noise levels within the limits of the chart paper.

TABLE II EXTERIOR NOISE ENVIRONMENT OBSERVED AT 13 LOCATIONS ALONG THE O'HARE EXTENSION ALIGNMENT — APRIL 11-14, 1978

Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_{1}	L_{EQ}
2e	Rush Hour	62 dBA	64 dBA	71 dBA	78 dBA	92 dBA	79 dBA
	Day	59	60	64	75	85	72
	Day[1]	60	61	64	76	88	75
	Evening	57	58	61	64	68	62
	Night	57	58	60	62	65	60
3e	Rush Hour	63	64	69	76	87	75
	Day	62	64	68	74	79	70
	Evening [Before 10:00 p.m.]	63	65	71	79	84	75
	Evening [After 10:00 p.m.]	51	52	54	58	71	58
	Night	53	54	56	60	73	60
4e	Rush Hour	66	67	69	76	88	75
	Day	67	69	72	82	96	82
	Evening	62	64	67	82	94	80
	Night	62	63	66	70	74	67
5e	Rush Hour	64	66	67	70	73	68
	Day	66	67	69	73	82	71
	Day[1]	64	65	68	75	84	73
	Evening	62	62	65	68	71	65
	Night	58	60	62	66	71	64
6e	Rush Hour	66	68	70	73	76	71
	Day	66	68	70	74	86	74
	Evening	60	62	64	68	71	65
	Night	57	58	60	65	71	63

[1] Repeat

TABLE II [CONT.]

Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_{1}	L_{EQ}
7e	Rush Hour	64 dBA	65 dBA	70 dBA	76 dBA	86 dBA	74 dBA
	Day	65	67	70	78	86	75
	Day[1]	64	66	68	74	81	71
	Evening	66	67	70	77	84	74
	Night	62	65	69	78	86	75
8e	Rush Hour	63	64	68	73	79	70
	Day	64	67	70	74	82	72
	Evening	66	67	69	73	77	70
	Night	64	66	69	74	78	71
9e	Rush Hour	62	63	65	70	78	68
	Day	65	67	70	75	82	72
	Day[1]	63	65	67	70	76	68
	Evening	62	63	65	69	82	69
	Night	60	62	64	68	70	65
10e	Rush Hour	64	65	69	75	78	71
	Day	64	66	70	74	79	72
	Evening	65	67	70	74	80	71
	Night	62	65	69	74	80	71
11e	Rush Hour[2]	64	65	67	81	87	76
	Rush Hour	63	64	66	70	76	68
	Day[3]	61	63	66	70	80	72
	Day	61	63	66	70	74	67
	Evening	61	63	66	71	76	68
	Night	59	69	63	66	70	64

[1] Repeat
[2] Includes one commuter and one freight train passby
[3] Includes one commuter train passby

TABLE II [CONT.]

Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{EQ}
12e	Rush Hour	57 dBA	58 dBA	62 dBA	69 dBA	82 dBA	69 dB
	Day	59	60	64	67	70	64
	Evening	57	58	60	65	75	64
	Night	56	58	60	64	68	62
13e	Rush Hour	68	69	71	74	78	72
	Day	66	68	71	74	78	72
	Evening	62	65	68	70	74	68
	Night	59	62	65	69	74	67
14e	Rush Hour	62	64	70	76	81	72
	Day	68	70	74	79	82	76
	Evening	64	67	71	75	80	72
	Night	58	62	67	73	80	70

TABLE III INTERIOR NOISE ENVIRONMENT OBSERVED AT 4 LOCATIONS ALONG THE O'HARE EXTENSION ALIGNMENT — APRIL 10-13, 1978

Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{EQ}
1i	Rush Hour	32 dBA	34 dBA	38 dBA	43 dBA	48 dBA	40 dBA
	Day	29	30	33	40	48	38
4i	Rush Hour	36	37	39	45	54	43
	Day	36	37	40	46	55	44
	Evening	33	34	36	48	56	45
	Night	32	33	34	38	40	35
5i	Rush Hour	38	39	41	44	48	42
	Day	38	40	42	46	54	44
	Night	35	36	40	42	45	40
6i	Rush Hour	30	32	33	35	39	34
	Day	34	34	35	39	45	37

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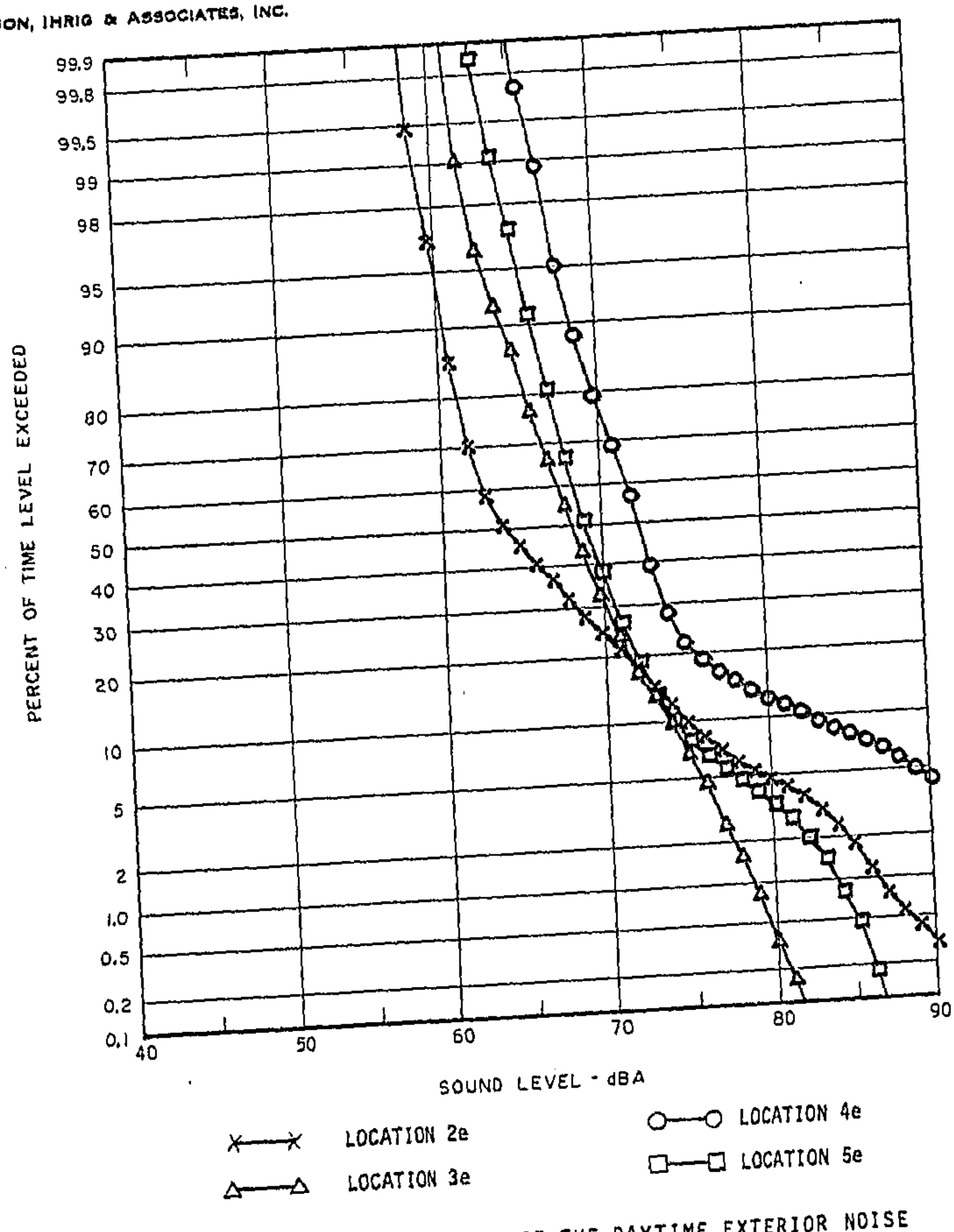


