Ain Shams University
Faculty of Engineering
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Effect of Architectural Treatments on Acoustic Environment

Case Study: Underground Stations

By

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Statement

This thesis is submitted to Ain Shams University for the degree of Master in Architecture . The work included in this thesis was accomplished by the author at the Department of Architecture, Faculty of Engineering, Ain shams University from 2006 to 2010.

No part of this thesis has been submitted for a degree or a qualification at any other university or institute.

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All Reverberation Time and background noise level Measurements were conducted after permission from the National Authority for Tunnels by an Academic Team from AinShams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultan and Dr Tamer El Nady With the help and support if the ex Transport Minister: professor Essam Sharaf during measurement phases, whereas Platform maximum noise levels are conducted by the Author.

Abstract

Title: Effect of Architectural Treatments on Acoustic Environment
Case Study: Underground Stations

Presented by: Manar Mohamed Hassan

This study investigates the effect of applying acoustic treatments inside two selected underground stations in the Greater Cairo Metro Network where platform noise levels reach unacceptable limits. Improving the acoustic environment inside the selected stations took in two procedures; firstly, evaluating the acoustical environment inside by field measurements for two acoustical indicators; Reverberation Time and Sound pressure levels, to be compared with standard noise limits. Secondly, underground stations techniques of noise control at the path are reviewed and applied in two acoustical models of the selected stations on platform areas using **ODEON4.2** software to measure the effect of applying several acoustic treatments on noise reduction on stations platform. Finally, a graph was plotted to show the relation of the sound absorption materials area versus the corresponding noise reduction on the selected stations platform levels. Results showed that Ceiling and under-platform locations were found to be the best treatment locations that reduce train noise in the selected stations; As under-platform location is the nearest to the noise source, thus reducing noise before reflecting into the space, while the treatments located at the ceiling reduce reverberation time and crowds' noises.

Keywords: Noise Control, Acoustic Treatments, Architectural Treatments, Reverberation Control, Underground Metro Stations Noise, Subway Noise, Rapid Transit Noise.

Summary

In response to the growing transportation needs in Egypt, Rapid Transit Networks were extended through Greater Cairo to provide smooth, reliable and fast moving means of transportation. Consequently environmental noise generated by these Rapid Transit Facilities brought significant concern to researchers, seeing that excessive noise exposure is a potential related health hazard.

Recently, environmental authorities in Egypt paid a great attention to noise monitoring in order to evaluate noise problems and their impact leading to mitigation and assessment plans. Several surveys were conducted to evaluate the acoustic environment inside the Greater Cairo Metro underground stations. Yet noise control solutions have not been closely investigated.

This thesis aims at studying the effect of applying acoustic treatments inside the Greater Cairo Metro underground stations in order to improve their acoustic environment.

Mubarak and **Sadat,** two stations in line2 are selected for acoustical investigation. They are both interchanging stations that connect the Greater Cairo Network lines 1&2. Both stations are characterized by full daily ridership. In addition, their platform noise levels exceed acceptable limits as stated in several noise monitoring surveys.

Thesis starts studying the architectural space characteristics of platform areas in underground stations, acoustic environment within it and the related acoustic indicators limits and criteria. Reverberation Time and Sound pressure levels, two acoustic indicators are measured in the selected stations using a sound level meter and **MLSSA** system. Measurements results were analyzed and compared with standard criteria in order to evaluate the acoustic environment inside these stations. Then, techniques of noise control at the path are reviewed and applied at two acoustical models of the selected stations on platform areas using **ODEON4.2** software to compare various acoustic treatments effect on noise reduction. Finally thesis sums up a group of recommendations concerning the most appropriate location for placing acoustic treatment materials that achieve most noise reduction.

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Abbreviations

APTA	:	The American Public Transit Association.
A_{TU}	:	Total power of Absorption for the unoccupied room in metric Sabine.
A_{TO}	:	Total power of Absorption for the occupied room in metric Sabine.
A_{Δ}	:	Power of Absorption for the other room boundaries in Sabine.
A_{Floor}	:	Power of Absorption for the station flooring in metric Sabine.
A_{People}	:	Power of Absorption for standing adults 2 persons per 1m2 in metric Sabine.
A_a	:	It is the total absorption at the specified frequencies after treatment.
A_b	:	It is the total absorption at the specified frequencies before treatment.
α		Sound Absorption Coefficient.
BART	:	Bay Area Rapid Transit.
CTA	:	Chicago Transit Authority.
dB(A)	:	A-weighted decibel (decibels).
Dnl - ldn	:	Day-night average sound level.
EPA	:	Environmental Protection Agency.
FTA	:	Federal Transit Administration.
GCM	:	Greater Cairo Metro System.
ISO	:	Intentional Organization for Standardization.
LAE-SEL	:	A-weighted sound exposure level- the time integral of sound. level over the course of a single event.
L_{Aeq}	:	A-weighted equivalent sound level.
L_{AeqT}	:	Sound level associated with the sound energy averaged over a specified time period.
L_{Amax}	:	A-weighted maximum sound level during a noise event or specified time period.
LNP	:	The noise pollution index (denoted by LNP): can be calculated from the relation, $lnp = leq + 2.56\sigma$ [σ (standard deviation)]
L_{WA}	:	Sound power level per unit length for a sound source.
$L_{X\text{(e.g., }L_{10})}$	:	The sound level exceeded x percentage of the time during a specified time period.
L_1	:	Represents the maximum noise events, fast noise events like

train air siren, which takes about 1% of the measuring period.

L_5 : Represents noise levels exceed 5% of the measuring period.

L_{10} : It is the peak noise index, Represents noise levels exceed 10% of the measuring period.

L_{90} : It is the noise climate index, which represents the noise level exceeded for 90% of the measurement period.

L_{95} : Represents noise levels exceed 95% of the measuring period.

L_{99} : It is the background noise level, which represents mostly the lowest noise level during the measurement period.

MBTA : Massachusetts Bay Transportation Authority

MLSSA : Maximum Length Sequence System.

MPH : Mile per hour.

NAT : National Authority For Tunnels.

NCB : Balanced Noise Criterion.

NIOSH : National Institute For Occupational Safety And Health.

NIPTS : Noise-induced permanent threshold shift.

NITTS : Noise-induced temporary threshold shift.

NPL : Noise pollution level.

NR : Noise rating.

OSHA : Occupational Safety And Health Act.

PCF : Pound Cubic Feet.

RH : Relative Humidity.

RIR : Room Impulse Response.

RMS : Root Mean Square.

RT_M : Measured reverberation time in seconds.

RT_{OC} : RT estimated occupied.

V : Volume in m^3.

SIL : Speech Interference Level.

SLM : Sound Level Meter.

SPL : Sound Pressure Level.

TEL : Transit Exposure Level.

TTC : The Toronto Transit Commission.

TTS : Temporary Threshold Shift.

WHO : World Health Organization.

WMATA : Washington Metropolitan Area Transit Authority.

Glossary

American Public Transit Association:
This association provides design guidelines for noise produced by transit trains. These guidelines include limits for vehicle interior, exterior, station platform, and fan and vent shaft noise levels.

At-Grade [1] or Direct Fixation Track
Track that is fixed directly to surface of the Ground without engraving.

Ballast [1]
Layer of coarse stones supporting the sleepers.

Bored Tunnel[1]
A tunnel which has been constructed by drilling usually with a tunnel boring machine (TBM).

Cut-And-Cover Tunnel
A shallow tunnel which has been constructed by digging a cutting and then covering it over after construction.

Fast Meter Weighting
The maximum sound level is measured using a sound level meter set to the “fast meter response,” which is similar to a root mean square (rms) averaging time of 0.125 sec.

Grinding
A process for removing a thin layer of metal from the top of the rail head in order to remove roughness and/or to restore the correct profile. Special grinding trains are used for this.

Heavy Rail (Metro, Subway, Rapid Transit, Or Rapid Rail):
It is an electric railway with the capacity for a heavy volume of traffic and characterized by high speed and rapid acceleration passenger rail cars operating singly or in multi-car trains on fixed rails; separate rights-of-way from which all other vehicular and foot traffic are excluded; sophisticated signaling, and high platform loading.

ODEON
ODEON Room Acoustics Program Version 4.2, that supply Industrial, Auditorium and Combined Editions

Periodic Monitoring
The measurement performed to check if the noise of a vehicle has changed since initial delivery or after modification

Public Address System
Internal broadcasting system for announcements.

Rail Sleeper
The longitudinal steel beams on which the train runs. A transverse beam under the rails used to maintain track gauge and to distribute loads from the wheels. These may be wooden, concrete or steel.

Slow Meter Weighting
The maximum sound level is measured using a sound level meter set to the "slow meter response," which is similar to a root mean square (rms) averaging time of 1 sec.

Station[1]
Is a public transportation facility with a platform that board/alight passengers, It may include stairs; elevators; escalators; passenger controls (e.g., fare gates or turnstiles); lighting; signs; buildings with a waiting room, ticket office or machines, restrooms, or concessions. Station may be either underground, at-grade, or elevated stations.

Tie and Ballast:
Ballast Coarse stone etc. As the bed of a railway track or road Mixture of coarse and fine aggregate for making concrete.

Track
This consists of two rails held by clips onto sleepers (or slab).

Train
single vehicle or a number of coupled vehicles/units operating on a guided ground transport system

Type Testing
The measurement performed to prove that, or to check if, a vehicle delivered by the manufacturer complies with the noise specifications

Part 1: Evaluation of the Acoustical Environment inside the Greater Cairo Underground Stations.

1. Chapter 1: Greater Cairo Rapid Transit System

1.1. Introduction:

It is not possible to define noise exclusively based on the physical parameters of sound. Instead, it is common practice to define noise simply as unwanted sound. [2] However, in some situations noise may adversely affect health in the form of: [3]

Psychological Effects: including annoyance, interference with rest or sleep, interference with work performance and interference with sound communication.

Physiological Effects: including discomfort levels, permanent hearing loss, temporary hearing loss, and other general effects on health.

Transportation noise is the main source of environmental noise pollution, including road traffic, rail traffic and air traffic. [2] Railway noise generated inside underground stations propagates in a reverberant field where sound reflects on tunnel and station walls that may increase than those in the free field in surface stations. In addition, other noise sources in underground station like running engines, sirens and public address loudspeakers contribute to the station noise and may cause irritation to passengers, including poorly designed or operated public address systems. This research investigates the acoustic environment inside underground stations, noise generation, limits and treatments with special investigation in the Greater Cairo Underground stations aiming at Noise assessment in some selected stations.

1.2. Problem definition

Noise levels inside the Greater Cairo Metro underground stations exceed the permissible limits as reported in several local surveys conducted by environmental and academic authorities. This is attributed to the reverberant field built up inside the platform area where noises reflect within the platform space without dissipation. In addition, the building materials like; Ceramic tiles, fair face concrete and Granite tiles, which are characterized by low sound absorption coefficients, are used in platform areas finishing. These materials reflect sound highly thus increasing noise levels already in the space.

1.3. Research Objectives

The main purpose of this study is to provide an acoustically comfortable environment in underground stations by maintaining platform noise levels to acceptable limits. This can be achieved by studying procedures required to reduce noise according to the following steps:

1. Determination of the existing noise levels and noise generation characteristics in selected underground stations.
2. Investigation of the potential for reduction of underground station noise.

1.4. Research Methodology

This research is divided into two parts. The first part begins with introducing how railway noise is generated in underground station, with related indicators, measurements and noise limits and ends with an evaluation of the acoustic environment inside some selected underground stations. In the second part, Noise Assessment and mitigation techniques used to lower noise levels inside underground stations are investigated with an application of these techniques in the selected underground stations.

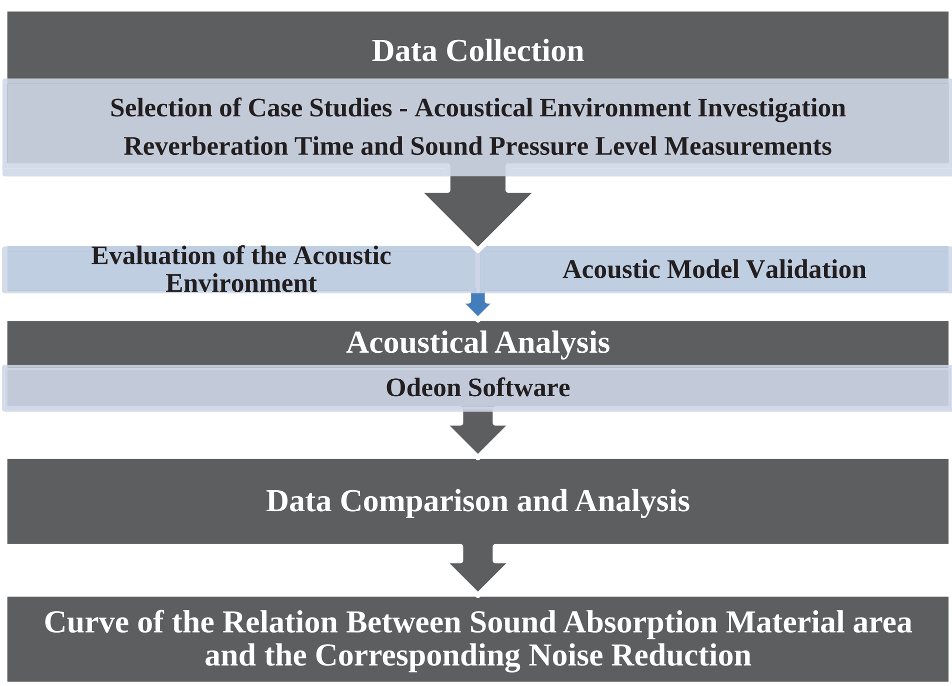

Figure 1-1:Research Methodology Diagram

1.4.1. Data Collection

The data collection phase included reviewing noise monitoring surveys and noise mitigation techniques in underground stations. Some underground stations are selected for acoustical investigation where measurements are conducted as will be discussed.

1.4.1.1. Selection of Case Study

Noise monitoring surveys conducted by Ministry of State for Environmental Affairs and the National Research centre recorded noise levels in the Greater Cairo Metro Network throughout 2004-2005. In both line1&2 in the Greater Cairo Metro underground stations, noise levels recorded were reviewed for maximum noise indicators. Line2 underground stations recorded higher noise levels than those in line1 due to application of TV Closed Circuits and Public Address system, besides the crowds' noises.

Line2 underground stations are all standardized to have the same finishing materials, volume and spatial characteristics. **Mubarak** and **Sadat** underground stations are selected from line2 underground stations as they both share maximum noise levels recorded on their platform and have the same finishing materials and volume as the rest of underground stations.

1.4.1.2. Measurement Procedure

Noise measurements conducted in the selected underground stations are intended to measure **Reverberation Time** and **Maximum Platform Noise Levels** generated by the arrival and departure of trains on platform and also noise when no train is present in station where:

Reverberation Time measurements* were conducted in the selected underground stations where a loudspeaker driven by a power amplifier was used as a single source. The measuring signal was generated and received using the **Maximum Length Sequence System** [**MLSSA**] [4] whose post-processing functions calculated most of the acoustical parameters from the measured impulse response. All parameters were measured and predicted at octave bands 125 to 8000 Hz.

During train arrival and departure, Maximum A-weighted sound pressure

*Measurements of Reverberation time were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University lead by Dr. Ahmed El-Khateeb, Dr. Akram Sultam and Dr. Tamer El Nady.

levels L_{Amax} are measured according to the British Standard **BS EN ISO 3095:2005** in the selected underground stations on platform front, middle section and end using a **Solo** integrating sound level meter (Type II) set to the A-weighting network and Fast meter response.

1.4.2. Acoustical Analysis

Acoustical analysis is performed using **ODEON 4.2** software that uses geometrical acoustics in the prediction of all acoustical indicators. Two prediction models are set up for the selected underground stations. Reverberation time field measurements are used to validate the acoustical models where air absorption has also been taken into account by entering temperature and relative humidity readings at measurements time.

1.4.2.1. Acoustical Models Validation

The prediction models built for the selected underground stations are validated by comparing measured field Reverberation time in the unoccupied stations with the simulation predicted one. But first, people absorption have to be put into account, as passenger during peak hours contribute to the total absorption in station. Estimation of the passengers' total power of absorption in case of occupied station is calculated as follows:

1.4.2.2. Estimation of The Passengers Total Power of Absorption in Case of Occupied Station

Measurements of the Reverberation time are conducted in empty station as people absorb part of the sound energy that leads to inaccurate readings. [5] The Reverberation time is measured in unoccupied station then the related occupied reverberation time is estimated according to the following procedure: [6]

a) Total power of absorption in case of unoccupied station A_{TU}: [7]

$$A_{TU} = \frac{0.161V}{RT_M} \text{ Sabins} \quad \text{Equation 1-1}$$

$$A_{\Delta} = A_{TU} - A_{Floor} \text{ Sabins} \quad \text{Equation 1-2}$$

Where:

$$A_{Floor} = \alpha_{Floor} \times S_{Floor} \text{ Sabins} \quad \text{Equation 1-3}$$

b) Total power of absorption A_{TO} for the occupied station will be estimated through the following equation:

$$A_{TO} = A_{\Delta} + A_{people} \text{Sabins} \qquad \textbf{Equation 1-4}$$

$$RT_{OC} = \frac{0.161V}{A_{TO}} \text{Sabins} \qquad \textbf{Equation 1-5}$$

Where:

A_{TU}	Total power of Absorption for the Unoccupied room in metric Sabine
A_{TO}	Total power of Absorption for the Occupied room in metric Sabine
A_{Δ}	Power of absorption for the other room boundaries in Sabine
A_{Floor}	Power of Absorption for the station flooring in metric Sabine
A_{People}	Power of Absorption for standing adults 2 persons per 1m2 in metric Sabine
RT_M	Measured Reverberation Time in seconds
RT_{OC}	RT estimated occupied
V	Volume in m3
A_{Floor}	Absorption Coefficient for the station flooring
S_{Floor}	Surface area in m2

1.4.2.3. <u>Simulation Setup</u>

The acoustic environment is investigated inside the selected underground stations assuming full passengers occupation on both platform during the arrival of trains at both directions simultaneously. This setup is intended to imitate the noisiest case on platform, while assuming full passengers occupancy decrease the buildup generated noise in station hence reduce the actual required absorption. Crowds' noise is neglected, as the most dominant noise source is the train.

1.4.2.4. <u>Train Noise source</u>

Train noise is modeled as a line source aligned at the centre line of the train track at a height 1.5 from the track-bed. Train noise sound power level assigned to the acoustical model is derived from the Mean value of the A-weighted sound power level per unit length for railway noise during pass-by of rail vehicles [8] The average relative spectrum for electrically powered passenger railcars is used for train noise power equalization. Line sources used in the model generate noise levels relative to the maximum noise levels measured in the selected stations.

1.4.2.5. Receivers

Eight receiver points are distributed evenly over each platform at 18-m intervals along the platform in the middle of every car, 1.5 m from the platform edge, and at a height of 1.50 m above the platform floor, which is typically the ear height of the passengers.