FIGURE 2 STATISTICAL DISTRIBUTION OF THE DAYTIME EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

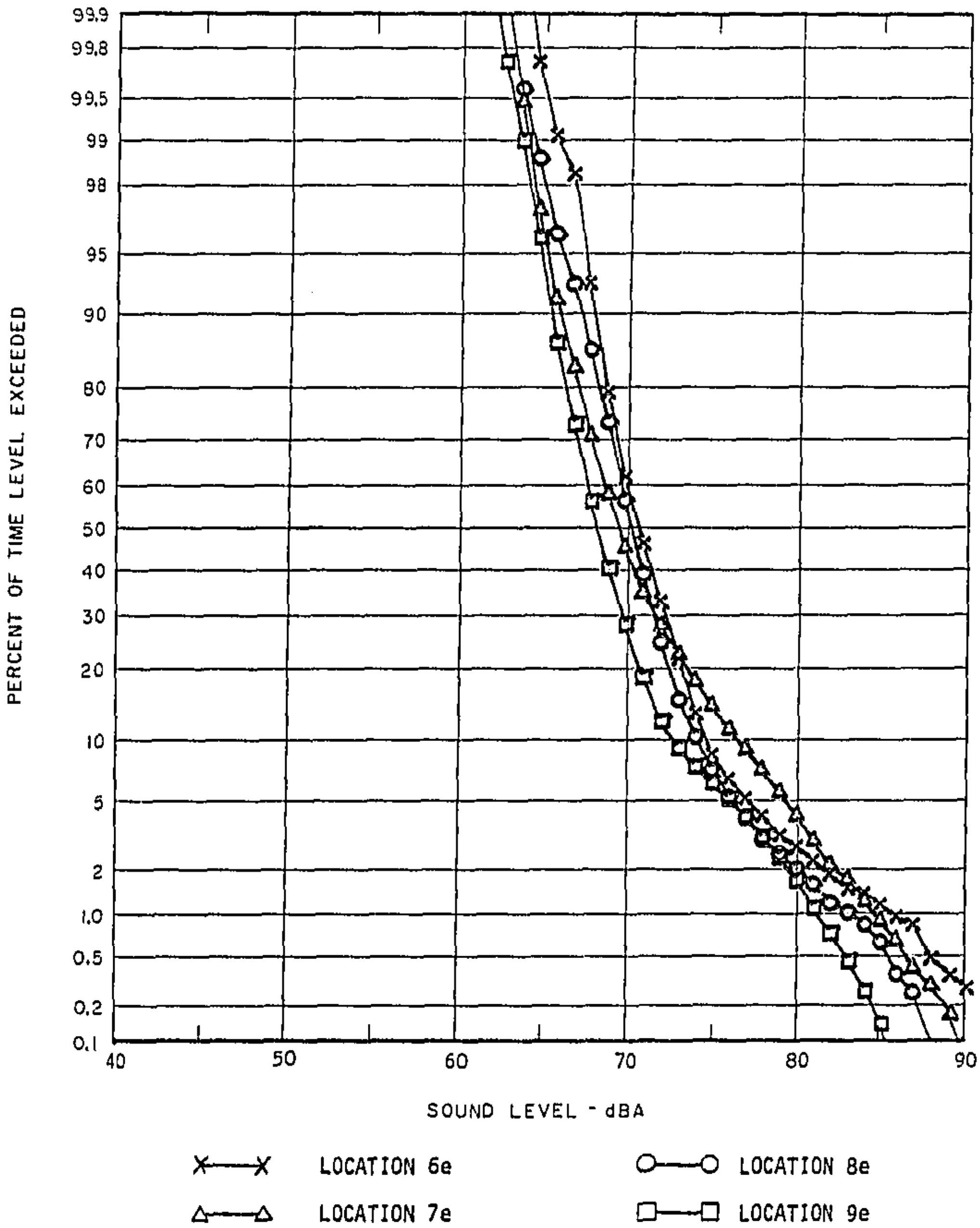


FIGURE 3 STATISTICAL DISTRIBUTION OF THE DAYTIME EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

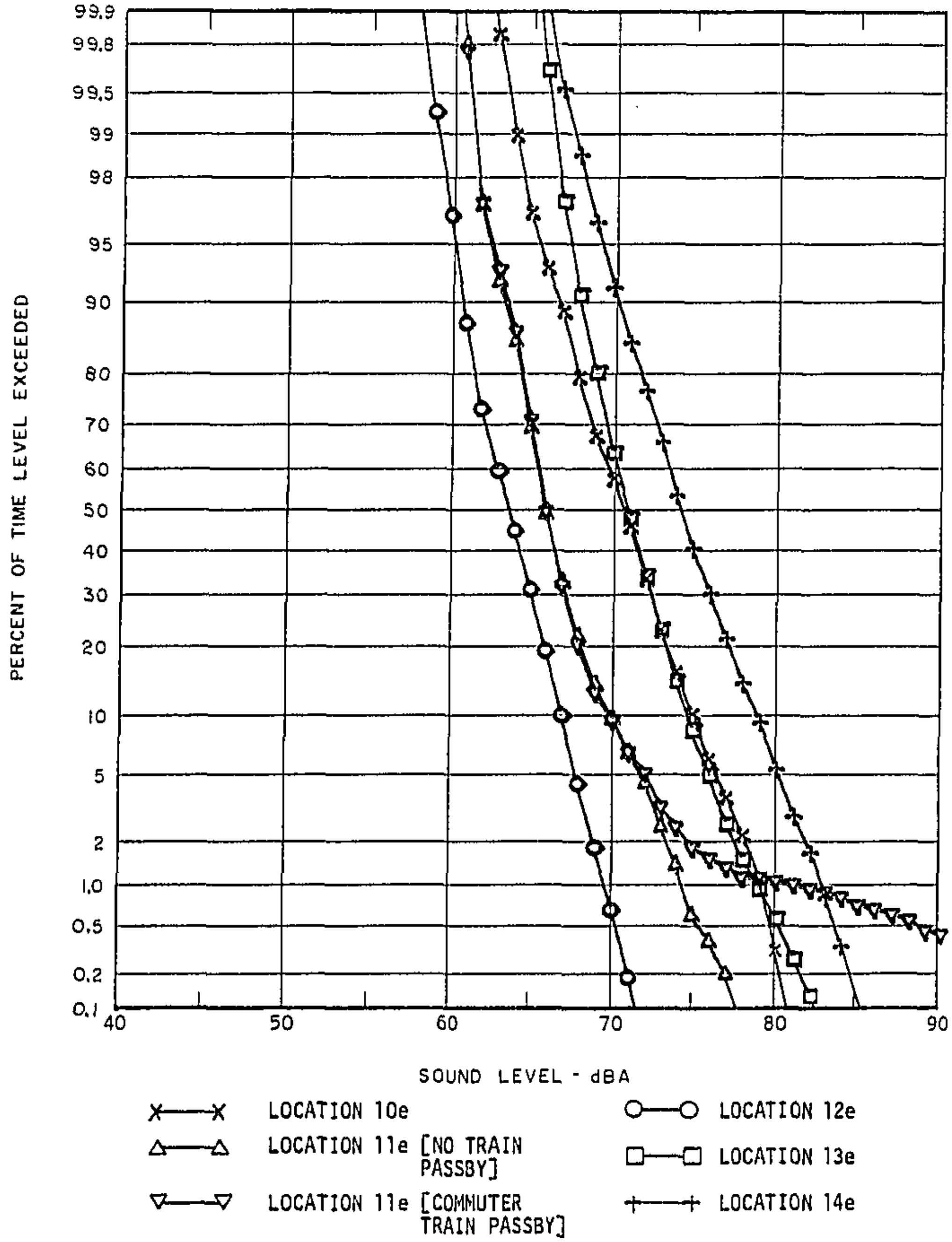


FIGURE 4 STATISTICAL DISTRIBUTION OF THE DAYTIME EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

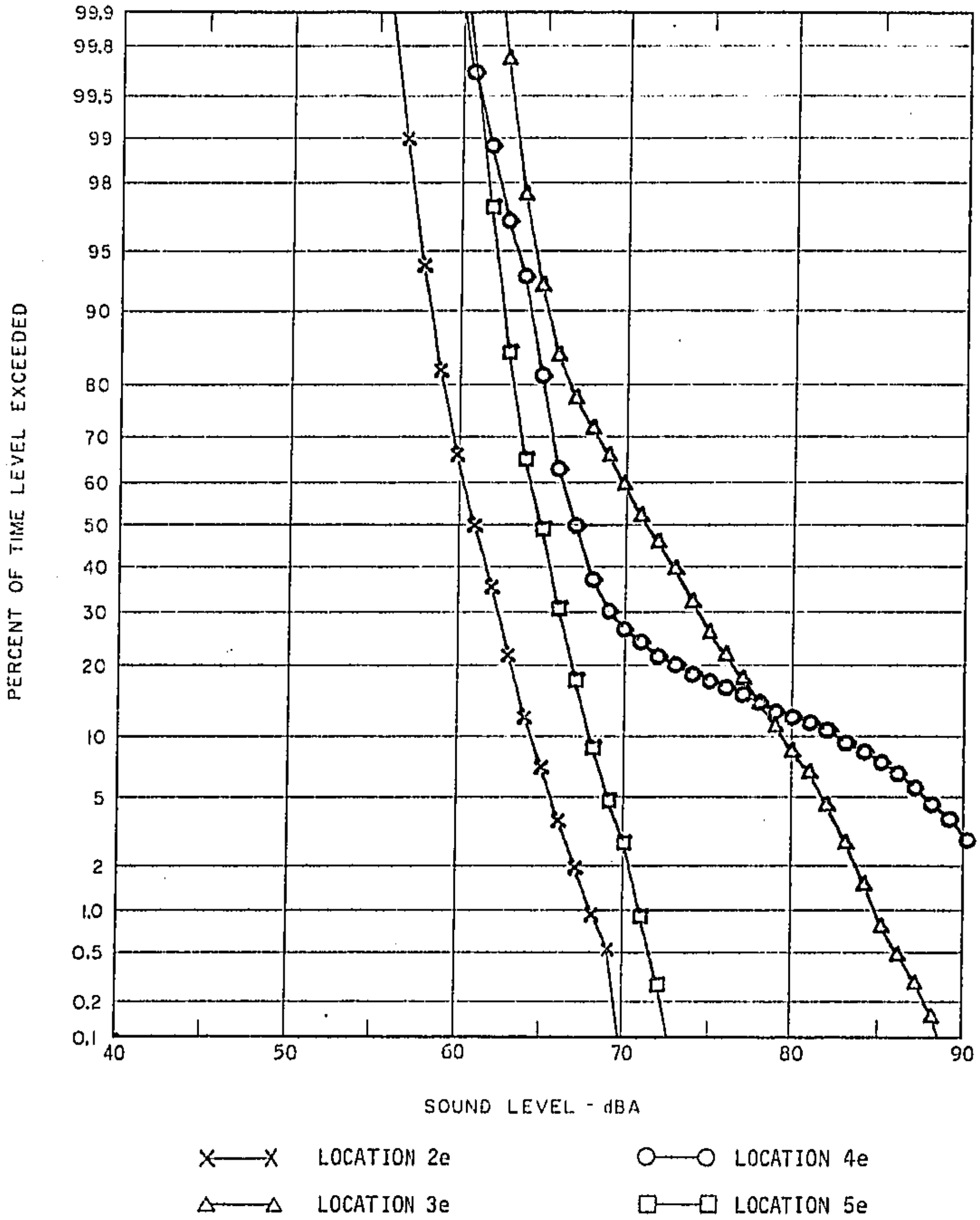


FIGURE 5 STATISTICAL DISTRIBUTION OF THE EVENING EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

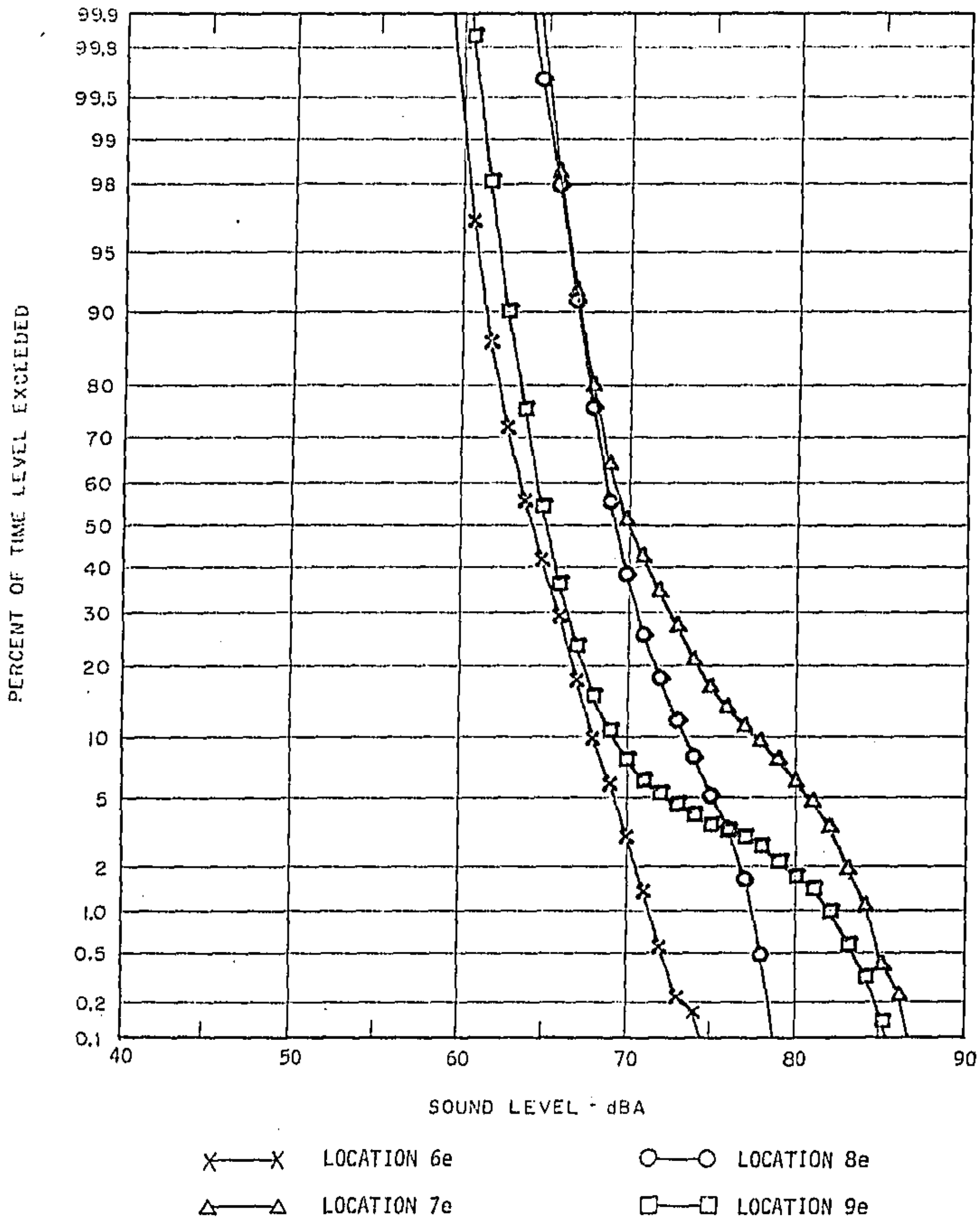


FIGURE 6   STATISTICAL DISTRIBUTION OF THE EVENING EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

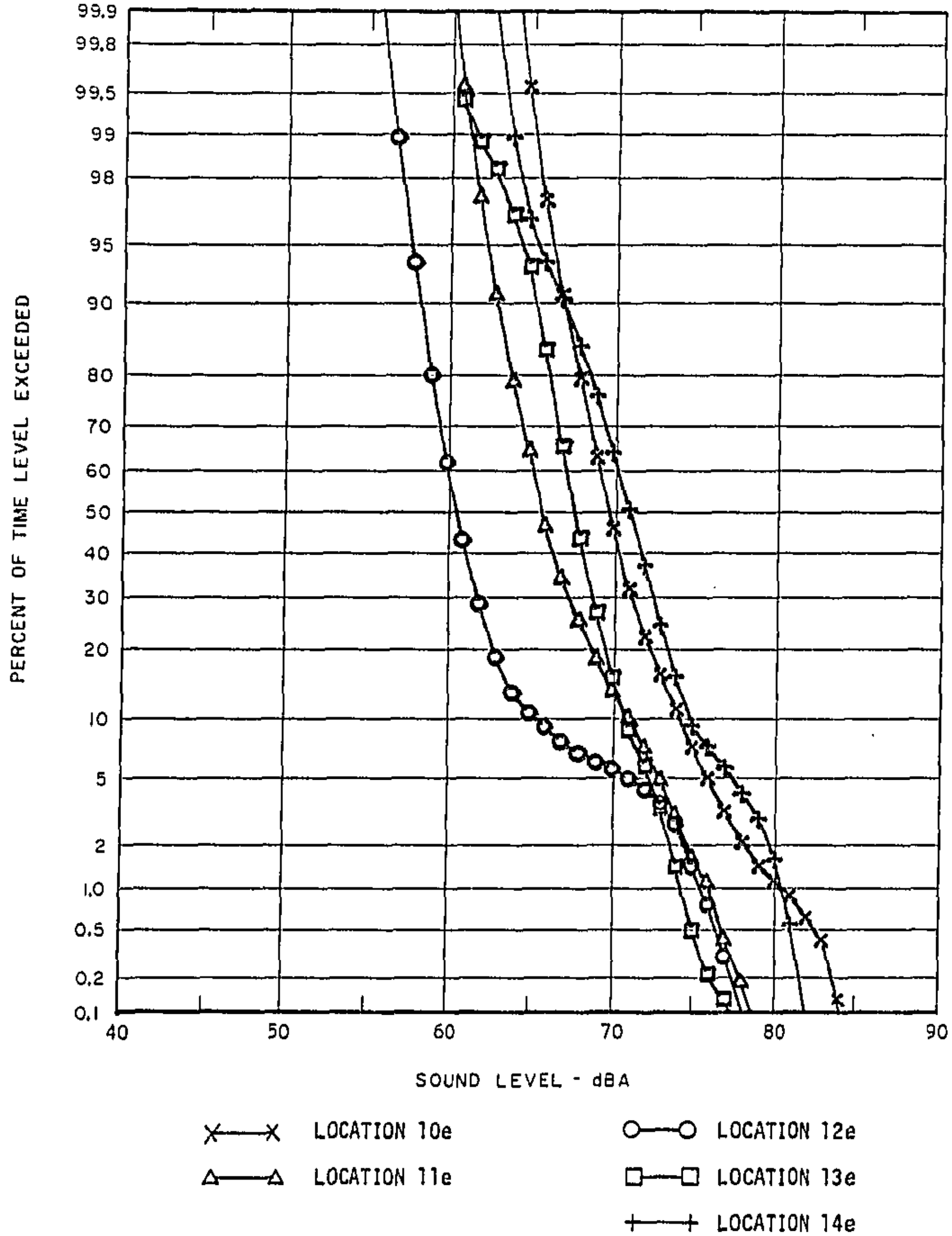


FIGURE 7 STATISTICAL DISTRIBUTION OF THE EVENING EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

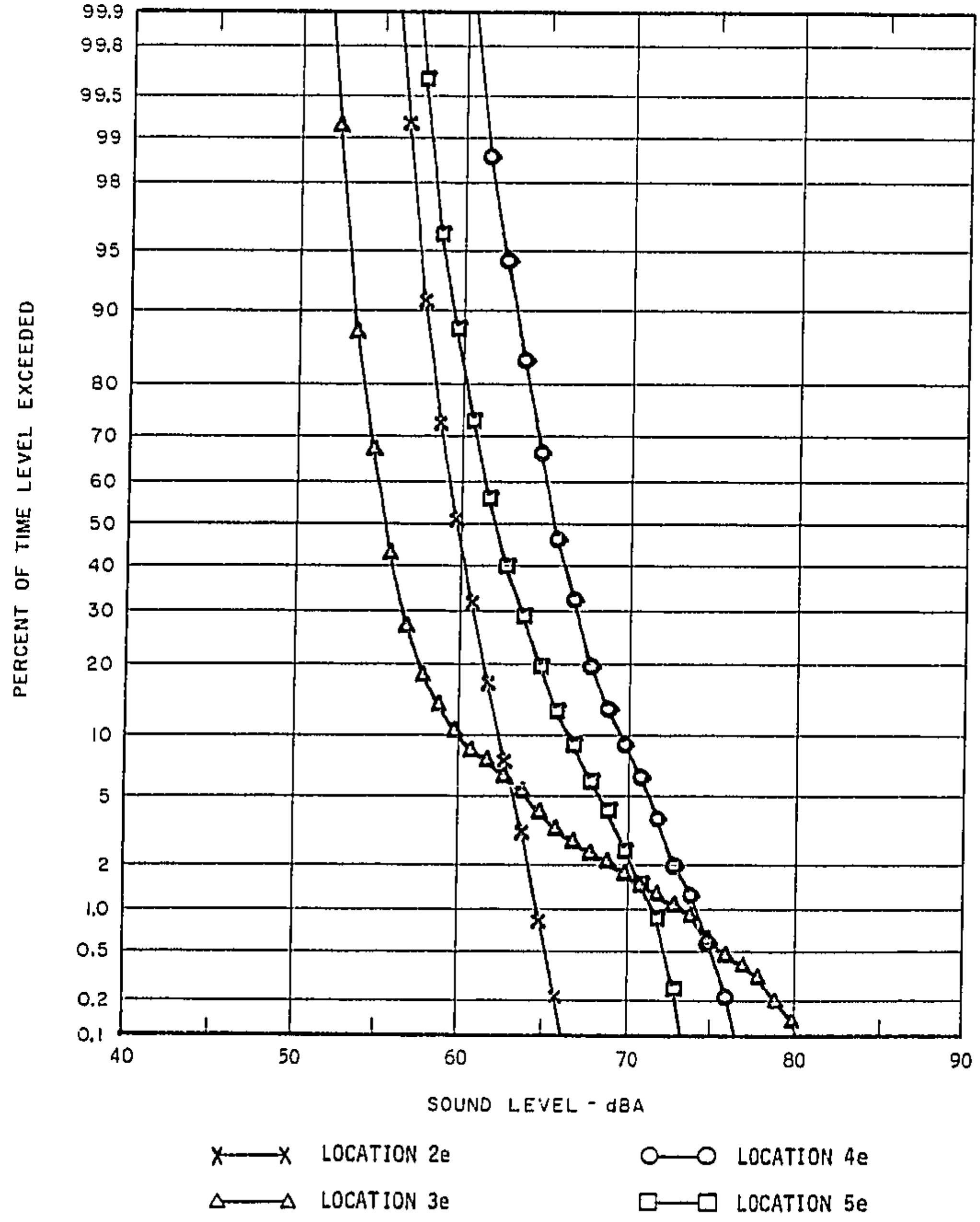


FIGURE 8 STATISTICAL DISTRIBUTION OF THE NIGHTTIME EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

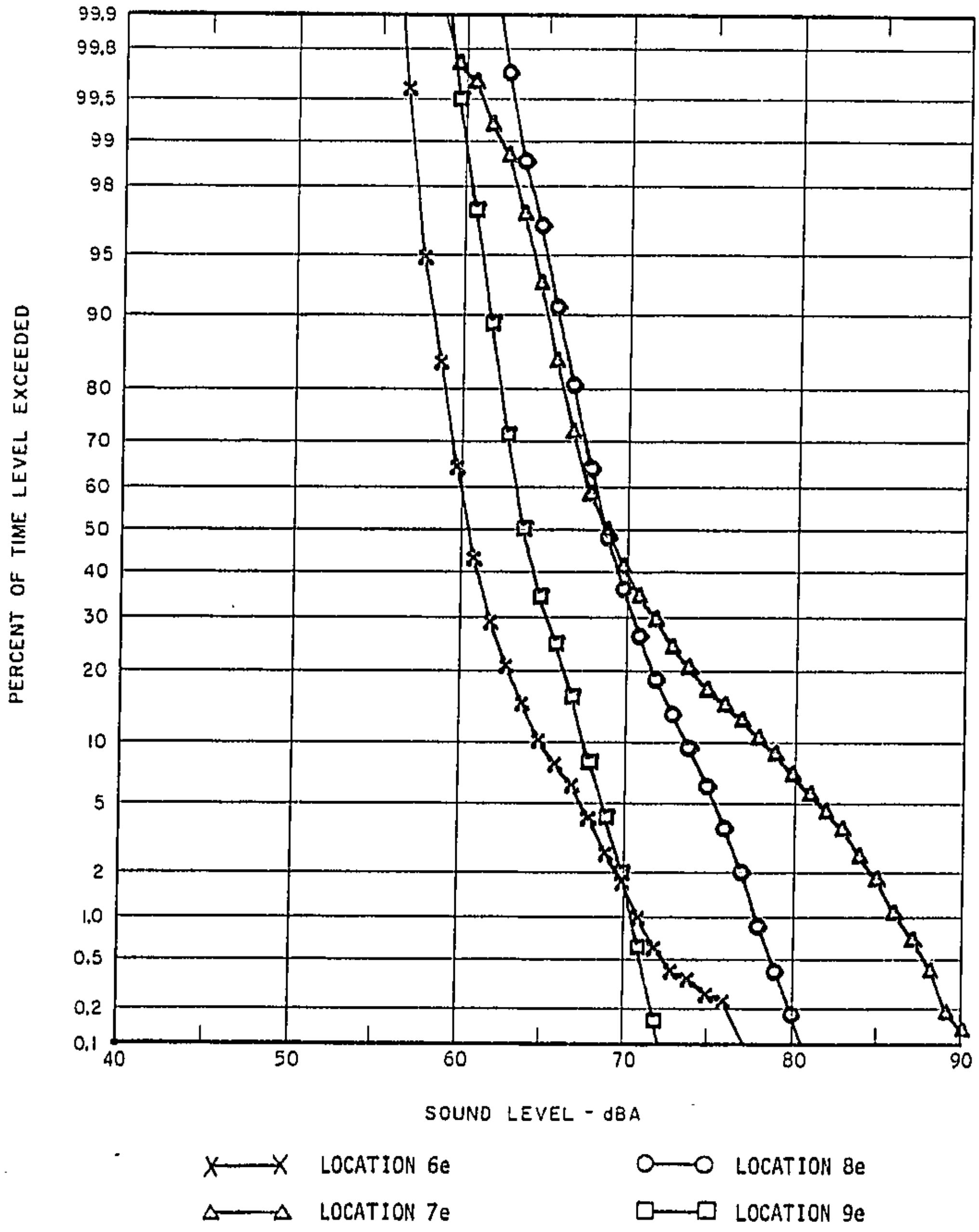


FIGURE 9 STATISTICAL DISTRIBUTION OF THE NIGHTTIME EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

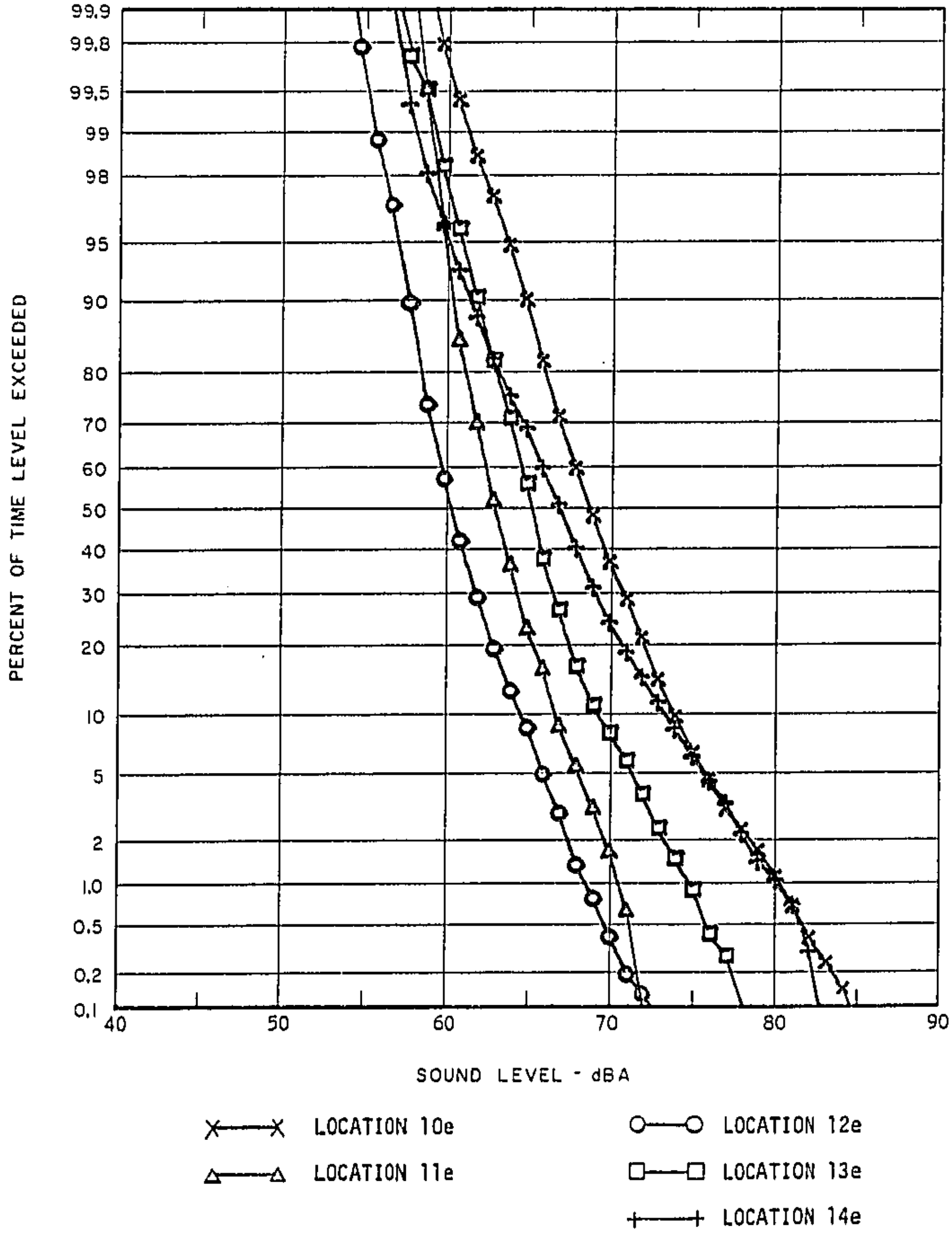


FIGURE 10 STATISTICAL DISTRIBUTION OF THE NIGHTTIME EXTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

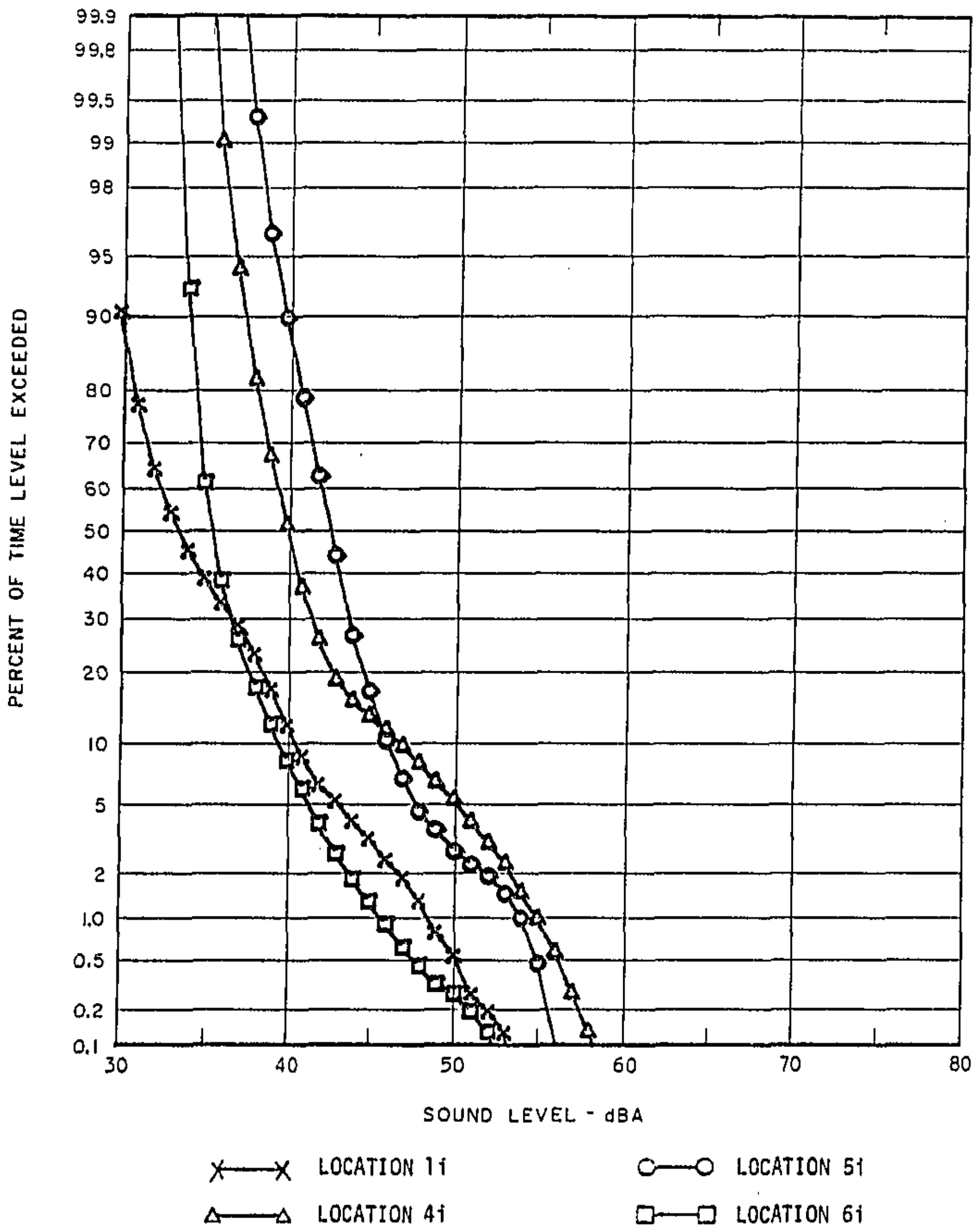


FIGURE 11 STATISTICAL DISTRIBUTION OF THE DAYTIME INTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

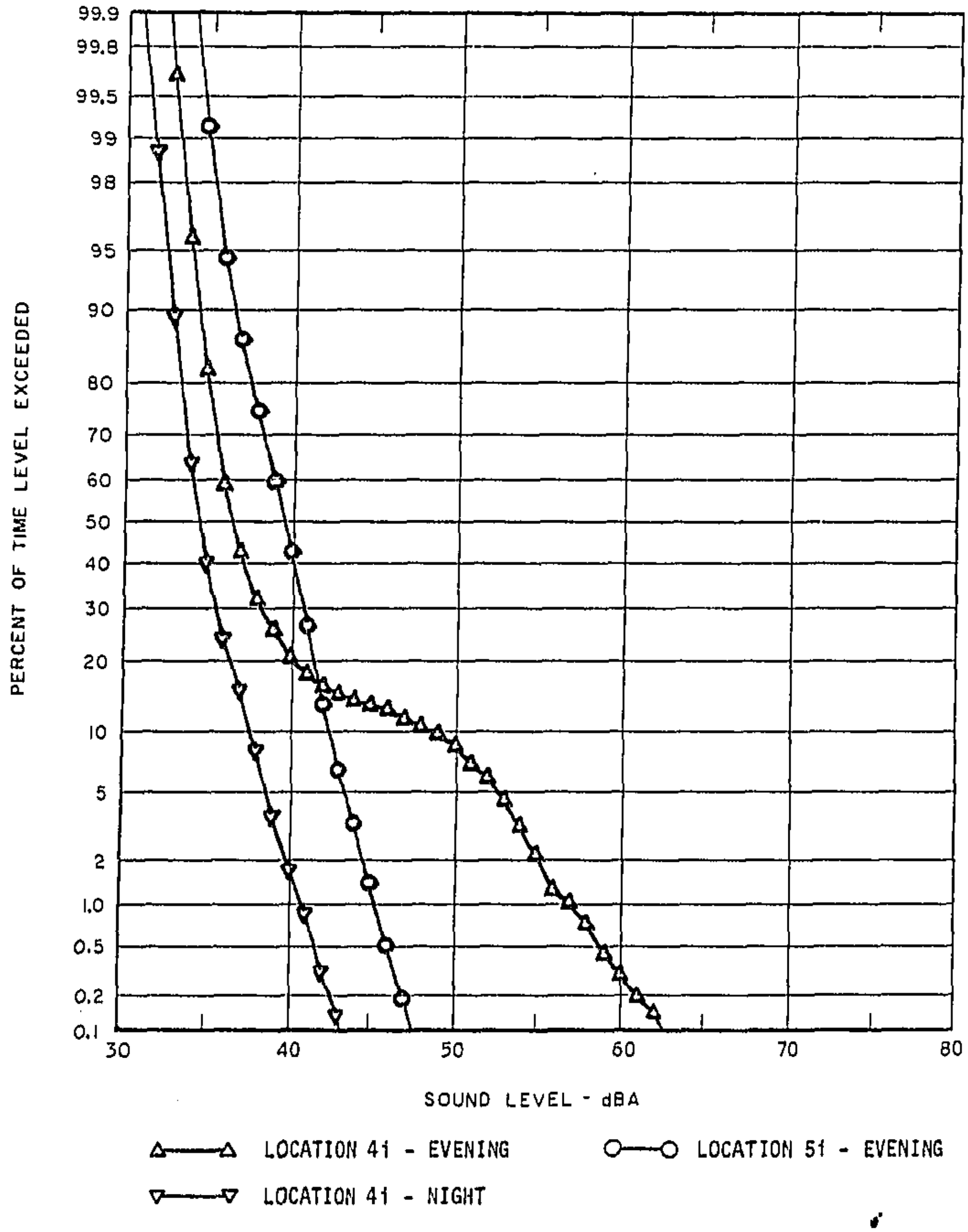


FIGURE 12 STATISTICAL DISTRIBUTION OF THE EVENING AND NIGHTTIME INTERIOR NOISE ALONG THE O'HARE EXTENSION ALIGNMENT

EXISTING VIBRATION LEVELS

The perception of vibration by people has been discussed extensively in the literature, however, most of the criteria are based on the results obtained from steady-state sinusoidal vibration excitation in laboratory environments. Relatively little information is available on the response of humans to low level random vibration or to transient vibration levels.

A number of scales for evaluating the effect of vibration on man have been devised. Units such as *Pal* and *Trem* have been presented for establishing scales of response to vibration similar to the A-weighted sound level or the various loudness scales which have been used for the determination of subjective response to noise levels. None of the scales have been widely accepted in evaluating human response to vibration levels and, in general, the criteria for response are presented as charts with ranges of response as a function of vibration frequency. As for the subjective response to noise, the human sensitivity to vibration varies with frequency. Therefore, the frequency must be taken into consideration in assessing annoyance due to vibration.

Figure 13 shows the response range of seated or standing persons to sustained sinusoidal vertical vibration velocity level. The curves show the vibration perception level ranges in decibels, dB, referred to 1.0 micro in/sec as a function of frequency in Hertz, Hz. Figure 13 indicates that above about 12 Hz, the human sensitivity to vibration velocity is not a strong function of frequency. That is, above 12 Hz, sensitivity to vibration is primarily determined by the velocity amplitude and is relatively independent of frequency. Since the frequency range over which human sensitivity is approximately proportional to velocity amplitude covers the range of principal vibration components from transit trains and since the noise level generated by the vibration of buildings' surfaces is approximately proportional to vibration velocity level, it is appropriate to present vibration criteria and data in terms of velocity level.

It should be noted that the curves presented in Figure 13 are based on data from experiments on the response of persons, seated or standing, exposed to steady-state vibration for 5 to 20 minute periods. Thus, the sensitivity curves of Figure 13 were determined under conditions in which subjects would be more likely to detect or be annoyed by the vibration than a person subjected to the occasional, brief [about 15 seconds at the most] vibration caused by passing transit trains.

The human perception curves have been used to assist in the evaluation of the vibration environment which exists along the O'Hare Extension alignment. Existing exterior vibration sources include automobiles, trucks, buses, underground mechanical equipment, and, on a local scale, pedestrians. Interior vibration results from building mechanical equipment, local occupant activity [especially on wood floors], and ground-borne vibration generated by exterior activities such as automobile, bus, truck and train traffic. Most of the vibration sources, except stationary mechanical equipment operating continuously, create transient vibration levels. The observed level of vibration at a particular location is the summation of the vibrations created by all the various sources, near and far. This is analogous to ambient community noise that represents the summation of many noise sources.

The vibration level data were taken simultaneously with, and at the same locations as, the sound level data. Vibration acceleration was measured using a piezoelectric accelerometer, with the signal recorded on one channel of the data tape recorder.

The data were analyzed to obtain a single-number velocity level weighted for the human perception threshold. To obtain the weighted velocity level from the acceleration data, an electronic integrator and filter with characteristics approximately the inverse of the perception curves in Figure 13 were used.

Although the weighting dicussed above is not a standardized measurement, such a weighted velocity level is a good single-number indication of the human response to vibration. The weighted velocity level equivalent to the imperceptible/ barely perceptible human sensitivity curve is 80 to 85 dB re 1.0 micro in/sec. Thus, weighted vibration velocity levels below about 80 dB are generally imperceptible as vibration to the average person under normal conditions.

The weighted vibration velocity levels obtained in this manner were statistically analyzed to obtain the same statistical parameters used to describe the existing noise levels; L_{99}, L_{90}, L_{50}, L_{10}, L_1, and L_{EQ}.

Table IV presents a complete tabulation of the statistical analysis of the exterior weighted vibration velocity levels observed at each measurement site. Review of the data indicates that all of the measurement positions experienced similar residual [L_{99} or L_{90}] vibration velocity levels, generally ranging between 40 and 50 dB. The L_{50} vibration velocity shows a greater range with levels between 43 and 57 dB during all of the times of day measurements were made.

Excluding the railroad passbys at Location 11e, the maximum L_{10}, L_1, and L_{EQ} were observed at Location 7e. The somewhat high vibration levels observed here were principally due to local vehicular traffic on Higgins Avenue traveling over a crack in the road surface. The high vibration levels observed at Location 11e during the railroad train passbys clearly show the effect a railroad train has on the vibration velocity level.

Table V presents a complete tabulation of statistical analysis of the interior weighted vibration velocity levels observed at each measurement site. Review of the data indicates that the levels are marginally lower or comparable to the levels observed at the exterior sites. The slightly lower levels are due mainly to the increased distance from roads and the expressway when compared with the exterior sites. At Location 1i the vibration is due principally to mechanical equipment since the vehicular movement in the parking lot is at a relatively slow speed.

Figures 14 through 17 are statistical distribution plots showing the detailed statistical distribution in terms of the weighted vibration velocity level exceedence in percentage of time for the exterior and interior measurement locations during the daytime. The plots are analogous to those plotted for noise level exceedence in Figures 2 through 12. As with the noise plots, these allow graphic comparison of the vibration velocity statistical distributions along different sections of the O'Hare Extension alignment. Examination of the vibration velocity levels presented on these figures shows that 80 dB is exceeded for very short time periods [less than 1% of the time] at Locations 7e and 11e. Thus, although the vibration velocity levels at these two locations may be barely perceptible by some individuals, the levels are such that they would not be considered disagreeable by most people.

To provide some indication of the frequency content of the measured ground-borne vibration, four representative examples of the vibration levels were analyzed statistically by octave bands. For the statistical analysis the unweighted vibration velocity level as a function of time was analyzed in each of the octave bands from 4 Hz through 500 Hz. The results of these analyses are shown on Figures 18 through 21.

Although each analysis indicates somewhat similar overall vibration velocity levels, they each have a somewhat different shape to the frequency analysis. These analyses do show that only at Location 7e [as previously discussed] are the levels such that they might be barely perceived.

TABLE IV MEASURED EXTERIOR VIBRATION VELOCITY LEVELS[1] AT 13 LOCATIONS ALONG THE O'HARE EXTENSION ALIGNMENT — APRIL 11-14, 1978

		dB re 1 micro in/sec					
Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{EQ}
2e	Rush Hour	42	44	46	50	61	55
	Day	42	44	47	50	54	48
	Day[2]	42	45	50	56	61	53
	Evening	37	40	43	48	54	46
	Night	37	40	43	48	53	45
3e	Rush Hour	41	44	49	56	65	54
	Day	43	45	48	52	60	50
	Evening [Before 10:00 p.m.]	40	43	48	55	63	53
	Evening [After 10:00 p.m.]	40	42	44	48	58	47
	Night	37	40	44	49	59	49
4e	Rush Hour	45	47	50	55	67	55
	Day	45	48	50	54	61	53
	Evening	44	46	49	52	64	52
	Night	44	46	50	60	64	55
5e	Rush Hour	45	47	50	56	69	56
	Day	46	49	52	56	62	54
	Day[2]	46	49	54	59	65	56
	Evening	44	46	49	53	63	52
	Night	41	44	48	54	61	51
6e	Rush Hour	49	51	56	62	68	59
	Day	48	52	57	63	71	60
	Evening	45	47	51	58	68	57
	Night	41	44	48	56	67	56

[1] Corrected for human perception curve [see text]

[2] Repeat

TABLE IV [CONT.]

Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{EQ}
		dB re 1 micro in/sec					
7e	Rush Hour	48	51	57	66	72	63
	Day	48	51	56	66	76	64
	Day[1]	46	50	55	65	77	64
	Evening	46	48	53	61	69	58
	Night	43	46	52	60	68	57
8e	Rush Hour	46	49	53	59	65	56
	Day	46	48	52	58	65	55
	Evening	45	47	51	58	64	55
	Night	42	45	49	53	59	50
9e	Rush Hour	44	48	53	58	62	55
	Day	46	48	50	55	63	53
	Day[1]	44	46	49	52	55	50
	Evening	41	43	47	52	56	49
	Night	41	44	49	57	64	54
10e	Rush Hour	46	48	53	59	64	56
	Day	46	48	52	56	62	55
	Evening	43	46	50	56	61	53
	Night	42	44	48	52	57	49
11e	Rush Hour[2]	46	48	52	73	81	69
	Rush Hour	46	48	51	58	64	55
	Day[3]	45	47	50	56	73	61
	Day	45	47	50	55	59	53
	Evening	42	44	48	53	60	51
	Night	42	45	50	56	64	54

[1] Repeat

[2] Includes one commuter and one freight train passby

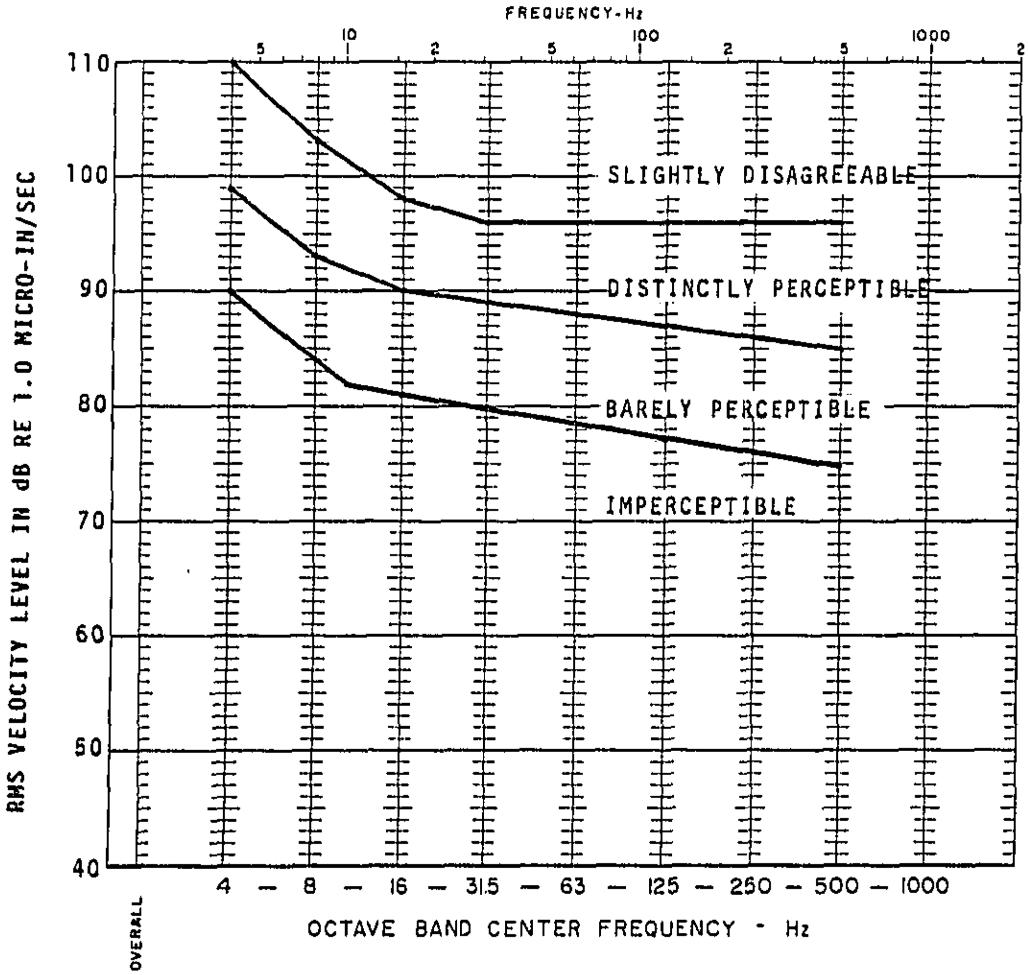
[3] Includes one commuter train passby

TABLE IV [CONT.]

Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{EQ}
		dB re 1 micro in/sec					
12e	Rush Hour	44	47	52	58	62	55
	Day	45	48	52	57	64	54
	Evening	42	44	49	55	61	52
	Night	40	42	47	52	58	49
13e	Rush Hour	45	48	52	58	67	56
	Day	42	45	49	54	58	51
	Evening	41	44	48	54	62	51
	Night	40	43	48	54	62	52
14e	Rush Hour	47	50	54	60	68	58
	Day	46	49	53	61	69	58
	Evening	43	47	51	56	65	55
	Night	42	45	49	56	64	53

TABLE V MEASURED INTERIOR VIBRATION VELOCITY LEVELS AT 4 LOCATIONS ALONG THE O'HARE EXTENSION ALIGNMENT — APRIL 10-13, 1978

		dB re 1 micro in/sec					
Location	Time of Day	L_{99}	L_{90}	L_{50}	L_{10}	L_1	L_{EQ}
1i	Rush Hour	39	41	44	49	52	46
	Day	38	40	44	49	56	48
4i	Rush Hour	40	43	46	50	54	48
	Day	--	--	--	--	--	--
	Evening	44	46	48	52	62	51
	Night	43	45	47	51	56	49
5i	Rush Hour	45	46	50	56	64	53
	Day	42	45	48	52	56	49
	Evening	40	43	47	51	55	48
6i	Rush Hour	45	48	52	59	68	56
	Day	44	47	51	57	64	54



THE CHART INDICATES THE RANGE OF RESPONSE LEVEL FOR SEATED OR STANDING PERSONS SUBJECTED TO VERTICAL MECHANICAL VIBRATION

FIGURE 13 MECHANICAL VIBRATION PERCEPTION LEVELS FOR PEOPLE SEATED OR STANDING

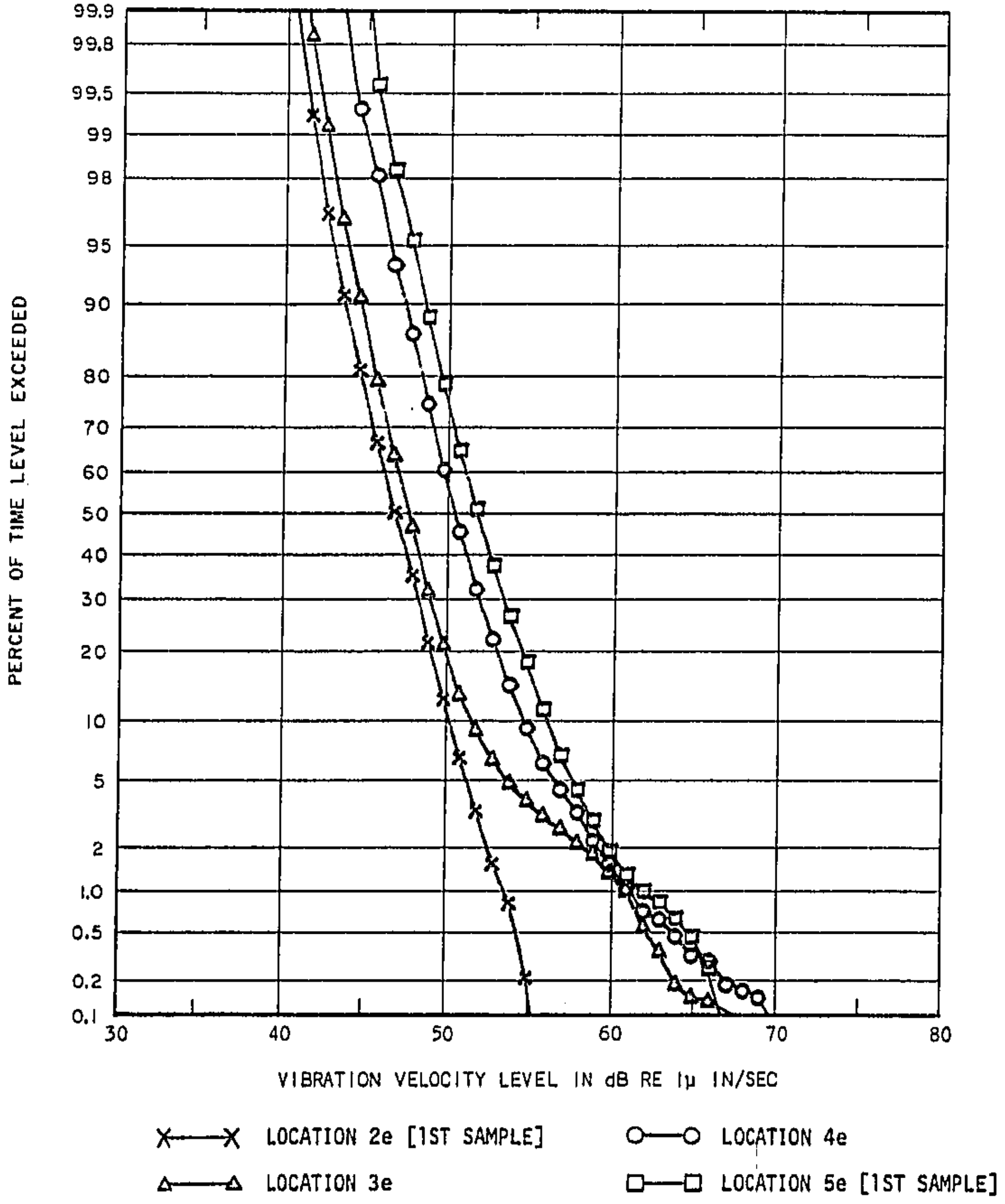


FIGURE 14 STATISTICAL DISTRIBUTION OF THE DAYTIME EXTERIOR VIBRATION VELOCITY LEVELS ALONG THE O'HARE EXTENSION ALIGNMENT

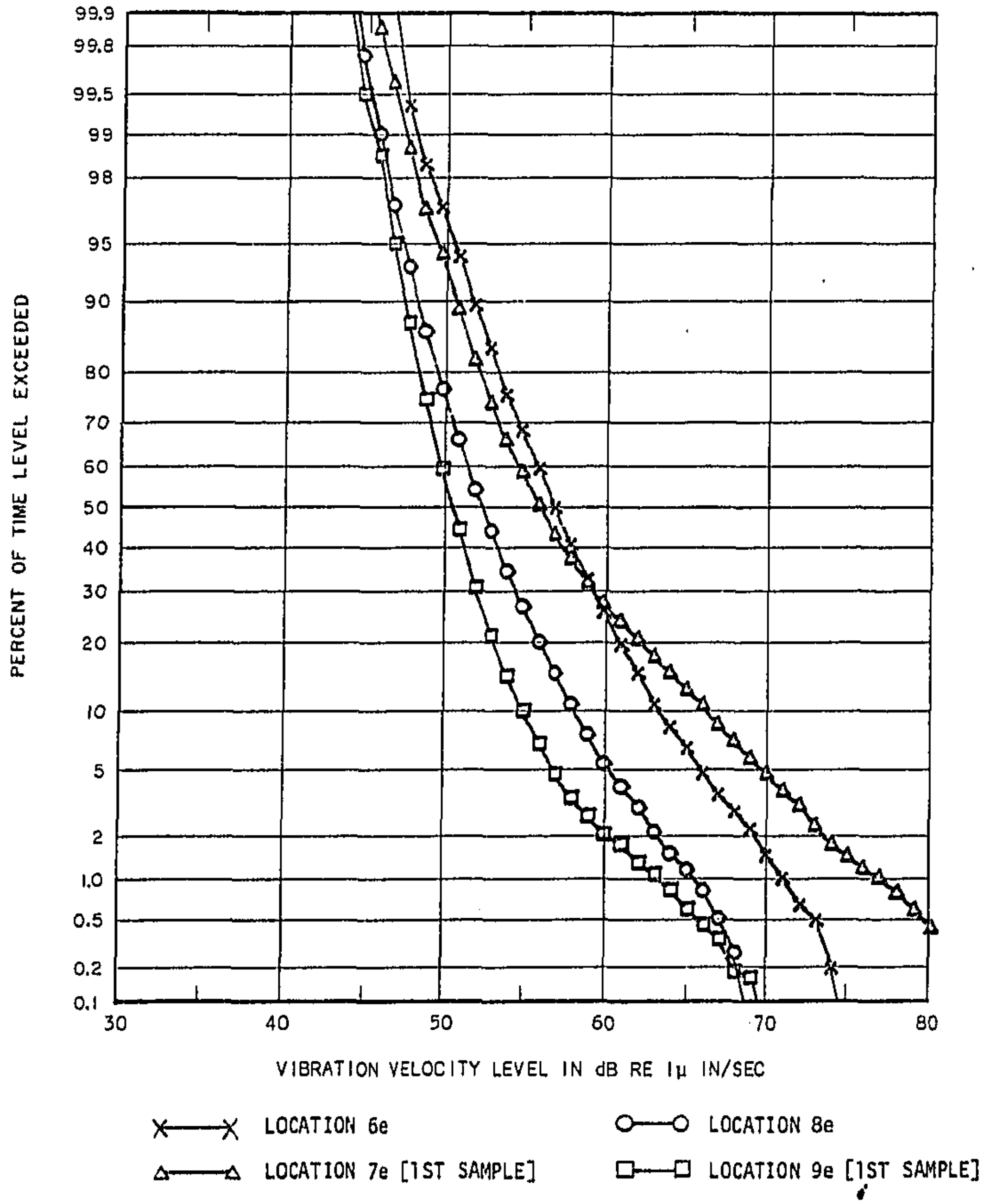


FIGURE 15 STATISTICAL DISTRIBUTION OF THE DAYTIME EXTERIOR VIBRATION VELOCITY LEVELS ALONG THE O'HARE EXTENSION ALIGNMENT

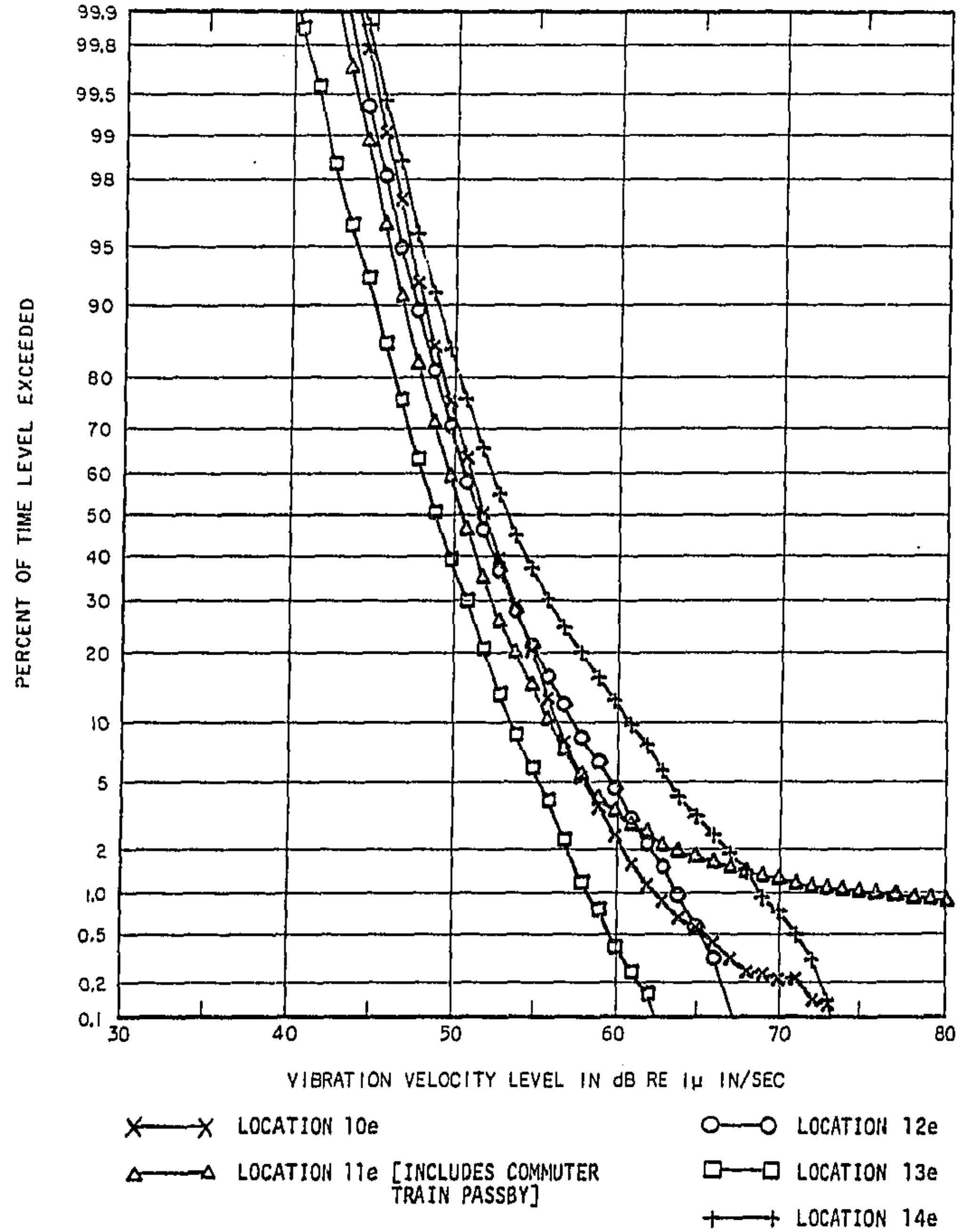


FIGURE 16 STATISTICAL DISTRIBUTION OF THE DAYTIME EXTERIOR VIBRATION VELOCITY LEVELS ALONG THE O'HARE EXTENSION ALIGNMENT

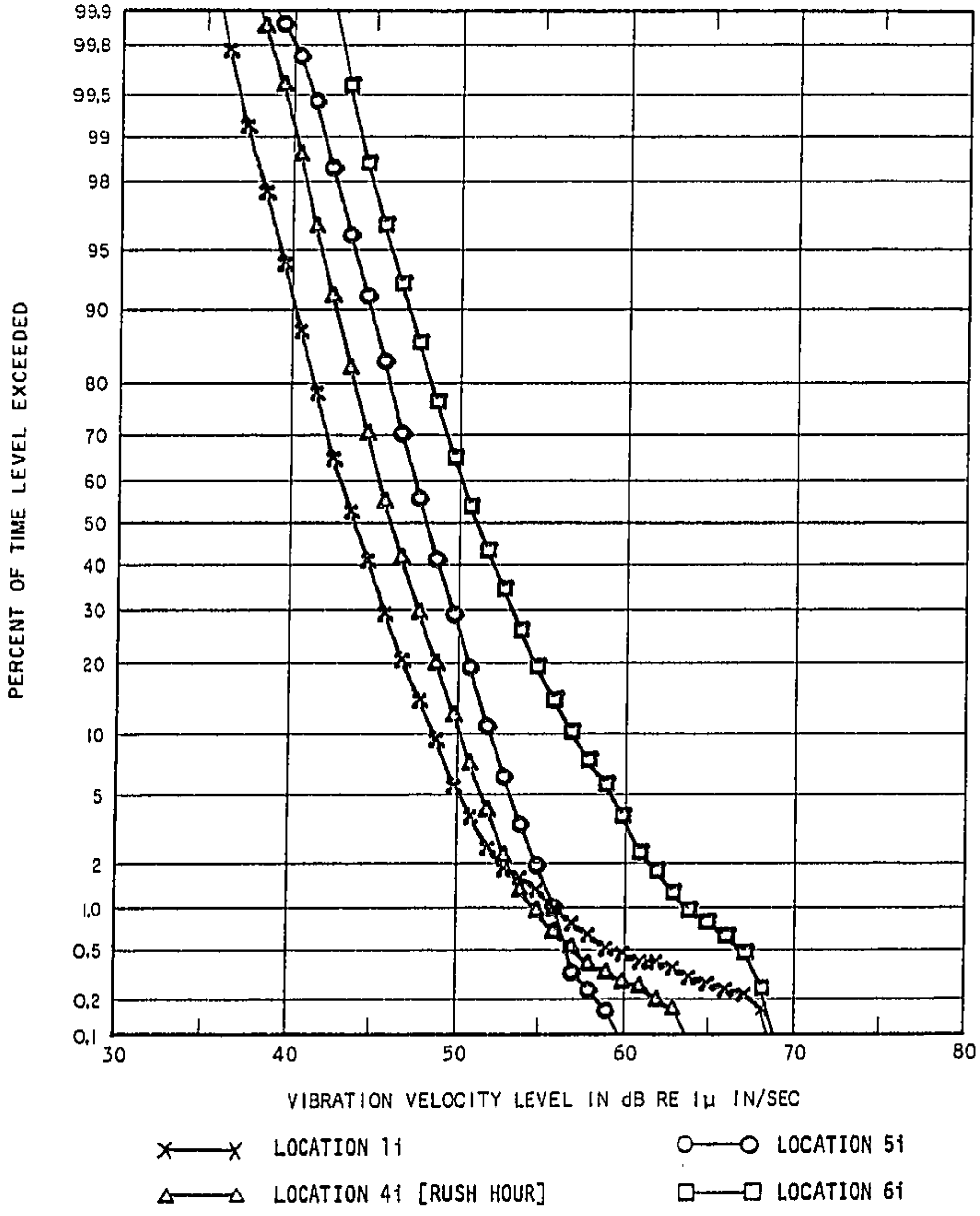
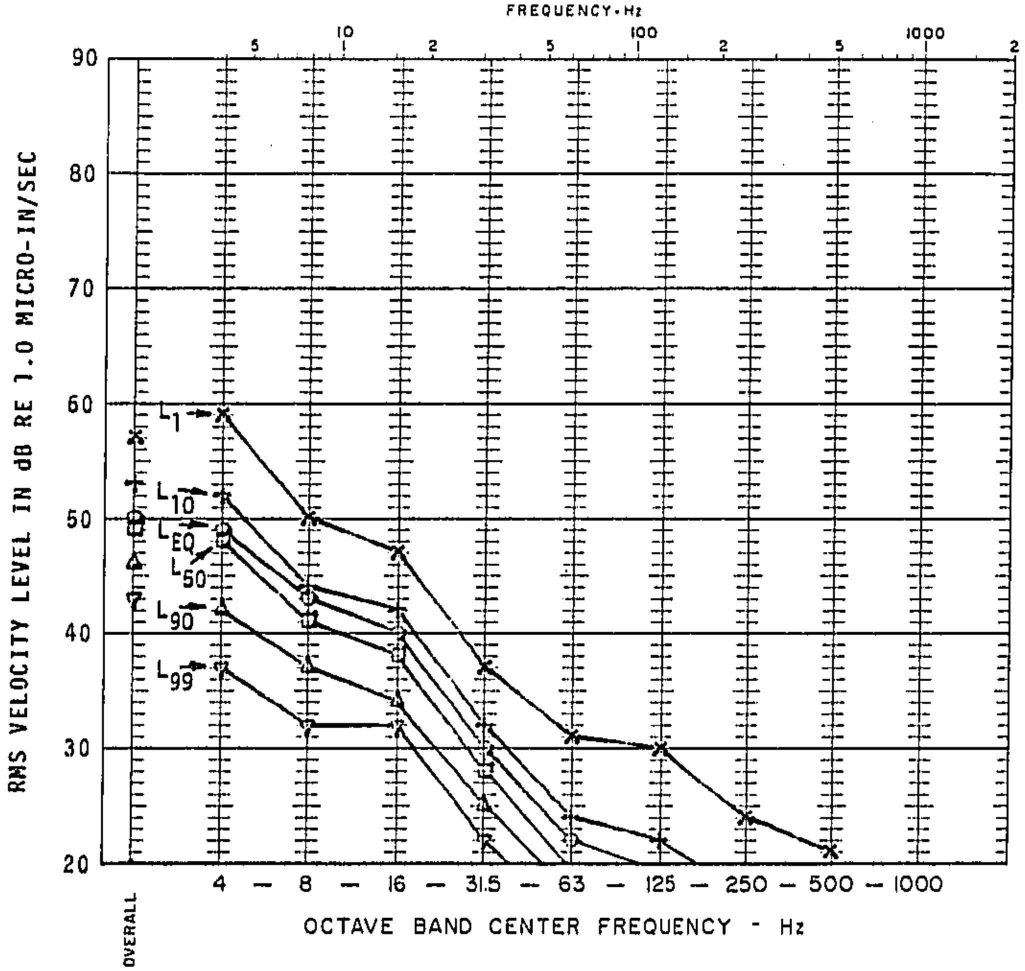
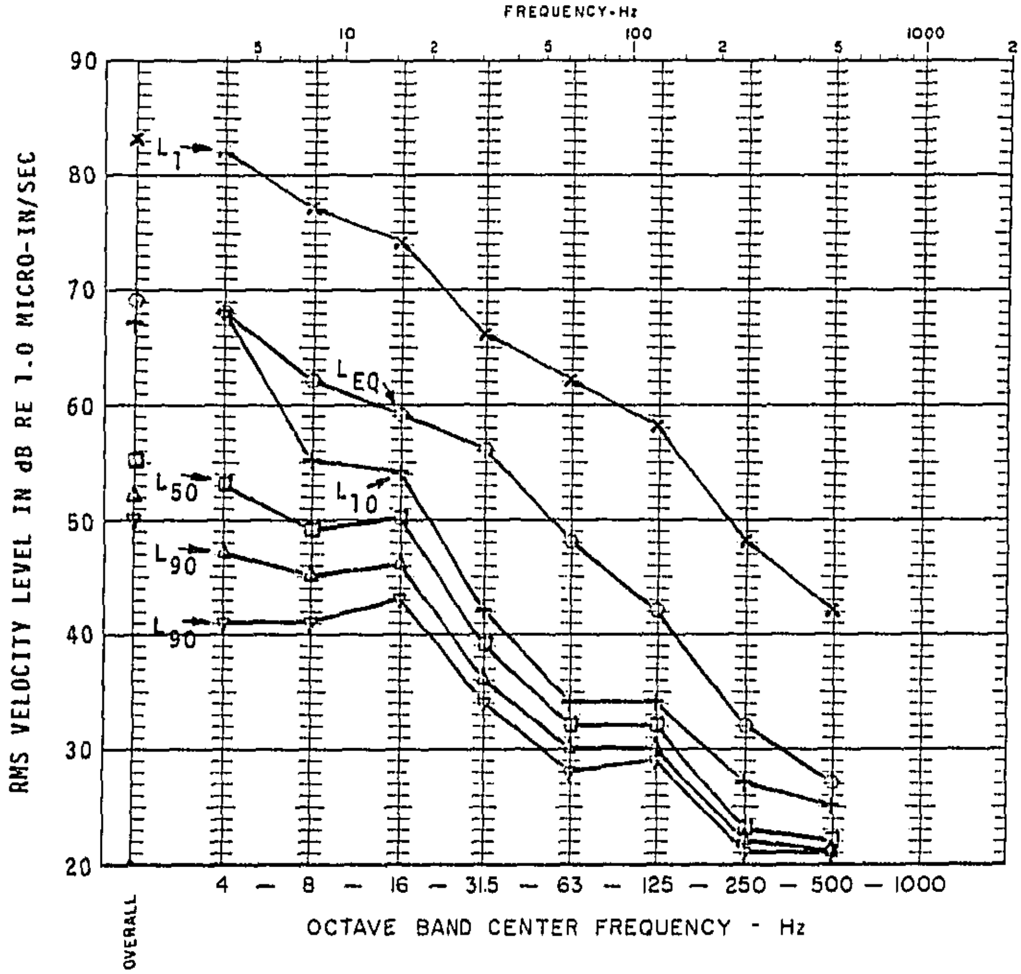


FIGURE 17 STATISTICAL DISTRIBUTION OF THE DAYTIME INTERIOR VIBRATION VELOCITY LEVELS ALONG THE O'HARE EXTENSION ALIGNMENT



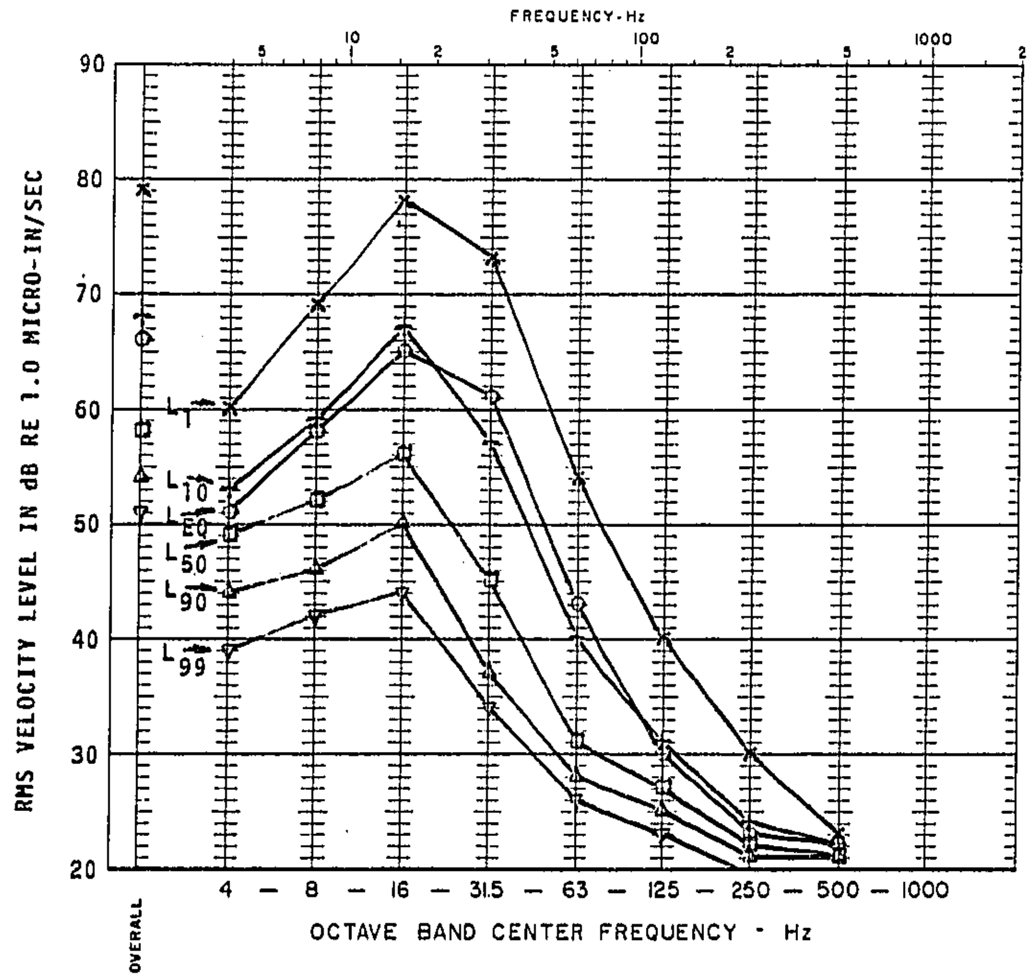
DATA SHOWN ARE THE STATISTICAL ANALYSIS OF THE VIBRATION VELOCITY OCTAVE BAND SPECTRUM

FIGURE 18 OCTAVE BAND VIBRATION VELOCITY LEVELS AS OBSERVED AT LOCATION 11 - DAY



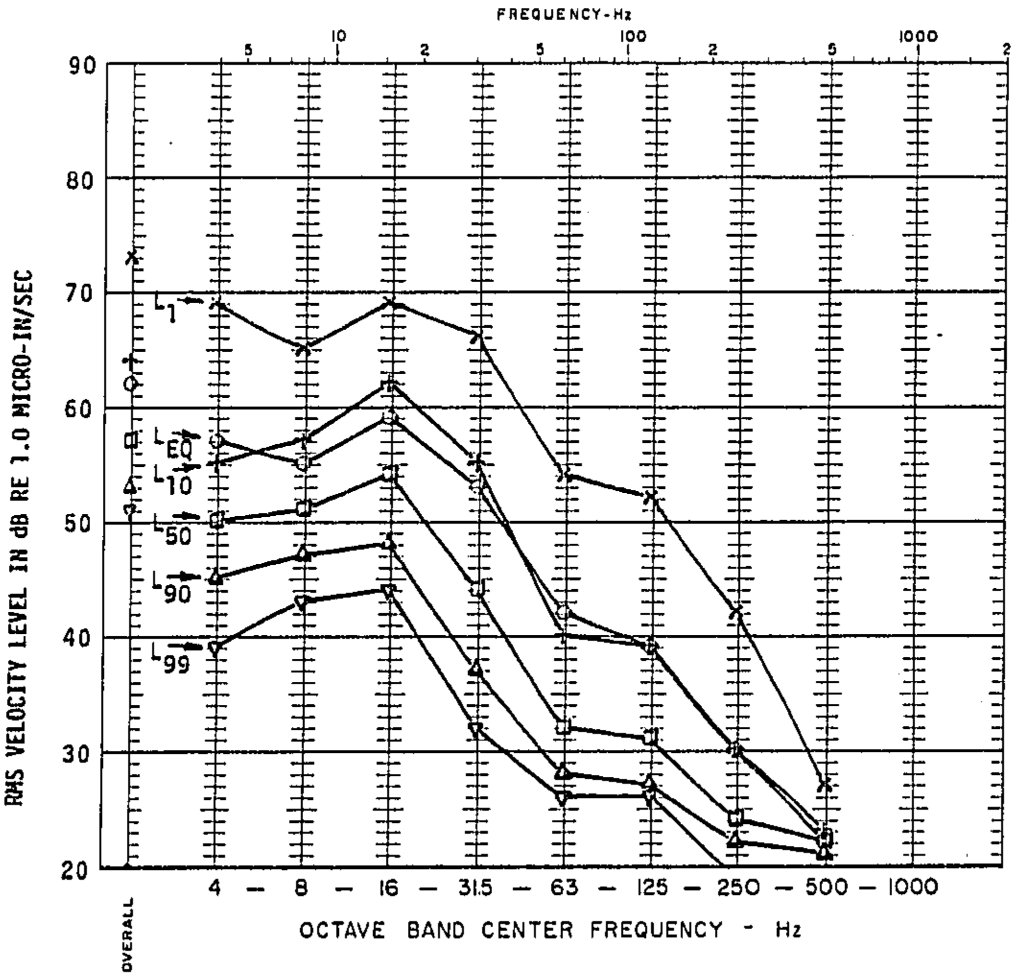
DATA SHOWN ARE THE STATISTICAL ANALYSIS OF THE VIBRATION VELOCITY OCTAVE BAND SPECTRUM

FIGURE 19 OCTAVE BAND VIBRATION VELOCITY LEVELS AS OBSERVED AT LOCATION 4e - RUSH HOUR



DATA SHOWN ARE THE STATISTICAL ANALYSIS OF THE VIBRATION VELOCITY OCTAVE BAND SPECTRUM

FIGURE 20 OCTAVE BAND VIBRATION VELOCITY LEVELS AS OBSERVED AT LOCATION 7e - DAY



DATA SHOWN ARE THE STATISTICAL ANALYSIS OF THE VIBRATION VELOCITY OCTAVE BAND SPECTRUM

FIGURE 21 OCTAVE BAND VIBRATION VELOCITY LEVELS AS OBSERVED AT LOCATION 14e - DAY

EXISTING NOISE AND VIBRATION FROM CTA OPERATIONS

In order to assess the contribution to the noise and vibration environment due to the operation of CTA trains in the Kennedy Expressway median, a series of noise and vibration measurements was made along an existing section of the Kennedy Rapid Transit Line. The wayside measurements were made at Location 14e, which is approximately 100 ft from the CTA alignment.