1.4.2.6. Acoustical Indicators

a) Reverberation Time

RT: defined from Sabine's equation [9]:

$$\mathbf{RT} = \frac{\mathbf{0.16V}}{\mathbf{V + 4mv}}\ \mathbf{Sec} \qquad \textbf{Equation 1-6}$$

b) Maximum A-weighted Sound Pressure Level (Fast weighting) Arrival and Departure of trains

This indicator evaluate the noise on platforms caused by arrival and departure of vehicles at platforms in stations defined by:

$\mathbf{L_{Amax}}$: The maximum value of the A-weighted sound pressure level determined during the measurement time interval T by using time weighting F (fast) [EN 61672-1] [1]

1.4.3. Comparative Analysis Approach

In the prediction models, line sources generate noise relative to the field maximum noise levels measured in the selected stations. These maximum levels are used as reference levels to be used in measuring the noise reduction achieved when acoustical treatments are applied to the stations. Noise reduction is investigated on eight receivers on each platform for the A-weighted maximum sound pressure level.

1.5. The Greater Cairo Metro System

The increasing population in Greater Cairo is expected to exceed 23·9 million in the year 2012. The present population is currently estimated at 18 million* that are densely packed into one city, forced by the surrounding topography to expand along the Nile River banks. The urban transportation corridors therefore follow a north/south corridor in order to reach the centers of highest population density.

Many studies are conducted to investigate transportation problems and the means to resolve it. International consultants from different countries were involved with local consultants from both, the private sector and the Egyptian universities over the last fifty years to study the traffic problems in Greater Cairo. The studies indicated that Cairo needs traffic networks that extends underground as possible and take the advantage of the existing surface railway lines. Traffic Tunnels save time, energy and may be preferred in the cities for environmental reasons. These reasons include limitation of outdoor noise, pollution, and visual intrusion, the conservation of districts or to enhance surface land values.†

In response to the growing transportation needs in Egypt, Metro Network is extended through Greater Cairo to provide smooth, reliable and fast moving means of transportation. It was planned to improve the population mobility and consists of 6 lines connecting different sides of Greater Cairo. Line1&2 are working at present and operating seven days a week including public holidays. The work on line 3 was started and there are three other future planned lines 4, 5 & 6. [11]The maximum train speed is 80 km/hour. The frequency of operation at peak periods is 3 minutes.

* Madkour, A., M. Hudson, and A. Bellaros. (1999) Construction of Cairo Metro Line 2. in Institute of Civil Engineers
† Wood, A.M. (2000) Tunnelling: management by design. New York: E & FN Spon.

1.5.1. Greater Cairo Metro (Line1 Network)

It was created by connecting the existing railway line from Helwan - south of Cairo - to the existing railway line Cairo to El Marg in the north east, by means of a new underground line below the Central Business District (Down town), making a total length of 44km. The construction of this line started in 1982 and was divided into two phases and was finished in 1999:

Phase 1: with a length of 28km, from Helwan to Mubarak Station in Ramses Square, including the 4.5 Km underground section.

Phase 2: included the electrification of the existing diesel hauled line from Ramses Square to El Marg. It involved renovation of the tracks, modernization of some stations and construction of 3 new stations.

1.5.2. Greater Cairo Metro (Line2 Network)

Second line runs from Shubra El Kheima in the north of Cairo to Al Moneeb station in the extreme south of the city’s urban mass as shown in Figure 1-1. The construction of this Line started in 1993 and, the line has 21.5 Km long, 20 stations, 6 at grade, 2 on viaduct and 12 underground. Interchange between Lines No. 1 and 2 are provided at Mubarak station in Ramses Square and Sadat station in Tahrir Square. To maximize the early use of the line, it has been executed in 5 phases; namely:

Phase 1 :(Shoubra El Khiema – Mubarak) – 8 Km long in October.1996.
Phase 2 :(Mubarak – Sadat) - 3 Km long in September.1997.
Phase 3: (Sadat – Cairo University) – 5.5 Km long in April.1999.
Phase 4: (Cairo University- Um Elmassreen) – 2.7 Km long in October 2000.
Phase 5: (Um Elmassreen - El Monieb) – 2.6 Km long in January 2005.

1.5.3. Greater Cairo Metro (Line 3 Network)

Line 3 will extend from the north west of Greater Cairo at Imbaba to the north east at Heliopolis serving also the Cairo International Airport. The Line shall cross under the two branches of the River Nile. The total length of the Line is approximately 30 km most of which is bored tunnel. The stations will be constructed by the cut and cover method. The basic design is currently in progress to be constructed in four phases; see Figure 1-2.

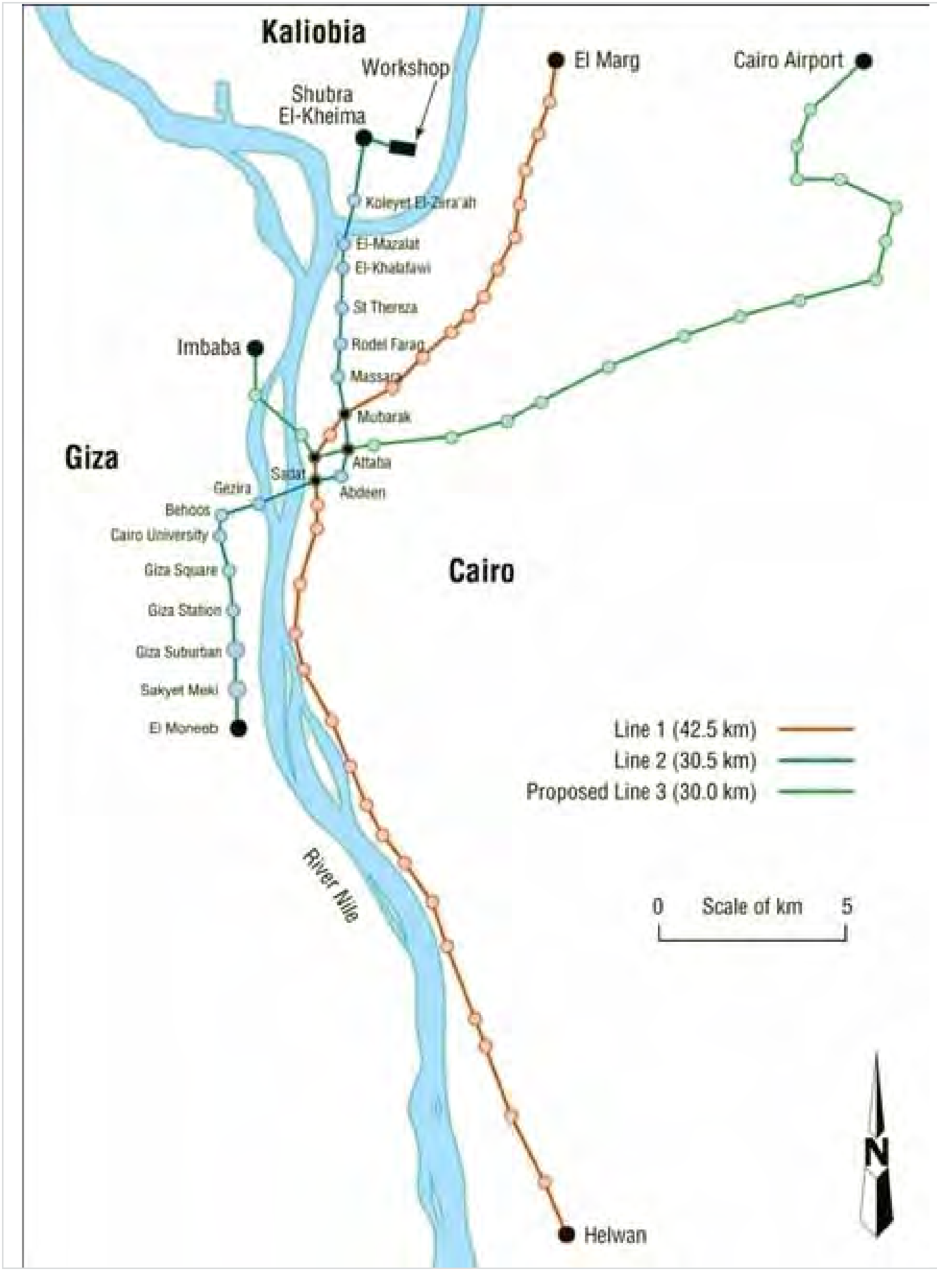

Figure 1-2: Greater Cairo Metro Network Map.*

*Madkour, A., M. Hudson, and A. Bellaros. (1999) Construction of Cairo Metro Line 2. in Institute of Civil Engineers P.104

1.6. Underground Stations Construction (Line2)

Thirty kilometers of underground railway network is built in the heart of Cairo in two lines 1&2. Line 2 links the pyramids of Giza on the west bank of the Nile to central and northern Cairo on the opposite bank. [11]

Line2, the Greater Cairo Metro network covers 21.5 km starting from northern to southern Cairo over 20 stations: surface stations, (at grade or via duct) and underground stations. Distance between every two successive stations does not exceed 500m.

The methods of tunnels construction affected the architectural space design of the Greater Cairo Metro (GCM) underground stations. Every station is a Box like designed to provide 2 or 3 levels each of area ranging from 3000 to 3500 m2. Underground Stations where interchange of Line1&2 take place are composed of 2 levels while other stations are composed of 3 levels.[7]

Underground stations are boxes rectangular in plan and are standardized within the same limits. This standardization led to the use of the same construction methods throughout the project and promoted efficient use of construction resources. The station boxes have excavation depths varying from 15–23 m and have accesses and airshafts attached to the main box as shown in Figure 1-3.

The stations are designed to be fully watertight and this required the use of reinforced concrete diaphragm walls (of up to 1.2 m width). The design of the diaphragm wall section was based on minimizing settlements caused by wall deflections where excavation was carried out close to other structures. The depth of the diaphragm walls was applied by injection of soft gel to limit water inflow through the sand and avoid excavation instability. In addition to diaphragm walls, bentonite/cement slurry walls were constructed to divide the stations into smaller boxes to allow sectioning of the excavation process. [11]

1.6.1. <u>The Tunnel Construction</u>

Tunnels extended underground are either bored in soil using the tunnel-boring machine (TBM) or constructed in Cut-and-cover method. Figure 1-4 shows cross section profile of line2 tunnel construction.

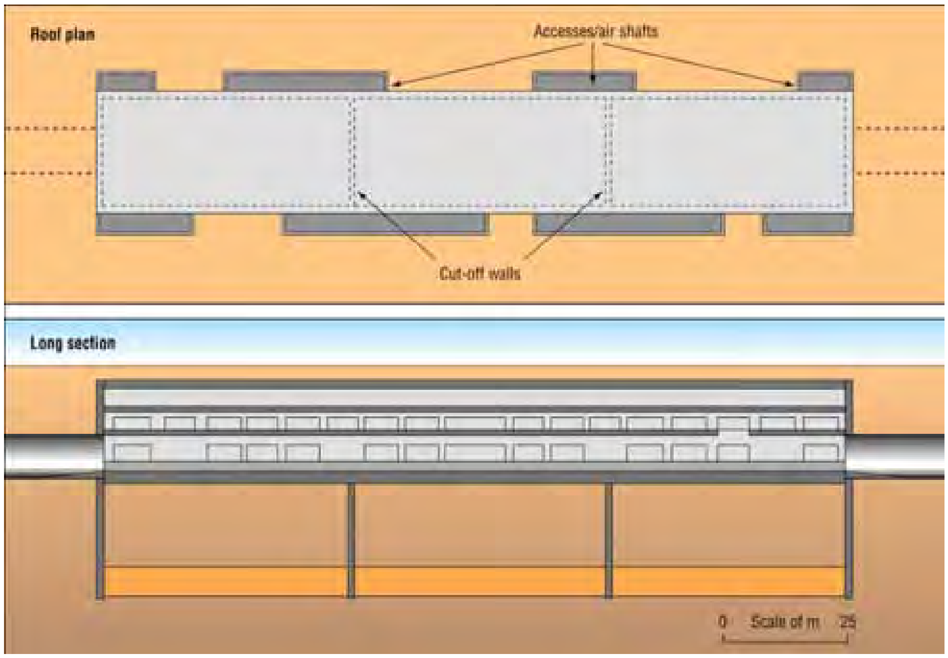

Figure 1-3:Plan And Longitudinal Section in a Typical Station*

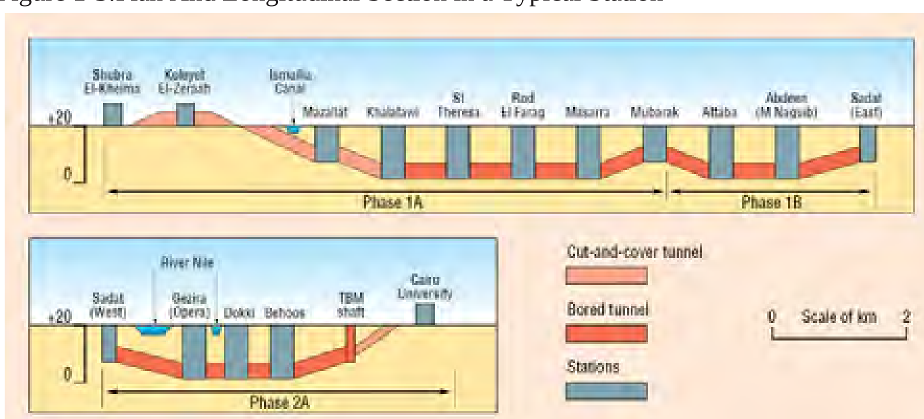

Figure 1-4: Cross Section Profile of Underground Stations. GCM (Line2 Network)†

1.6.1.1. Cut-and-Cover Tunnels

The cut-and-cover tunnels are constructed in the same manner as the stations and to the same water-tightness criteria except that the diaphragm wall retaining structure is used only for temporary ground

*Madkour, A., M. Hudson, and A. Bellaros. (1999) Construction of Cairo Metro Line 2. in Institute of Civil Engineers. p.7
†Ibid.p.2

support. Inside the diaphragm walls, an arched tunnel structure of cast in-situ reinforced concrete was placed against and surrounded by a waterproofing membrane to assist excavation and to improve water-tightness control. Slurry walls are constructed to divide the tunnels into sections.[11]

1.6.1.2. Bored tunnels

Tunnels are bored in soil using the tunnel-boring machine (TBM). The tunnel lining comprises seven segments and a key, with the key introduced longitudinally to complete the ring. The lining is tapered with a nominal segment length of 1.5 m and to install the tunnel lining to the alignment's minimum horizontal curve radius of 201 m.[11]

Figure 1-5:Completed Bored tunnel between Attaba and Naguib Stations. Downtown Greater Cairo.*

1.7. Components of Underground Station

The planning of subway stations is subjected to rigid technical standards that include applying safety precautions, providing operation and maintenance services spaces. Durability and ease in maintenance are recommended for all previous mentioned issues. Besides, the user have to find his way through the station easily without any complexity in design.

Most underground stations are rectangular boxes in shape and have the same requirements that make them all within the same standard limits in design and construction.

Underground station consists of an entrance from the street level that leads down to the ticket level that is the first level underground. Intermediate levels accommodate service and technical rooms that are present under ticket levels. A group of stairs and escalators passing the intermediate level join ticket level with the platform level where passengers wait for the train.

* Ibid.P.10

1.7.1. Tickets Hall Level

It is a large hall with two groups of ticket windows facing each other. It is the first underground level you can reach from the street through the entrance stairs. Some Tickets halls contain small shops that sell newspapers, magazines and stationery. The hall contains two groups of Automatic ticket barriers that lead to stairs and escalators on both side of railway platform or to an intermediate level above the railway platform that also lead to it. Besides there are service rooms for ventilation and air condition that reach the street through ventilation ducts.[7]

1.7.2. Intermediate Level

It consists of two groups of stairs and escalators that lead passengers to one of the two railway directions. The rest of the intermediate level is occupied by service rooms for operation and maintenance, station lighting, alarm systems and closed TV circuit for the station. [7]

1.7.3. Platform Level

It is a raised level surface along both sides of the railway line inside the station where people wait for several minutes for the coming train. Platform space should provide information and guidance through maps and signs that show directions. In addition, closed TV circuit and internal public address systems broadcast information when necessary. Platform width depends on no. of passengers expected to ride the Metro line. Railway platform is connected to upper levels through Stairs and escalators. The platform length is around 144 m and is designed to accommodate an eight-car train. [7]

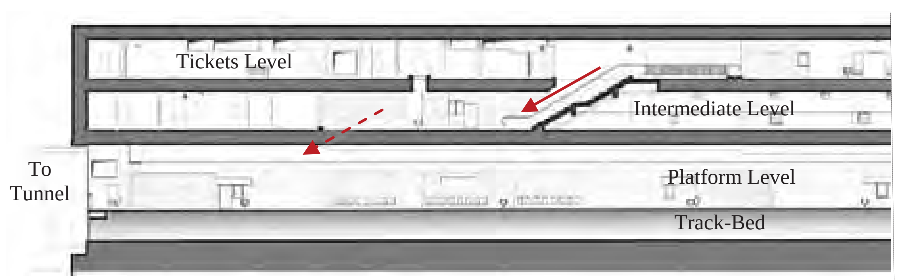

Figure 1-6: Half Section at a typical Underground Station.*

*Generated by the author

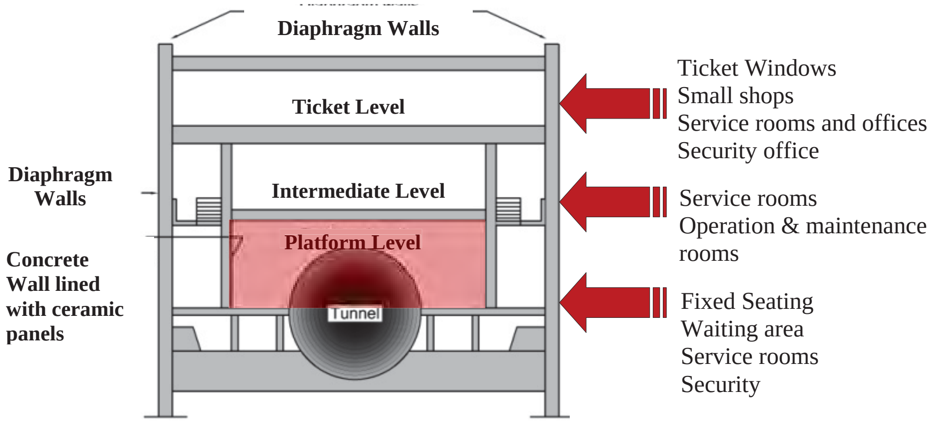

Figure 1-7:Underground Station Section (Components of underground station).*

1.8. Underground Station Platform Design Criteria(Line2)

Station size and platform width depends on number of passengers expected to use the Metro according the following criteria: [7]

1. Site location near public facilities that attracts people.
2. Intersection of major traffic axes like Ramses and Tahrir squares.
3. Population density and increase in number of work trips during the day.