Platform noise measurements were made at the Addison Station and the Jefferson Park Station to assess the patron exposure to motor vehicle noise emanating from the Kennedy Expressway traffic.

Wayside Noise

Wayside noise measurements were made at Location 14e, which is approximately 100 ft from the CTA alignment. This measurement location is separated from the CTA alignment by three Expressway traffic lanes and one exit lane, and by Leland Avenue which had little traffic during the time when the measurements were taken.

The noise level statistics presented in Table II, and on Figures 4, 7, and 10 indicate that the noise climate in this area where the Kennedy Rapid Transit Line already exists does not have a markedly different noise climate when compared to other similar areas without the CTA trains operating in the Expressway median. Figure 22 shows a time history of the noise level for a portion of the daytime noise sample at Location 14e. The time history chart indicates that the CTA train passbys are discernable in most cases, and are in general comparable to other transient noise events such as bus, truck or motorcycle passbys, or jet aircraft flyovers. The noise level from the CTA train passbys at this location ranged from 79 dBA to 84 dBA with the highest noise level arising from long trains with flat wheels.

Wayside Vibration

Wayside vibration measurements were made at Location 14e along with the noise measurements at a distance approximately 100 ft from the CTA alignment.

The weighted vibration velocity statistics are presented in Table IV and Figure 16. The octave band statistical distribution for the daytime sample at this location is shown in Figure 21. The data presented in each of these figures and the table indicate that the vibration is below the level of perception for most people. The vibration velocity levels observed here are not markedly different than the levels observed at many of the other measurement locations adjacent to the Kennedy Expressway without the CTA trains operating in the Expressway median.

Figure 22 shows a time history of the weighted vibration velocity level for a portion of the daytime sample at Location 14e. Both the noise and weighted vibration velocity levels are shown enabling a correlation to be determined between the two. The time history chart indicates that the CTA train passbys are discernible in most cases, but that in many cases the truck passbys have a greater weighted vibration velocity level. To indicate the contribution of individual events to the overall spectrum and vibration velocity level, an octave band analysis of individual events was performed. Figure 23 shows the octave band vibration velocity levels for individual events. A number of similar individual events were analyzed and the average of several samples is indicated on Figure 23. Figure 23 does indicate that the CTA train passbys do in general produce the highest octave band vibration velocity levels. However, the levels are still well below the level of perception for most individuals.

Platform Noise

In order to assess the noise exposure of patrons waiting on the station platform of a station located in the Expressway median, noise measurements were made on the platforms of the Addison Station and the Jefferson Park Station located along the Kennedy Rapid Transit Line in the Expressway median.

Patron noise exposure arises from both the vehicular traffic on the Expressway and CTA trains arriving and departing the station. Most of the noise the patrons are exposed to comes from the vehicular traffic in the Expressway median which usually arises from both sides of the platform. Table VI presents the noise levels measured on these station platforms. Figure 24 presents the statistical distribution of these noise samples.

Examination of these data indicates that the noise levels waiting patrons are exposed to are quite high. Although the peak noise level of a train arrival, departure, or passby is approximately 10 to 15 dBA less than that encountered in the older subway stations, the continuous noise produced by vehicular traffic is a significant detriment to the noise environment of the patron waiting for a train on the station platform. With the steady high ambient noise level on the station platform, intelligibility of speech is reduced considerably. Although the patrons are exposed to relatively high steady noise, the noise levels measured are such that they are well below the OSHA [Occupational Safety and Health Act] standards, and thus do not have the potential for any hearing damage.

The individual passbys, arrivals, and departures of CTA trains at the stations are clearly discernable, although the noise level is often the same as that produced by the vehicular traffic. Recognition of train arrivals, departures, and pass throughs arise due to the difference in character between the vehicular traffic on the Expressway and the trains entering and leaving the station. Audible recognition of a train approach is beneficial, letting the patron know a train is coming and keeping him from standing too close to the edge of the platform.

TABLE VI DAYTIME NOISE ENVIRONMENT OBSERVED ON EXPRESSWAY MEDIAN STATION PLATFORMS - APRIL 13, 1978

Location	L_{99}	L_{90}	L_{50}	L_{10}	L_{1}	L_{EQ}
Addison Station Platform at center of platform 20 minute sample	78 dBA	81 dBA	84 dBA	89 dBA	92 dBA	86 dBA
Jefferson Park Station						
Outbound Side [arriving passengers] 13 minute sample	74	76	80	86	91	82
Inbound Side [departing passengers] 9 minute sample	74	80	84	88	93	85

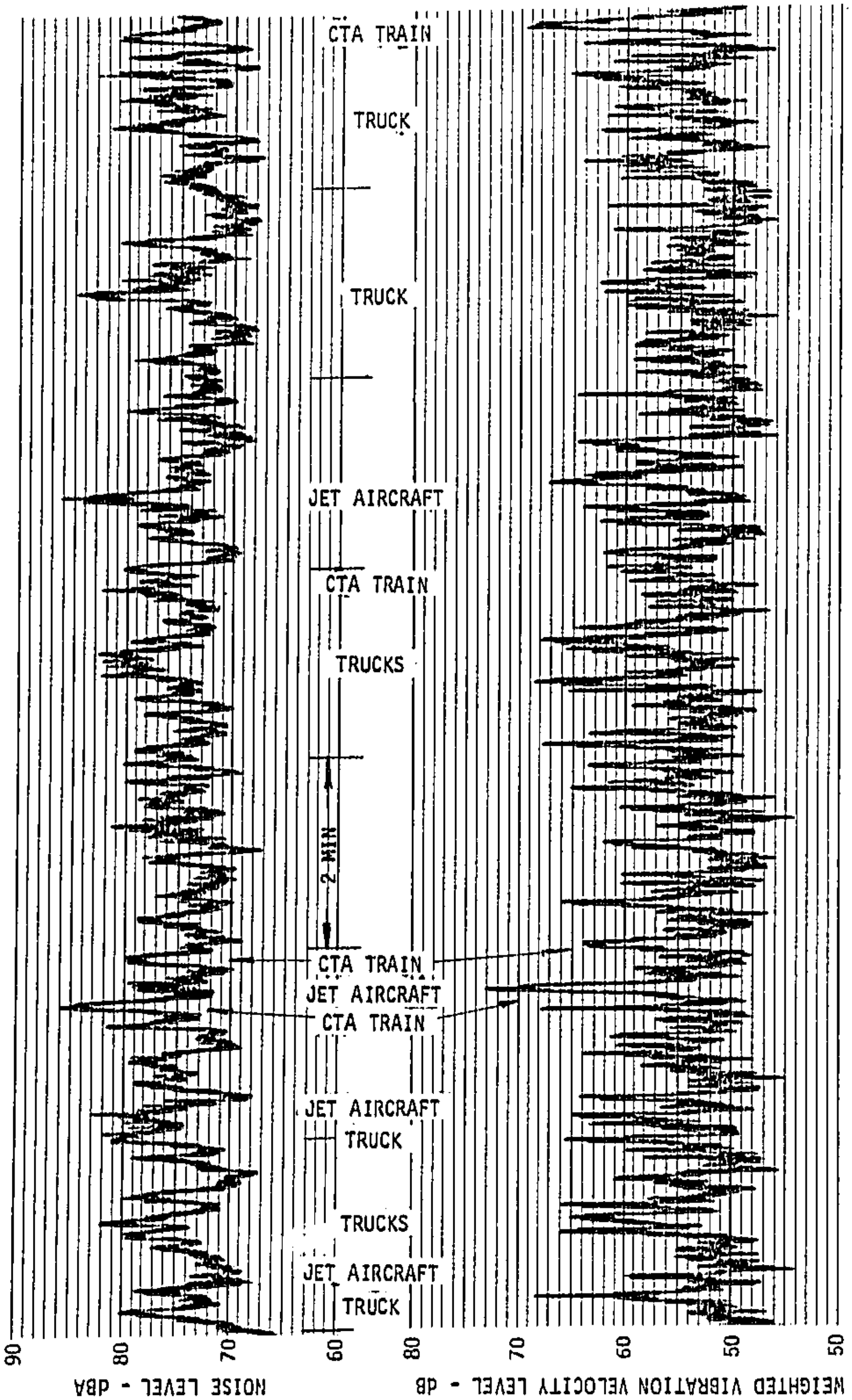


FIGURE 22 TIME HISTORY OF NOISE AND VIBRATION VELOCITY LEVELS AT LOCATION 14e - DAYTIME

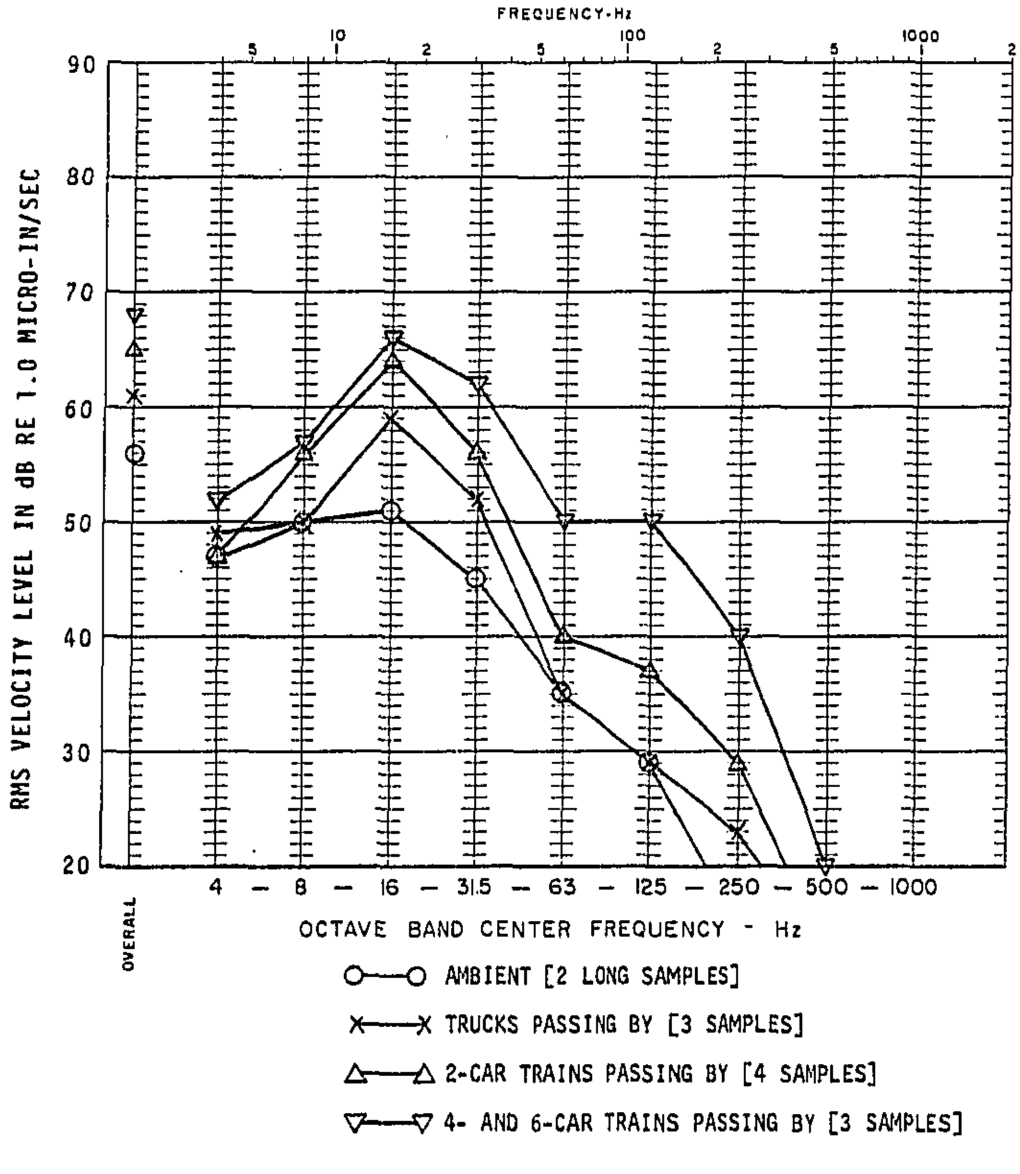


FIGURE 23 OCTAVE BAND ANALYSIS OF INDIVIDUAL EVENTS AT LOCATION 14e

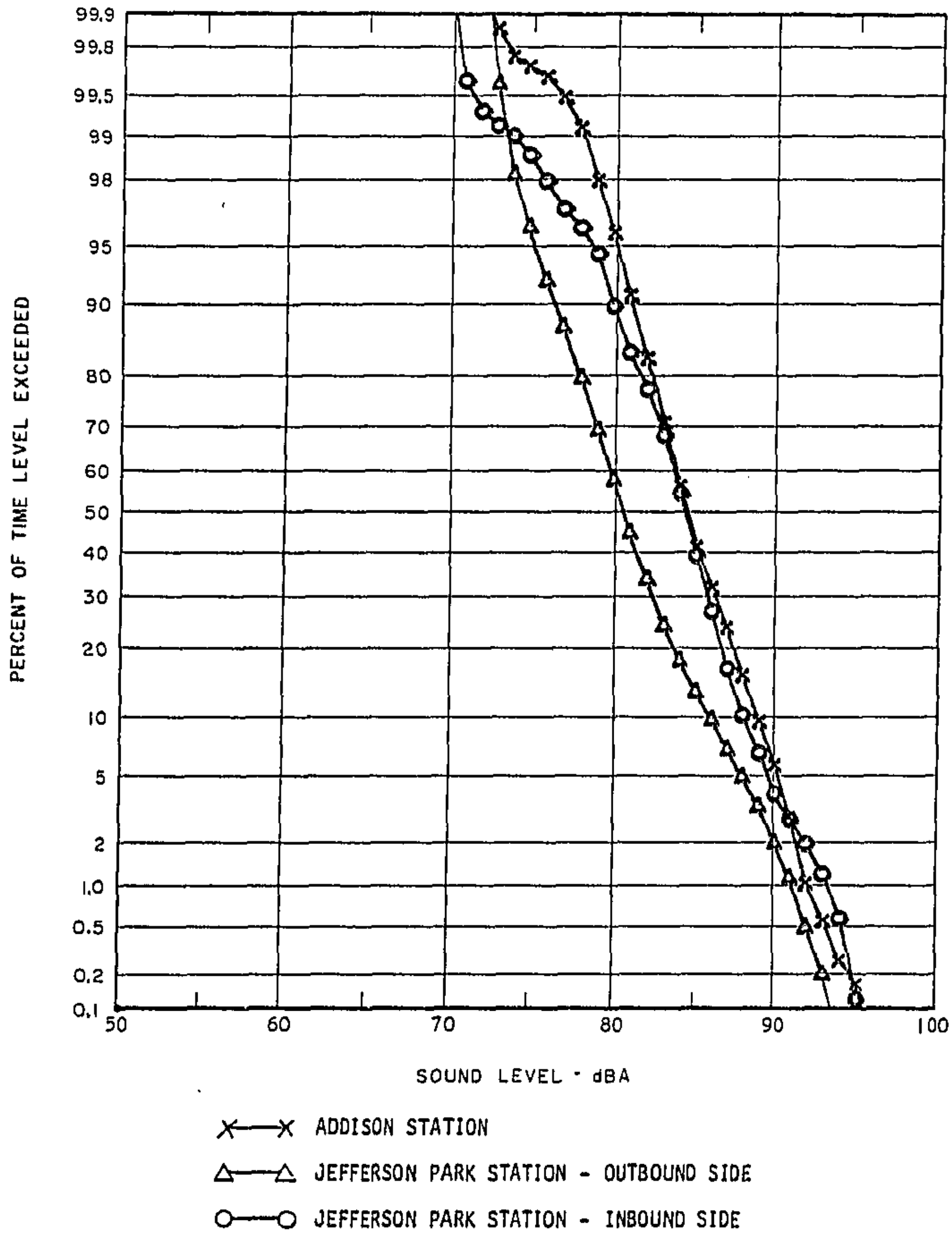


FIGURE 24 STATISTICAL DISTRIBUTION OF THE DAYTIME PLATFORM NOISE OBSERVED AT 2 STATIONS LOCATED IN THE KENNEDY EXPRESSWAY MEDIAN

NOISE AND VIBRATION CRITERIA

Criteria for permissible noise levels in nearby buildings and wayside communities due to the transit train operations must be related to the type of community, to the type of occupancy and activity taking place in the building or community and must be related to the prevailing average and peak noise level in the building or community in the absence of new transit system noise. Obviously a passby noise level of a given magnitude will be more objectionable in a quiet park-like environment or in a quiet residential area at night than it will be in a busy commercial area during the day or, in fact, during the night when there are few occupants in a commercial area.

A complete discussion of the criteria for different land use categories was given in the report prepared for the Chicago Urban Transportation District [CUTD] on the Distributor West Segment and revised in the report for CUTD on the Franklin Line. A full discussion and review of the criteria and its applicability to the O'Hare Extension is contained in Section II of this report, Noise and Vibration Control Design Criteria.

Table VII has been included to indicate the normal expected range of ambient noise for the five generalized community categories along transit system corridors and to indicate the ambient noise range measured along the proposed O'Hare Extension.

The noise levels measured along the O'Hare Extension alignment indicate that the existing noise levels are within the normal expected range [except at one location at night] for "freeway or highway corridors." Considering the land use and occupancy of the neighborhoods together with the measured noise levels, and the fact that special noise insulation measures have already been utilized in some noise critical buildings, the noise and vibration design criteria for freeway and highway corridors are appropriate for use along the entire length of the O'Hare Extension alignment.

TABLE VII GENERAL COMMUNITY CATEGORIES ALONG TRANSIT SYSTEM CORRIDORS

Category	Area Description	Daytime Average Ambient Noise Levels: Normal Expected Range	Daytime Average Ambient Noise Levels: Measured L_{50} along O'Hare Extension	Nighttime Average Ambient Noise Levels: Normal Expected Range	Nighttime Average Ambient Noise Levels: Measured L_{50} along O'Hare Extension
I	Low Density urban residential, open space park, suburban residential or quiet recretational area. No nearby highways or boulevards.	40-50 dBA	---	35-45 dBA	---
II	Average urban residential, quiet apartments and hotels, open space, suburban residential, or occupied outdoor area near busy streets.	45-55 dBA	---	40-50 dBA	---
III	High Density urban residential, average semi-residential/commercial areas, parks, museum and non-commercial public building areas.	50-60 dBA	---	45-55 dBA	---
IV	Commercial areas with office buildings, retail stores, etc., primarily daytime occupancy. Central Business Districts.	60-70 dBA	---	55-65 dBA	---
V	Industrial or Freeway and Highway Corridors	Over 60 dBA	64-74 dBA	Over 60 dBA	56-69 dBA

NOISE IMPACT IDENTIFICATION

The ambient noise levels measured in the vicinity of the O'Hare Extension alignment are very high, as expected for a highway corridor along the landing path to the O'Hare International Airport through which the line will run. In the design of the new transit line it is important to be sure that noise from transit train operations will not be intrusive and will not result in noise impact in buildings near the alignment. To this end, it is necessary to identify the noise and vibration sensitive structures in order to determine which areas of the alignment, if any, may require special consideration with regard to noise and vibration reduction designs. The identification process included an inspection of the buildings and potentially noise critical areas along the O'Hare Extension alignment coupled with noise and vibration measurements at representative locations along the route.

Among the possible noise sensitive buildings found along the O'Hare Extension alignment are residential homes, apartments, a church, a medical center, a school, and several hotels. There are some buildings which have computer facilities, and some buildings with intrusion alarms [such as banks] which are sensitive to sound and/or vibration.

Investigation in the past has shown the vibration and noise produced by transit train operations are not of sufficient level to present any potential danger or impact to computer facilities or bank vault seismic and sound detection devices. This is particularly true considering the already high ambient noise and vibration levels in the area due to jet aircraft landings at O'Hare International Airport and vehicular traffic on the Kennedy Expressway. The building and/or bank vault intrusion alarms and computers have a low sensitivity to this type of vibration and noise in order that the alarms are not actuated and computers impacted by the normal activity of the building occupants and outside transportation.

The entire length of the O'Hare Extension alignment will be at-grade ballast and tie in the median of the Kennedy Expressway, except where the line leaves and follows the O'Hare Airport entry road terminating under the Airport parking lot. On both sides of the Expressway there are residential houses and apartments, none closer than approximately 100 ft to the median due to the configuration of frontage roads and Expressway lanes. For this reason a detailed discussion of noise impact on individual houses and apartments is not included. Basically, it is recommended that the single-event maximum noise level criterion for a train passby be 80 dBA at the single family dwellings and 85 dBA at multi-family dwellings or hotels.

The current laws and regulations intended to progressively quiet the noise generated by automobiles, buses, trucks, and airplanes, and the effects of the City of Chicago Noise Ordinance will reduce the noise level along the O'Hare Extension alignment over the next 10 to 20 years. Thus, it is important to consider that while most of the buildings and residents are accustomed to high noise levels, the transit system should be designed for minimum reasonable airborne noise in order to be compatible with the future development of the environment along the alignment.

Although the recommended maximum single-event noise level at the various possible noise sensitive buildings are essentially the same, a listing which summarizes the structures considered is shown in Table VIII.

As previously discussed in Section III, noise measurements were made inside three structures which have already been designed to reduce the existing noise due to the Expressway traffic and jet aircraft. Thus, the transit train passbys will not adversely alter the interior noise environment in these buildings. Although noise measurements were not made inside Taft High School, the side of the school where the exterior measurements were made, closest to the Expressway, had few windows [some were bricked up] and less critical educational activities occurring on this side of the school, i.e., driver training and sports, which indicated that reduction of noise due to Expressway traffic and jet aircraft has already been accomplished and special reduction of transit train noise should not be necessary.

Noise and vibration measurements inside the basement of the O'Hare Airport parking structure were made to assess the existing vibration, and to a lesser extent noise, in order to determine whether the existing and future environment will be compatible with airline computer systems, if at some future date this area is used for airline check-in as originally planned at the time of the parking structure's construction. If these check-in facilities are actually implemented, it is recommended that the maximum ground-borne noise from transit train operations not exceed 50 to 55 dBA, equivalent to what would be recommended for a typical commercial space.

Both the FAA air traffic control tower and the airport hotel which are located between the parking lot and airport terminal are located a sufficient distance away from the O'Hare Station and the transit train alignment to preclude any noise or vibration impact from transit train operations.

TABLE VIII NOISE CRITICAL BUILDINGS IDENTIFIED ALONG THE O'HARE EXTENSION ALIGNMENT

Building and Location	Recommended Outdoor Airborne Noise Criterion for 6-Car Train Passbys
Single Family Dwellings along entire O'Hare Extension	80 dBA
Multi Family Dwellings along entire O'Hare Extension	85 dBA
Office Buildings and Banks with intrusion alarms along entire O'Hare Extension	85 dBA
Chicago Marriott O'Hare, 8535 West Higgins Avenue, and similar Hotels in the area	85 dBA
Holy Resurrection Serbian Orthodox Church on Redwood Street	80 dBA
Norwood Medical Center, 7742 West Higgins Avenue	85 dBA
Taft High School, off Natoma Avenue	80 dBA

RECOMMENDED NOISE AND VIBRATION CONTROL MEASURES

The following recommendations on noise and vibration control measures are based on the noise and vibration measurements, the Design Criteria [see Section III of this report] and the identification of noise sensitive buildings. These basic recommendations are supplemented by Section II, "Design Recommendations and Evaluations."

Wayside Noise

The preceeding sections have indicated that the noise environment around the O'Hare Extension alignment is of high levels, typical of areas bordering an expressway and airport flight path, but atypical of areas with similar activities located away from the expressway and airport flight paths. Considering present and anticipated future noise levels emanating from the expressway and from jet aircraft it is recommended that a concrete New Jersey style highway barrier be used along the entire length of the O'Hare Extension on each side of the tracks. This barrier is 32" high for most of the alignment, but will be at least 5 ft high at the Harlem and Cumberland Stations. The barrier is similar to that presently used around stations and along some sections of the existing Kennedy Rapid Transit Line. The barrier should be located as near as possible to the transit alignment separating the alignment on both sides from the traffic on the Kennedy Expressway.

Depending on the location of the barrier with respect to the alignment, the barrier should reduce the noise of a transit train passby by 3 to 9 dBA. This is a substantial reduction, and can be accomplished with a rather low barrier because most of the noise emanates from the wheel/rail interface. The reduction of the noise level by 3 to 9 dBA will reduce the noise of a transit train passby so that the maximum level at any building 100 ft or more away from the alignment will be less than 80 dBA. This will allow the noise level criterion to be met all of the most noise sensitive buildings along the alignment.

Station Platform Noise

Discussion of the noise observed on two existing station platforms located in the Kennedy Expressway median indicated that high noise levels were present, due principally to the Expressway traffic. Reduction of this noise is possible by the use of a sound barrier which would block the noise from the vehicles which would normally impinge on patrons waiting on the station platform. Ideally this barrier would extend from the top of grade or top of the New Jersey style barrier to the roof of the station structure. Practically, the barrier needs to extend to a height that will still allow the patrons to view the upper parts or roofs of the vehicles on the Expressway. Utilization of a barrier on each side of the station between the tracks and Expressway should reduce the platform noise by approximately 4 to 6 dBA at a position at the center of the platform.

In order to adequately block the transmission of the noise, the barrier should have no openings or cracks and should have sufficient weight to give approximately 15 to 20 dB sound transmission loss at 500 Hz. Nominally, a wall weighing about 2.5 lb/ft^2 or more should provide this amount of transmission loss providing that the material is sufficiently limp or non-resonant. Materials that will perform appropriately include: concrete, fiberglass [plastic], glass, plywood, and transite.

Ground-Borne Noise at the O'Hare Airport

The O'Hare Extension alignment goes underground as the line approaches the O'Hare International Airport. The subway and O'Hare Terminal Station are beneath the O'Hare Airport parking lot. Patron access to the station will be from the basement area near where airline check-in counters have been proposed.

The crossover preceeding the station is located beneath the parking lot and at a sufficient distance from the patron access area that even if this basement area is used for airline check-ins at some future time, the noise and vibration from transit trains operating on the crossover with standard invert will be satisfactory. Trains entering and leaving the station will be moving sufficiently slow [<25 mph] that noise and vibration from transit trains operating on standard invert within the Station will also be satisfactory.