1.8.1. Platform Length

It depends on the Train length. In Line1, the platform exceeds the train length by 20 m while in Line2 the platform exceeds the train length by 6 m to be in most stations 144 m. [7]

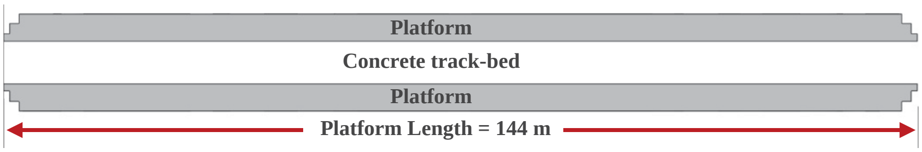

Figure 1-8: Underground Station Platform Length (line2).†

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*Generated by the Author
†Generated by the Author

1.8.2. Platform Width

The platform width depends on number of passengers expected to enter and leave the station according to the following classification: [7]

Category 1 Passengers entering and leaving over 30,000 per hour, by another mean 600 passenger/Train/Direction needs 2 platforms each of width not less than 5 m.

Category 2 Passengers entering and leaving between 15,000 and 30,000 per hour or 400 passengers/Train/Direction needs 2 platforms each of width not less than 4 m.

Category 3 Passengers entering and leaving less than 15,000 passengers per hour or 200 passenger/Train/Direction need 2 platforms each of width not less than 3 m.

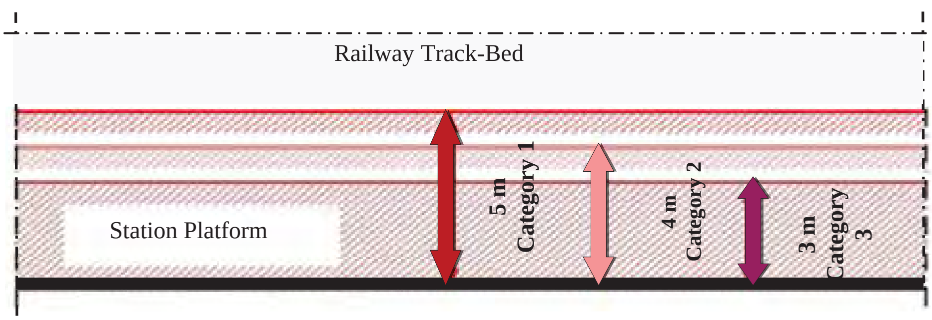

Figure 1-9: GCM Underground Station Platform Width Categories (line2).

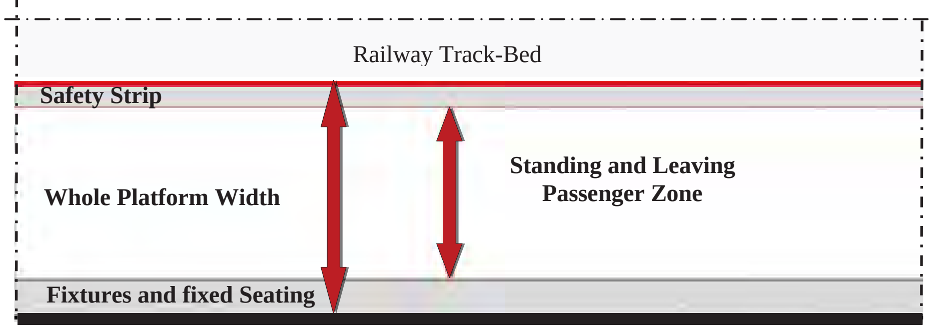

Figure 1-10: GCM Underground Station Platform Width Occupancy Diagram (line2).*

Platform width is divided into 3 longitudinal strips (for the whole platform length): [7]

*Generated by the Author

a) For fixtures, equipment and fixed seating 80 cm .
b) Safety stripe 50 cm at the edge of the platform.
c) Waiting area stripe occupied by 2/3 of the entering passengers during 2 1/2 min (frequency of operation) assuming that 2/3 of the passengers are going to one of the two directions of the Metro Line.

1.8.3. Platform Occupancy

During peak hours, between 2 successive trains, every passenger occupy 0.5m from the platform length while waiting for coming train except for the driver' cabin zone, while every 2 passengers occupy an area of 1 m^2 [7].Passengers leave the GCM at the rate of 100 passengers per meter of passage width. [7]

Figure 1-11: Typical Underground Station Platform.*

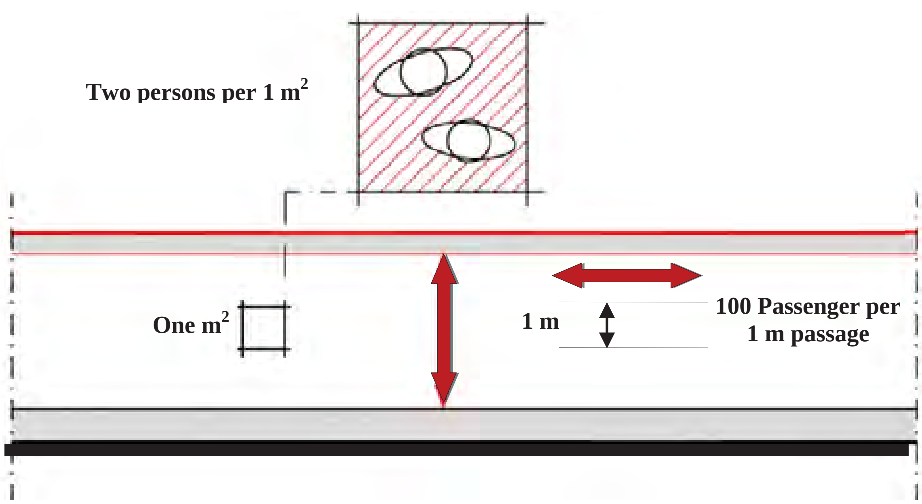

Figure 1-12: Waiting Passengers Occupancy diagram (line2)..†

*Tunnels. http://www.arabcont.com. [Accessed 9- 2009]
†Generated by the Author

1.8.4. Finishing Materials

Finishing materials in underground stations must appear safe and solid to passengers and staff. Besides, they must be durable, easy to clean and economical. The following section describes the specific requirements for the various elements in underground stations with referring to the GCM underground stations, in particular Line2 network.[12]

1.8.4.1. Walls

Claddings are needed where the infiltration of water through wall cracks cannot be avoided. These mostly occur in concrete slab constructions, which had to be cast overhead, from below against existing structural parts. The classical bored-pile and diaphragm wall constructions are prone to leaks in the long run. Therefore, cladding is the best solution to cover them with drainage grill under them directly to collect leakage water. Wall surfaces - claddings and possibly paint coatings - must be easily cleanable (without becoming worn or scratched). Decorative elements should be easily replaceable. Apart from the construction and maintenance costs, there are no restricting factors for wall designs. This turns them into one of the most important and rewarding parts of the design.[12]

Ceramic panels are used in the GCM underground station wall lining. plain Light colored ceramic panels are used all over the station while Colored Designed patterns ceramic panels are used in the station platform .Drainage grills are placed below the cladding directly to collect infiltration water.

Figure 1-13: Ceramic panel Cladding in Opera Station, Gezira, Greater Cairo.*

1.8.4.2. Flooring

Flooring materials in underground stations must be highly durable, abrasion-proof and fire-resistant. Patterning should not show dirt. Once worn, the materials should be easily replaceable and of the same quality. Low liquid absorption, suitability for vacuuming and resistance to strong cleaning agents are all indispensable.[12] Granite has shown the best performance in

Figure 1-14: Granite Flooring in Attaba Station, Downtown, Greater Cairo.†

* Brinckerhoff, P. Greater Cairo Metro. http://www.pbworld.com. [Accessed 2009-]
†Cairo Metro. http://www.subways.net/egypt/cairo.htm. [Accessed 9- 2009]

regard to these requirements. This is why it has been the only flooring material used in recent years. A wide strip of other colored granite with a rough surface is placed within the floor pattern as a safety precaution in order to prevent slipping of the ground. Colored patterns are used to direct passengers to stairs or exits.

All underground stations in line2 are finished with Granite flooring in all the station levels, light grey in color with dark colored stripes in ticket level.

1.8.4.3. Ceilings

In the case of suspended ceilings, they have to be as light-colored and lightweight as possible. In some cases, light-reflecting ceilings - often with a semi-matte luster - are installed to increase luminosities and make the low spaces appear higher. [12]

In all Line2 underground stations, ceilings are treated with mineral wool based coating in the ticket level, intermediate level and the platform level. This acoustic coating reduces railway noise in addition to crowd noises. In addition, metal ceiling is used in some places to hide mechanical equipments; see Figure 1-15.

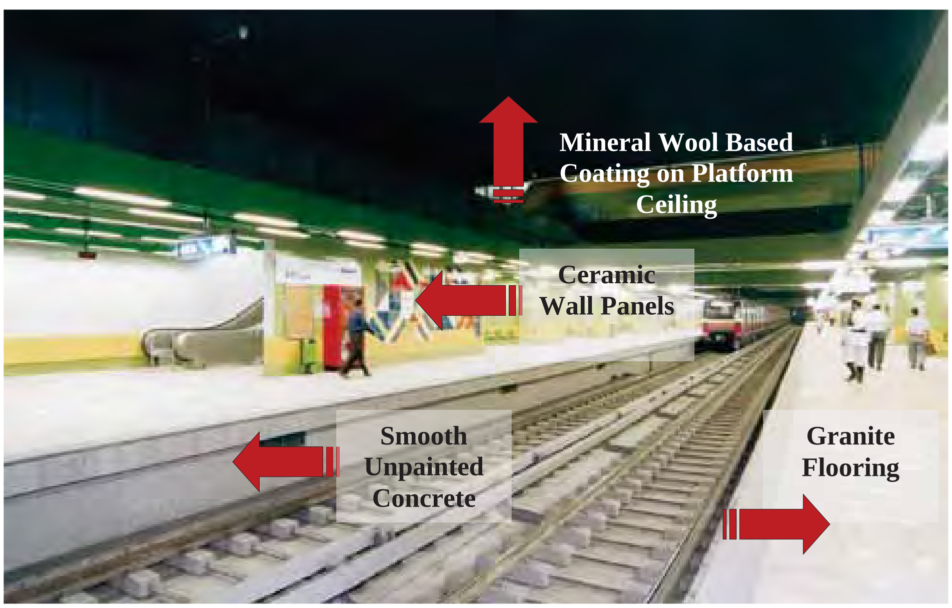

Figure 1-15: Finishing Materials of GCM Underground Stations (Line2) Attaba Station, Down Town, Cairo.*

*Cairo Metro. http://www.subways.net/egypt/cairo.htm. [Accessed 9- 2009]

1.8.5. Acoustical Environment

For transit industry, acoustics is concerned with all noise and vibration control problems related to rapid transit system operations. An understanding of the effects of noise and vibration is necessary for the establishment of acceptable acoustical criteria. The two basic-goals in noise and vibration control are:[3]

- To provide system patrons with an acoustically comfortable environment by maintaining noise levels in vehicles and stations within acceptable limits.
- To reduce the impact of system operation on the community by minimizing transmission of noise and vibrations to adjacent properties.

1.8.5.1. Sound Absorption Characteristics for Finishing Materials in GCM Line2 Underground Stations

In Line2 underground stations, platforms are finished with granite flooring. The platform walls are lined with ceramic panels that cover the station diaphragm walls. While some parts of the walls are lined with ceramic tiles directly on masonry walls covering vertical ventilation ducts; see Table 1-1. All these materials are characterized by high sound reflectivity. Current acoustic treatment on the station ceiling in the form of mineral wool based coating absorb noise in station, yet maximum noise levels exceeds allowable limits as will be discussed later. Absorption Coefficients of some finishing materials used in line2 underground station are plotted in Figure 1-16.

Finishing Materials					
Finishing Materials	Platform	Floor	Granite Tiles	Plain Concrete 5 Cm	
		Walls	Designed Pattern Ceramic Panels	Ceramic Tiles on Masonry	Trowel Cement Plaster on Masonry
		Skirting	Ceramic Tile 30 Cm Height Under Panels on Wall		
		Ceiling	Acoustic Paint	Lighting Fixture	Ac Ducts
	Railway Line	Floor	Smooth Concrete		
		Sidewall	Smooth Concrete		
		Ceiling	Mineral Wool Based Coating		

Table 1-1: GCM Underground Stations Platform Finishing Materials.[*]

[*]National Authority for Tunnels Specifications.

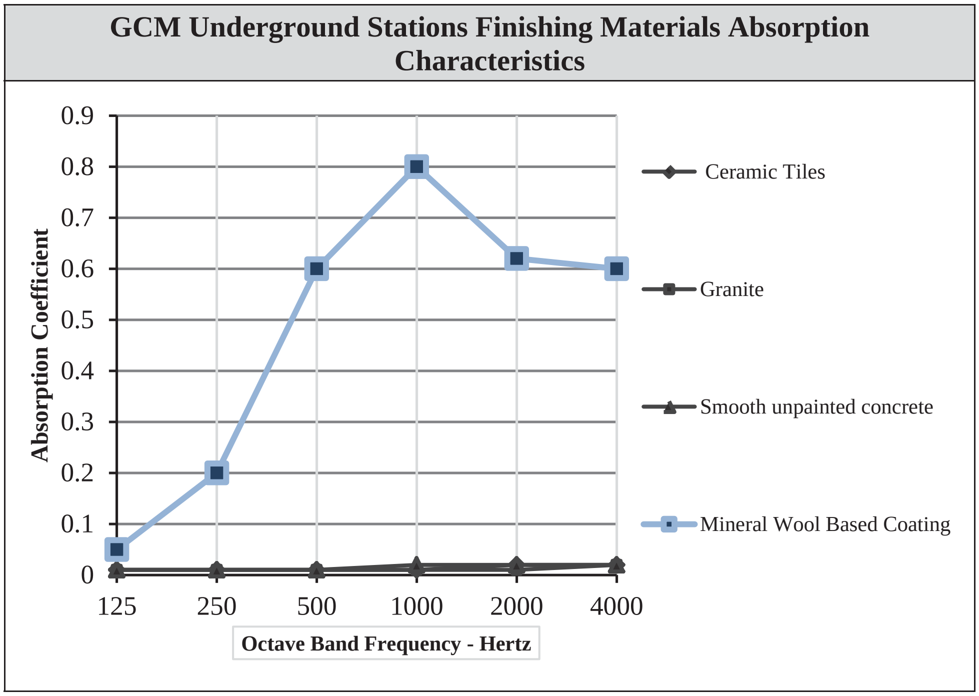

Figure 1-16: Absorption Coefficients of Some Finishing Materials Used in Line2 Underground Station.*

1.9. Literature Review

Many field surveys were conducted in Egypt to investigate transportation noise especially that is generated from Rapid Transit System. These surveys aim at evaluating and assessing noise people are subjected to. The Ministry of State for Environmental Affairs and The National Research Center conducted two surveys to quantify noise in the Greater Cairo Metro System (GCM) where noise levels are measured inside Stations, tunnels and onboard (inside the train). The following section will list noise surveys related to GCM noise and other foreign studies that specialized in the same field.

M. A. Abdalla(1993)[13] conducted a field survey to compare the statistical noise levels radiated from buses and some of the GCM Line1 stations as well as the surface electric train (Tram). The A-weighted sound pressure levels were measured onboard in the GCM line1 train over the trip from Ramsis station to Helwan station from 10:20 to 11:00 a.m.

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*Cairo Metro. http://www.subways.net/egypt/cairo.htm. [Accessed 9- 2009]

Period in min	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40
L1	81.5	90	78.1	78	81.5	76.5	81.5	85
L10	78	80	75	74.5	77.6	74.5	77	79.5
L50	73.5	74	70.5	72.5	74	67	74.5	75.5
L90	65.5	67	66	69	69	63.5	72	71
L99	61	63.5	63.5	65.5	65	62	70.5	66
Leq	74.9	77.5	72.0	72.7	74.6	70.3	75.2	76.8

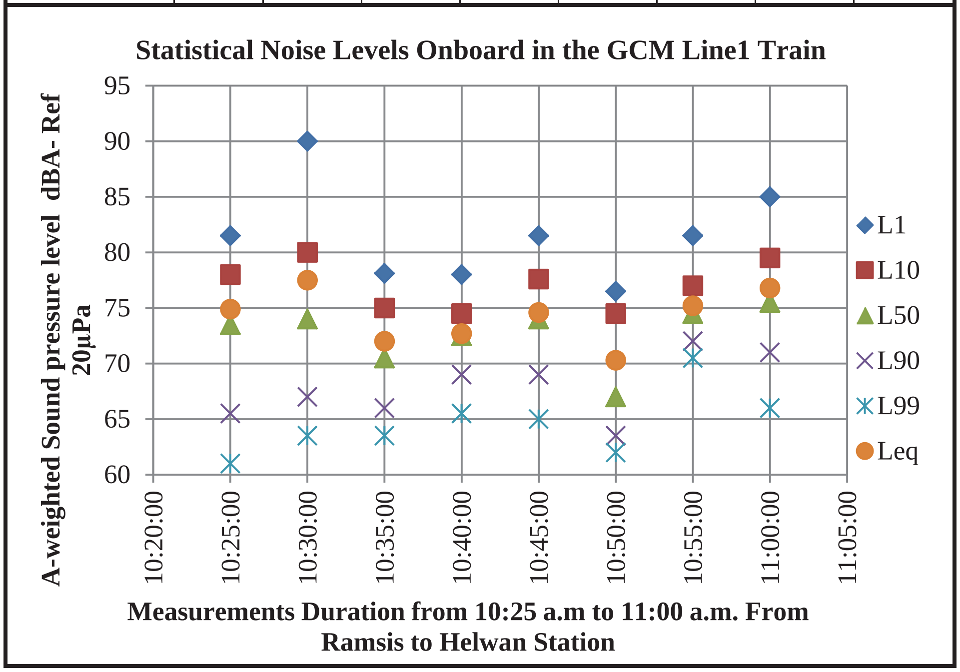


Table 1-2: Top - Measurement Results of Statistical Noise Levels Onboard in the GCM Line1 Train (over 40 minutes from 10:20 to 11:00 a.m.) *

Figure 1-17: Measurement Results of Statistical Noise Levels Onboard in the GCM Line1 Train (over 40 minutes from 10:20 to 11:00 a.m.) †

Noise levels measured onboard exceeded the maximum allowed noise of 68 dB(A) where the equivalent continuous noise level L_{Aeq} measured lied within the range of 70-77.5 dB(A) as shown in Figure 1-17. The Max level L1 reached 90 dB(A) due to the use of Alarm signals with duration of 3 seconds. The measured noise level onboard when the train is in the tunnel was greater than noise level at the surface (at-grade); this is contributed to reflections of sound at the tunnel wall that increase noise levels.

*Abdalla, M.A., A comparative statistical study of noise levles due to underground train in Greater Cairo. Engineering Research Bulletin, 1993.V.4: p. 151.
†Graph Generated by the Author.

He concluded that:

1. The dominant source of noise in the GCM is the train siren applied during arrival and departure of a train.
2. The noise levels can be reduced by increasing the tunnel volume.
3. The noise levels can be reduced by the treating the tunnel walls to improve its acoustic characteristics.

MOSTAFA E ALY(2005) [14] investigated GCM noise problems and related health hazards when he measured noise on station platform and onboard. Different noise indices were compared with international criteria and national laws to show that noise levels in underground stations of the GCM line2 are unacceptable. The international criteria used in comparisons were adapted by the US Department of Housing and Urban Development (HUD 1971, 1985).

Measurements of equivalent sound level L_{Aeq} in dB(A) are taken during the hours starting from 7:00 a.m. to 9:00 p.m. at the platform of each station and onboard. Percentile noise indices L_1, L_{10}, L_{50}, L_{90}, L_{99} and Noise pollution index LNP were calculated using cumulative curve for each level versus time curve. L_1, L_{99} and LNP results for Mubarak and Sadat stations are listed in the following tables:

Underground station	Noise level dB(A)	According to USHUD criteria
Mubarak station	103 dB(A)	clearly unacceptable
Sadat station	103 dB(A)	

Table 1-3: Maximum Noise level L_1 on the Station Platform [*]

Underground station	Noise level dB(A)	According to USHUD criteria
Mubarak station	75 dB(A)	clearly unacceptable
Sadat station	79 dB(A)	

Table 1-4: Background Noise L_{99} [†]

Underground station	Noise level dB(A)	According to USHUD criteria
Mubarak station	105 dB(A)	clearly unacceptable
Sadat station	105 dB(A)	

Table 1-5: Noise Pollution Index (LNP) on Platform Compared with the Criteria for LNP [‡]

Noise at the platform area is generated by the interaction between the train and the air around it in the tunnel or in the station (aerodynamic noise), and by the friction between the wheels and the rails (mechanical

[*] ALY, M. (2005) Noise assessment inside the second-line of the Greater Cairo Underground Metro. Sadhana. 30(1): p. 47-55.Extracted from graphs p.51
[†] Ibid. Extracted from graphs. p.52
[‡] Ibid. Extracted from graphs. P.53

noise). Noise Indices were found clearly unacceptable due to the use of the train siren and application of brakes at train arrival. The increase of LNP is due to the increase in measured sound levels and standard deviation (σ). While the increase in (σ)is due to the great difference between noise recorded for the train siren and brakes compared with the passengers crowd noises and the automatic alarm signal in some stations. He concluded that:

1. The noise generated on the platform are due to the aerodynamic and mechanical noise. Noise levels on platform increase due to the reflection of sound on the cylindrical tunnel walls near both of the tunnel ends. Train noise inside the tunnel increase due to all train noise reflected to the centre axis of the tunnel.
2. The noise levels on the platform increases due to use the train siren and the application of brakes.
3. Finishing materials used in wall linings contribute to the increasing noise levels on the platform.

He recommended some solutions such as:

1. Treating the tunnel and platform walls with sound absorbing materials to decrease the reflection of sound.
2. Changing the platform wall lining with smooth ceramic tiles by other kind of material that have more sound absorption coefficient to decrease the total noise levels on platform.

In Egypt State of the Environment **Kamal, M. et al**(2005) [15] conducted a survey to measure GCM noise levels in Line1&2 during 2004-2005. Measurements were taken on the station platform, onboard inside the passengers' cars and inside the driver's cab. Results of maximum noise level measurements $\mathbf{L_{Amax}}$ in Line2 underground stations taken during morning and evening were respectively 96.2 and 93.3 dB(A) on platform. The study concluded that:

1. Noise Levels in the line2 are higher than those of Line1 during peak hours due to noise emitted by passengers' movement and individual conversation that raise noise levels.
2. Noise levels in underground stations are higher than levels in surface stations (at grade - and via duct) stations. Levels increase onboard when train enters the tunnel due to sound reflections that are explained by lack of using sound absorbent materials in coating the tunnel walls.
3. Operation of internal closed TV circuit and public address system increase sound levels inside underground stations.

4. The highest noise level recorded in the survey during passage of railway car was in Mubarak station due to passengers' capacity on both platforms. The highest continuous equivalent sound level A-weighting was recorded during peak hours 91.8 dB(A).

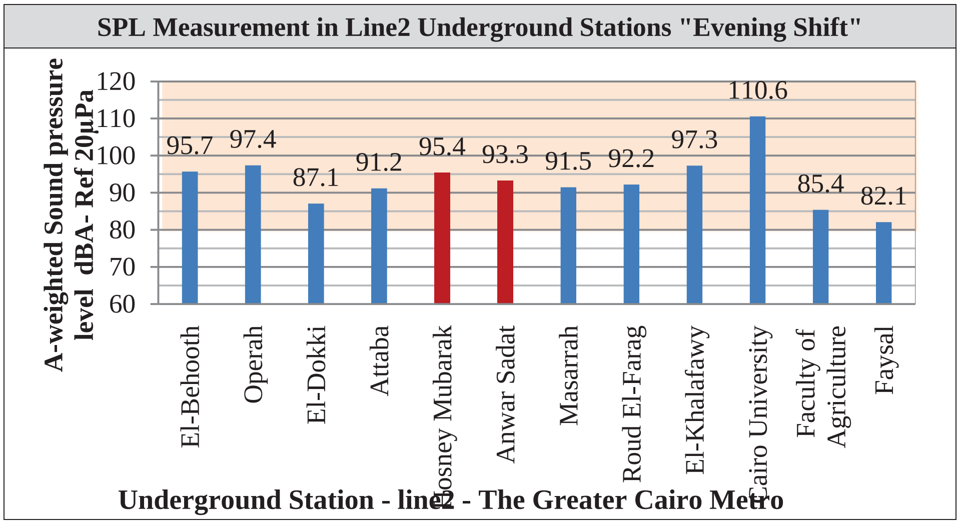


Figure 1-18: Measurements Taken in GCM Line2 During Evening Shift*

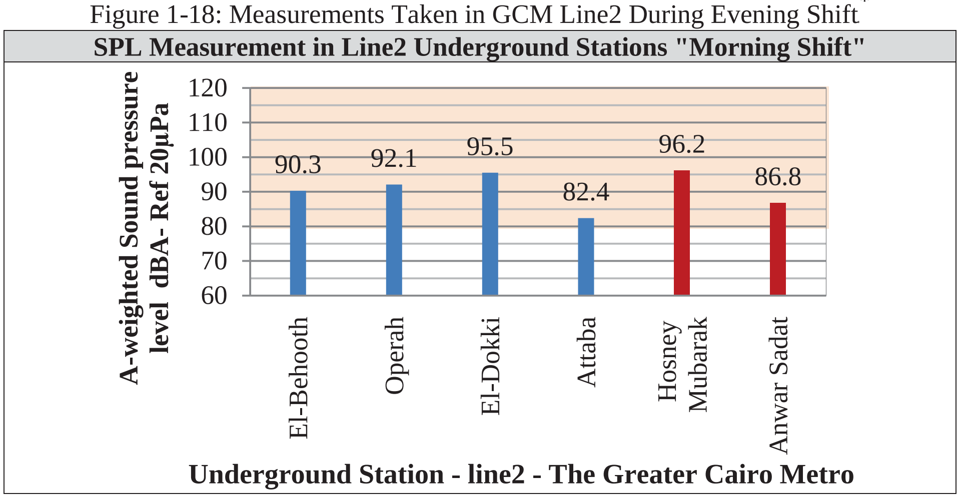


Figure 1-19: Measurements Taken in GCM Line2 During Morning Shift.†

* Kamal, M., (2006) Egypt state of the Environment Report, in Noise. Ministry of state For environmental Affairs: Arab Republic of Egypt. Generated from Tables in Annex 2-2 P.185-186.
† Ibid P.185-186.

Gershon et al(2006) [16] conducted environmental noise survey in the New York City subway system. Over 90 noise measurements were taken using a sound level meter. Average and maximum noise levels were measured on underground stations platform, while maximum levels were measured onboard. Other measurements are conducted at several bus stops for comparison purposes.

The subway platforms measurements were taken at three different locations on each platform. These locations were:

1. The front end (the end at which the lead car came to rest when stopped at the platform)
2. The middle section of the platform
3. The rear section of the platform (the end at which the rearmost car came to rest when stopped at the platform)

For all samples, other conditions that could affect noise levels were noted (e.g., passing trains, air brake release, police sirens, etc.). Platform measurements began when the operating motor of the first car of an inbound train was flush with the rear edge of the platform. Measurements continued until the train came to a complete stop, usually after 30 to 40 s.

An average sound pressure levels (SPL) was computed for each platform measurement by taking the arithmetic mean of the 5-s interval readings within each measurement. SPLs are typically averaged logarithmically to compute an equivalent continuous exposure level (L_{Aeq}), a measure used to summarize periods of exposure to time-varying noise levels. SPLs were arithmetically averaged because noise levels were not sampled continuously for each measurement, but rather at regular 5-sec intervals.

Fifty-seven average SPL measurements (encompassing 377 5-s interval SPLs) were taken on underground station platforms in 17 different underground stations. Forty of the 57 measurements had durations of 30 s or less; the longest lasted 90 s. All 57 average levels were over 75 dB(A), the threshold level above which there is a duration dependent risk of NIHL .

Table 1-6 presents measurement durations, mean and maximum 5-s interval noise levels for all platform measurements with platform measurement location and station type.

Measurements made at the back of the platform had the highest mean level and fraction of average exposures over 85 and 90 dB(A); however, neither mean noise levels nor exceedance fractions differed significantly by platform location. Stations that are major transfer points had statistically significantly higher mean noise levels (mean difference 3 dB(A), p = 0.002) than smaller local stations and had a statistically higher fraction of measurements over 85 dB(A) (p = 0.006). Measurement conditions associated with average platform noise levels over 85 and/or 90 dB(A) included track curvature, presence of two trains at a platform simultaneously, excessive brake squealing, debris on the railway tracks, and release of compressed air from air brakes on the trains. Major transfer point stations consistently had the highest noise levels.

Measurement duration (s)				Noise level dB(A)				
						Highest	Percent	Percent
Location/station type	**n**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**5-s interval**	**(%) >85 dB(A)**	**(%) >90 dB(A)**
Overall	57	34.0	10.8	85.7	3.9	106.0	58.0	12.2
Back of platform	19	38.9	14.2	86.1	4.8	106.0	63.2	21.1
Middle of platform	19	33.2	8.0	85.1	3.9	105.0	63.2	5.3
Front of platform	19	30.0	7.1	86.0	3.0	105.0	47.4	10.5
Major transfer point	24	32.3	7.1	87.5	3.1	106.0	79.2	16.7
Local station	33	35.3	12.7	84.5	4.0	105.0	42.4	9.1

Table 1-6: Noise Levels and Exceedance Fractions in Subway Stations[*]

The average noise level measured on platforms was 86 ± 4 dB(A). Maximum measured levels were 106, 112, and 89 dB(A) on platforms, onboard, and at bus stops respectively. These results indicated that noise levels in underground stations and bus stop environments have the potential to exceed recommended exposure guidelines from the World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA), given sufficient exposure duration. Risk reduction strategies following the standard hierarchy of control measures should be applied, where feasible, to reduce underground noise exposure. The study suggested the following:

1. A number of engineering controls may be implemented by subway system agencies to reduce noise levels in the subway environment. These include sound dampening acoustical materials placed in particularly noisy sections of a subway line and repair and improved maintenance of tracks, braking mechanisms, and equipment in general.

[*] Gershon, R., et al. (2006) Pilot Survey of Subway and Bus Stop Noise Levels. Journal of Urban Health: Bulletin of the New York Academy of Medicine.

2. Newer subway systems can be designed to reduce noise using rubberized rails, acoustical tiles, and other effective techniques.

1.10. Conclusion

- Underground station platform is considered an irregular space due to the vast difference between its dimensions. Moreover, most building materials that are used in platform finishing are characterized by high sound reflectivity and are deficient in noise reduction.
- The noise levels in underground stations are higher than the levels in surface stations (at grade - and via duct) stations due to sound reflections on tunnel and station walls.
- Noise Levels in the line 2 are higher than those in Line 1 due to :
    - Operation of closed TV circuit and public address system
    - Alarm signal applied when train enters the station.
    - Crowd Noise during Peak hours.

<table>
<tr><th colspan="4">Egypt State of the Environment Report [15]</th></tr>
<tr><th colspan="2">Acoustical Indicators</th><th>closed TV circuit Operating</th><th>closed TV circuit Closed</th></tr>
<tr><td rowspan="2">Statistical Noise Indicators</td><td>L_{95}</td><td>58 - 84.5dBA</td><td>66.5- 81.5 dB(A)</td></tr>
<tr><td>L_5</td><td>77- 98.5dBA</td><td>79- 93.5dBA</td></tr>
<tr><td>Maximum A-weighted SPL</td><td>L_{Amax}</td><td>82.1 -110.6 dB(A)</td><td>82.4 – 96.2 dB(A)</td></tr>
<tr><th colspan="4">The National Research center Survey [14]</th></tr>
<tr><td rowspan="2">Statistical Noise Indicators</td><td>L_{99}</td><td colspan="2">71.6 - 82 dB(A)</td></tr>
<tr><td>L_1</td><td colspan="2">100-107 dB(A)</td></tr>
</table>

- In line2 underground stations, all platform ceilings are treated by mineral wool based coating to absorb excess train and crowd noises, yet maximum noise levels measured in these underground stations exceeds acceptable limits as stated in several noise monitoring surveys.

- A number of engineering controls may be implemented by rapid transit system agencies to reduce noise levels in the underground environment either by the following procedures:
    - Repairing and improving maintenance of tracks, braking mechanisms, and equipment in general.
    - Placing acoustical materials in particularly noisy sections in underground station to decrease noise levels.
    - Treating tunnel walls with sound absorbing materials to decrease the reflection of sound and improve its acoustic characteristics.

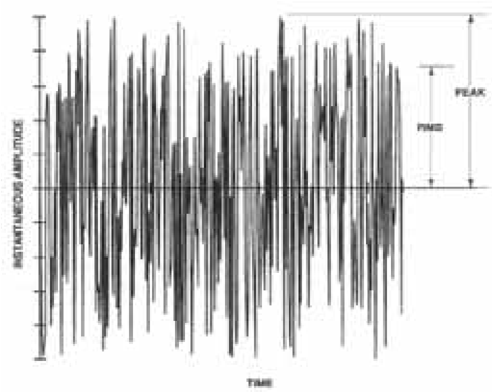
Part 1: Evaluation of the Acoustical Environment inside the Greater Cairo Underground Stations.

2. Chapter 2: Underground Station Noise

2.1. Generation of Railway Noise

The principal noise sources generated from a railway train are the propulsion system, motors and gearing, and the wheel/rail system. The wheel/rail noise usually dominates the generated noise signature. Design and maintenance of both propulsion system and wheel/rail system are important in order to maintain acoustical comfort for passengers.[3]

The dominant cause of railway noise is the interaction between the wheels and the rail. Excitation of wheel-rail noise on tangent track generally is attributed to rail and wheel surface roughness, train traveling on smooth wheels and smooth continuous welded (joint-less) rail emit a steady wide-band noise, called rolling noise. [17]



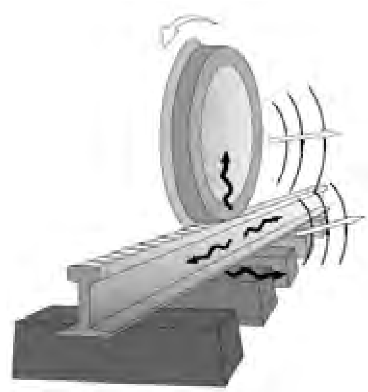


Figure 2-1: Left - Random Waveform Example*

Figure 2-2: Right - Illustration of The Mechanism of Generation of Rolling Noise†

Most noises do not comprise simple tonal components, but very complex waveforms that have continuous frequency distributions. Such sounds are often called "broadband" that means the frequency distribution covers a wide range of frequencies. Figure 2-1 is an illustration of broadband random noise similar to a waterfall or wheel/rail noise. The term "random" indicates that the magnitude of the noise cannot be precisely predicted for any instant of time. [18]

In Rapid Transit Systems, noise levels generated in underground stations ranges from 80 dB(A) to 115 dB(A) at high frequency ranges as shown in Figure 2-3 and Figure 2-4.

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*NELSON, J.T., (1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. Council, Editor., Federal Transit Administration in Cooperation with the Transit Development Corporation p.12

†Thomson, D. (2009) Railway Noise And Vibration: Mechanisms, Modelling And Means. Great Britain: Elsevier Ltd..p.7

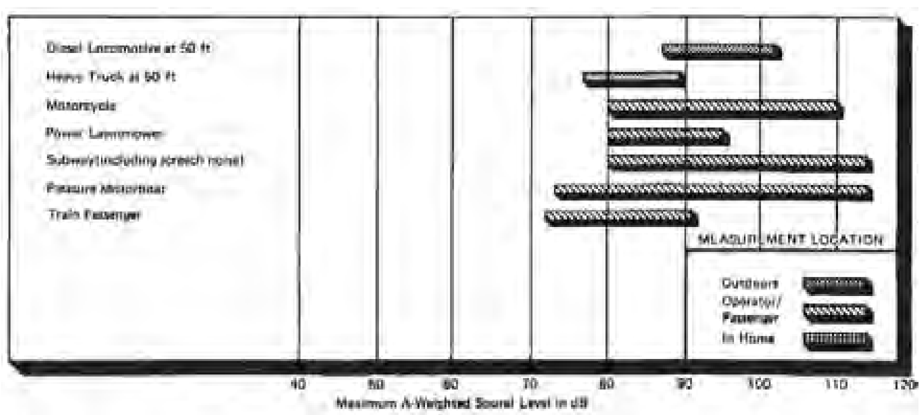

Figure 2-3: Typical Range of Common Noises.*

The first step in selecting noise control treatments is to identify the source of noise to be able to determine the most effective treatment that reduces it. [18]

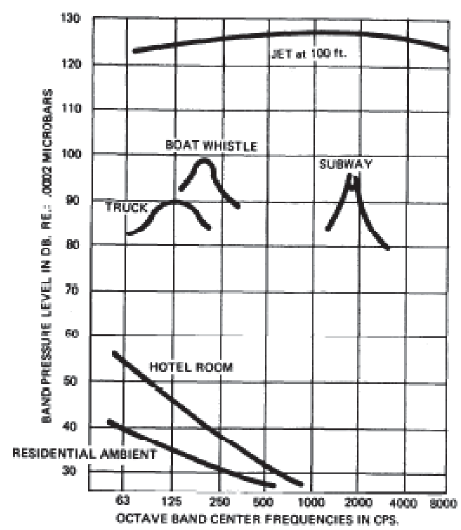

Figure 2-4: Railway Noise Spectra.†

There are several descriptive terms for various types of wheel/rail noise. The terms rolling noise and tangent track noise are both used to refer to noise produced by rail and wheel roughness and material heterogeneity. Rolling noise occurs at curved as well as tangent track. The term impact noise refers to noise generated by rail imperfections, joints, and more significantly. Much of tangent track rolling noise at severely worn rail or with flatted wheels may include substantial impact noise due to wheel/rail contact separation. The terms wheel squeal and curving noise both refer to the noise generated at curves. Curving noise includes both wheel squeal and wheel/rail howl, the latter being the less common, while wheel squeal is due to a stick slip phenomenon involving nonlinear interaction of the wheel with the rail; see Figure 2-5:

* Cheremisinoff, N.P. (1996) Noise Control In Industry A Practical Guide. USA: Noyes Publications.p.3
† Ibid.p.13

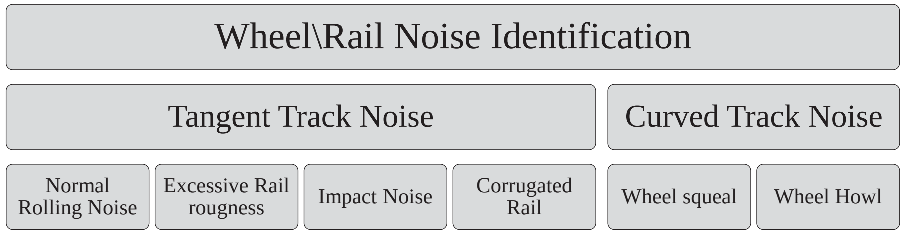

Figure 2-5: Categorization of Wheel/Rail Noise .[*]

2.1.1.1. <u>Normal Rolling Noise</u>

Normal rolling noise occurs at smooth ground rail with optimum rail and wheel profiles. The rail appears smooth and free of spalls, pits, shelling, and corrugation.