MEASUREMENT LOCATION MAPS

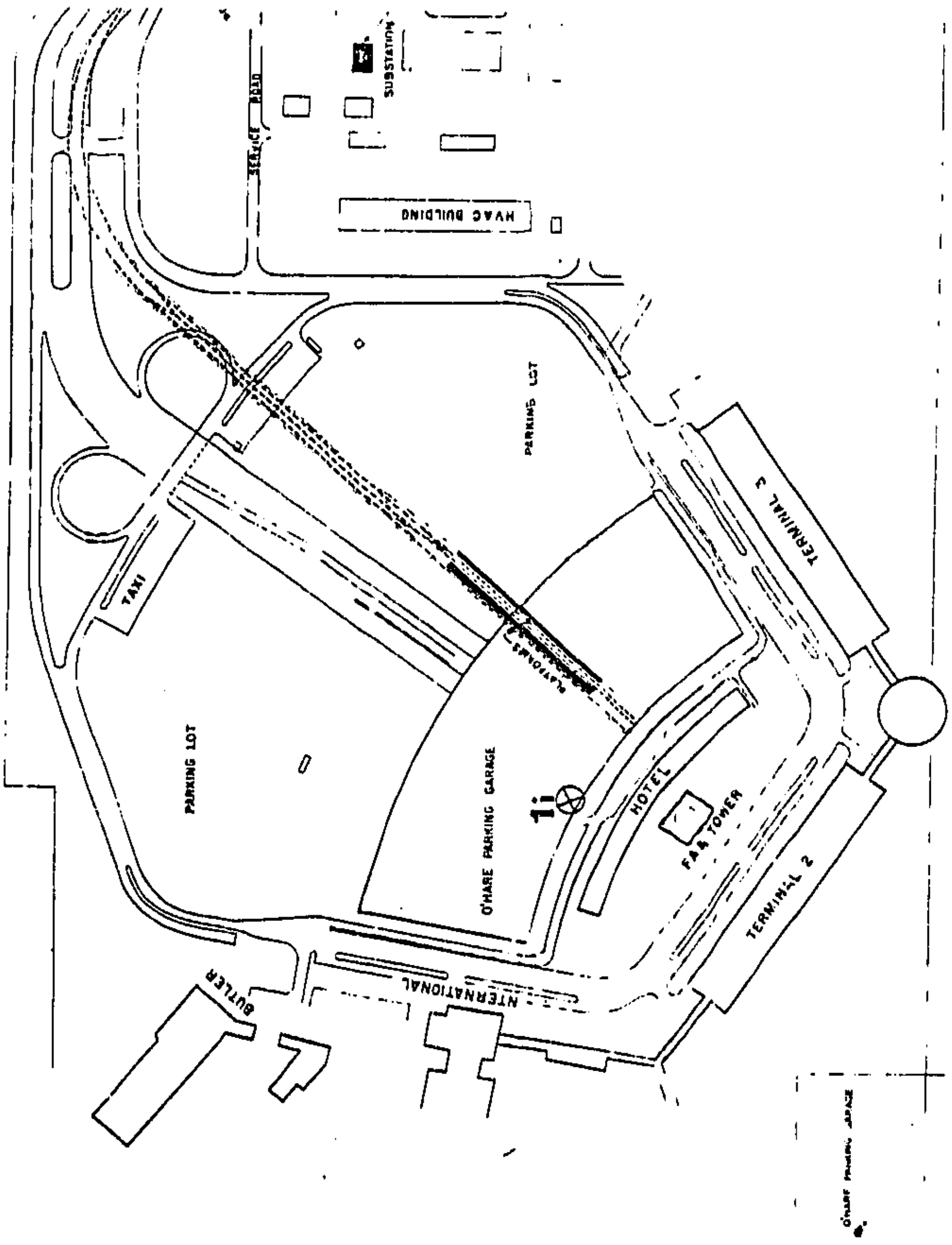


FIGURE 25 MEASUREMENT LOCATION 1i

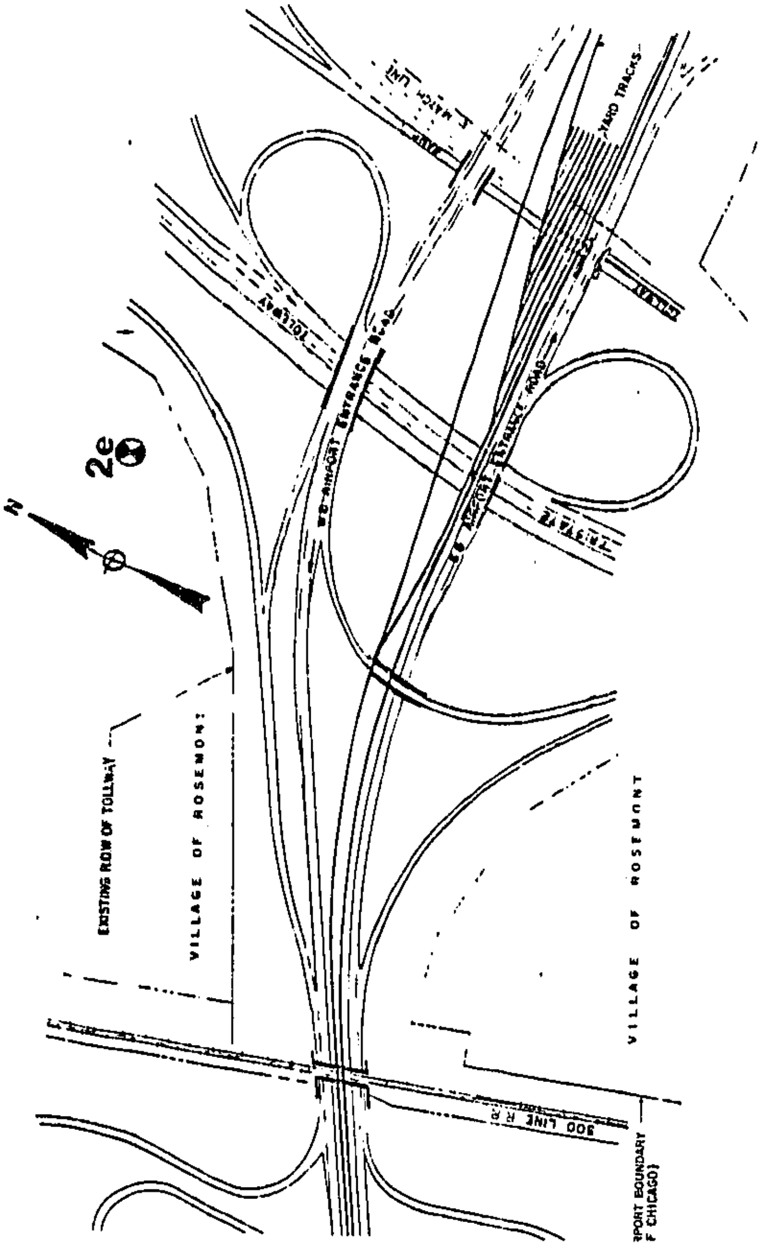


FIGURE 26 MEASUREMENT LOCATION 2e

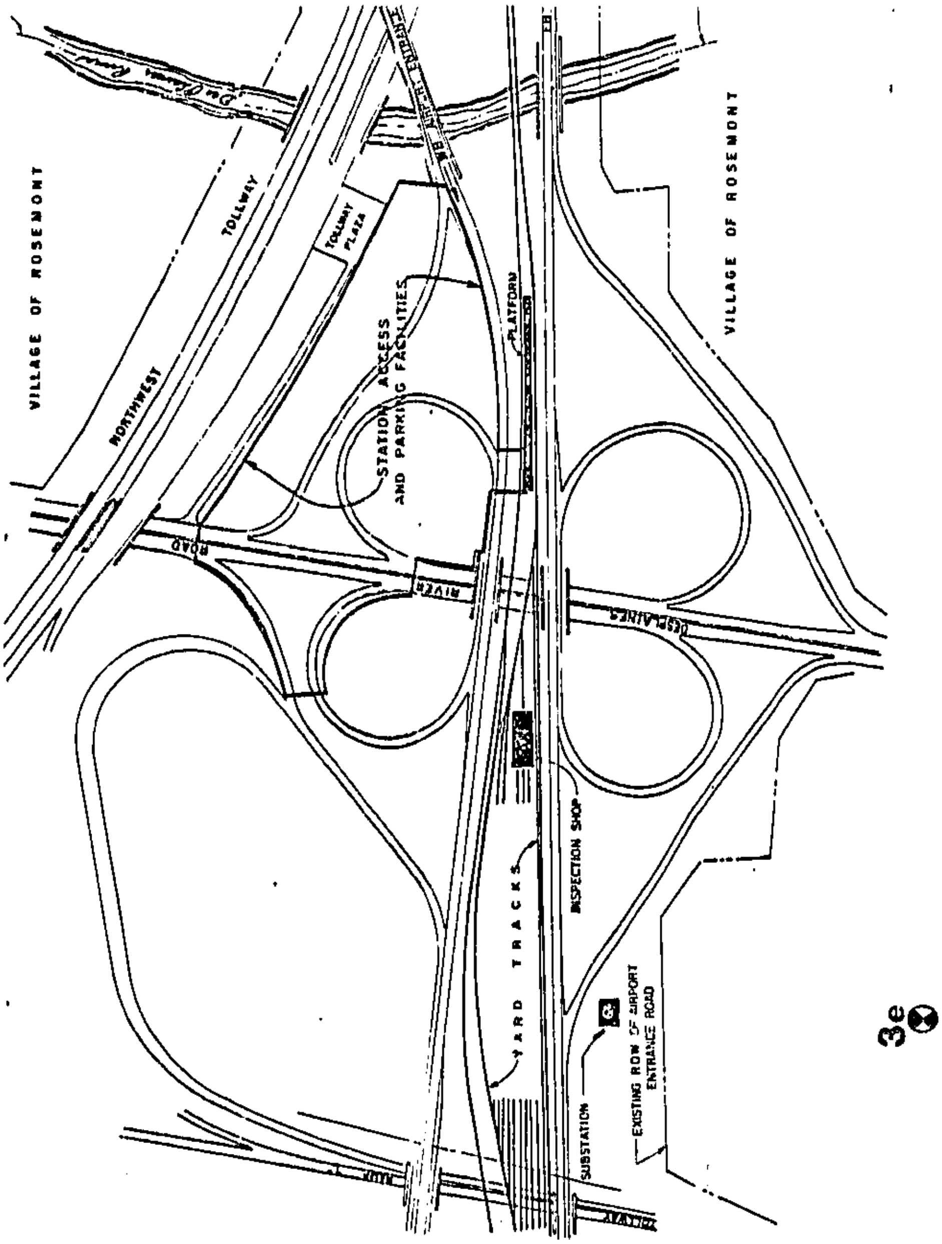


FIGURE 27 MEASUREMENT LOCATION 3e

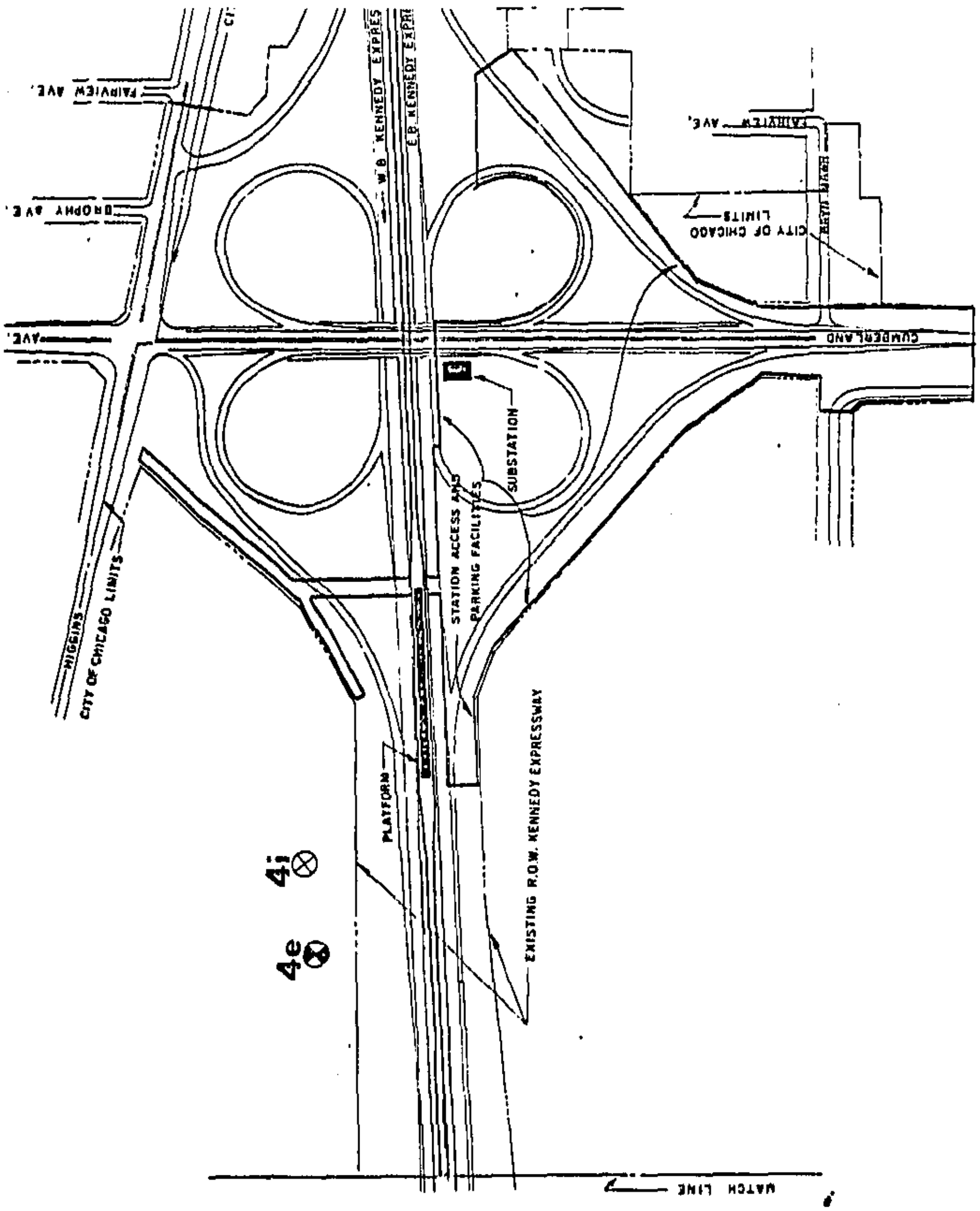


FIGURE 28 MEASUREMENT LOCATIONS 4i AND 4e

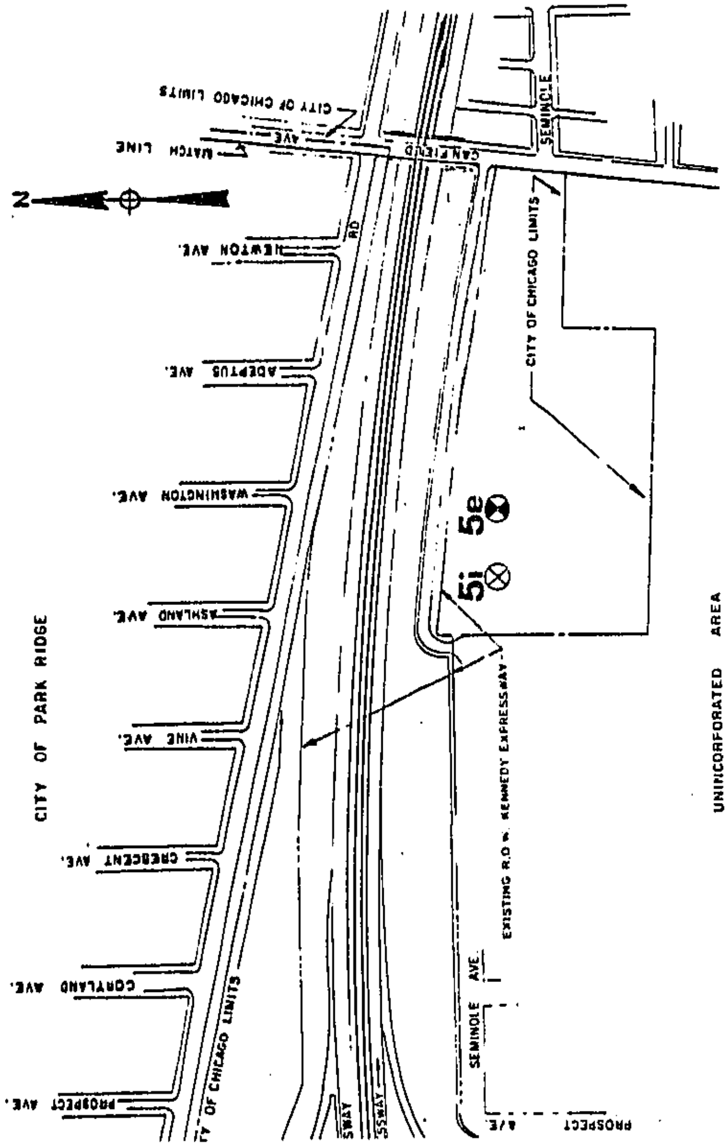


FIGURE 29 MEASUREMENT LOCATIONS 5i AND 5e

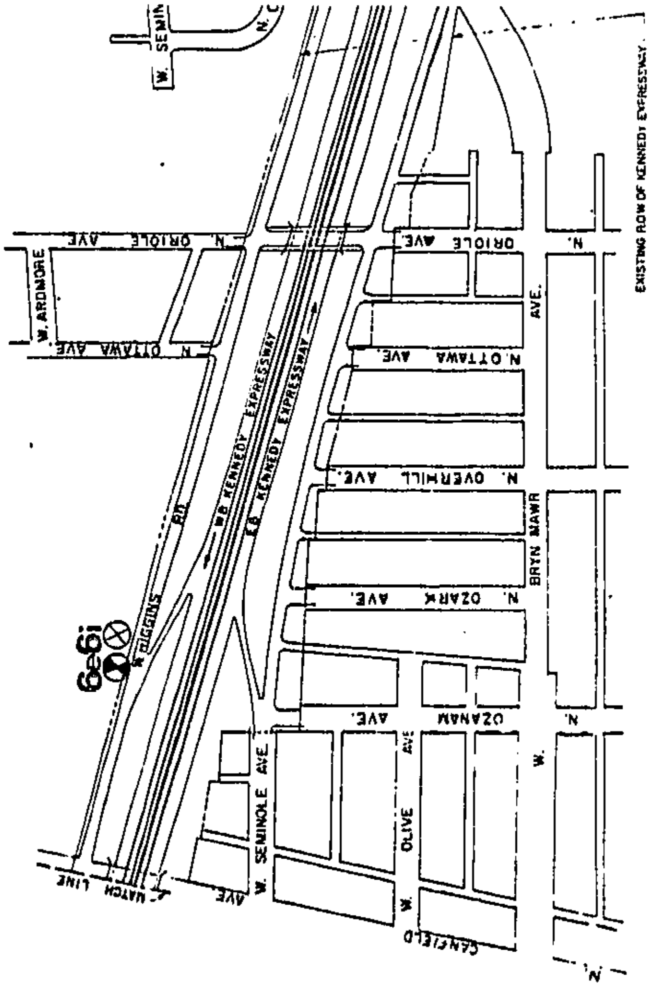


FIGURE 30 MEASUREMENT LOCATIONS 6i AND 6e

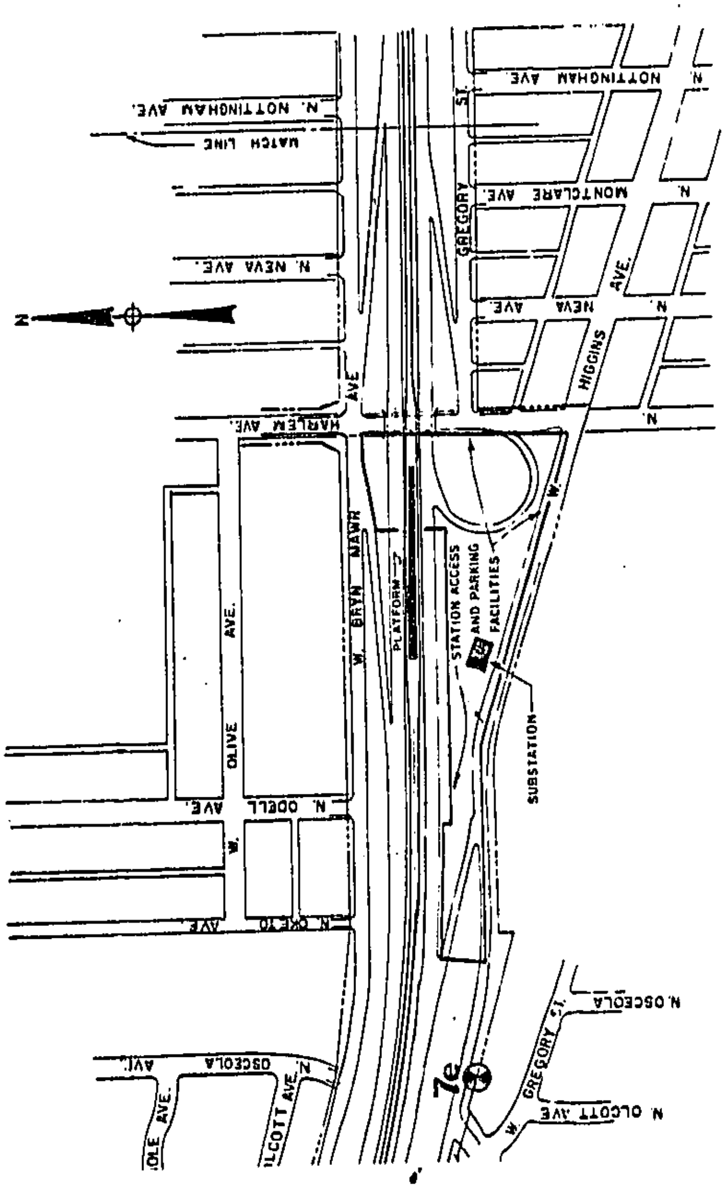


FIGURE 31 MEASUREMENT LOCATION 7e

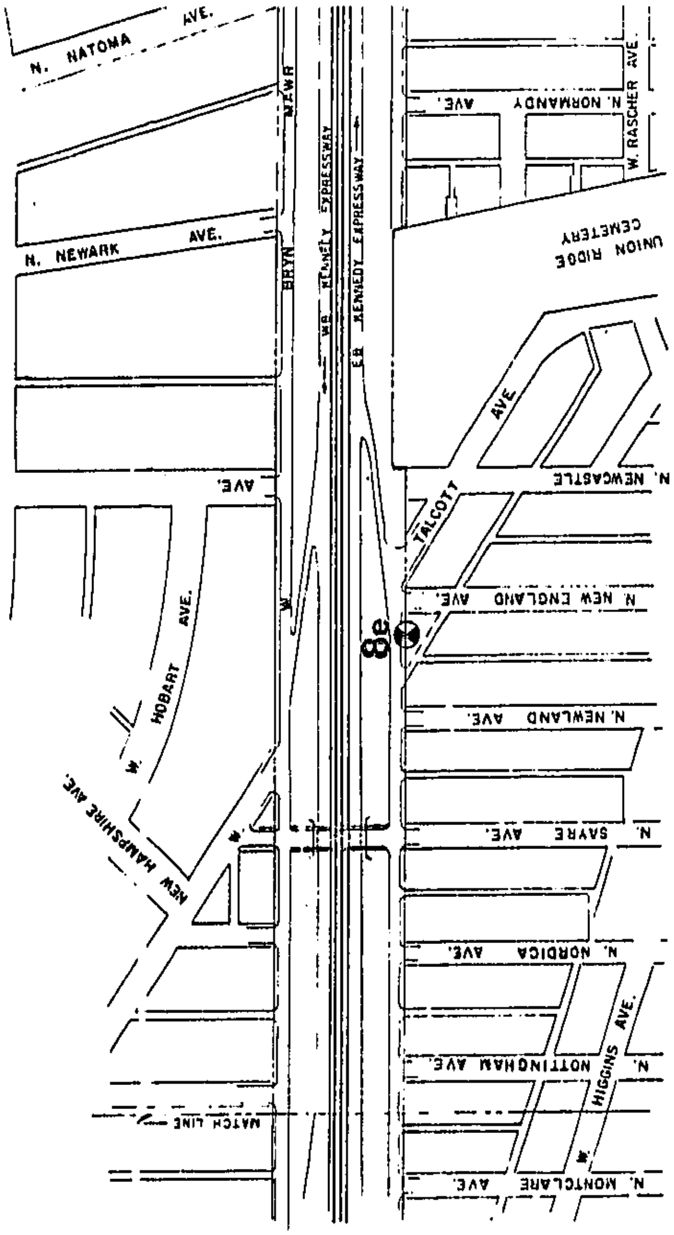


FIGURE 32 MEASUREMENT LOCATION 8e

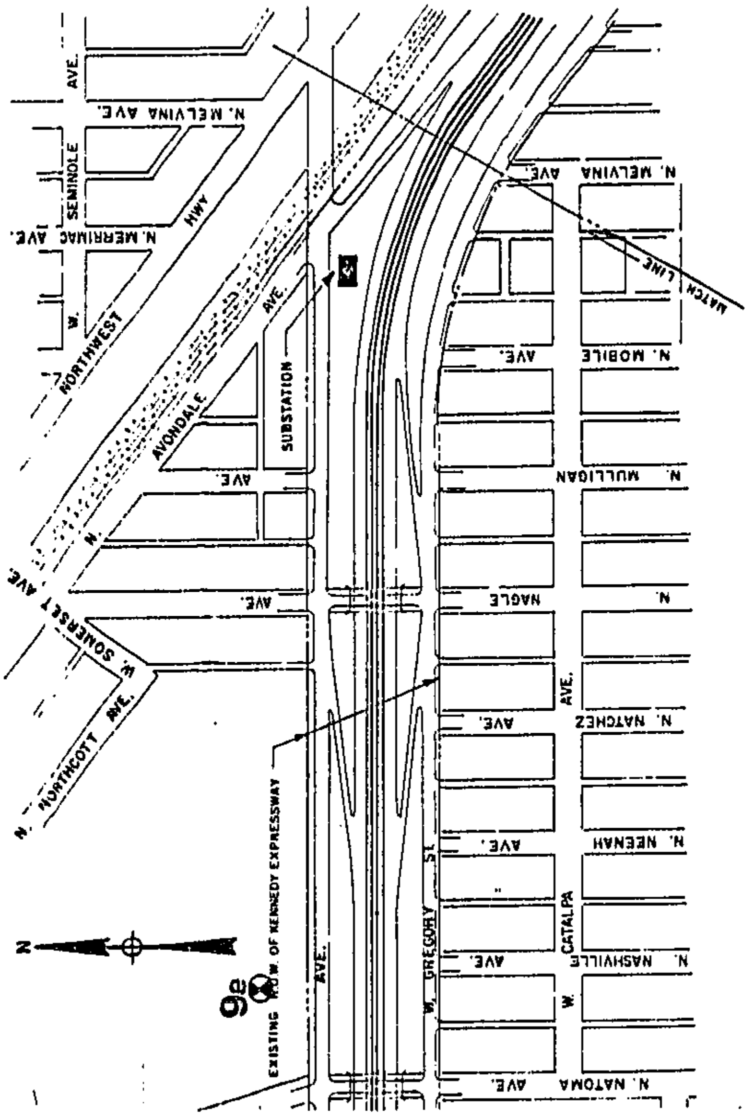


FIGURE 33 MEASUREMENT LOCATION 9e

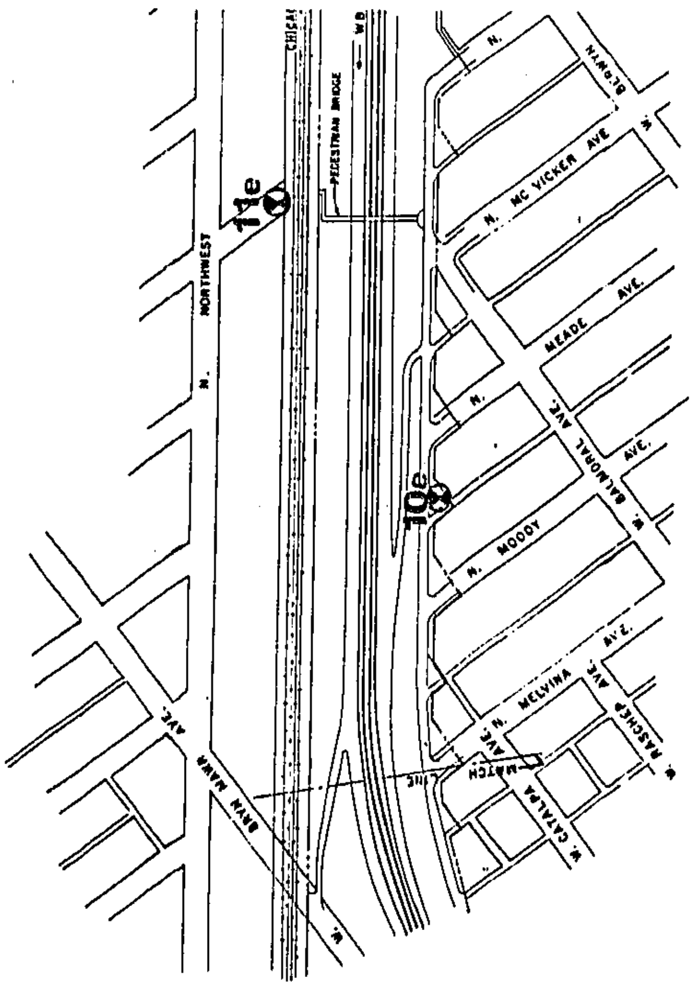


FIGURE 34 MEASUREMENT LOCATIONS 10e AND 11e

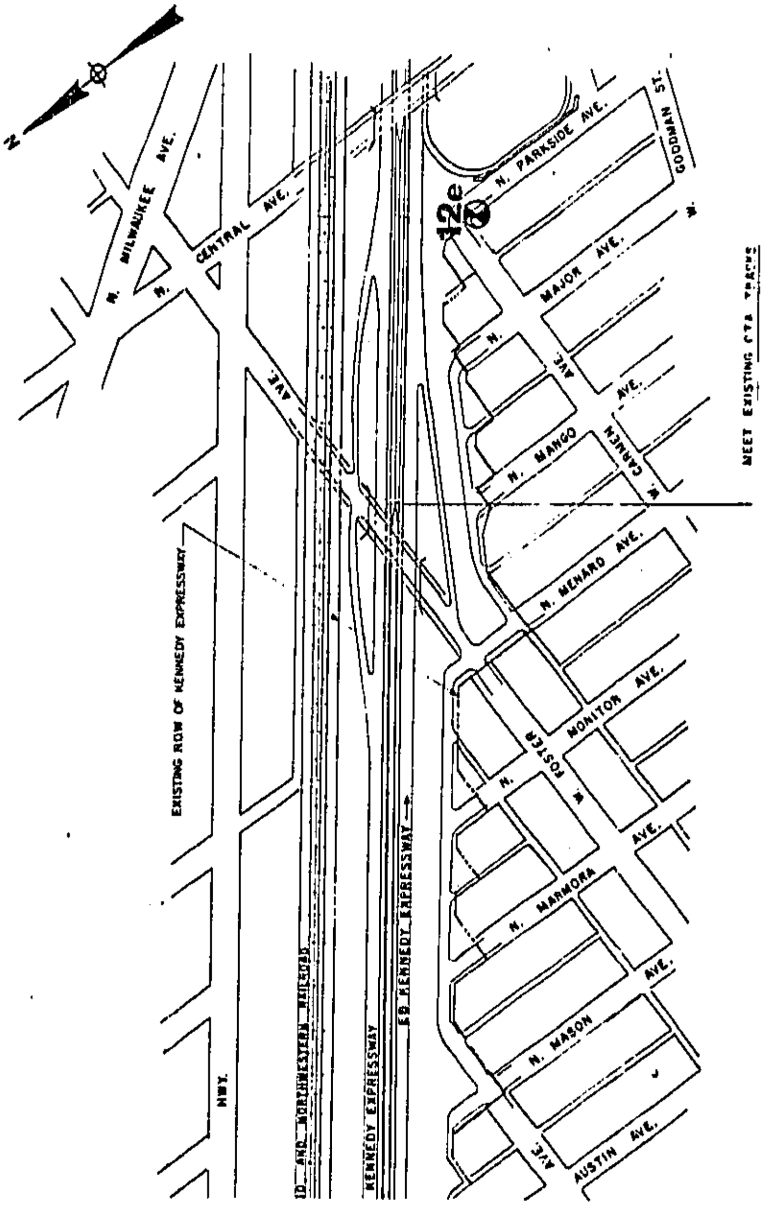


FIGURE 35 MEASUREMENT LOCATION 12e

II. DESIGN RECOMMENDATIONS AND EVALUATIONS

TRACK SYSTEMS

Within the past decade, a number of track fastening and support systems have been developed which provide a means for reducing the noise and vibration generated by transit train operations. These systems have also been designed to improve the stability and maintainability of the track system.