2.1.1.2. <u>Excessive Rolling Noise</u>

Excessive rolling noise results from random roughness and is caused by rough rails and wheels without identifiable rail corrugation, joints, or other large imperfections in the running surface. Excessive rolling noise would normally arise after a period of no rail grinding or wheel truing. Excessive rolling noise also may exist despite rail grinding, where the rail grinding is minimal or does not provide a smooth, uniform contact wear pattern edge definition.

2.1.1.3. <u>Impact Noise Control</u>

Impact noise may be the most significant source of noise at transit systems where rail grinding and wheel truing are not performed or are performed on an infrequent basis. The causes of impact noise include chips, burns, rail joints, and excessive curvature of the rail surface in the longitudinal direction.

2.1.1.4. <u>Corrugated Rail Noise</u>

Noise caused by rail corrugation is the most objectionable type of wheel/rail noise occurring at tangent or moderately curved track, and one of the most difficult to control. The harsh tonal character of corrugation noise makes it one of the most easily heard and identifiable types of community noise. Rail corrugation noise can be painful to transit system patrons and interferes with conversation, and many complaints concerning excessive noise from rail transit systems are directly related to rail corrugation. Descriptive terms for noise caused by rail corrugation

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[*] NELSON, J.T., (1997) <u>Wheel/Rail Noise Control Manual</u>, T.R.B.N.R. Council, Editor., Federal Transit Administration in Cooperation with the Transit Development Corporation p.68

are “roaring rail” or “wheel/rail howl.” Roaring rail or wheel/rail howl at severely corrugated track may be a special type of periodic impact noise resulting from loss of contact between the wheel and rail.

2.1.2. Curved Track Noise

Wheel/rail noise at curved track may differ considerably from such noise at tangent track and may include a combination of normal and excessive rolling noise, impact noise, noise resulting from corrugation, wheel squeal resulting from stick-slip oscillation, and wheel howl.

2.1.2.1. Wheel Squeal

It is the most common form of curving noise, caused by stick-slip oscillation during lateral slip of the tread over the rail-head.

2.1.2.2. Wheel Howl

It occurs at curves and may be related to oscillation at the wheel’s lateral resonance on the axle, caused by lateral slip during curving. At short radius curves where train speeds may be limited to 32 km/h, rolling noise may be insignificant relative to wheel squeal.

2.1.3. Railway Noise Radiation

Sound radiation by the rail is usually modeled by assuming that the rail is a cylinder of diameter equal to the height of the rail. Noise radiation partitioning between the rail and wheel is difficult to quantify accurately because of the closely coupled nature of the wheel and rail and their proximity to one another. Even the ties can be considered significant noise radiators. For continuous smooth ground rail, much of the theoretical literature suggests that the rail is the most significant radiator of noise. [18]Numerous experimental data suggest, that wheel-radiated noise is of similar significance as that of the rail. Noise radiation by the rail is still significant at 500 Hz, while for very low frequencies, the radiation efficiency declines.

2.1.3.1. Directivity

The radiation pattern for sound radiated by train is primarily distributed as dipole radiators. Dipole radiation is consistent with noise radiation from a wheel, and, for this reason, the wheel is the dominant radiator of noise. However, much of the noise radiated by the rail may also be radiated in a dipolar fashion. [18]

2.1.4. Railway Noise Emission Limits

Sound power levels generated from railway trains are quantified in the following table according to vehicles type and speed.

Local Transportation Type of vehicle	Power per Unit Length of a Train L_{WA} 100 km/h dB(A)	A-Weighted Maximum SPL L_{AFmax} 80 km/h 7-5m
Subways, rapid transit trains	93	79
Street cars	93	79

Table 2-1: Emission Limits for Railway Car Noise (Measured on a Test Track With Low Surface Roughness)*

2.1.5. Railway Noise Propagation

As the train passes, acoustic waves which compose the pass-by noise propagate away from the train and the energy contained within them is distributed over a large area, which might be visualized as an imaginary cylinder with its center along the track.

Noise spreading reduces its energy density, manifested as a decrease in loudness as the distance increase. This occurs in surface stations while in underground stations sound waves propagate along the axis of the track cylindrically to reflect on the tunnel body or the station boundaries. Friction is another mechanism that decreases railway noise amplitude by actually decreasing the amount of energy in the wave. Some of the acoustic wave energy is being converted into heat energy by the viscosity of the air, especially at the higher frequencies. This will further decrease the loudness of the noise and will alter the character of the pass-by noise, similar to turning down the treble adjustment on a car radio.

Although both of the previous mentioned mechanisms are effective in reducing the amplitude (loudness) of a propagating acoustic wave, the distance required to attenuate train pass-by noise to an acceptable level is often much further than the distance to the nearest affected receptor. Therefore, other means of controlling train noise may be necessary. [18]

2.1.5.1. Noise in Free Field (Wind and Temperature Gradients)

The speed of sound in air is independent of frequency and varies only slightly with humidity and atmospheric pressure. At a temperature of 20° *c* the speed of sound is approximately 344 m/sec. The air temperature can have a significant effect on the speed of sound as it increases about 0.61 m/sec for each 1° C increase in temperature. [18]

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*Kurze, U.J., R.J. Diehl, And W. Weibenberger. (2000) Sound Emission Limits For Rail Vehicles. Journal of Sound and vibration 231(3)

2.1.5.2. Noise in Underground Stations

Sound Field in underground station is characterized by being reverberant due to sound reflections on station boundaries. Sound rays reflect on station walls, ceiling and floor with a reflection pattern according to the station form. In case of box-section underground stations, sound rays reflect as shown in Figure 2-7. While in case of rounded stations, sound rays reflect to focus in the middle zone of the station, which lead to much annoyance.

Inside tunnel, reverberation increase as the tunnel volume is less than that of the underground station. Noise levels in both rounded and box-section tunnel are high, however the reflection pattern varies according to the tunnel section form; see Figure 2-7.

2.1.5.3. Noise Onboard (Inside Railway Car)

Noise inside the railway car can cause irritation to passengers especially when windows are open while the train is moving inside the tunnel[15]. Figure 2-8 illustrates the three ways noise and vibration can reach occupants of passenger cars:

1. External airborne sound and flow turbulence cause pressure fluctuations on the car shell which transmits a portion to the interior.
2. Structure-borne vibration is transmitted from wheels, motors, and under-car equipment along solid paths to interior surfaces which then vibrate and radiate noise inside.
3. Sound is generated within the car itself.

2.2. Measurements of Railway Noise in Underground Stations

An understanding of noise generation mechanisms and knowledge of the capability of measurement techniques are the bases for railway noise assessment development. [10] Exterior and interior rail noise are measured in order to:

- To characterize the noise emitted by train vehicle.
- To compare the noise emissions of various trains on a particular track section.

And the results may be used, either for: [10]

1. **Type Testing:** the measurement performed to prove that, or to check if, a vehicle delivered by the manufacturer complies with the noise specifications

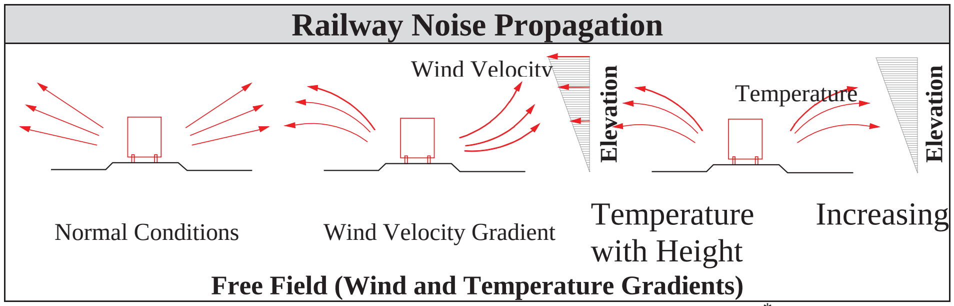


Figure 2-6: Atmospheric Effect on Sound Propagation*

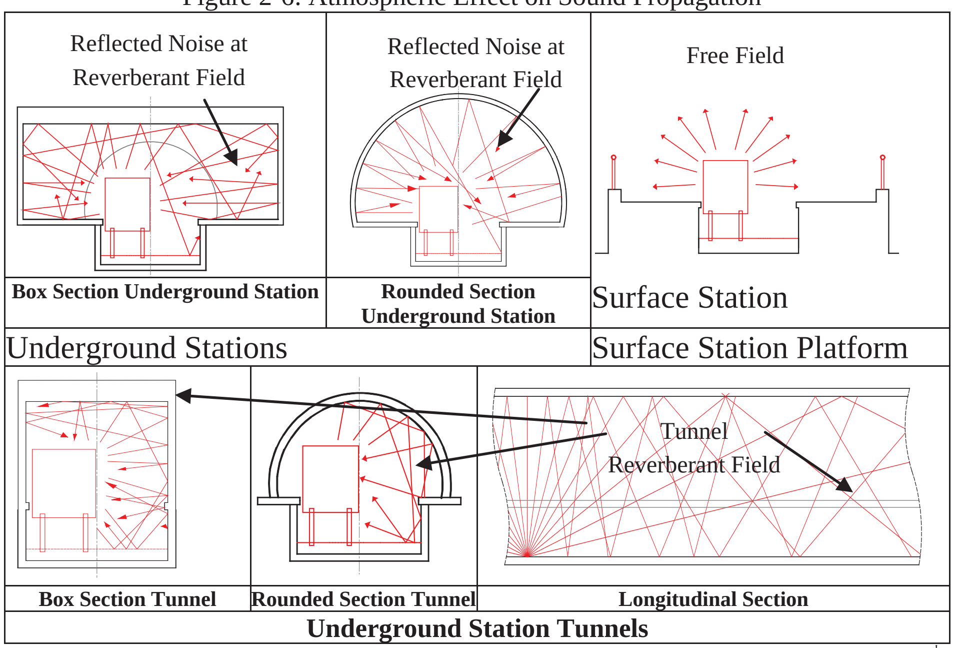
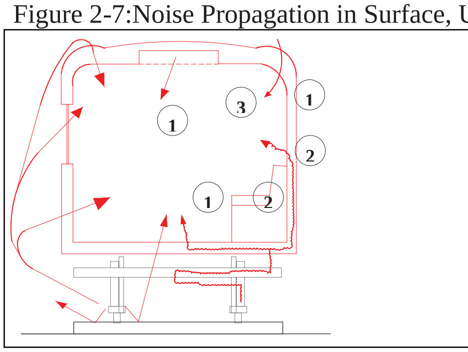


Figure 2-7:Noise Propagation in Surface, Underground Stations platform and Tunnels†



Onboard (Inside Vehicle)

1. External airborne noise transmitted through car shell.
2. Structure-borne noise and vibration.
3. Airborne noise from interior sources.

Figure 2-8: Left- Noise and Vibration Paths to Railway Car Interior‡

* Nelson, J.T.,(1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. COUNCIL, Editor., Federal Transit Administration in Cooperation with the Transit Development Corporation. P.

†Generated by the Author

‡Harris, C.M. (1979) Handbook of Noise Control. 2nd edition ed., New York: McGraw-Hill book Company .p.33-18

2. **Periodic Monitoring Testing:** the measurement performed to check if the noise of a vehicle has changed since initial delivery or after modification.
3. **Environmental Assessment Test:** The measurement performed for collecting data to be utilized in prediction method for environmental assessment.

The procedure and equipments used for railway noise measurement will be discussed in the following section in order to characterize and quantify noise emitted by train to be utilized in environmental assessment.

2.2.1. Measurement Quantities

Experiments have been made to evaluate the various physical measurement scales that most closely correlate with subjective evaluations of noise. For noise such as street traffic, transit vehicles and general community noise, it has been found that the sound level meter "A" weighting scale gives good and adequate correlation with subjective evaluation of response to noises. Thus the "A" weighted sound level, which can be read directly from a sound level meter, is best for evaluating, on an engineering basis, the probable response of people to the noise created by transit car noises.[3] while sound power level and directionality, often used to characterize such noise sources, are difficult to measure for such large sources.[18]

The indicators applied to quantify noise depend on the noise source and purpose for the noise measurement. There are hundreds of metrics defined that are commonly used in transportation noise engineering; see Table 2-2.[19]

Transportation Noise Metrics Used for Railway Noise			
Metric name	**Metric symbol**	**abbreviation**	**Metric description**
A-weighted equivalent sound level	L_{AeqT} **(T _ time increment)**	L_{Aeq}	Sound level associated with the sound energy averaged over a specified time period.
A-weighted maximum SPL	L_{Amax}	L_{Amax}	A-weighted maximum **SPL** during a noise event or specified time period.
Percent exceeded sound level	L_X **(e.g., L_{10})**	—	The sound level exceeded X percentage of the time during a specified time period.
A-weighted sound exposure level	**LAE**	**SEL**	The time integral of sound level over the course of a single event.

Table 2-2: Summary of Commonly Used Transportation Noise Metrics .*

*Kutz, M. (2004) Handbook of transportation engineering. New York McGraw-Hill.p.483

There are some generally accepted practices for quantifying rail noise: For single events, such as a train passing through a community, the A-weighted maximum **SPL** $\mathbf{L_{Amax}}$ or the sound exposure level (**LAE** or **SEL**) is applied. For the cumulation of multiple events, the A-weighted equivalent sound level ($\mathbf{L_{Aeq}T}$ or $\mathbf{L_{Aeq}}$) or the day-night average sound level (**DNL** or **Ldn**) is applied. For train horns, $\mathbf{L_{Amax}}$ is applied. Refer to Table 2-2 for metric descriptions. [19]

Considering a notional time history of the noise during a train pass-by, as shown in Figure 2-9, several different single number quantities are used to define the railway noise level. [1] The times **0** and **t** are chosen to include the whole pass-by, or more practically they are usually defined as the points at which the level is 10 or 20 dB below the maximum level.

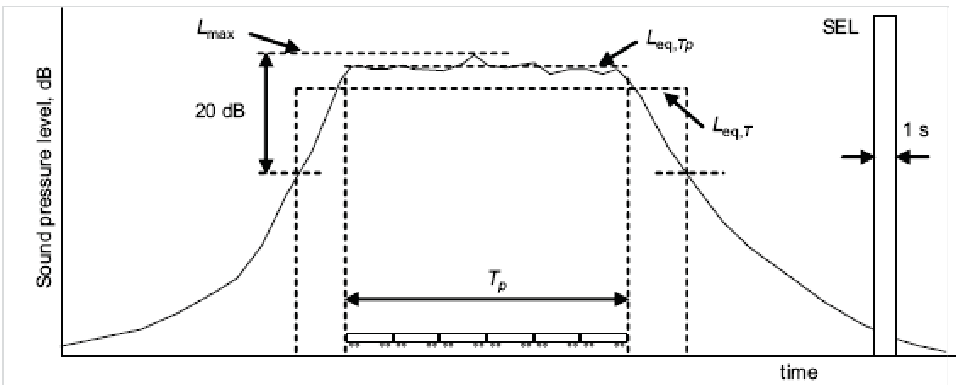


Figure 2-9: Notional Time History of Train Pass-By Noise Indicating Various Quantities.*

2.2.1.1. A-Weighted Maximum SPL, L_{Amax}

This is the maximum A-weighted sound pressure level (with the averaging set to 'fast') over the pass-by time interval **T**. The term 'maximum level' is also used to refer to the average level of the plateau region during a pass-by. This is more useful than the actual maximum level, which can be influenced by a single noisy wheel, but is less well defined.

$\mathbf{L_{Amax}}$ is the maximum noise level that occurs during an event or pass-by. Unlike other cumulative or statistical noise metrics such as **Ldn**, it is the maximum noise level actually heard during the event or pass-by. It is desirable to use $\mathbf{L_{Amax}}$ since:

*Thomson, D. (2009) Railway noise and vibration: mechanisms, modelling and means. Great Britain: Elsevier Ltd. Appendix A.

- It is representative of what people hear at any particular instant.
- I is straightforward to measure with a standard sound level meter.
- Noise limits in vehicle specifications are usually in terms of $\mathbf{L_{Amax}}$
- Because $\mathbf{L_{Amax}}$ represents the sound level heard during a transportation vehicle pass-by, people can relate this metric with other environmental noises, such as an aircraft flyover or a truck pass-by.

2.2.1.2. SEL (Sound Exposure Level)

The **SEL** is formed from the integral of the squared pressure over the whole pass-by (including the rising and falling parts), normalized to 1 second:

$$\mathbf{SEL = 10log\left(\frac{1}{T_0}\int_0^T \frac{p_A^2}{p_0^2}dt\right)dB}$$ Equation 2-1[1], [10]

Where $\mathbf{T_0 = 1}$ sec. is the reference time interval
T is the measurement time interval in sec.
$\mathbf{P_A(t)}$ is the A-weighted instantaneous sound pressure in Pa
$\mathbf{P_0}$ the reference sound pressure; P_0 = 20 μPa.

Single event level, **SEL**, is related to the A-weighted equivalent continuous sound pressure level, $\mathbf{L_{Aeq},T}$, by the following equation:

$$\mathbf{SEL = L_{Aeq,T} + 10log(T/T_0)dB}$$ Equation 2-2[1]

As the passage time is usually longer than 1 sec this will give a level that is higher than the maximum level. The SEL can readily be used as input to a calculation of long-term noise exposure based on equivalent sound levels, $\mathbf{L_{Aeq}}$. **[1]**

2.2.1.3. Short-Term Equivalent Levels

The short-term equivalent levels, $\mathbf{L_{Aeq},T_p}$ are defined in a similar way to long-term $\mathbf{L_{eq}}$ values. These have the form

$$\mathbf{L_{Aeq,Tp} = 10log\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} \frac{p_A{}^2(t)}{p_0^2}dt\right)dB}$$

Equation 2-3[1], [10]

Where $\mathbf{L_{Aeq},T_p}$ is the A-weighted equivalent continuous sound pressure level on the pass-by time in dB;
$\mathbf{T_P=T_2-T_1}$ is the measurement pass-by time interval beginning at $\mathbf{T_1}$ and ending at $\mathbf{T_2}$ in sec; see Figure 2-10.
$\mathbf{P_A(t)}$ is the A-weighted instantaneous sound pressure in Pa;
$\mathbf{P_0}$ the reference sound pressure; $\mathbf{P_0}$ = 20 μPa.