Most of the O'Hare Extension Alignment will be at-grade with short sections of aerial structure and subway. The significant section of subway is located in the region of the O'Hare International Airport, leading into the O'Hare Station. The possible rail fixation systems include:

[1] ballast and ties

[2] direct fixation resilient fasteners on concrete invert

[3] resiliently supported ties on concrete invert

[4] floating slab trackbed

Although all of these track systems produce less noise and vibration than old methods of rail fixation such as wood blocks cast directly in the concrete invert for subway, or tie on steel structure for elevated sections, the latter two track systems mentioned above are specifically intended for reduction of ground-borne noise and vibration at particularly noise sensitive locations near subways. Along the O'Hare Extension, due to the high levels of pre-existing ambient noise, it will not be necessary to utilize either of these track systems for additional noise or vibration reduction. Thus these two systems are not discussed further herein. The following discussion presents a review of the first two track systems and the acoustical performance achieved by each.

Ballast and Tie

In general terms, ballast and tie [wood or concrete] track installations in subways result in the lowest airborne noise in the subway, i.e., the lowest noise exposure for patrons in the trains, because of the airborne sound absorption of the ballast. However, there have been instances where ballast and tie track installations in subways have resulted in high levels of ground-borne vibration and noise causing excessive noise exposure in buildings near or adjacent to the subways. The high levels of ground-borne vibration and noise result from the vibration produced at the wheel/rail interface being transmitted to the subway structure, and then to the adjacent ground, by the relatively stiff ballast supporting the ties.

In order to have adequate resilience of the ballast, and to avoid crushing of the ballast stones due to load concentration, it is necessary to use a thick layer of ballast, at least 18", in a subway installation. Even with a deep ballast layer, it is possible for excessive crushing and compaction to occur because of the rigid invert support [in contrast to the resilient earth support for surface ballast and tie installations]. A bituminous layer or ballast mat below the ballast can be used to help reduce this effect. The depth of the ballast required results in greater depth of subway structure than for any of the other designs. Further, the compaction and crushing of the ballast which can occur with use causes progressively increasing stiffness and higher transmitted vibration and noise.

For short subway applications where the alignment passes beneath an expressway, road or railroads, continuation of the ballast and tie trackbed is ideal in that in most cases there is no structural requirement for rigid invert support [i.e., a concrete base under the ballast is not necessary] and the support is that of the relatively resilient earth. A notable exception is the East River Road Tunnel which does require a structural invert slab. However, no adverse noise or vibration effects are anticipated with this design due to the short length of the tunnel and relatively large distance to any nearby buildings.

For at-grade applications the ballast and tie track support system is ideal from a noise standpoint, due to the sound absorption of the ballast. For all-concrete aerial structures, a ballast and tie trackbed is beneficial from an airborne noise viewpoint due to the sound absorption of the ballast. For aerial structures of composite steel/concrete construction with concrete deck, use of a ballst and tie trackbed is the recommended design for controlling noise resulting from transit train operations to levels consistent with other configurations of modern aerial structures.

The main difference between all-concrete and composite steel/concrete girder aerial structures is that mechanical vibration of steel girder webs results in the steel/concrete girder radiating a greater low frequency sound level than with all-concrete structures. This is of little consequence for wayside observers out-of-doors since it has negligible effect on the loudness of the sound from the transit trains, either with or without a sound barrier wall. However, this effect does have noticeable consequence when the sound is transmitted into a building adjacent to the aerial structure, particularly buildings with the ligher weight types of structures typical of single family residences. The added or greater low frequency sound energy from the composite steel/concrete structure is transmitted readily into the buildings due to the fact that all types of structures provide less reduction of sound transmitted from outside to inside for the lower frequency ranges. The net result is that with the composite steel/concrete structure the noise transmitted into nearby buildings includes a low frequency "rumbling noise" component not present with all-concrete structures. This low frequency noise can be of a high level of loudness and can be intrusive. The addition of sound barrier walls to the structure does not improve the situation, i.e., the barrier wall does not reduce the level of the low frequency rumbling noise from the composite structure.

If the composite steel/concrete aerial structures are used on the O'Hare Extension at the few sections of aerial structure, it is recommended that a ballast and tie trackbed be used to minimize the low frequency "rumbling noise" which can be intrusive at a considerable distance from the alignment, even with the existence of the expressway and jet aircraft arrivals and departures at nearby O'Hare International Airport.

Inside the transit vehicle the ballast and tie trackbed affords the lowest level of noise over all other track support systems on aerial structures due, again, to the absorptive quality of the ballast. The noise produced by the transit vehicles and perceived inside the vehicle is absorbed and diffused to a much greater degree with the ballast than with the hard reflective concrete deck surface.

Direct Fixation

A wide variety of designs of resilient direct fixation rail fasteners have been tried both in service and in test installations. This type of rail fixation uses one or two elastomer pads of various thicknesses, dependeing on the design details, and obtains the vibration isolation or reduction of vibration and noise transmitted to the subway structure [therefore reducing the vibration transmitted via the ground to adjacent buildings] by interposing the elastomeric pad or pads between the rail and the invert. The designs can all be characterized by two basic types, the rail fastener with unbonded elastomer pad, such as the TTC fastener, and the fastener with bonded elastomer pad, such as the BART fastener, shown on Figures 36 and 37, respectively.

The direct fixation fastener design consists essentially of a flat steel plate for anchoring the rail and a flat elastomer pad located between the plate and the concrete invert. In some of the unbonded fastener designs elastomer pads are placed both between the rail and the plate and between the plate and the invert. Many designs of both the bonded and unbonded variety of resilient direct fixation fasteners have been devised and tried but they are all in effect a variation of the basic designs as represented by the TTC and BART fastener. This type of fastener can be used to provide electrical isolation, can be used to reduce the overall height required in subways, provides a means for reducing ground-borne and structure vibration levels, and has been found to be technically and economically feasible, providing satisfactory and proven performance.

Tests of the acoustical performance of the various resilient direct fixation fasteners indicate that there are measurable but small differences in noise and vibration performance for the different configurations. This is because there is actually little difference in the net spring rate or stiffness for the various fasteners. The fasteners are all required to limit lateral and longitudinal deflections of the rail and this places limitations on the degree of resilience that can be obtained. The designers for each type of rail fastening do attempt to design for minimum vertical spring rate to reduce vibration transmission but the limitations on lateral and longitudinal stiffness result in vertical stiffnesses that do not vary over a wide range.

The resilient direct fixation, D.F., fasteners exhibit higher levels of airborne noise [affecting patron noise exposure on the trains] than the ballast and tie track support system [as previously discussed]. Trains traveling on resilient D.F. fasteners do, in general, produce less ground-borne noise than ballast and tie track, but higher levels than either the resiliently supported ties or floating slab trackbed. However, due to the location of the O'Hare Extension subway with respect to nearby structures, the ground-borne vibration from the transit trains traveling on resilient D.F. fasteners should be satisfactory.

Essentially equivalent levels of airborne noise between the subway installations with ballast and tie roadbed and resilient D.F. fasteners can be achieved with the use of sound absorption material on the tunnel interior surfaces.

If the train speed in the subway is 35 mph or less, then the transit trains traveling in subway on resilient D.F. fasteners without sound absorption will create about the same noise level as the train traveling at-grade on ballast and tie at high speed [70 mph]. Thus for the O'Hare Extension the noise exposure of a passenger would be about the same when traveling at high speed in the expressway median as when traveling at a slower speed in the short section of subway with resilient D.F. fasteners and no absorption.

For at-grade applications, it is assumed that the ballast and tie trackbed will be used and that a concrete slab trackbed with resilient D.F. fasteners is not contemplated; this scheme would only create higher levels of wayside noise.

For aerial applications, the resilient D.F. fasteners are recommended if an all-concrete aerial structure is built. If the composite steel/concrete aerial structure is used, then a ballast and tie trackbed is recommended as discussed previously.

Summary

To summarize, the recommended type of track support systems are as follows [these are also indicated in the Noise and Vibration Design Criteria]:

[1] The at-grade sections of the alignment should be ballast and tie.

[2] The aerial sections of the alignment should be

- a. all-concrete aerial structure with resilient D.F. fasteners or
- b. composite steel/concrete aerial structure with ballast and tie trackbed on a concrete deck

[3] The subway sections of the alignment should be

- a. ballast and tie trackbed with no sound absorption material added to the tunnel or
- b. all-concrete trackbed with resilient D.F. fasteners with sound absorption added to subway sections where the train speed is greater than 35 mph.

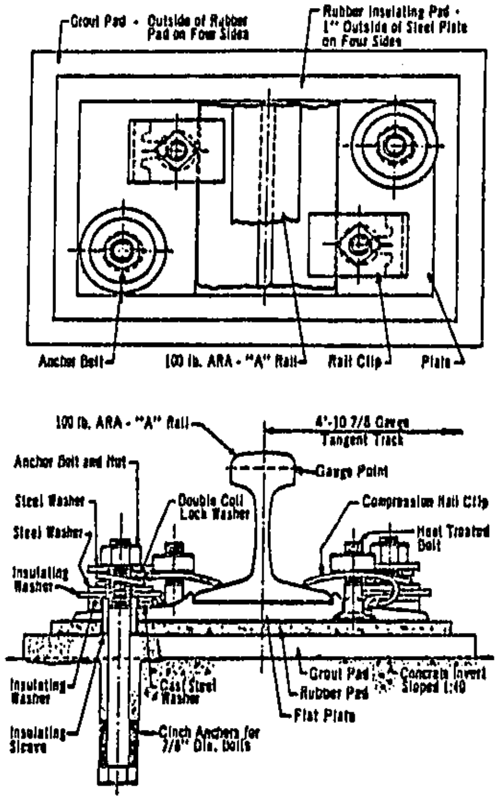


FIGURE 36 TORONTO TRANSIT COMMISSION RESILIENT DIRECT FIXATION RAIL FASTENER WITH UNBONDED ELASTOMER PAD

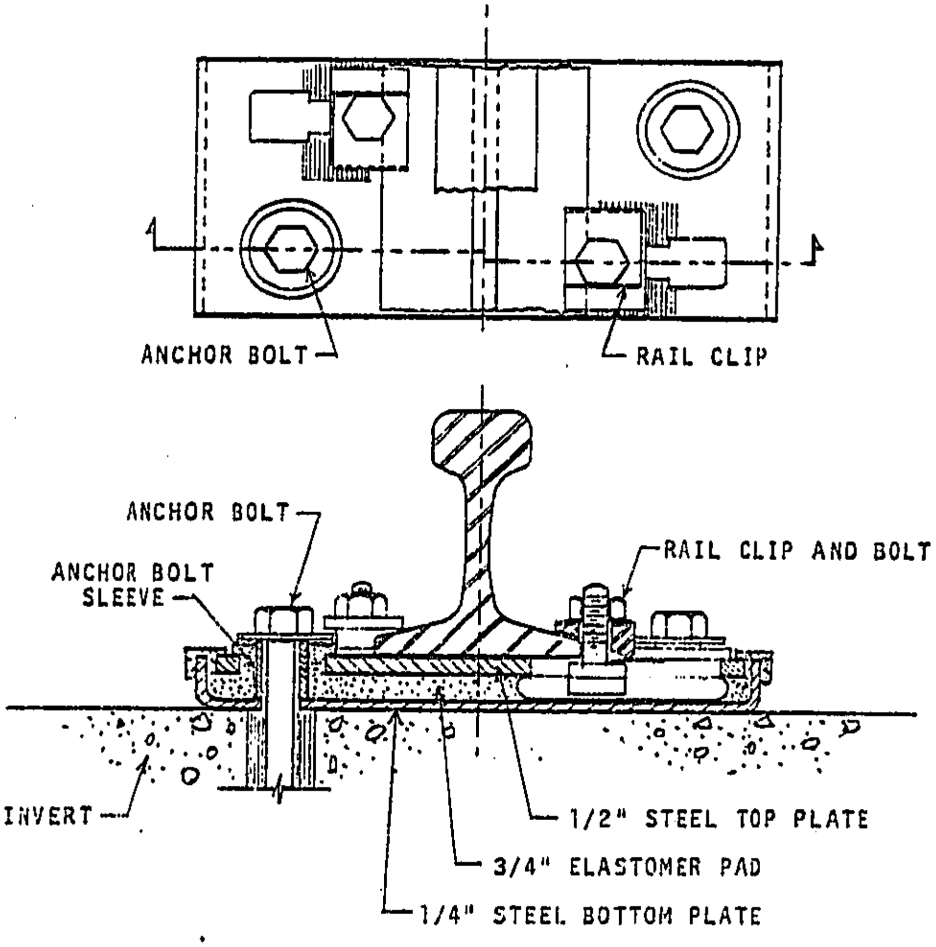


FIGURE 37 BART [LANDIS] RESILIENT DIRECT FIXATION RAIL FASTENER WITH BONDED ELASTOMER PAD

GENERAL STATION ACOUSTICS

Traditionally the CTA stations and other rapid transit systems, particularly the underground stations, have been highly reverberant, noisy spaces where the patrons have been subjected to very intense noise from transit train operations. The application of acoustical treatment to the interior surfaces of transit stations and to the under-platform areas adjacent to the transit cars makes it possible to substantially reduce the noise due to all sources in the transit stations and particularly to reduce the noise due to transit train operations in underground stations.

For the O'Hare Extension, at the underground O'Hare Station, the use of sound absorption material installed on the under-platform areas, the train room walls and ceilings, and the ceilings and walls of mezzanine areas is contemplated for control of noise and reverberation in the Station. Similarly, enclosed areas of above-grade stations will have ceiling and, possibly wall mounted absorption materials. These design features are highly desirable and recommended because it is essential that acoustic control be included in the design of modern transit system facilities in order to provide a satisfactory and attractive environment for the transit system patrons.

Basically, the inclusion of acoustic treatment in the design of a transit system station accomplishes five major purposes:

[1] Control and reduction of noise from transit train operations,

[2] provision for good intelligibility of announcements from the public address system,

[3] control of general crowd noise generated by patrons talking and walking,

[4] assistance in the control of noise from the station ventilation system and other mechanical equipment, and

[5] assistance in the control of external noise from automobile traffic and aircraft operations, which is especially important for above-grade stations.

The acoustic treatment accomplishes these objectives by the absorption of sound energy as it impinges on the interior surfaces of the station thus preventing multiple reflections and the build-up of reflected or reverberant sound energy. The amount of control of reverberation and the consequent reduction of noise obtained is dependent upon the area of the acoustical treatment, the absorption coefficient and the placement of the treatment. The five basic goals which are to be accomplished with the acoustic treatment can be realized by application of the Noise and Vibration Design Criteria.

The purpose of this section is to provide a discussion of the recommended arrangements or placements of the acoustical treatment for accomplishing the objectives of the Noise and Vibration Design Criteria.

Sound Control in the Underground O'Hare Station

The basic designs of subway stations are favorable for developing high noise levels and transmitting these noise levels from one area to another, such as from platforms to mezzanine areas. Because the interior surfaces of subway structures are generally concrete, steel or other hard materials, the untreated enclosed spaces are highly reverberant causing a build-up of sound level because of the low rate of sound energy absorption at the surfaces. The hard surfaces of an untreated subway station result in multiple reflections of sound and the efficient transmission of sound energy from point to point and the low rate of sound absorption results in transmission over long distances in the enclosed space.

In subway stations, because of the physical arrangement and because the main noise source is the transit trains with all the noise sources in the confined spaces beneath the transit cars, sound absorption materials on the walls near the undercar space can be used to efficiently reduce noise by absorbing sound energy near the source. Absorption near the source reduces the amount of sound energy fed to the reverberant sound field and reduces the sound transmitted along the platform in addition to giving the normal reduction obtained by reducing the reverberant build-up of sound level. Obtaining the maximum benefit from sound absorbing material requires that the material be installed in the proper locations. With appropriate design of the sound absorption system, the same material can be used to substantially reduce noise levels in stations as trains arrive and depart, to reduce noise levels from patrons [crowd noise], to assist in reduction of noise from the ventilation system and auxiliaries, and to control the reverberation time to maximize PA system intelligibility.

Figure 38 indicates a comparison of noise levels observed in two BART stations; one with under-platform treatment and ceiling treatment to control reverberation and noise, the second with the ceiling treatment only because most of the under-platform treatment was omitted. Both of the BART stations in which the measurements were made have sufficient acoustical treatment present to reduce the reverberation time to about the same range, i.e., about 1.2 seconds. However, the two stations do have a different acoustical treatment in that the under-platform surfaces at the Lake Merritt Station have a complete and continuous treatment of 4" thick glasswool with a sheet plastic cover while the 19th Street Station at the time of the measurement had almost no acoustical treatment under the platform, only one row of acoustical tile units spaced at about 2 ft on center.

The data on Figure 38 show dramatically the effect of the relatively small area of treatment which can be placed under the platform, even when the transit trains move at a slow speed. In the 19th Street Station where the continuous treatment was omitted, the noise level was about 4 dBA greater. In the middle and low frequencies the difference in noise level was 5 to 8 decibels. Since the O'Hare Extension Alignment terminates at the O'Hare Station, the transit trains will be traveling at a very slow speed when in the Station. Thus it might be thought that the effects of sound absorption materials would be minimal. The results at BART for slow-speed trains points out the importance of proper placement of sound absorbing material even when the transit trains operate at a slow speed.

Tests and measurements with present CTA transit cars indicate that the performance in acoustically treated stations will be as outlined above with considerably quieter operation than in the present untreated stations.

One point that should be made is that it may be thought that if the application of some acoustical absorption material provides good results, the application of more will provide even better results. This is true to a certain extent, that is up to the optimum or near optimum value. However, with further application of absorption material very little is accomplished because of the law of diminishing returns or the "knee" which occurs in the curve of noise reduction versus applied absorption area. Thus, the application of greater than optimum areas of the acoustical material in the stations is a very uneconomical way to achieve a given amount of noise reduction. It is possible, therefore, within economic and architectural limitations, to accomplish only a certain amount of noise reduction with sound absorption treatment on the platform area and mezzanine interior surfaces. Beyond that point other noise control procedures must be instituted if needed.

There are two other areas associated with stations which do require acoustical treatment for noise control; [1] Entrances and [2] Ancillary Spaces. Entrances require acoustical treatment in those areas where the entrance is a complete enclosure, that is, in areas other than the open roof or open side wall section of an entrance, in order to control reverberation and noise created by patrons. Ancillary spaces need acoustical absorption treatment to control airborne noise generated by mechanical and electrical equipment which is installed in the spaces, particularly for control of noise from ventilation equipment.

The first step in the design of the absorption treatment for a station is the selection of the reverberation time appropriate to accomplish the objectives of the design and the determination of the amount of absorption required to attain the selected reverberation time. Selection of the reverberation time then provides information on the minimum amount of absorption treatment which must be installed to achieve the control of reverberation time for maximizing public address system intelligibility and providing adequate control of general noise in the space, such as the crowd noise created by the patrons. Since the treatment in a transit station should be continuous, the derivation of the amount of absorption required to give results near the optimum reverberation time defines the width of treatment required or the total amount of treatment required per foot of length of the subway station.

The second part of the design procedure is selection of the location of the absorption material required for reverberation control in order to provide for the maximum noise control which can be obtained with the absorption material for the major noise source, the transit trains.

The third step in the design procedure is to select the appropriate absorption coefficient for the acoustical treatment and particularly the absorption coefficient for low- and mid-frequencies or the ratio of low-frequency, mid-frequency and high-frequency absorption coefficients. It is possible, due to the selection of inappropriate absorption materials or materials with inappropriate ratios of low-frequency to mid-frequency and high-frequency absorption, to have adequate control of mid- or high-frequency noises but inadequate control of low-frequency noise.

The final step in the design process is the selection of the appropriate acoustical materials to be considered for use in the stations and the determination of recommended design details and arrangements for the material installation.

Analysis of the acoustical treatment in the underground station spaces indicates that the optimum treatment for noise control is obtained with a reverberation time of about 1.2 to 1.4 seconds for the train room or platform areas for large multi-track stations such as the O'Hare Station, and 1.0 to 1.2 seconds for mezzanine or concourse areas. That is, with sufficient absorption to reduce the reverberation time to about 1.3 to 1.4 seconds in typical large train rooms, the absorption material is used efficiently to obtain noise reduction. In very large train rooms, such as the WMATA Metro subway stations or high ceiling multi-track stations, the use of a design criterion of 1.4 to 1.6 seconds is appropriate. Further treatment and further shortening of the reverberation time results in very little additional noise control or noise reduction because of the relationship of added absorption to noise reduction. Adding a 50% greater amount of absorption to that which will achieve the 1.3 second reverberation time, would give only about 1.5 decibels of additional reduction of the reverberant sound level, a very ineffective use of material and an unnecessary and inappropriate expense.

Since the acoustical treatment should be continuous along the station platform, mezzanines and corridors, it is appropriate to define the treatment required in terms of width of treatment per lineal foot of structure. For general guidelines and preliminary studies the treatment areas can be defined in terms of percentage coverage of applicable surfaces.

The location of sound control material in the transit stations is an important consideration in the architectural design of the station and the recommended locations for the materials are, in order of priority as follows in Table IX.

TABLE IX PRIORITIES OF LOCATION FOR SOUND CONTROL TREATMENTS IN SUBWAY STATIONS

I. Platform Areas:

1. Under-platform edges

2. On side walls opposite platform, from trackbed to 3 ft above top-of-rail

3. On side walls opposite platform, from 3 ft to 9 ft above top-of-rail

4. Between structural members on platform area ceilings

II. Mezzanine and Corridor Areas:

1. Wall panel absorption system

2. Between structural members on ceilings

As indicated above, the optimum location for the sound absorption treatment is on the under-platform edges, opposite the vehicle trucks, and the side walls opposite the platform, as far as reduction of the transit train noise is concerned. The one further factor that should be considered in determining the optimum location for the material is that it is essential for maximum efficiency of the applied material in reducing noise that there be some absorption on both vertical and horizontal surfaces: this is true in any enclosed space. Where the sound absorption is located primarily on either a horizontal surface or on vertical surfaces, the efficiency is reduced because the sound reflections on the surfaces at right angles to the absorbing surfaces are prolonged and have the effect of reducing the overall absorption efficiency. For example, in large rectangular spaces, application of sound absorbing material only on the ceiling can sometimes result in noise and reverberation reduction of only 20% to 30% of the amount expected on the basis of calculations assuming good diffusion or compared to the effectiveness which can be obtained if the same material is distributed uniformly on horizontal and vertical surfaces.

Figure 39 is a cross-section drawing showing a typical arrangement of a subway station platform area and mezzanine area showing recommended locations for the sound absorption treatment. The treatment shown for the platform area is a combination of under-platform treatment, side wall treatment and ceiling treatment. For the mezzanine area the treatment shown is a combination of wall and ceiling treatment. For corridor areas the treatment could consist of wall and ceiling treatment or simply ceiling treatment.

The general guidelines for acoustical treatment of the platform areas in subway stations are presented in Sections C.1, C.3 and C.4 of the Noise and Vibration Design Criteria. The design guidelines applicable to the O'Hare Station are reiterated here. For the platform and concourse areas, the acoustical treatment should consist of coverage of at least 50% of the total ceiling area and 30% to 60% of the wall areas, depending on ceiling height. For corridors and other smaller cross-section spaces, the acoustical treatment should cover 30% of the side walls and 50% of the ceiling area.

The following paragraphs present some general information on the characteristics of the sound absorbing treatment which should be used and which will accomplish the reverberation and noise control results as outlined above.

Selection of Acoustical Material:

Acoustical treatment for transit system stations consist basically of three elements:

1. The sound absorption media or material,

2. a protective covering, and

3. an architectural or trim facing.

For some treatments, each of these elements is an individual material and for others the functions are combined. For example, glasswool blankets encased in plastic bags with a perforated or expanded metal covering is one type of treatment with individual materials for each function. Acoustical tile with painted or vinyl facing is an example of treatment with combined functions. Another element which must be considered in the overall design is the fastening or mounting procedure since each type of treatment requires a different fastening system. Finally, the acoustic treatment should be of non-flammable materials to comply with safety criteria.

It should be noted that certain flammable materials are effective for sound absorption, however, other non-flammable materials are available and every effort should be made to use non-flammable materials for the O'Hare Station acoustic treatment. The following discussion includes comments on both flammable materials and non-flammable materials and their effectiveness in order to provide designers with sufficient information to make effective material selections.

For a number of reasons it is advisable that sound absorption treatments with low frequency absorption coefficients of high value be used in transit system station platform and mezzanine areas. This requires that the absorbing media or material be relatively thick, however, it also minimizes the total area of treatment required.

One of the most economical materials for sound absorption treatment is glasswool or glass fiber boards or blankets. Unfortunately, many of these materials are flammable because of the binder used. However, there are varieties of glasswool available that are non-flammable, usually because no binder material at all is used in the specific product. Glass fiber is available in a number of different forms including flexible, semi-rigid and rigid boards [ordinary duct liner for example]. Table X indicates the sound absorption coefficients that can be expected for various thicknesses of glass fiber. For acoustical treatment, the recommended density for glass fiber is 2 to 6 lb/cu ft. This density range is assumed in Table X. It is usually most economical to use multiple layers of 1" thick material for the thicker treatments since 1" thickness is a high volume product, more readily available than single layers of greater thicknesses.

A disadvantage of glass fiber materials, particularly the non-flammable products, is that a protective or retaining covering and facing are generally required. Some other non-flammable materials - such as cellular glass blocks - can be used for some applications with no protective covering or facing.

TABLE X TYPICAL SOUND ABSORPTION COEFFICIENTS TO BE EXPECTED FROM GLASS FIBER SOUND CONTROL MATERIALS MOUNTED DIRECTLY AGAINST A CONCRETE SURFACE

	Sound Absorption Coefficients				
Frequencies in Hz	125	250	500	1000	2000
1" thick Glass Fiber	.08	.30	.65	.80	.85
2" thick Glass Fiber	.20	.55	.80	.95	.90
3" thick Glass Fiber	.45	.80	.90	.95	.90

Most transit system structures are all-concrete with the result that they are highly reflective at low frequencies. For this reason it is important that the sound absorption treatment have substantial low frequency absorption. Section C of the Noise and Vibration Criteria specifies the minimum sound absorption properties of the acoustical treatment that will be used in the O'Hare Station. Although 1" thick glass fiber meets some of these criteria, to ensure that there is sufficient low frequency absorption in the station areas it is recommended that the treatment in the subway station platform areas be made up of 2" to 4" thick absorption material. For platform ceilings and mezzanine areas 2" thickness is adequate. Treatment 1" thick will be sufficient in other areas of the stations such as entrances, corridors, etc. For the subway station applications it is necessary to provide a facing and to enclose glass fiber absorption material in a film or wrapping to prevent accumulation of dust and to permit washing of the facing. This type of covering slightly decreases the high frequency absorption and slightly increases the mid and low frequency absorption. The net effect is a slight improvement, compared to the bare material, in reducing the overall levels of train noise.

Since there are fire resistance requirements for the acoustical treatment material, the use of both plastic film for protective covering and glass fiber materials with a resin binder may be prohibited for specific applications. Alternate materials are available. An alternate for plastic film covering which gives good performance against water and dust is close weave glass fiber cloth. Because of surface tension a water spray will generally not penetrate the glass fiber cloth. The Owens-Corning Fiberglas Company provides a fireproof glass fiber material denoted TIW, Thermal Insulating Wool, which has no binder. This is a multi-purpose material for industrial applications at temperatures up to 1000°F and is also denoted M-1000 Insulation for marine application. Since this material does not have a binder, its use requires mechanical retention, for example, a fiberglass cloth bag and metal screen.

For under-platform overhang treatment a recommended material assembly is a 3" to 4" thickness of non-flammable glasswool with an appropriate non-flammable plastic film cover of not more than 4 mils thickness or a glass cloth covering and a facing of expanded metal or hardware cloth. For platform areas and mezzanine ceilings the recommended design is 2" glasswool with appropriate covering and either perforated sheet metal or slit-and-slat configuration facings. Such treatment can be arranged in panels of appropriate size and shape to fit the architectural requirements.

An alternate recommended material for under-platform overhang treatment - a material which does not require a protective cover or facing and which is non-flammable - is the cellular glass block material made by Pittsburgh Corning Company; Geocoustic Blocks. These blocks are an incombustible, low density, cellular glass that is rigid and self-supporting, requiring only a mechanical fastening. The faces of the blocks are slotted to increase the absorption. The 4" thick blocks have good sound absorption characteristics and transit system experience indicates that they require little maintenance when used in areas not accessible to the public. This material generally should not be used in thicknesses less than 2" and should not be used in any location subject to mechanical abuse. The best applications are under-platform overhangs, fan and vent shafts and behind architectural facings.

For areas other than platforms and mezzanines, ordinary acoustical tile or panels of 3/4" or 1" thickness are appropriate. These materials - which may be of compressed glasswool or other appropriate fire resistant cellular material - can be of the type with painted or vinyl facing. Also, as for mezzanine areas, panels of glasswool blankets with perforated metal facing can be used.

Recommended Installation Procedures of Acoustical Material:

The recommended acoustical treatment material for the O'Hare Station ceilings and walls is the cellular glass block material, such as the Pittsburgh Corning Company Geocoustic Blocks. The material should be of 2" or 4" thickness in platform areas, 2" thickness in mezzanine areas and 1" to 2" thickness at other locations. This material is recommended because of the non-flammability and lack of need for protective covering film or cloth or for mechanical protection in many applications. For economy and acoustical efficiency, the alternate material recommended is glasswool without binder using a glass cloth covering or bag. This material should be of 2 to 6 lb/cu ft density and of 2" to 4" thickness in platform areas, 2" thickness in mezzanine areas and 1" thickness at other locations. Mechanical protection facings of hardware cloth or expanded metal or architectural facings of perforated metal or slit-and-slat panels should be used with this material.