The duration $T_P=T_2-T_1$ may be chosen to represent the length of a vehicle or of the whole train (**Tp**, the length of the train, divided by its speed) or it may be the time between points at which the level is 10 or 20 dB below the maximum level.

2.2.1.4. TEL (Transit Exposure Level)

The **TEL** is formed from the same integral as the **SEL**, i.e. over the whole pass-by, but is normalized by the passage time **Tp** rather than the measurement time:

$$TEL = 10\log\left(\frac{1}{T_p}\int_0^T \frac{P_A^2(t)}{P_0^2}dt\right)dB \quad \text{.............................. Equation2-4}^{[1],[10]}$$

Where: **TEL** is the A-weighted transit exposure level in dB;
T is the measurement time interval in sec.
T_P is the pass-by time of the train in seconds which is the overall length of the train divided by the train speed;
$P_A(t)$ is the A-weighted instantaneous sound pressure in Pa;
P_0 the reference sound pressure; P_0 = 20 µPa.

Transit exposure level, **TEL**, is related to single event level **SEL**, and to the A-weighted equivalent continuous sound pressure level, L_{Aeq},T by the following equations:

$$TEL = SEL + 10\log 10(T_0/T_p) \quad \text{..................................... Equation 2-5}^{[1]}$$

$$TEL = L_{A\,eq,T} + 10\log(T/T_P) \quad \text{... Equation 2-6}^{[1]}$$

Where T_0 = 1 sec is the reference time interval.

2.2.2. Measurements Conditions Form Railway Noise

The quantities to be measured for railway noise at all microphone positions are specified in the following table.

Measuring conditions		Measurement procedure
Trains moving at constant speed	For Whole Trains (This Includes Single Vehicle Trains)	Transit Exposure Level, **TEL**, or the A-Weighted equivalent continuous sound pressure level on the pass by time, L_{Aeq},Tp as the case may be.
	For Parts of Trains	The A-weighted equivalent continuous sound pressure level on the pass-by time, L_{Aeq},Tp.
Stationary vehicles	-	A-weighted equivalent continuous sound pressure level, Lp_{Aeq},T.
Accelerating or braking train	-	Maximum A-weighted sound pressure L_{Amax}.Set to fast response

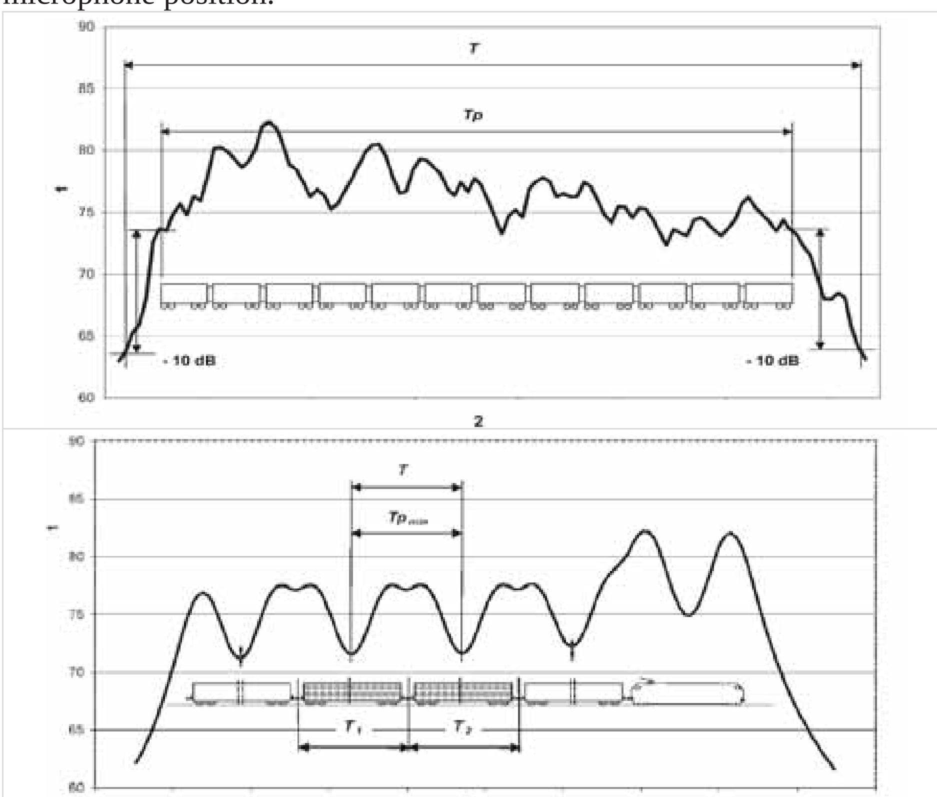
Table 2-3: Railway Noise Measurement Conditions *

*(2005) Railway applications —Acoustics —Measurement of noiseemitted by railbound vehicles. European Committee For Standardization.

If frequency analysis is required, it should be made at least in one third octave bands according to EN ISO 266: a typical frequency range could be 31,5 Hz to 8 kHz.

2.2.3. Measuring Time Interval T, and Train Pass-By Time, Tp [10]

Measurement time interval **T** is chosen so that the measurement starts when the A-weighted sound pressure level is 10 dB lower than found when the front of the train is opposite the microphone position. The measurement is stopped when the A-weighted sound pressure level is 10 dB lower than found when the rear of the train is opposite the microphone position.



Key: 1 A-weighted sound pressure level dB
2 Time

Figure 2-10: Top-Selection of Measuring Time Interval, T, for a Whole Train. *
Figure 2-11: Bottom-Selection of Measuring Time Interval T for Parts of a Train. †

*(2005) Railway applications —Acoustics —Measurement of noiseemitted by railbound vehicles. European Committee For Standardization.p.6
†Ibid.p.6

2.2.4. Measurement Instrumentation

The instrumentation system, including the microphones, cables and recording devices should meet the requirements for a type 1 instrument specified in EN 61672-1. [10]

- The microphones should have an essentially flat frequency response in a free sound field.
- The 1/3 octave band filters should meet the requirements of class 1 according to EN 61260.
- A suitable windscreen should always be used.

Before and after each series of measurements a sound calibrator meeting the requirements of class 1 according to EN 60942 should be applied to the microphone(s) for verifying the calibration of the entire measuring system at one or more frequencies over the frequency range of interest. If the difference between the two calibrations is more than 0.5 dB all the measurement results should be rejected.

2.2.5. Measurements Locations on Underground Station Platform

For Underground stations, Sound Pressure Level measurements are taken on platform for noise generated by the passing, arriving and departing train in stations and at stopping points. Measurement locations for railway noise in underground station are described in Figure 2-12 as follows: [10]

1. The microphone should be placed on the platform at a distance of 3 m from the centre line of the nearest track at a height of 1.5 m ± 0.2 m above the platforms in those places where there is an interest in the sound pressure level.
2. The microphone axis should be horizontal and directed perpendicularly to the track. Other measurements may be made at corresponding positions on neighboring platforms.
3. The A-weighted maximum **SPL** using time weighting fast, $\mathbf{L_{Amax}}$, should be measured. A drawing of the cross-section shall be given in the test report.

Reverberation time is measured on the station platform at several points to get the average.[20]

2.2.5.1. Sound Pressure Levels on Platform

Figure 2-13 shows a typical recording of the A weighted sound level measured on the platform. Noise is generated as a rapid-transit train enters and leaves the station. Noise sources during train entry and departure include wheel-rail interaction, mechanical brakes, impulsive air release from the brake system, door operation, air-conditioning, and train auxiliary equipment. (The Ambient sound level is determined by other sources such as air-handling systems and escalators. [17]

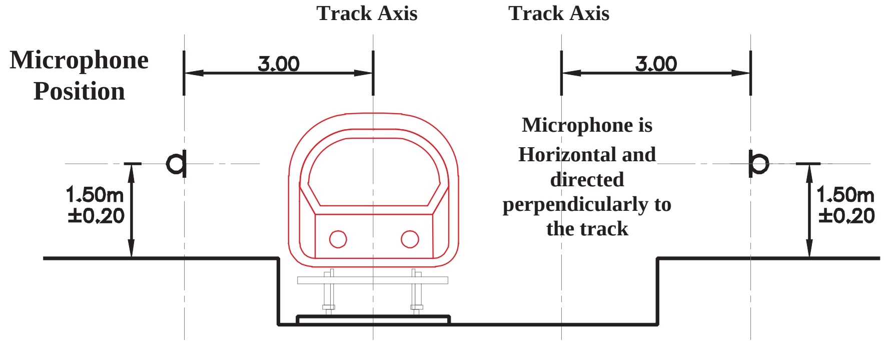


Figure 2-12: Measurements Locations on Underground Station Platform.*

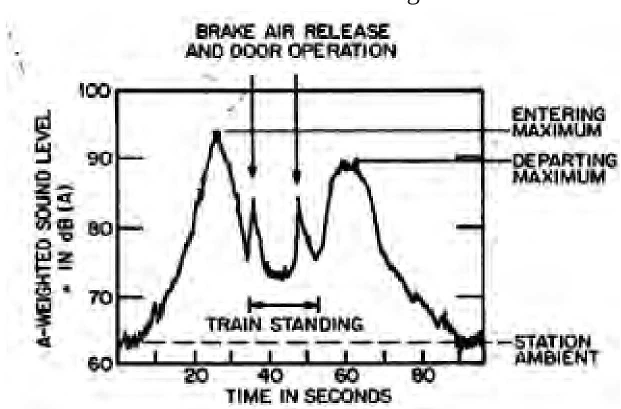


Figure 2-13: Noise on a Station Platform Vs. Time as Rapid Transit Train Enters and Leaves a Station.†

2.2.6. Measurements Locations inside Tunnel

Train noise in tunnels is measured from fixed microphones between the rails under the train, and if space permits, alongside it. Microphones (with appropriate wind screens) on trains often are mounted in the track area or; for rapid transit trains, outside between the cars, 120cm above floor height.[21] While the reverberant sound measurements are conducted outside the train when operating in the tunnels, on the walkway if existing.[20]

*Generated by the Author
†Harris, C.M. (1979) Handbook of Noise Control. 2nd edition ed., New York: McGraw-Hill book Company.p.33-15

2.3. Railway Noise Criteria

Various noise and vibration environments require criteria in order to reduce annoyance, discomfort, speech and sleep interference, and to reduce their hazardous effects. This has resulted in different rating measures being devised to account for these effects. [22] The following section will review noise levels criteria used to asses noise generated inside underground stations.

Train vehicle interior and exterior noises generally have separate standards, though the sources are the same. Limits recommend for train interior and exterior operational noises are listed in Table 2-4. [3] [17]

Vehicle Exterior Equipment Noise Levels - Free Field		
Vehicle Equipment Noise	In Free Field at 4.5 m from Track Centre Line Propulsion system operating equivalent to 80 mph (130 km/h)	90 dB(A) [3]
	In Free Field at 4.5 m from Centre line Propulsion system operating equivalent to 60 mph (100 km/h)	84 dB(A) [3]
	In Free Field at 4.5 m from Centre line In Open Stationary Train, Auxiliaries Operating	65 dB(A) [3]
Vehicle Exterior Noise	In Free Field at 7.5 m from Centre line 8-Car Train running at 60 km/h	78 dB(A)*
Decrease in criteria for presence of pure tones		3 dB(A) [3]
Vehicle Interior Noise Levels (Empty Car)		
In open (ties and ballast) at maximum speed		68 dB(A)
In open (concrete track bed) at maximum speed		72 dB(A)
In tunnels	At maximum speed	78 dB(A)
	Train Making Headway In Tunnel, Windows Closed: At 60 Km/h	72 dB(A)
	Train In Traction And Braking With Windows Closed	75 dB(A)
All auxiliaries operating, car stationary and Door Operation		65 dB(A)[3] NAT Specs

Table 2-4: Vehicle Interior and Exterior Noise Limits †

*National Authority for Tunnels Specifications.
†Knight, K.G. (1973) Guidelines and Principles for Design of Rapid Transit Facilities,W.H. Paterson. Washington: Institute for Rapid Transit.

2.3.1. Vehicle Exterior Equipment Noise Levels - Free Field.

The following criteria are related to train noise in the free field and are mentioned only as a reference for the generated train equipment noise limits. According to Rapid Transit Facilities Guidelines[18] train noise is checked at 4.5 m from the train centre line by placing the train cars on jacks and allowing free-wheeling. Measurements should be taken at the level of the truck axles in a free-field environment away from reflective or shielding surfaces. Propulsion system noise level should not exceed 90 dB(A) with propulsion motors and wheels operating at (130 km/h). Similarly, 84 dB(A) should be the criterion for operation at (100 km/h).[3]

A limit of 65 dB(A), at 4.5m from the car centerline, should be established as possible for noise levels from auxiliary equipment when the car is stationary. The criterion includes air brake noises such as the rapid release of “dumping” of air at terminals. These criteria should be reduced 3 dB(A) if significant pure tones in the range from 300 Hz. to 4000 Hz. are present. Pure tones are significant if any 1/3 octave band sound pressure level is 4 dB, or more, higher than the average of the two adjacent 1/3 octaves containing no pure tones.

According to National Authority of Tunnels, free field noise levels generated by a train are measured at 7.5 m from the centre line of the track, and should not exceed 78 dB(A) at 60 km/h.

2.3.2. Vehicle Interior Noise Levels

Interior noise criteria apply to measurements taken in a complete but empty train (car) and made 120cm to 180cm above the car floor at all points 30 cm or more from a wall surface.

For ease of communication and passenger comfort the sound level should not exceed 68 dB(A) in open. In all vehicles for public conveyance, it is desirable to maintain a background sound level that afford some degree of speech privacy for passengers. Adequate speech privacy in non-compartment cars requires sound levels not less than about 60 dB(A). Efforts to reduce interior sound levels below these criteria would be undesirable.

According rapid transit facilities design guidelines maximum limits for interior noise level is 78 dB(A). It could be established in underground stations. This require acoustical tunnel treatment or additional care in the acoustical design of the vehicles if they were to be operated extensively at maximum speeds underground. [3] While the **National Authority for**

Tunnels maximum noise level limits for interior noise is 72 dB(A).

A consistent goal for background noise created by the car auxiliary equipment and the air conditioning and ventilating system when the car is stationary is 65 dB(A) or less. [3] Noise produced by operation of only the vehicle doors should not exceed 65 dB(A) measured 30 cm or more from the door.

1. British old coach 145 km/hr
2. USA coach127 km/hr
3. French coach 127 km/hr
4. Modern sealed cars at 40 to 129 km/hr in open and in tunnels.
5. German coach 127 km/hr

British coach 145 km/hr

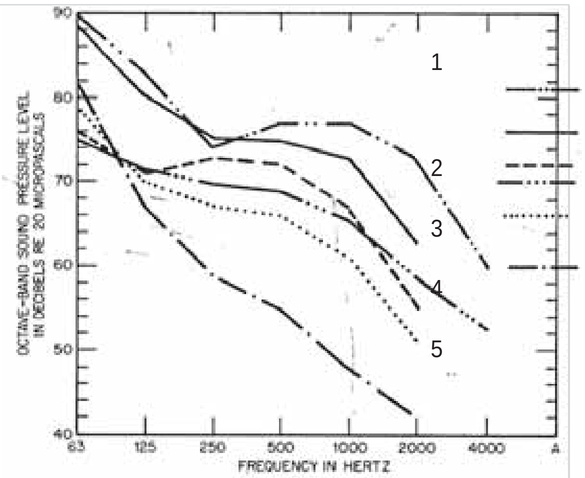


Figure 2-14: Passenger Car Interior Noise Spectra.*

2.3.2.1. Vehicle Interior Noise Levels in Tunnels

Appropriate noise abatement techniques should be used to reduce high noise levels from high speed train operation in tunnels to an acceptable level. Maximum interior Train noise levels in tunnels is 78 dB(A) according to the APTA guidelines [3], [17] and 72 dB(A), 75 dB(A) for constant speed train and train in traction, braking phase respectively according to the **National Authority for Tunnels**. An acoustical absorption system may be provided in the tunnels or additional sound insulation maybe provided on the cars to meet this criterion.

Tunnel sound absorption treatments can provide 5 dB or more reduction in noise levels inside the car. Reducing tunnel noise by a sound absorption system improves the acoustical environment for system employees and aids in complying with the hearing conservation requirements of the Occupational Safety and Health Act. Minimum design reduction in reverberant noise levels with acoustic treatment can reach 10 dB(A).[3]

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*Harris, C.M. (1979) Handbook of Noise Control. 2nd edition , New York: McGraw-Hill book Company.p.33-20

2.3.3. Underground Station Platform Noise Levels

2.3.3.1. Maximum Platform Noise Levels

The maximum sound level is measured using a sound level meter set to the "fast meter response," which is similar to a root mean square (**rms**) averaging time of 0.125 sec. In practice, the **rms** sound level is often determined by averaging the sound energy over the pass-by duration to average out minor fluctuations in sound level due to abnormally rough wheels, impacts, etc. Minor fluctuations of noise level can also be energy averaged using the "slow" sound level meter response characteristic, equivalent to an **rms** averaging time of 1 sec. The difference between the "slow" sound-level meter measurement and the "fast" sound-level meter measurement for a smoothly varying train pass-by signature is a fraction of a decibel. A problem may arise, however when measuring the maximum sound level using the slow meter response for very rapidly rising pass-by noise levels, in which case the fast sound-level meter response should be used. Most trains require at least 1 sec to pass a measurement location, a time that is consistent with the slow meter response. The slow meter response is entirely adequate for measuring maximum pass-by noise from heavy rail transit trains of four or more cars at distances beyond one car length. [18]

A. Moving Train

Trains operating at top speeds of 130 km/h and using maximum acceleration and braking levels could enter or leave stations at about 80 km/h depending on platform length, approaching and leaving grades, station spacing and other factors. Noise levels should be limited to a maximum of 80 dB(A) by an appropriate acoustical design. [3] In the case of express trains operating through the stations, noise levels should be limited to 85 dB(A). [18] Absorption materials to control noise must be applied and for adequate noise reduction, about 30 percent coverage of walls and ceilings will be necessary depending on the size and shape of the train room. [3]

According to APTA, Trains entering and leaving subway stations should not produce noise levels in excess of 85 dB(A). The Noise levels 5 dB below these limits are desirable. While according to the **National Authority for Tunnels,** noise levels at any point of the station platform should not exceed 82 dB(A) at train arrival at and departure (windows closed). Platform noise levels are normally measured at 1.5m above the platform, roughly midway between the platform edge and rear wall, or 1.5m from the platform edge, whichever is closer to the track. The noise levels apply to the total noise level, including noise due to wheel/rail sources as well as traction motor equipment, vehicle ventilation and air conditioning equipment, and brake systems.

B. <u>Stationary Train</u>

Stationary car noise should be limited to 65 dB(A) at 4.5 m from the train. Station noise levels should therefore be limited to about 67 dB(A) maximum any-where on the train platform. [3]

According to the **National Authority for Tunnels,** railway noise levels for a stopping train should not exceed 65 dB(A) at any point of the station platform while doors are open.

Criteria for the maximum A-weighted sound levels usually are considered acceptable for the acoustic environment, Lower levels, though desirable in all cases, may be disproportionately costly[17].

2.3.3.2. <u>Platform Background noise levels</u>

Underground station platform is an indoor space where moderately fair listening conditions and steady background noise are required for an acceptable acoustical environment.

Preferred acoustical Criteria for transportation facilities are indicated in Table 2-5 where the recommended station background noise and reverberation time recommended criteria are shown to control speech intelligibility of the public address systems.

Transportation facilities Use of space	**Requirement for noise control**					**Requirements for interior design**		
	Desired Background	**Vibration Sensitivity**	**Speech Privacy**	**Maximum sound**	**Maximum vibration**	**Reverberation time**		
						Non-projection	**Projection**	**Sound Amplification**
Terminal	NC 45-50 NC 55[3]	Not Critical	No concern	Very high sound levels	Heavy machinery	0.8s-1.0s	-	-
Waiting	NC 35-45	Not Critical	No concern	General activity	Footfalls	1.2s-1.6s	-	Y
Ticketing	NC 35-45	Not Critical	No concern	General activity	Footfalls	1.2s-1.6s	-	Y

Table 2-5: Transportation Facilities Guidelines for Building Design.*

*Croker, M.J. (1997) <u>Encyclopedia of Acoustics</u>. Vol. 3. New York: John Wiley & Sons, Inc. p.1014

Ventilation system noise is probably the simplest to control by selection of the fan locations and acoustical design of the fans. Since this noise may be regarded as steady state during lengthy periods of operation, an appropriate design criterion for station platforms would be 55 dB(A).[3]

Noise criteria (NC) curves were first introduced to evaluate existing noise problems in interior spaces such as offices, conference rooms, and homes. It was found that a background noise that fitted the original NC curves was not completely neutral. The noise had components that sounded both ‘‘hissy’’ and ‘‘rumbly.’’ [23]

The original NC curves were also based on the ‘‘old’’ octave bands. The NC curves were revised to produce a more nearly neutral background noise spectrum. These curves, called the preferred noise criterion (PNC) curves to distinguish them from the older NC curves, were also based on the present-day octave bands. Finally, the PNC curves were revised to make equal the perceived loudness for the octave bands that contain the same number of critical bands. The rating number on the NCB curves is the average of the NCB values in the 500 Hz, 1000 Hz, 2000 Hz, and 4000Hz octave bands. The NCB curves specify the maximum noise levels in each octave band for a specified noise criterion rating. The NCB rating of a given noise spectrum is the highest penetration of the noise spectrum into the NCB curves. The numerical values for the NCB curves are given in Table 2-7. [23]

The NCB curves specify the maximum noise levels in each octave band for a specified noise criterion rating. The NCB rating of a given noise spectrum is the highest penetration of the noise spectrum into the NCB curves.[23] The numerical values for the NCB curves are given in Table 2-7.

NCB, dB	**Octave band center frequency, Hz**								
	31.5	**63**	**125**	**250**	**500**	**1,000**	**2,000**	**4,000**	**8,000**
50	79	69	62	58	55	52	48	45	42
55	82	72	67	63	60	56	54	51	48
60	85	75	71	67	64	62	59	56	53
65	88	79	75	71	69	66	64	61	58
70	91	82	79	76	74	71	69	66	63
75	94	85	83	80	78	76	74	71	69

Table 2-6: Octave Band Sound Pressure Levels Associated with the 1989 Balanced Noise Criterion (NCB) Curves.*

* Kutz, M (2004) Handbook of transportation engineering. New York: McGraw-Hill.

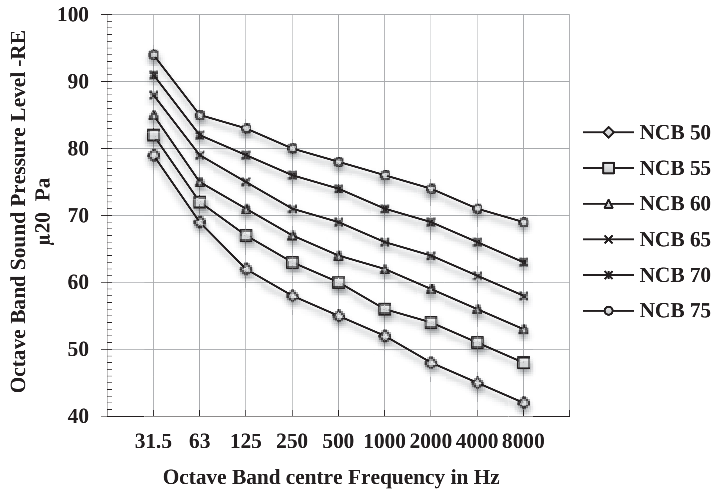


Table 2-7: Octave Band Sound Pressure Levels Associated with the 1989 Balanced Noise Criterion (NCB) Curves.

The suggested balanced Values of balanced Noise Criteria (NCB) Ratings for Steady Background Noise in indoor Spaces where moderately fair listening conditions are required for acceptable speech are between 50 and 60. These values may be used to determine if an existing acoustic situation is satisfactory for its anticipated usage, and to determine the acoustic treatment required to make the background noise acceptable if the noise level is too high. The values given in Table 2-8 apply for background noise consisting of both equipment noise (air conditioning systems, machinery, etc.) and activity noise due to the activity of the people in the room. [23]

Activity and Type of Space	NCB Rating
Moderately Fair Listening Conditions Required	
Light maintenance shops, industrial plant control rooms, kitchens, and laundries	45–55
Acceptable speech and telephone communication areas: Shops, garages	50–60

Table 2-8: Recommended Values of Noise Criteria (NCB) Ratings for Steady Background Noise in Various Indoor Spaces.*

2.3.3.3. Reverberation Sound Field

Maximum reverberation time on the station platform should be limited to a maximum of 1.6 to 2.0 sec at mid frequencies to reduce speech

*Barron, R.F. (2003) Industrial Noise Control and Acoustics. New York: Marcel Dekker, Inc.p.252

interference. [18] Taking into account the size of some stations, for optimum results the reverberation time of the platform areas is preferred to be reduced to the range of 1.0 to 1.4 seconds [20]for the mid-frequency range. Low reverberation times are desirable but depend on station size and design as well as acoustic treatment. This should allow intelligibility of public address system announcements and patron voice communication. [20]

2.4. Conclusion

- Railway noise generated from wheel/rail interaction is significant at 500 Hz, while for very low frequencies, the radiation efficiency declines.
- Sound power level per unit length for a common subway train moving at 100 km/h is 93 dB(A).
- Measurements performed inside underground stations for assessing the acoustical environment should comply with the British standard BS EN ISO 3095:2005.
- Excessive noise on platform is investigated using the following indicators:
  - A-weighted Maximum Sound Pressure Levels, $\mathbf{L_{Amax}}$. measured during an event, train arrival and departure or train pass-by.
  - Reverberation Time
- Maximum allowed noise levels on platform are summarized in the following table:

Underground station Platform Noise Levels [3], [17]	
Entering And Leaving Trains	80 dB(A) [3] 82 dB(A) *
Passing Through Trains	85 dB(A)[18]
Stationary Trains (doors open)	67 dB(A) 65 dB(A) *
Only Station Ventilation System Operating	55 dB(A) [3]
Maximum Platform Reverberation Time	1.6 to 2 sec at mid frequency [3] 1.0 to 1.4 mid frequency [20]

*National Authority for Tunnels Specifications.

Part 1: Evaluation of the Acoustical Environment Inside the Greater Cairo Underground Stations.

3. Chapter 3: Evaluation of the Greater Cairo Underground Stations Noise

3.1. Introduction

During 2004-2006, two surveys were conducted inside the GCM underground stations to evaluate platform and onboard noise levels. [14],[15] Results showed that noise levels in the GCM underground stations reached unacceptable limits recommending mitigation solutions to improve the acoustic environment in these stations.[15], [13], [14].

In Egypt State of the Environment Report, Maximum platform noise levels reached 96 and 93 dB(A) on Mubarak and Sadat Platforms respectively; see Table and Figure 3-1.These noise levels are considered unacceptable and need to be reduced to 82 dB(A), the maximum allowable platform noise levels according to **NAT** specifications.

Egypt State of the Environment Report Survey[15]							
Sound Pressure Level dB(A)	**Measurement Time**	**L_{Aeq}**	**Max P**	**Min L**	**Max L L_{Amax}**	**L 95**	**L 5**
Morning TV circuit not operating	**Mubarak** **10:15 p.m.**	81.4	110.2	66.5	96.2	70.3	84.0
Evening	**Mubarak** **08:45 p.m.**	80.9	108.5	68.0	95.4	70.5	88.0
Morning TV circuit not operating	**Sadat** **09:00 p.m.**	84.1	109.2	74.7	93.3	75.0	89.0
Evening	**Sadat** **10.45 p.m.**	77.0	107.2	64.6	86.8	68.0	81.5

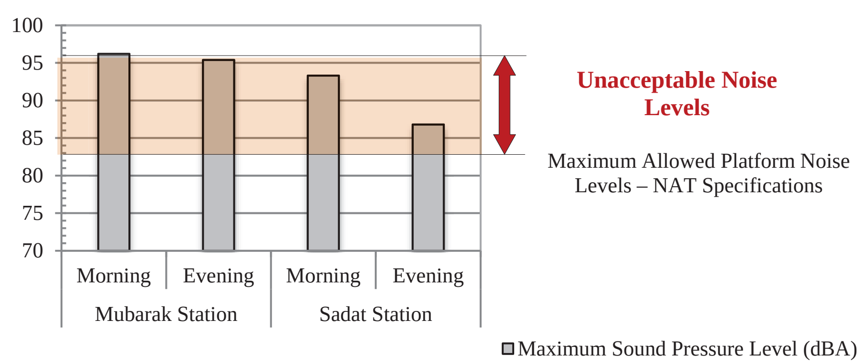


Table 3-1: Above -Maximum platform noise levels in Mubarak and Sadat stations*

Figure 3-1: Below - Unacceptable Noise Levels in Mubarak and Sadat stations†

In this research, the acoustical environment inside the selected underground stations shall be investigated through measuring the reverberation time, the background noise and the maximum platform noise levels as follows:

*Kamal, M.,(2006) Egypt state of the Environment Report, in Noise. Ministry of state for environmental Affairs: Arab Republic of Egypt. Annex 2-2 P.184

†Graph Generated by the Author

3.2. Reverberant Field at Station platform

Reverberation is most audible in large spaces with hard surfaces, where the sound echoes around long after the sound is emitted from the source.[24] The amount of reverberation in a space depends on the size of the room and the amount of sound absorption. Underground stations spaces are characterized by having special space proportions; in length, width and height where sound reflects building up reverberant field that classical room acoustics theories cannot be applied.[25]

Reverberation time is measured in the selected underground stations to verify if reverberant field contribute to station noise levels and to be compared with reverberation criteria in such spaces. RT measurement procedure and results in the selected underground stations will be discussed as follows:

3.2.1. RT Measurement Procedure

Reverberation Time measurements were conducted in **Mubarak** and **Sadat** stations on both platforms* where a loudspeaker driven by a power amplifier was used as a single source. Measurements were conducted in empty station[5] with a measuring signal was generated and received using the **Maximum Length Sequence System [MLSSA]**[4] whose post processing functions calculated most of the acoustical parameters from the measured impulse response. All parameters were measured and predicted at octave bands 125 to 8000 Hz.

Measurement locations were distributed along each platform on eight locations, at 18-m intervals, in the middle of every car, 1.5 m from the platform edge and at a height of 1.20 m above the platform floor; see Figure 3-2.

Reverberation Time Measurments Procedure

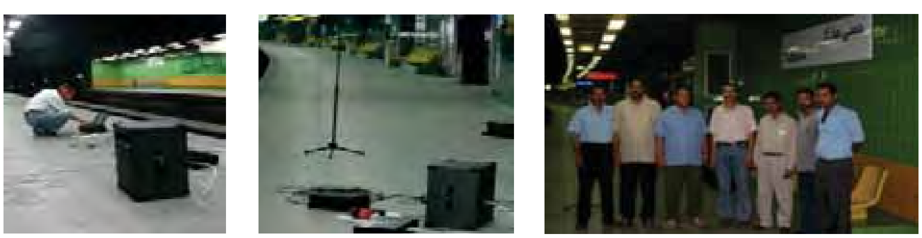


Figure 3-2: Reverberation Time Measurements on the GCM Underground Stations

*Measurements of Reverberation time were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultam and Dr Tamer El Nady.

3.2.2. RT Measurements Results

Train noise is very significant at mid frequencies especially at 500 Hz, While at low frequencies, noise is not perceived by patrons.[20] Reverberation time is important to be checked at the mid frequencies to see if it lies within the acceptable design limits in underground stations.[18] Table 3-2 lists maximum, minimum and average RT values measured in the selected underground stations at the mid frequency 500 Hz. The Room Impulse Response **RIR** measured along the platform and the measured RT values at octave bands centre frequencies are shown from Figure 3-3 to Figure 3-5 .

Mean **RT** in both of **Mubarak** and **Sadat** stations is approximately 1.4 sec which is considered optimum for speech and public address systems as recommended in design criteria for underground stations. This RT values is preffered for moderate speech conditions required in transportation facilities spaces.

RT values are higher at both of the platform ends than the rest of platform; see Figure 3-3 for **RT** values at 500 Hz. **RT** values decrease at the platform middle section because of the lower portion of ceiling at the platform middle section that is treated with mineral wool based coating; see Figure 3-7.

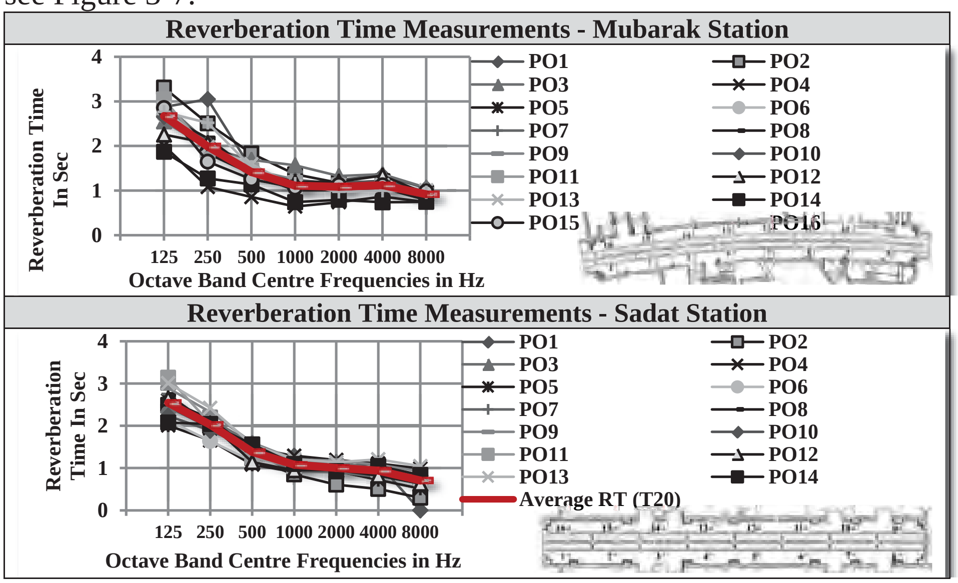


Figure 3-3: Reverberation Time Measurements on 16 Receivers on Both Selected Station Platforms.*

* Measurements of Reverberation time were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultam and Dr Tamer El Nady.

RIR at The Measured Points in Sadat Station

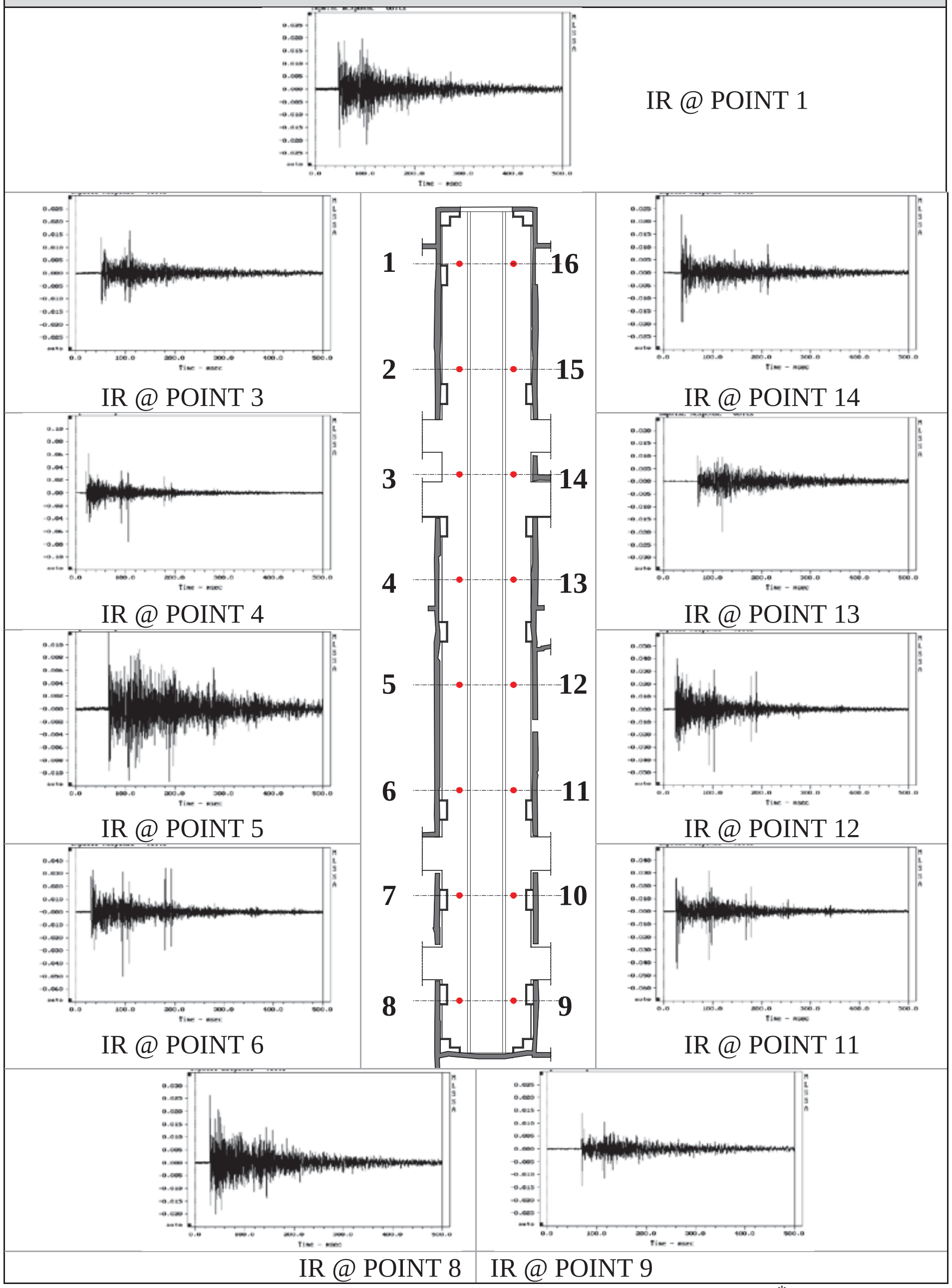


Figure 3-4: RIR at The Measured Points in Sadat Station.*

*Measurements of Reverberation time were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultam and Dr Tamer El Nady.