The expected sound absorption coefficients for glass fiber treatments have been given in Table X . The numbers given in this table are, in many instances, somewhat less than will be found in the literature. For these materials, the figures given in the table are the maximum that can be expected in a normal, practical installation. The figures given for laboratory tests are often obtained under very special conditions designed to maximize the absorption coefficient and do not always represent realistic values.

For the under-platform treatment, the recommended arrangement is the use of either 3" to 4" thick mechanically retained glass fiber material of 2 to 6 lb/cu ft density wrapped with close weave glass cloth or 4" thick slotted Geocoustic Blocks. The material should be mounted to give maximum coverage of the under-platform area. At stations with significant platform overhangs, absorption material should be placed on the underside of overhang surface as well as the vertical wall. The minimum treatment for the under-platform area is a 2.5 ft width of continuous treatment on the vertical wall.

For the under-platform treatment, if glass fiber wrapped in glass cloth is used, the panels should be retained in place using either an expanded metal facing, hardware cloth facing or perforated metal facing. The use of expanded metal or hardware cloth is the most economical and is satisfactory where the material is not visible to patrons. Where the material is visible to patrons on the opposite platform a better appearance can be obtained through the use of perforated metal facing.

Wherever perforated metal or slit-and-slat facings are used, the open area should be at least 30% of the total area. With the use of either expanded metal or perforated metal facing, the attachment to the under-platform surfaces can be through the use of simple metal brackets. Air space should be provided around the edges to allow free circulation of air to prevent loading of the acoustical material panels due to air pressure transients created by the train movements. Panels with perforated metal or slit-and-slat facings - either for under-platform or ceiling and wall installations - should have a dimpled screen placed between the metal facing and the face of the acoustic blanket to establish an air space of about 1/2" thickness between the perforated facing and the blanket or glass cloth bag. This air space serves two purposes: (1) It allows the sound waves to diffuse over the entire face of the acoustic material, thereby assuring full efficiency as a sound absorber and (2) the air space allows free air flow for pressure equalization to help prevent loading of the facing by air pressure transients, especially if high flow resistance material is used as a cover for the glasswool.

For the ceilings and walls of the train rooms there are a number of treatment configurations available. Table XI indicates some of the basic materials. Materials equivalent to the glass fiber products in Table XI are marketed by other companies such as Johns-Manville Company and Pittsburgh

Plate Glass Company and should be given equal consideration. The list is only intended to be representative.

For treatment on flat, continuous surfaces and for platform or mezzanine ceiling areas the use of sectioned or continuous panels consisting of a metal or plastic slit-and-slat system or a perforated metal facing with fiberglass or cellular glass blocks between the facing and the concrete surface is appropriate. However, it should be remembered if a continuous panel system or a suspended acoustical tile ceiling type of system is used, that it is essential that gaps or openings be provided to permit free air flow between the acoustical treatment panels and the concrete surface behind in order to prevent loading of the acoustical panels by the air pressure transients created by train movements. If pressure equalization provisions are not provided it is found that in some instances the loading due to the air pressure transients does eventually cause fatigue failure of the fastenings, allowing the panels to come loose from the mounting surface and fall.

TABLE XI SOUND ABSORPTION MATERIALS RECOMMENDED FOR CONSIDERATION AS ACOUSTICAL ABSORPTION TREATMENT IN THE O'HARE STATION

Material	Approximate Sound Absorption Coefficients with Rigid Backing	
	250 Hz	500 Hz
4" Thick Geocoustic Blocks, 12" x 18", *Slotted:*		
Unspaced	1.0	1.0
Spaced 2" in both directions	0.90	1.0
Spaced 6" in both directions	0.60	0.65
4" Thick Geocoustic Blocks, 12" x 18", *Perforated:*		
Unspaced	0.80	0.85
Spaced 2" in both directions	0.80	0.95
Spaced 6" in both directions	0.55	0.60
2" Thick Geocoustic Blocks, 12" x 18", *Perforated:*		
Unspaced	0.80	0.70
Spaced 2" in both directions	0.75	0.70
Spaced 4" in both directions	0.40	0.60

TABLE XI (CONTINUED)

Material	Approximate Sound Absorption Coefficients with Rigid Backing	
	250 Hz	500 Hz
2" Thick Plain Glasswool of 2 to 6 lb/cu ft density wrapped with glass cloth	0.60	0.80
2" Thick Owens-Corning Aeroflex Duct Liner [3 lb/cu ft density] or Type 702 Blanket faced with a vinyl or neoprene coating	0.55	0.80
2" Thick Owens-Corning Glass Cloth Faced Boards backed with Type 703, 704, or 705 Board	0.55	0.85

The last two materials listed in Table XI are recommended only for applications where flammable materials are acceptable. Note that several combinations of spaced and unspaced Geocoustic Blocks are listed. The absorption coefficients for the spaced configurations are based on the gross area of the treatment, i.e., the block area plus the area of the spaces between blocks. Use of spaced configurations can result in material economy, however, to avoid loss of low frequency absorption the 4" thick units should be spaced not more than 6" and the 2" thick units not more than 4" apart. For lowest cost and for non-flammability, Geocoustic Blocks should be specified to be unpainted and without surface coating or wrapping.

Some materials, such as vinyl or neoprene coated or glass cloth faced glasswool board, can be painted or are available with appropriate surfaces so that no further facing is required, particularly for a ceiling application. However, the flammability of the material must be considered for each type of application. As discussed above, an alternate arrangement is the use of plain glass fiber boards or blankets wrapped in a close weave glass fiber cloth and faced with a perforated sheet metal, slit-and-slat system, or other facing. With this latter arrangement the facing material must have at least 30% open area to avoid degradation of the sound absorption coefficient.

The recommended covering for any side wall treatment is perforated sheet metal with at least 30% open area. Perforation patterns such as: 1/16" diameter holes staggered at 7/64" center, 1/8" diameter holes at 3/16" centers, and 3/16" diameter holes at 5/16" centers provide adequate open area. There are, of course, other combinations of equivalent performance.

The acoustical material applied to coffer areas could be of a pre-formed perforated metal panel with glass fiber behind. The material can be applied directly against the face of the concrete ceiling. This is similar to the design used for the WMATA Metro system stations and does provide a durable installation with excellent sound absorption characteristics. The minimum thickness of the glass fiber material should be 2".

A basic panel system for ceilings and, possibly, walls, for the mezzanine and corridor areas can be arranged to provide the acoustical absorption very simply. The panel may be of perforated metal, a slit-and-slat configuration of boards or metal or some form of architectural trim which has at least 30% open area and no bars or sections that are greater than 2" width between openings. Such an arangement will provide for a completely transparent acoustical face. Acoustical material can then be located at 1/2" to 6" distance behind the face and could be cellular glass blocks or non-flammable glasswool of 2" thickness.

For corridors and entrances the sound absorption treatment can consist of wall or ceiling treatment as described above for platforms and mezzanines, or the absorption could be an application of 3/4" to 1" thick acoustical tile, acoustical ceiling board, cellular glass blocks, or sound absorption assembly such as perforated sheet metal with fiberglass blankets behind the sheet metal facing. The absorption coefficient should be at least the value listed in Section C of the Noise and Vibration Criteria for each type of space, considering the type of mounting used.

For the ancillary spaces two basic types of materials are recommended. For spaces with equipment which radiates relatively low noise levels or in which the noise is intermittent, such as in switchgear rooms or shops, the recommended acoustical treatment is a 1" thick glass fiber application. An alternate could be the use of 3/4" or 1" thick acoustical tile, acoustical ceiling board or painted duct liner board for the absorption material. In spaces with noisy equipment such as fans, pumps and chillers, the acoustical treatment material should be of 2" minimum thickness. In such spaces the material need not have an architectural trim facing. Application of 2" thick [two layers of 1" thickness] duct liner blanket to the walls and ceiling, perhaps with hardware cloth facing for mechanical protection, gives an economic sound absorption treatment that has appropriate absorption characteristics.

In the ancillary spaces with the higher noise level equipment, the treatment area required is 30% of the wall and 50% of the ceiling area and the sound absorption material must be distributed reasonably uniformly over the ceiling in panels or patches and the wall material must be distributed over at least two adjacent walls. That is, the material should not be concentrated on one part of the ceiling or concentrated on two opposite walls but rather must be distributed between the ceiling and walls and with the wall treatment located to give approximately equal division of area on walls located at right angles to each other.

Sound Control in Above-Grade Stations

The above-grade stations of the O'Hare Extension will all be located in the median of the Kennedy Expressway. Due to the steady flow of traffic on the Expressway at all times of day, a primary concern is reducing the traffic noise perceived by the transit patrons while waiting for the transit trains.

One way to reduce this traffic noise to the levels in Table XIII.1 of the Design Criteria, is to have sound barriers block the sound path between the noise source and the patron area. Ideally such barriers should be located at the outer edge of the transit right-of-way, as near as possible to the expressway. If for non-acoustical reasons these barriers cannot be implemented, then acoustically treating the platform roofs of the above-grade stations will help reduce the noise from traffic on the expressway.

Platform noise levels may be increased by up to 3 dBA due to reflection of the expressway noise down to the platform by the roof of the station. The platform roofs of the above-grade stations should be acoustically treated to minimize reflections. Additionally, careful shaping of the roof to minimize the interception, reflection downward and even possible focusing of expressway traffic noise onto the platform is advisable. This absorption treatment is not necessary for reduction of the transit train noise, and in the absence of the noise from traffic on the expressway, trains entering and leaving will meet the noise design goals for above-grade stations without acoustical absorption material. The treatment area required is 50 to 60% of the roof area, or the extent allowed by architectural limitations. The sound absorption material should mostly be located directly over the transit train tracks and the outer edges of the platform to minimize the reflections of the expressway traffic noise to the platform area.

For enclosed areas, such as the mezzanine or concourse areas, where the only available location for sound absorption material is on the ceiling, acoustical treatment should be arranged to cover at least 50% of the total area of the ceiling. Because of the presence of openings and obstructions at the escalators, elevators and stairways, there should be sufficient sound diffusion in the mezzanines to partially compensate for the fact that the sound absorbing material will all be located on one surface. Suitable acoustical materials for the above-grade station mezzanines are the same as the materials for the underground station mezzanine which is previously discussed [at least equivalent to 1" thick glass fiber boards].

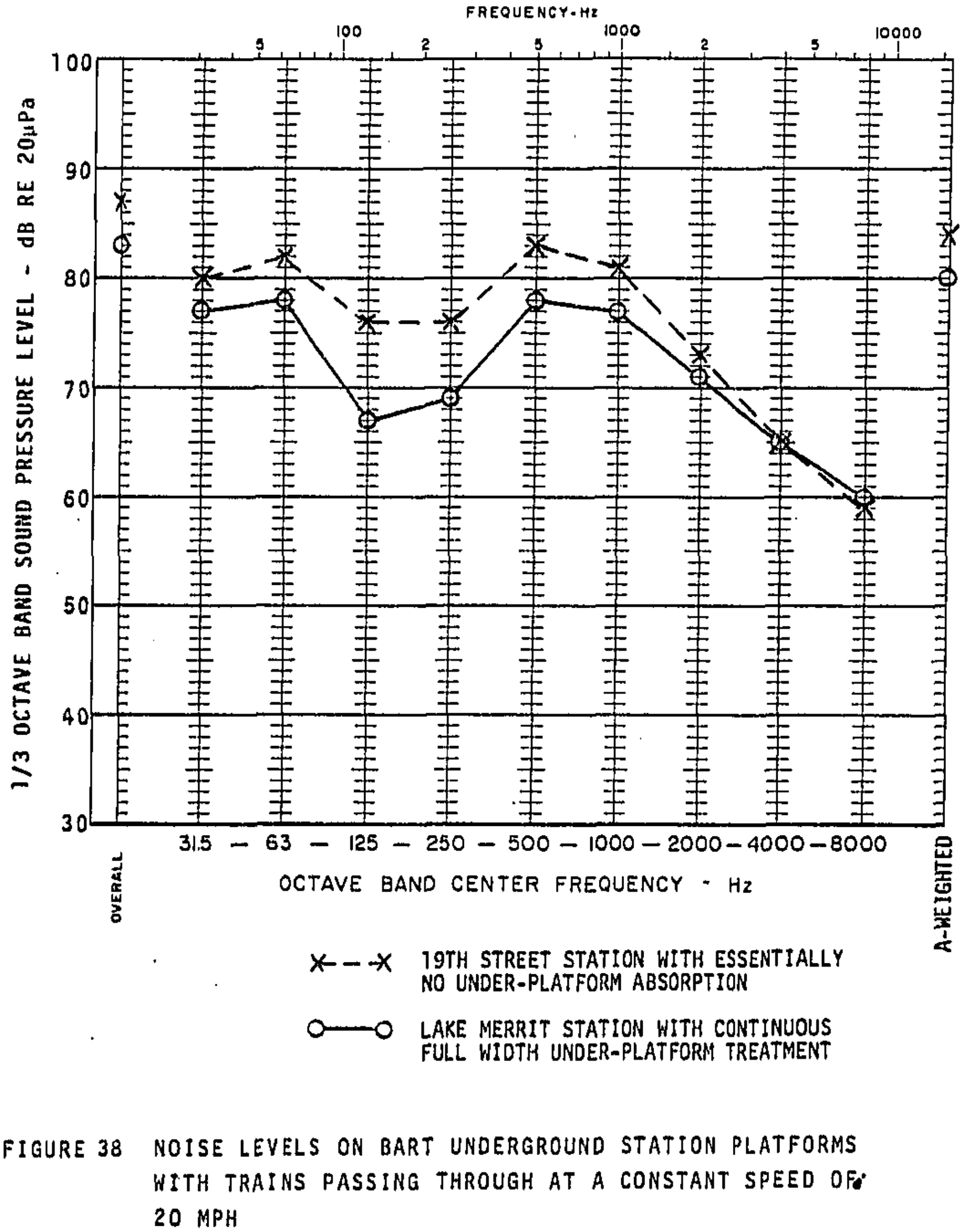


FIGURE 38 NOISE LEVELS ON BART UNDERGROUND STATION PLATFORMS WITH TRAINS PASSING THROUGH AT A CONSTANT SPEED OF 20 MPH

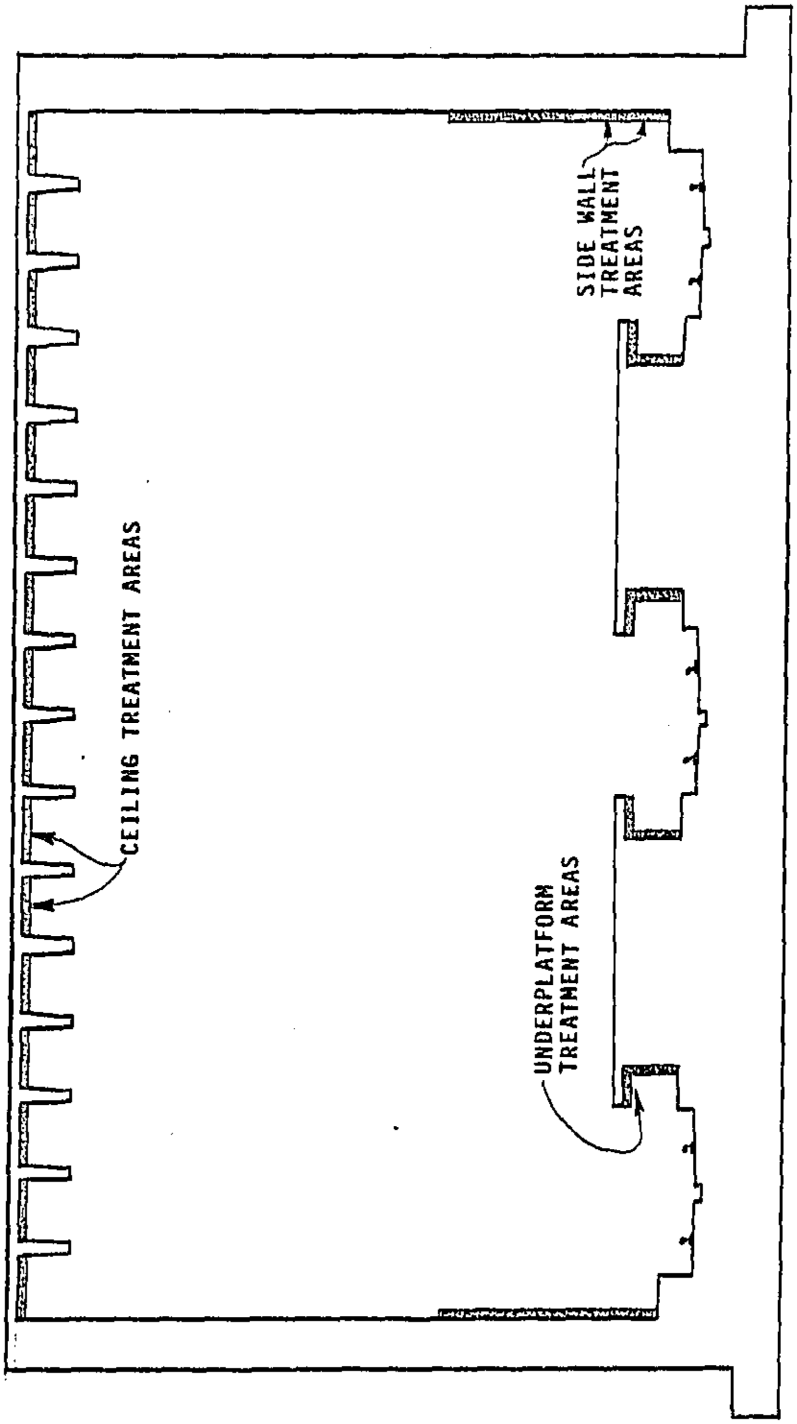


FIGURE 39 CROSS-SECTION OF THE O'HARE STATION CONFIGURATION SHOWING AVAILABLE AND RECOMMENDED AREAS FOR SOUND ABSORPTION TREATMENT

SOUND FROM ANCILLARY TRANSIT FACILITIES

There are sources of sound associated with a transit system other than trains alone. The subway ventilation fans are capable of generating significant sound levels and can create intrusion in neighboring noise sensitive areas. The noise from such fan shafts is discussed in the section "Fan and Vent Shaft Noise Control."

Power substations are also capable of generating sound which, although relatively low in level, can be obtrusive due to its tonal and continuous nature. The five substations to be built as part of the O'Hare Extension will all be located in close proximity to the expressway and sufficiently separated from residential dwellings that they should not present a noise impact, assuming normal substation construction which encloses the components of the substation within a building. The noise emitted from the substations should, however, be in compliance with the criteria of Table XIII.6 for continuous noises contained in the Noise and Vibration Criteria.

The sound power levels generated by the station ventilation and under-platform ventilation fans which may be used in the O'Hare Station should be in compliance with the criteria of Table XIII.7 contained in the Noise and Vibration Criteria. If the sound power levels produced by these fans are too high, it may be prohibitively expensive or even not technically feasible to adequately reduce the noise to the station criteria levels.

METHODS OF NOISE AND AIR PRESSURE CONTROL ASSOCIATED WITH FAN SHAFTS, VENT SHAFTS AND PORTALS

Fan and Vent Shaft Noise Control

A source of noise from transit operations which has been found to create intrusion or annoyance is the noise from fan and vent shafts. For the O'Hare Extension, the subway alignment which is long enough to have fan and vent shafts is located within the high noise area of the O'Hare International Airport. In this area, train operations will be limited to a maximum speed of 35 mph.

Fan shafts can radiate a continuous noise into the community from the ventilation fans operating in the shaft. A vent shaft is not, in itself, a noise source, however, it provides a path to the nearby community for sound from transit train operations in the subway tunnel. Thus, the fan shafts can contribute a steady noise into the community when the fans are operating, while both the fan and vent shafts can be sources of transient noise whenever a transit train passes the shaft.

Since the subway section of the O'Hare Extension is relatively short there will be few fan and vent shafts. Also, as mentioned above, the subway is in the immediate area of the O'Hare International Airport where there are very high levels of exterior noise due to jet aircraft landings and departures. Other factors contributing to the minimization of intrusion from the fan and vent shafts include the relatively slow train speed and the fact that the ventilation fans will normally be used for emergency purposes only.

Thus no sound absorption or other noise reduction treatment will be needed for the fan and vent shafts, since the openings will not be in a noise sensitive area. However, the criteria for fan sound power levels, given in Table XIII.7 of the Noise and Vibration Design Criteria for subway ventilation fans, should be followed.

Air Pressure Control at Portals

A factor related to passenger comfort and which should be considered in the design of a subway is the pressure transients which can occur when trains enter and leave the portal at speeds above 35 to 40 mph. The acceleration of the air in the tunnel due to piston action of the trains as trains enter a portal, the airflow through vent and fan shafts as trains pass the shafts, and the reduced static pressure behind the train and in the trailing cars (which returns to atmospheric as the trains exit the portal] all create pressure transients which affect the ears of passengers on board the trains. At higher speeds, without transition sections at the portals to reduce the rate-of-change in pressure, these pressure transients can be uncomfortable or painful to the passengers.

For the O'Hare Extension, the only subway section which is long enough to require consideration of pressure transients is the subway at the O'Hare Airport. The portal entry and exit at this subway section will be 35 mph or less and thus should not require any special design features to reduce the rate-of-change of the pressure at the portal.

ACOUSTICAL BARRIERS

For reduction of transit train passby noise when the train is traveling on at-grade or aerial structure, a barrier wall which physically blocks the path of noise between the source and receiver can be used. The use of sound barrier walls may be needed in noise sensitive areas even when continuously welded rail and modern state-of-the-art transit vehicles are utilized.

Along the O'Hare Extension alignment are a number of buildings which could be considered noise sensitive structures. However, no sound barrier walls will be needed to reduce the passby noise at these buildings due to several factors:

[1] The existing expressway traffic creates higher noise levels than anticipated from the operation of the transit trains.

[2] Jet aircraft landings and departures create high noise levels in the areas adjacent to the O'Hare Extension. These noise levels are considerably higher than will be produced from transit train operations.

[3] The anticipated passby noise levels from the transit trains for many operating modes will produce lower noise levels than recommended as acceptable for similar areas with considerably lower level of ambient or community noise.

Considering the above factors and the fact that a New Jersey style barrier [lower than a sound barrier wall] will be erected in the expressway median for safety reasons, the use of a sound barrier wall should not be necessary at any point along the O'Hare Extension Alignment.

It is recommended that acoustical barriers be used where feasible at the expressway median stations to reduce the noise exposure of patrons waiting on the station platforms. This barrier is discussed in the section "General Station Acoustics, Sound Control in Above-Grade Stations."

CONSTRUCTION NOISE

One of the impacts associated with a rail rapid transit system project is the short-term noise and vibration impact of construction activities. As with any large project, the construction of a rapid transit system involves the use of machines and procedures which, in the past, have resulted in intense noise levels and, occasionally, high vibration levels in and around the construction site. The O'Hare Extension Alignment will include primarily an at-grade configuration with subway structure near the O'Hare International Airport. Since most of the alignment is in the median of the Kennedy Expressway, only limited demolition work will be required. The construction activities will include clearing, grading, excavating, pile setting, drilling, materials handling and placement, erection and finish work and will involve the use of all the various kinds of machines and procedures which are associated with these activities.

In recent years considerable progress has been made in the reduction and control of construction noise through modifications of the equipment to reduce noise generated at the source, through modifications of construction procedures and by selection of those construction procedure alternates which are less noisy. Also, in many areas and for many types of construction projects there have been noise limits or noise standards included in the construction contracts or applied by governmental agencies in order to limit the noise impact from the construction. For the construction of the O'Hare Extension, the City of Chicago Noise Ordinance, administered by the Department of Environmental Control, will effectively limit the noise impact from construction activity. The efforts at reducing construction noise have produced considerable success and with new construction projects the work can be and is accomplished with considerably less noise impact than is traditionally expected.

The three general configurations of transit way structures, subway, aerial and at-grade have different construction techniques involved and, hence, produce somewhat different noise and vibration. Although most of the construction noise impact will arise from at-grade construction, the noise impact from construction of aerial structure and subway is also included for those areas near the alignment where these structures will be present.

For at-grade construction the impact will be due to demolition [if any]; clearing and grading; placement of materials, including any retaining walls and the ballast and ties and track; plus any finishing activities such as fencing and landscaping.

For the aerial structure configuration the activities will include demolition [if necessary]; ground clearing and grading; erection of foundations including, possibly, pile driving; construction of the aerial structure columns; erection of girders or concrete deck and the finishing.

For subway construction the acoustical impacts will be of two different characters. In the areas where tunneling is used, the only impact due to the construction activities [except at access shafts] will be the ground-borne vibration due to the excavation process, either the tunnel boring machine or drilling. Also, there may be some ground-borne vibration due to the vehicles used to remove material. For cut-and-cover subway there will be impacts due to ground clearing, excavation, erection and finishing activities.

Airborne Noise from Construction

Controls should be exercised over construction noise both for the protection of hearing of contractor employees and to protect the public from excessive and unnecessary noise levels as they conduct their normal activities near the construction site.

To avoid intrusion in buildings near construction sites it is necessary to provide criteria for maximum noise levels permitted by construction operations. They must, of course, be more restrictive during normal rest or recreation periods than during normal daytime periods of high activity, and the limitations must take into account the duration of the noises. The recommended criteria are shown in Table XII, Parts [1] and [2].

The criteria given in Table XII, Part [3] indicate the limits which should be placed on the sound level created by any individual piece of construction equipment used on the job, including hand tools, stationary power tools, vehicles and heavy equipment.

The criteria stated in Table XII, Part [3] are from Section 17-4.8 of the City of Chicago Noise Ordinance. The criteria would be difficult to meet with some vehicles and tools current in 1978, but the progressive nature of the criteria reflects improvements in noise characteristics expected for new equipment. Contractors should be encouraged to utilize the quiet equipment which will be available and to maintain effective control on noise generated by aging equipment.

The criteria indicated in Table XII are primarily intended for application in residential areas, semi-residential/commercial areas, and commercial areas, i.e., Area Categories I, II, III and IV as defined by Table XIII.2 of the Noise and Vibration Design Criteria. For industrial/highway corridor areas, Category V, the use of construction noise limit specifications may not be necessary. Due to the generally high noise levels existing adjacent to the O'Hare Extension Alignment, if the ambient noise level at an affected structure exceeds the allowable noise limit, then the ambient noise level will become the new allowable noise limit.

TABLE XII CONSTRUCTION NOISE LIMITS

[1] Continuous Noise

Affected Structure	Maximum Allowable Continuous Noise Level - dBA	
	Daytime	Nighttime
Residential		
- in quiet residential areas	60	50
- on arterial or in multi-family residential areas	65	55
- in semi-residential/ commercial areas	70	60
	At All Times	
Commercial		
- in Semi-residential/ commercial areas	70	
- in commercial areas with no nighttime residency	75	
Industrial		
- All Locations	80	

TABLE XII [CONTINUED]

[2] Intermittent Noise

Affected Structure	Maximum Allowable Intermittent Noise Level - dBA Daytime	Nighttime
Residential		
- in quiet residential areas	75	60
- on arterial or in multi-family residential areas	80	65
- in semi-residential/ commercial areas	85	70
	At All Times	
Commercial		
- in semi-residential/ commercial areas	85	
- in commercial areas with no nighttime occupancy	85	
Industrial		
- All Locations	90	

[3] Equipment Noise Emission Restrictions [from City of Chicago Noise Ordinance]

Type of Equipment	Noise Limit
(1) Construction and industrial machinery, such as crawler-tractors, dozers, rotary drills and augers, loaders, power shovels, cranes, derricks, motor graders, paving machines, off-highway trucks, ditchers, trenchers, compactors, scrapers, wagons, pavement breakers,	

TABLE XII [CONTINUED]

Type of Equipment	Noise Limit	
compressors, and pneumatic powered equipment, etc., but not including pile drivers.		
Manufactured after 1 January 1972	94 dBA	
Manufactured after 1 January 1973	88 dBA	
Manufactured after 1 January 1975	86 dBA	
Manufactured after 1 January 1980	80 dBA	
(2) a. Highway Trucks [motor vehicle with a gross vehicle weight of 8000 lb or more]		
Manufactured after 1 January 1973	86 dBA	
Manufactured after 1 January 1975	84 dBA	
Manufactured after 1 January 1980	75 dBA	
	Noise Limit in Relation to Speed Limit	
b. Operation of Highway Trucks	35 mph or less -	86 dBA
	Over 35 mph -	90 dBA

Use only equipment which will meet the noise limits specified when measured 50 ft from the equipment in substantial conformity with the provisions of SAE J366a and SAE J952b, in accordance with the measurement procedures specified in the Noise Ordinance of the City of Chicago, and as specified below.

TABLE XII [CONTINUED]

[4] Impact Noise Restrictions

Prevent noise emanating from construction sites, measured at the boundary, from exceeding a peak impulse or impact noise level of 140 dB, as measured with a standard impulse sound level meter [or alternatively, 125 dBC fast as measured on a Type 2 General Purpose sound level meter] or a noise level of 90 dBA slow as measured on a Type 2 General Purpose sound level meter.

[5] Measurement Procedures

(a) Except where otherwise indicated, perform all noise measurements using the A-weighted network and (slow) response of an instrument complying with the criteria for a Type 2 General Purpose sound level meter as described in ANSI S1.4. Measure impulsive or impact noises with an impulse sound level meter complying with the criteria of IEC 179 for impulse sound level meters. As an alternative procedure, a Type 2 General Purpose sound level meter on C-weighting and (fast) response may be used to estimate peak values of impulsive or impact noises. Transient meter indications of 125 dBC (fast) or higher will be considered as indications of impulsive noise levels of 140 dB or greater.

(b) Measure noise levels at buildings affected acoustically by the Contractor's operations at points between 3 ft and 6 ft from the building face to minimize the effect of reflections.

(c) Measure noise levels at points on the outer boundaries of Construction Limits or Special Construction Sites for Noise emanating from within.

(d) Where more than one criterion of noise limits are applicable, use the more restrictive requirement for determining compliance.

(e) When conditions require that demolition or construction activities be located less than 50 ft from the construction limits or boundary of a Special Construction Site, the

TABLE XII [CONTINUED]

noise level may exceed 90 dBA by the amounts shown below, except do not exceed the noise levels at the affected structure specified in Sections [1] and [2] above.

Distance of Source from Boundary - ft	Permissible Excess
0 - 5	20
6 - 10	14
11 - 20	8
21 - 30	5
31 - 40	2
41 - 50	0

Ground-Borne Vibration from Construction

Because of the nature of some construction activities, high amplitudes of ground-borne vibration may result in some impact in neighboring community areas. Blasting and impact pile driving are two types of activities traditionally associated with high levels of ground-borne vibration. It is also possible that some types of heavy vehicles and excavation activities can generate sufficient ground-borne vibration level to be perceptible or noticeable in nearby buildings.

The vibration levels created by the normal movement of vehicles including graders, loaders, dozers, scrapers and trucks generally are the same order of magnitude as the ground-borne vibration created by heavy vehicles running on streets and highways. Large trucks and buses operating on city streets and on highways generate ground-borne vibration due to wheel/roadway interaction and particularly high vibration levels can be associated with truck and bus operations on rough or pock-marked streets. In general, the ground-borne vibration from vehicle operations on streets, even very rough streets, is not sufficient to create noticeable impact on adjacent community areas. This vibration is of a level that is generally imperceptible or barely perceptible and is considered acceptable, producing little or no impact. Thus, it can be expected that the normal vehicle activities at the construction sites will not generate sufficient ground-borne vibration to result in significant impact.

Blasting, drilling and excavation procedures can result in ground-borne vibration levels which are perceptible or noticeable in adjacent community areas. The amplitudes of vibration from such activities are limited for safety reasons by procedural techniques. For example, through the use of time delay charges in blasting the maximum amplitude of the ground-borne vibration is limited to a level well below the criteria for structural damage to adjacent facilities. Impact pile drivers, which create considerable noise and vibration, also produce vibration levels which are well below the intensity required for structural damage to adjacent buildings and other facilities.

Tunnel boring machines also create ground-borne vibration, however, experience to date indicates that the vibration from the use of such machines is considerably less in intensity than that from blasting or pile driving and that it is not significantly greater than the vibration created by heavy trucks traveling on city streets. The ground-borne vibration levels from a boring machine are probably intermediate between the ground-borne vibration levels created by operations of transit trains and the operations of mainline railroad vehicles and may, therefore, produce some short-term intrusion.

In reducing the ground-borne vibration from construction activities, the most important factor is the selection of construction techniques. The use of drilled piles or vibratory pile drivers in lieu of impact pile drivers can completely eliminate pile driving as a source of ground-borne vibration. The use of tunnel boring machines rather than blasting would considerably reduce the ground-borne vibration due to tunnel boring. Most of the other types of construction activities do not cause significant ground vibration. For those which do or may be expected to create some significant ground vibration the best procedure is to locate the activity at a point distant from nearby community buildings. Ground-borne vibration attenuates rapidly with distance in soil and by appropriate selection of locations for construction yards, gravel dumps, muck train terminals, etc., the possibility of ground-borne vibration impact can be minimized.

III. NOISE AND VIBRATION CONTROL DESIGN CRITERIA

III. NOISE AND VIBRATION CONTROL DESIGN CRITERIA
[Section XIII of O'Hare Extension Design Criteria]

NOISE AND VIBRATION CONTROL

A. GENERAL

1. Purpose

The primary objectives of noise and vibration control are:

- Provision of an acoustically comfortable environment for system patrons by maintaining noise and vibration levels in transit vehicles and stations within acceptable limits.

- Provision for reducing or minimizing the adverse impact of system operation on the community by minimizing transmission of noise and vibration to adjacent buildings and structures.

Achievement of these objectives requires design oriented to the reduction of airborne and ground-borne noise generated by transit sources which is experienced by the patrons or which is transmitted to adjacent facilities. Attention should also be given to patron noise exposure caused by traffic in open stations adjacent to highways, streets or other noise sources such as railroad operations. Airborne noise is produced by transit trains traveling on the transit right-of-way, by the auxiliary equipment on the transit cars and by ancillary facilities such as ventilation systems and traction power substations. Ground-borne noise is generated by transit trains due to the vibration transmitted from the transit train wheel/rail interface through the ground to adjacent buildings, where the vibration can be reradiated as audible noise.

2. <u>Scope</u>

There are many areas in and near the transit system where acoustical control provisions are needed. These areas include:

For the comfort of transit system patrons and employees:

- Station platforms, mezzanines, concourses, corridor and entrance areas.
- Vehicle interior noise.
- Vehicle exterior noise when in stations.

For the protection of the wayside community near the system:

- Fan and vent shafts and other transit system ancillary facilities.
- Vehicle exterior noise.
- Transit structures which may radiate airborne or ground-borne noise to

community areas or buildings adjacent to the transit line.

Control of the noise can be accomplished by two different approaches: [1] limiting the noise generated by the transit system equipment and [2] limiting the noise transmitted into stations and the wayside community by applying noise control features to fixed facilities. Since the O'Hare Extension will use existing CTA transit vehicles, meeting the criteria will require noise and vibration control applied to the fixed facilities, possibly including special noise reduction features such as the use of sound barrier walls.

The actual noise levels produced by the transit system equipment and the mechanisms of noise generation are not discussed in this document. These subjects are covered in a separate report on Noise and Vibration. These criteria, therefore, concentrate only on the goals and procedures for control of noise and vibration by applying noise control features to fixed facilities.

3. Basis

The noise and vibration control criteria are based on data obtained from existing rail transit systems and experimental studies done at these systems. The determination of noise and vibration control criteria include consideration of the levels which can be achieved through controls that are feasible, both technically and economically, of the noise levels that are considered acceptable to system patrons in stations, and of the noise levels which will be acceptable to the public. The acceptability of noise generated by transit train operations is largely dependent on the type of wayside community and the activities taking place at a site.

One of the basic references for the noise and vibration control criteria is "Guidelines and Principles for Design of Rapid Transit Facilities", Section 2-7, Noise and Vibration, to be issued by the American Public Transit Association (APTA). This document defines design goal sound levels in station areas, in transit vehicles and the design goals for noise transmitted from transit train operations and ancillary facilities into the wayside community.

Another factor affecting the criteria is the City of Chicago Noise Ordinance administered by the Department of Environmental Control.

The criteria specified in this document include the consideration of the requirements and intent of the Noise Ordinance for limiting environmental noise in Chicago.

The background information, the published guidelines and the noise ordinance requirements, coupled with experience obtained from operations of new rail transit systems which have favorable noise performance characteristics resulting from the use of modern design concepts and equipment, all provide information leading to the determination of appropriate criteria and procedures for noise and vibration control.

B. NOISE AND VIBRATION CONTROL REQUIREMENTS

1. <u>Station Noise Level Design Goals</u>

The control of noise levels in stations is an important factor in determining overall satisfaction of patrons with the system. The noise level limits for stations are intended to establish a gradual transition for the patrons from the outdoor noise levels through the stations to the typical noise levels they will experience when riding in the transit cars. Station noise level design goals are appropriate since, for example, the acoustical treatment of subway stations has a strong influence on noise levels with cars entering, passing through or standing at a platform. One of the factors which strongly influences station noise in enclosed spaces is the "reverberation time", defined as the time required for a sound to decay in level by 60 decibels after the source has stopped. The acoustical control requirements for stations, therefore, include limits on the range of the reverberation time. Table XIII.1 lists the design goals for underground and at-grade stations.

TABLE XIII.1 STATION NOISE CONTROL REQUIREMENTS

Underground Stations	Design Goal
On Platform, trains entering and leaving	80 dBA
On Platform, trains passing through	85 dBA
On Platform, trains stationary	68 dBA
On Platform or in Mezzanine Areas - with only the station ventilation system and other auxiliaries operating	55 dBA
Manned Booths in Station Areas - noise due to ventilation system and booth equipment	50 dBA
Range of design reverberation time at 500 Hz for train room or Platform Areas	1.2 to 1.4 secs
Range of design reverberation time at 500 Hz for Mezzanine and Concourse Areas	1.0 to 1.4 secs

At-Grade Stations	Design Goal
On Platform, trains entering and leaving -	
ballast and tie trackbed	75-80 dBA
concrete trackbed	80-85 dBA
On open Platform, noise from traffic on nearby streets, highways or expressways	75 dBA L_{50} 80 dBA L_{10}
On open Platform, noise from stationary sources	60 dBA
Enclosed Public Spaces - ventilation system and other sources	55 dBA
Manned Booths in Station Areas	50 dBA
Range of design reverberation time at 500 Hz for enclosed areas	1.0 to 1.2 secs

2. <u>Ground-Borne Noise Level Design Criteria</u>

For underground transit operations, noise from transit trains can be transmitted as vibration through the ground and transformed into sound in buildings by radiation from the vibrating room surfaces. The sound in nearby buildings due to subway operations takes the form of a very low frequency rumble, since higher frequency vibrations are attenuated very rapidly in passing through the soil, in making the transition from soil to building structure, or in transmitting from subway structure to a building through a vibration isolation medium.

Permissible noise levels in nearby buildings and wayside communities due to the transit train operations must be related to the type of community, to the type of occupancy and activity taking place in the building or community and must be related to the prevailing average and peak noise level in the building or community in the absence of the transit system noise. A passby noise level of a given magnitude will be more objectionable in a quiet park-like environment or in a quiet residential area at night than it will be in a busy commercial area during the day or during the night when there are few occupants in the area. Table XIII.2 lists five generalized categories of wayside communities in which transit system facilities may be located and the normal range of ambient noise expected in each community category.

TABLE XIII.2 NOISE LEVELS IN GENERAL COMMUNITY CATEGORIES

Category	Area Description	Normal Expected Range of Daytime Average Ambient Noise Levels	Normal Expected Range of Nighttime Average Ambient Noise Levels
I	Low Density urban residential, open space park, suburban residential or quiet recreational area. No nearby highways or boulevards.	40-50 dBA	35-45 dBA
II	Average urban residential, quiet apartments and hotels, open space, suburban residential, or occupied outdoor area near busy streets.	45-55 dBA	40-50 dBA
III	High Density urban residential, average semi-residential/commercial areas, parks, museum and non-commercial public building areas.	50-60 dBA	45-55 dBA
IV	Commercial areas with office buildings, retail stores, etc., primarily daytime occupancy. Central Business Districts.	60-70 dBA	55-65 dBA
V	Industrial or Freeway and Highway Corridors.	Over 60 dBA	Over 60 dBA

Based on the typical noise levels encountered in transit corridor communities and based on considerations of noise intrusion or acceptability for different types of occupancies and building uses, the noise level limits given in Table XIII.3 have been determined to be appropriate as the design goal maximum noise levels for ground-borne noise from transit trains.

TABLE XIII.3

A. CRITERIA FOR MAXIMUM GROUND-BORNE NOISE FROM TRANSIT TRAIN OPERATIONS FOR VARIOUS BUILDING USE CATEGORIES

Type of Building or Room	Ground-Borne Single-Event Passby Noise Design Criteria
Concert Halls and TV Studios	25 dBA
Auditoriums and Music Rooms	30 dBA
Churches and Theatres	35 dBA
Hospital Sleeping Rooms	35-40 dBA
Courtrooms	35 dBA
Schools and Libraries	40 dBA
University Buildings	35-40 dBA
Offices	35-45 dBA
Commercial Buildings	45-55 dBA

B. CRITERIA FOR MAXIMUM GROUND-BORNE NOISE FROM TRANSIT TRAIN OPERATIONS FOR RESIDENTIAL BUILDINGS

Community Area Category		Maximum Single-Event Passby Ground-Borne Noise Level Design Criteria		
		Single Family Dwellings	Multi-Family Dwellings	Hotel/Motel Buildings
I	Low Density Residential	30 dBA	35 dBA	40 dBA
II	Average Residential	35 dBA	40 dBA	45 dBA
III	High Density Residential	35 dBA	40 dBA	45 dBA
IV	Commercial	40 dBA	45 dBA	50 dBA
V	Industrial/Highway	40 dBA	45 dBA	55 dBA

3. Airborne Noise Level Design Criteria

Noise from train operations at-grade or on aerial structure is transmitted through the air and into the wayside community. The noise is transient due to the short duration of the train passby, but the transit operations, although of comparable level to many existing noises, can represent a new noise nuisance in the community.

In measuring, evaluating and defining criteria for the passby noise radiated into the wayside community, the use of a single event maximum noise level is appropriate for transit facility design. Noise level limits for train operations should be related to the five general categories of community areas presented in Table XIII.2 and the type of building. The single-event maximum noise level design criteria for airborne noise from transit trains in each of the community areas and for several types of buildings or occupancies are given in Table XIII.4

TABLE XIII.4 GUIDELINES FOR MAXIMUM AIRBORNE NOISE FROM TRAIN OPERATIONS

Community Area Category		Single-Event Passby Maximum Noise Level Design Criteria: Single Family Dwellings	Multi-Family Dwellings	Commercial Buildings
I	Low Density Residential	70 dBA	75 dBA	80 dBA
II	Average Residential	75 dBA	75 dBA	80 dBA
III	High Density Residential	75 dBA	80 dBA	85 dBA
IV	Commercial	80 dBA	80 dBA	85 dBA
V	Industrial/Highway	80 dBA	85 dBA	85 dBA

These design criteria are applied to nighttime operations because the sensitivity to noise is greater at night than during daytime hours. These criteria should be applied outdoors and referenced to the building or area under consideration but not closer than 50 feet from track centerline. Because of the transient nature of train noise, community acceptance should be expected if the noise levels do not exceed these criteria at night at the affected buildings or use areas.

For some types of buildings or occupancies, maximum noise level limits should be applied regardless of the community area category. Table XIII.5 lists criteria for maximum airborne noise from transit train operations in these areas.

TABLE XIII.5 CRITERIA FOR MAXIMUM AIRBORNE NOISE FROM TRAIN OPERATIONS

Building or Occupancy Type	Single-Event Passby Maximum Noise Level Design Criteria
Amphitheatres	60 dBA
"Quiet" Outdoor Recreation Areas	65 dBA
Concert Halls, Radio and TV Studios, Auditoriums	70 dBA
Churches, Theatres, Schools, Hospitals, Museums, Libraries	75 dBA

4. Ancillary Facility Noise Level Limits

There are sources of community noise from a transit system other than train operations alone. The underplatform heat removal fans and subway emergency ventilation fans are capable of generating significant noise levels and, if fan shafts or ducts are untreated and/or fan shaft openings are located close to residential or other noise sensitive areas, then excessive community noise levels can be created. Power sub-stations are also capable of generating noise which, although relatively low in level, can be obtrusive due to its tonal and continuous nature. Both heat removal or station ventilation fans and power sub-stations are examples of what are termed "continuous noise sources", as opposed to the transient noises caused by passing trains or temporary operation of emergency ventilation fans.

A relief shaft is not, in itself, a noise source, however, it provides a path to the nearby community for sound from trains passing in the subways. The noise transmitted through the shaft is therefore a contributing factor to transient noises in the community. Thus, acoustical treatment of fan and relief shafts is frequently required and some defined noise level limits are needed to define the noise reduction treatment necessary and to provide for efficient use of materials.

In defining noise level criteria from ancillary systems, the five general community areas defined in Table XIII.2 are used. The maximum noise levels for both transient (e.g., transit train passbys) and continuous noises are given in Table XIII.6.

TABLE XIII.6 CRITERIA FOR NOISE FROM TRANSIT SYSTEM ANCILLARY FACILITIES

Community Area Category		Maximum Noise Level Design Criteria: Transient Noises	Continuous Noises
I	Low Density Residential	50 dBA	40 dBA
II	Average Residential	55 dBA	45 dBA
III	High Density Residential	60 dBA	50 dBA
IV	Commercial	65 dBA	55 dBA
V	Industrial/Highway	75 dBA	65 dBA

The limits in Table XIII.6 should be applied at 50 feet from the shaft outlet or other ancillary facility or should be applied at the setback line of the nearest buildings or occupied area, whichever is the shorter distance. Transient noise design limits apply to short time duration events such as train passby noise transmitted from vent shaft openings. Continuous noise design limits apply to noises such as fans, cooling towers, or other long duration noises except electrical transformer hum. The design limits for transformer noise or hum should be 5 dBA less than given for continuous noises in Table XIII.6.

To provide a basis for the design of fan noise control measures and to achieve an acceptable balance between the cost of quiet fans and the cost of noise control measures, it is necessary to specify maximum permissible sound power level ratings for the fans. The maximum acceptable sound power levels from the subway emergency ventilation fans and the underplatform heat removal fans are given in Table XIII.7.

The specified sound power levels refer to fans operating without a silencer or attenuator attached. Silencers are produced by many manufacturers and are one of the primary methods that can be used to control fan noise. The attenuation they can provide must, therefore, be available as a method of achieving additional noise reduction in critical situations and may not be used to bring an excessively noisy fan into compliance with the sound power limit requirement.

The advantages of the use of fans even quieter than specified should be emphasized. With the recommended sound power level specifications, noise abatement measures will be needed on most fans. If fans generating sound power levels 10 dB below the recommended maximum ratings are used, considerably less acoustical treatment will be neeeded with a possible net savings in cost.

TABLE XIII.7 CRITERIA FOR VENTILATION FAN MAXIMUM SOUND POWER LEVELS

Octave Band Center Frequency - Hz	Subway Emergency Ventilation Fans - Sound Power Level - dB re 10^{-12} Watts	Underplatform Heat Removal Fans - Sound Power Level - dB re 10^{-12} Watts
63	87	76
125	96	76
250	98	75
500	99	72
1000	99	78
2000	94	78
4000	91	71
8000	90	70

Fans shall have certified sound power levels not to exceed the above decibel ratings, re 10^{-12} watts, when operating under specified load conditions and measured at the fan in accordance with the AMCA test code. Emergency ventilation fans shall be operated in both directions with inlet bell and outlet cone for sound power verification tests.

C. NOISE AND VIBRATION CONTROL PROCEDURES

1. <u>Subway Station Areas Directly Related to Street Traffic Noise</u>

a. <u>Areas Involved:</u>

- Entrance areas.
- Stairs, Escalators and Elevators from street level.

b. <u>General Considerations:</u>

- These areas should be shielded from street and highway traffic noise, where practicable.
- The reverberation time of the area should be in the range of 1.0 to 1.2 seconds at 500 Hz when area is unoccupied.

c. <u>Acoustical Treatment:</u>

- Width of treatment equivalent to 20 to 25 percent of the cross-section perimeter or 70 to 100 percent of the ceiling is required. The treatment can consist of an absorptive wall panel system, an acoustical panel or other acoustical absorption assembly applied to the ceiling or a combination of these. The acoustical treatment should have a Noise Reduction Coefficient, NRC, of at least 0.65.

2. <u>At-Grade Station Areas Related to Noise From Street Traffic, Highway Traffic and Railroad Operations</u>

a. <u>Areas Involved:</u>

- Entrance areas.
- Stairs, Escalators and Elevators.
- Platforms.
- Corridor and Mezzanine areas.

b. <u>General Considerations:</u>

- Where feasible and practical, these areas should be shielded from street, highway and railroad vehicle noise.
- For open areas, particularly platforms, from the noise standpoint, it is desirable to have sound barriers blocking the sound path between the noise source and the patron area.

c. <u>Acoustical Treatment:</u>

- Enclosed areas such as stairs, corridors or mezzanines should have sound absorption treatment applied as given by C.1.c., C.3.c., C.4.b., and C.5.b.

3. <u>Concourse and Mezzanine Areas</u>

a. <u>Areas Involved:</u>

- Circular areas.
- Fare Collection areas.

- Stairs and Escalators.
- Corridors.

b. General Considerations:

- The maximum noise level from mechanical and electrical equipment should not exceed 55 dBA in the absence of occupants.
- For spaces in typical or standard size stations, the reverberation time of the area should be 1.0 to 1.2 seconds at 500 Hz when the area is unoccupied.
- For large concourse areas in large multi-track, multi-platform stations (e.g., O'Hare Station), the reverberation time should be 1.2 to 1.4 seconds at 500 Hz when the area is unoccupied.

c. Acoustical Treatment:

- Typical configuration mezzanines and corridors should have acoustical treatment panels or assemblies covering at least 30 percent of the walls and 50 percent of the ceiling. In narrow spaces the treatment could be concentrated on the ceiling, covering 70 to 100 percent of the ceiling area. The acoustical treatment should have an NRC of at least 0.65 and a minimum absorption coefficient of 0.65 at 500 Hz (e.g., 1" thick glass fiber boards of 2 to 6 lb/cu ft density).

- Large concourse areas, such as at the O'Hare Station, should have acoustical treatment panels or assemblies covering at least 60 percent of the walls and 50 percent of the ceiling. The acoustical treatment should have an NRC of at least 0.65 and a minimum absorption coefficient of 0.65 at 500 Hz.

4. Platform Areas in Subway Stations

   a. General Considerations:

   - Maximum noise level due to station ventilation system and other operating auxiliaries should not exceed 55 dBA.
   - For typical platform configurations, the reverberation time of the train room should not exceed 1.2 seconds at 500 Hz when the area is unoccupied.
   - For large multi-track, multi-platform stations, the reverberation time of the train room should not exceed 1.4 seconds at 500 Hz when the area is unoccupied.

   b. Acoustical Treatment:

   - The underplatform edge vertical and horizontal surfaces should be covered with an acoustical material having a minimum absorption coefficient of 0.45 at 125 Hz and 0.75 at 250 Hz (e.g., 3" thick glass fiber boards or a spray-on material on metal lath).

- Ceilings should have an acoustical treatment covering 50 percent of the ceiling area and having a sound absorption coefficient of at least 0.55 at 250 Hz (e.g., 2" thick glass fiber boards).
- For typical configuration center platform stations, the side walls should have an acoustical treatment covering 30 percent of the wall area with the treatment concentrated on the lower portion of the wall, near the invert. The treatment should have an absorption coefficient of at least 0.55 at 250 Hz.
- For large multi-track, multi-platform stations, the side walls should have an acoustical treatment covering 60 percent of the wall areas and with an absorption coefficient of at least 0.55 at 250 Hz.

5. At-Grade Station

a. General Considerations:

- The noise level in enclosed areas,

excluding platforms with canopies, due to ventilation system and other stationary equipment sources should not exceed 55 dBA.

b. Acoustical Treatment:

- At least 50 percent of the ceiling of enclosed mezzanine, concourse and platform areas, excluding platform areas with canopies, should be covered with acoustical material having an NRC of at least 0.65 and a minimum absorption coefficient of 0.60 at 500 Hz.

6. Ancillary Areas in Stations

a. Areas Involved:

- Toilet, locker and service rooms.
- Electrical equipment, train control equipment and traction power equipment rooms.
- Mechanical equipment rooms.

b. General Considerations:

- Spaces for fans and other potentially noisy equipment shall be separated from public areas as much as possible. Access to such noisy areas should be through double doors or sound-treated doors.

c. Acoustical Treatment:

- Toilet, locker and service rooms should have acoustical treatment applied to cover 60 to 100 percent of the ceilings for control of reverberation and noise. The acoustical absorption material should have an NRC of at least 0.55.
- Electrical equipment rooms, train control equipment rooms and traction power equipment rooms with noise generating equipment should have acoustical treatment covering at least 40 to 50 percent of the ceiling area. The acoustical material should be an equipment room type of ceiling/wall treatment, such as 1" thick glass fiber board, and should have an NRC of at least 0.65.
- Mechanical equipment rooms housing fans, chillers, pumps and other equipment which generates high sound levels should have sound absorption treatment equivalent to 2" thick glass fiber board or blanket (minimum NRC of 0.75) applied to cover 30 percent of the total wall area and 50 percent of the total ceiling area in the rooms. In other spaces with equipment

which generate only low or moderate noise, the acoustical treatment should be as indicated above for electrical equipment rooms.

7. <u>Fare Collection and Vertical Circulation Machinery</u>

   a. <u>Equipment Involved:</u>

      - Fare Collection equipment.
      - Escalators.
      - Elevators.

   b. <u>General Considerations:</u>

      - For equipment located in public areas and for all normal operating conditions, the noise level at 3 ft from the above listed equipment shall not exceed 55 dBA for steady-state noise, either in free space or in installed condition, and transient noises shall not exceed 60 dBA measured using the fast meter response.

8. <u>Running Tunnels</u>

   a. <u>General Considerations:</u>

      - Sound absorption materials shall be applied to the side walls of the subway running tunnels with direct fixation track to provide 8 to 10 dBA reduction of the in-tunnel noise for areas where train speeds exceed 35 mph. This will provide for 5 to 8 dBA reduction of the car interior noise in air conditioned cars and 8 to 10 dBA reduction for cars with operable windows or other natural ventilation openings. No treatment is needed for ballasted track tunnels.

b. Acoustical Treatment:

- The sound absorption system for the subways shall consist of a continuous application of spray-on absorption material, or approved alternate, on both side walls in tunnel and box structures.
- Spray-on mineral fiber material shall be applied with the area of treatment being nominally the full height of the side walls from the invert up for a 1/2" to 5/8" application and 3/4 the height of the side walls from the invert up for a 3/4" to 1-1/4" thick application.
- As shown by similar applications, the sound absorption system shall demonstrate sufficient durability and exhibit maintenance-free characteristics.

9. Fan and Relief Shafts

a. Areas Involved:

- Fan and Relief shafts with surface gratings or openings.
- Surface or above-grade openings or louvers for mechanical and/or electrical equipment.

b. General Considerations:

- The noise emanating from surface or above-grade gratings, louvers or openings shall be limited to conformance with Table XIII.6.

c. Acoustical Treatment:

- Relief shaft noise reduction shall be achieved by absorption treatment in the shafts — applied to the walls and ceilings.
- Fan shaft noise reduction shall be achieved by use of standard duct attenuators in shafts where the fans are near the surface gratings. For shafts with fans located remotely from the grating the noise reduction shall be acheived by the use of standard attenuators and sound absorption treatment applied to the fan rooms and

shaft walls and ceilings with the combination to achieve the total attenuation required.

10. Vibration Isolation of Subway Structures

a. Locations Involved:

- Any point where the subway structure is in very close proximity or directly against a building structure or building foundation elements.

b. General Considerations:

- Vibration isolation in the form of a resilient element should be provided between the subway structure elements and building structure elements for noise critical buildings to prevent direct transmission of noise and vibration to buildings.

c. Isolation Elements:

- The resilient element between the two structures should consist of intervening soil of at least 2 feet thickness or depth, or should be an elastomer pad between the subway structure and building.
- The elastomer pad shall be a 1" or 2" thickness closed-cell expanded neoprene

selected to give proper support with deflection of 10 to 20 percent.

11. Aerial Structures

a. General Considerations:

- For noise sensitive areas, aerial structures shall be of all reinforced concrete construction with resilient direct fixation rail fasteners, or shall be of composite steel/concrete construction with ballast and tie track on a concrete deck.
- For aerial structures adjacent to noise critical buildings and facilities, a sound barrier wall blocking the path of noise shall be used.

12. Rail Fixation and Support

a. Areas Involved:

- Subway running tunnels.
- Subway stations.
- Aerial structures with concrete trackbed.

b. General Considerations:

- For running tunnels and stations in areas where adjacent buildings are not critical relative to ground-borne noise, resilient direct fixation rail fasteners on rigid invert shall be used.

- For running tunnels and stations adjacent to noise critical buildings and facilities, a vibration isolating trackbed with resilient direct fixation rail fasteners may be used if required.
- For all-concrete aerial structures, resilient direct fixation fasteners shall be used.
- For composite steel/concrete aerial structures, a concrete deck with a ballast and tie trackbed shall be used.

c. Fixation Systems:

- For standard trackwork, direct fixation rail fasteners shall be of the bonded elastomer pad type, having a vertical static stiffness in the range of 80,000 to 120,000 lb/in and spaced not less than 30" o.c. For special trackwork, the direct fixation rail fasteners shall be spaced not less than 18" o.c., or the fasteners arranged to have a rail support modulus of not greater than three (3) times the rail support modulus of standard trackwork.

- Vibration isolating trackbed, if required, may be of either the continuous or discontinuous floating slab type, providing a minimum mass of 1000 lb/ft along the track and a vertical natural frequency not above 16 Hz when unloaded.

13. Wayside Noise Reduction for At-Grade and Aerial Alignment

a. Locations Involved:

- Sections along the alignment where the criteria in Table XIII.4 of Section B.3 will be exceeded.

b. General Considerations:

- Noise reduction of airborne noise is best achieved by the use of sound barrier walls which physically block the path of noise between source and receiver.

c. Physical Characteristics:

- To be effective, the wall height should be such that the top of wall is 8" to 12" above the car skirt bottom.
- The wall should have no openings or cracks and have a minimum weight per unit area of 3.0 to 3.5 lb/ft^2.

- For aerial structures, sound barriers should be added to aerial structures with concrete trackbed where required. Sound barriers are not necessary on all-steel aerial structures because they are not effective on such structures.