RIR at The Measured Points in Mubarak Station

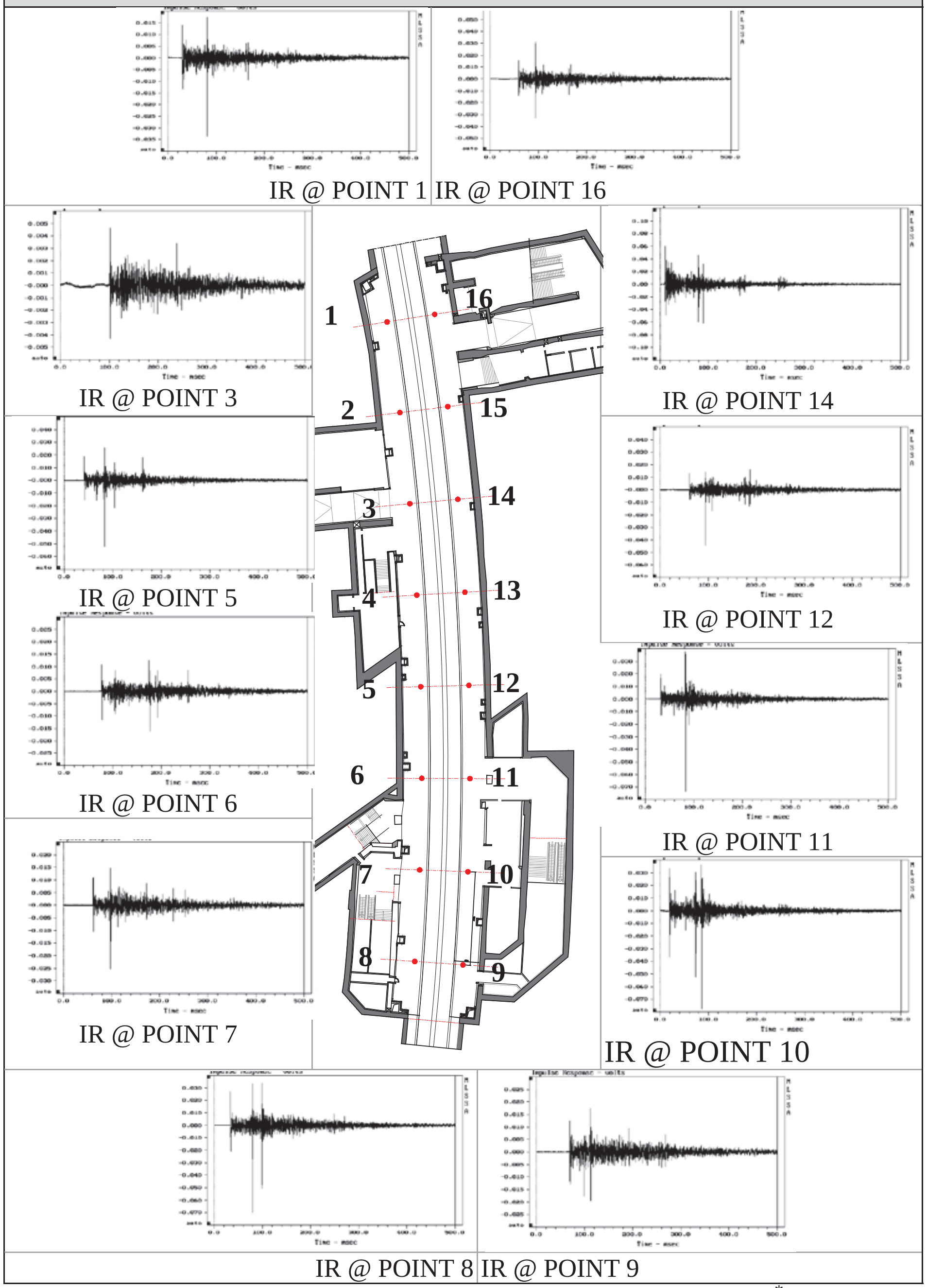


Figure 3-5: RIR at The Measured Points in Mubarak Station.*

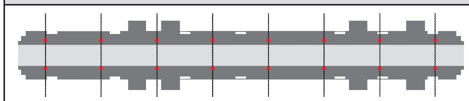
*Measurements of Reverberation time were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El

Mean Reverberation Time at 500 Hz			
RT-20dB [s]	Sadat	Mubarak	Recommended RT
	500Hz	500Hz	500 Hz
Max RT (T20)	1.605	1.831	Maximum limits 1.5 to 2 sec Preferable limits 1 to 1.4 sec
Min (T20)	1.083	0.856	
Average RT (T20)	1.383	1.417	

Table 3-2: Reverberation Time measurements in the Selected Underground Stations.*

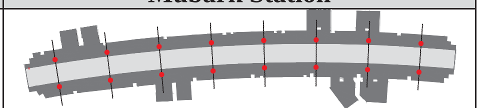
Reverberation Time at 500 Hz

Sadat Station

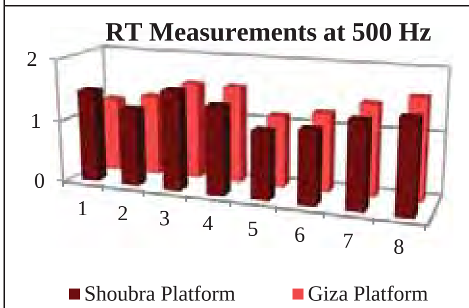


Measured Points in Sadat Station.

Mubark Station



Measured Points in Mubarak Station.



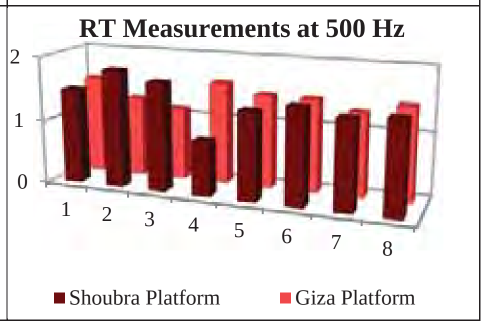


Figure 3-6: Reverberation Time Values at 500 Hz in Both Selected Stations.†

Reverberation Time at 500 Hz

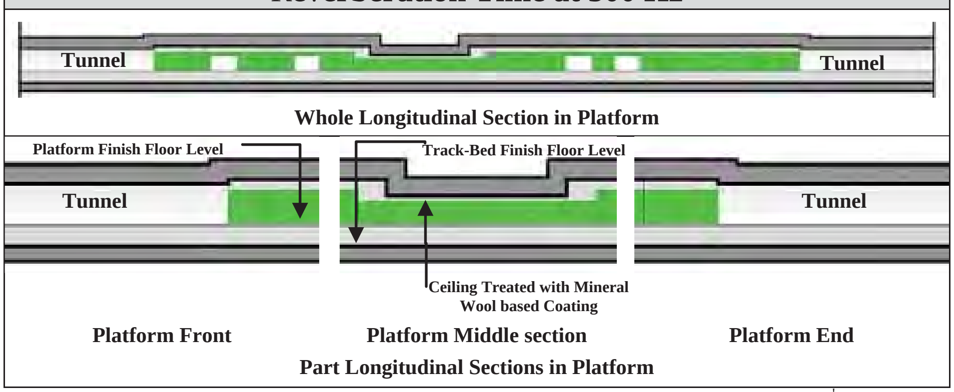


Figure 3-7: Longitudinal Section at the Selected Stations Platform.‡

Khateeb ,Dr Akram Sultam and Dr Tamer El Nady.
*Measurements of Reverberation time were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultam and Dr Tamer El Nady
†Graph Generated by the Author
‡Generated by the Author

3.3. Platform Background Noise

Moderate fair listening conditions in transit facilities require limiting background noise to NC 55[26] as well as the **APTA** guidelines maximum allowed background noise limits for A/C and ventilation systems and ancillary facilities.[3] Moreover, the suggested values of balanced Noise Criteria (NCB) Ratings for Steady Background Noise in underground station are between 50 and 60. [23] The later values apply for background noise consisting of both equipment noise (air conditioning systems, machinery, etc.) and activity noise due to the activity of the people in the room.

Platform background noise is measured and compared with Balanced Noise Criteria (NCB) to determine if noise levels are acceptable or else decide the control measure required to make these levels acceptable. In addition, background noise levels spectral analyses shall be used in the acoustical prediction models.

3.3.1. Background Noise Levels Measurement Procedure

Background noise levels Measurements were conducted using the **Maximum Length Sequence System [MLSSA]** in combination with Earthwork microphone to give spectral analysis of background noise.

3.3.2. Background Noise levels Results

Measured background noise levels are 79.7 and 81.2 dB(A) for **Mubarak** and **Sadat** stations respectively. Both measured stations noise exceeded the suggested 55 NCB criterion curve at mid and high frequencies, 250 to 4000Hz, as shown Figure 3-8. At peak hours, public address and crowds' noises contribute highly to the overall noise levels measured inside the station when the trains is not present.

Station	31.5	63	125	250	500	1000	2000	4000	8000	SPL dB	A-weighted SPL dB(A)
Mubarak	72.1	70.4	61.3	68.5	62	60.5	53.7	45.3	34.2	79.7	65. 1
Sadat	76.2	71.7	63.5	68.7	67.2	65	60.2	53.2	44.9	81.2	69.3
Design Criteria NCB 55	82	72	67	63	60	56	54	51	48	-	-

Table 3-3: Background noise levels measured in the middle of the selected Underground Stations and Sound Pressure Levels associated with the Balanced Noise Criteria (NCB) Curves.*

*Measurements of Background Noise were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultam and Dr Tamer El Nady.

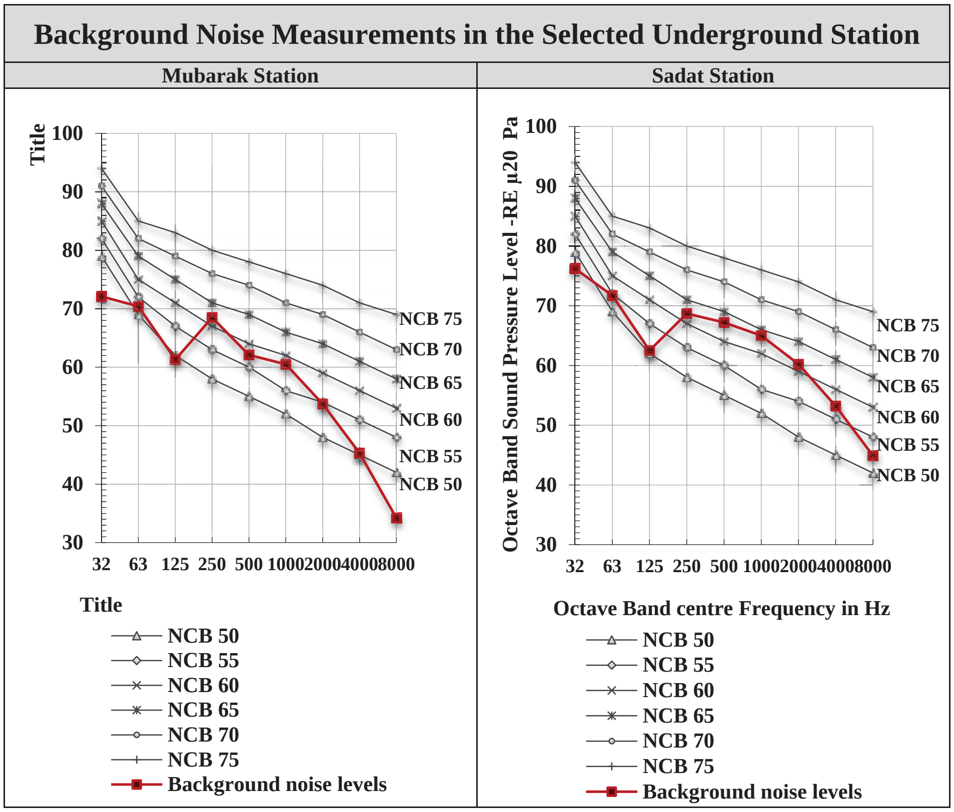


Figure 3-8: Background Noise Levels in the Selected Underground Stations.*

3.4. Platform Maximum noise Levels

Maximum platform noise measurements are conducted in the selected underground stations† to quantify maximum noise levels resulting from train arrival and departure along the station platform where the Maximum allowed noise levels should not exceed 80 dB(A)[3] in APTA guidelines and 82 dB(A)‡ in NAT specifications.

3.4.1. <u>Maximum Platform noise Levels Measurement Procedure</u>

The A-weighted maximum **SPL** (with the averaging set to 'fast') over the pass-by time interval T, called **L**$_{\textbf{Amax}}$, is measured according to the British Standard BS EN ISO 3095:2005 to be compared with allowable platform noise limits.

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*Measurements of Background Noise were conducted after permission from the National Authority for Tunnels by an Academic Team from Ain Shams University Lead By Dr. Ahmed El Khateeb ,Dr Akram Sultam and Dr Tamer El Nady.

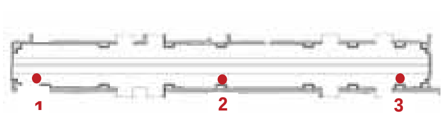
†Measurements of Maximum Platform Noise levels were conducted were conducted after permission from the National Authority for Tunnels by the Author.

‡National Authority for Tunnels Specifications.

Noise levels were measured using a **Solo** integrating sound level meter (Type II) set to the A-weighting network and Fast meter response. All measurements were taken between 12 P.M. and 2 P.M. The **SLM** was held during measurements pointing towards the subway train perpendicular to the rail track axis

For platform noise measurements, the **SLM** was approximately 1.2 m high from the ground and 1 m from the edge of the platform. Platform measurements began when the operating train was flush with the end of tunnel. Measurements continued until the train came to a complete stop, usually after 30 to 80 s.

Measurements were taken at three different locations on the platform in each station, at the front end (i.e., the end at which the lead car came to rest when stopped at the platform), middle section (the middle section of the platform), and end; the rear section of the platform (i.e., the end at which the rearmost car came to rest when topped at the platform); see Figure 3-9 and Figure 3-10



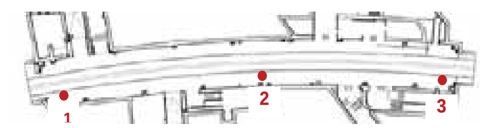


Figure 3-9: Measurement locations in Sadat station.
Figure 3-10: Measurement locations in Mubarak station.

3.4.2. Maximum A-weighted SPL Measurements Results

The measured A-weighted maximum **SPL** during arrival and departure of the trains ranges between 86 and 96 dB(A). These levels are a sum of the train noise and the station ancillary facilities noise as A/C systems, internal public address system, and TV closed circuit. Noise levels are considered unacceptable according to the **NAT** specifications and the **APTA** guidelines.

Noise levels at **Mubarak** and **Sadat** stations are relatively high due to the train operation and the passengers' crowd noise. During train arrivals and departures, the measured $\mathbf{L_{Amax}}$ noise levels reached 95 dB(A) at the front and end of the station platform, while noise levels on the platform middle section were lower due to the train deceleration and the ceiling treatment on the lower portion of the ceiling; see Figure 3-11. Train noise varies over the station platform as train arrives or departs at the front, middle section and end. This variation in noise levels all over the station platform will be considered in the acoustical prediction model; see Chapter 5.

Station noise levels are dependent on the location of the observation point and the stopping point of the train. When a train enters and stops with the front just before or just at the observation point, the maximum noise during entering is relatively low and the noise as the train leaves is relatively high because the train builds up to relatively high speed at the observation point on leaving. The opposite is true when the train stops with the rear of the" train near the observation point with the noise level being high during the approach of the train and low as the train leaves because it is some distance down the platform before achieving high speed.

The frequency contents for the A-weighted Maximum **SPLs** measured on the platform front, middle section and end are plotted in Figure 3-12 and Figure 3-13 where sound pressure levels increase at low and mid frequencies.

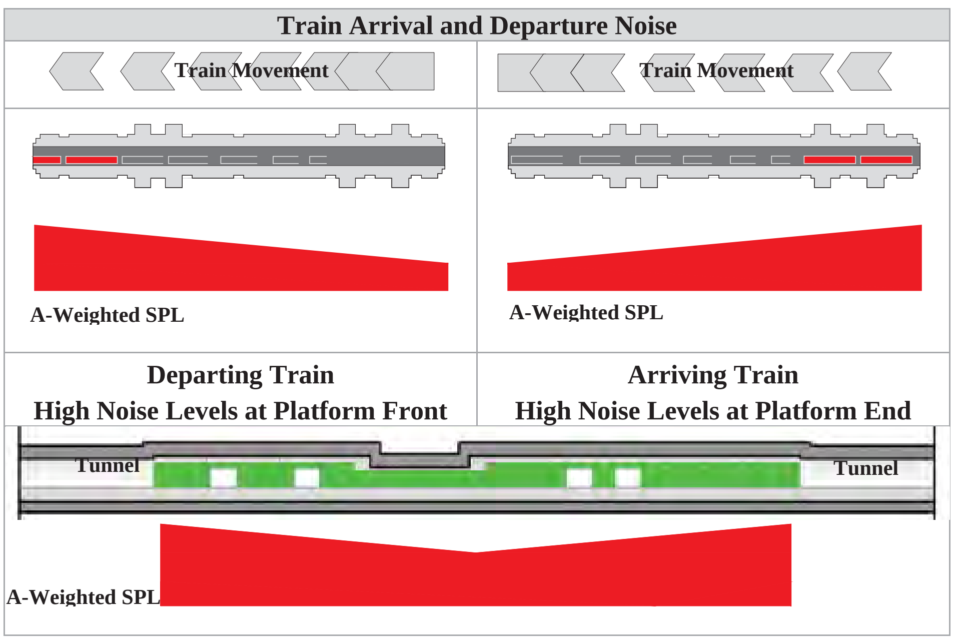


Figure 3-11: Maximum Noise Levels Over the Station Front, Middle Section and End.*

*Generated by the Author

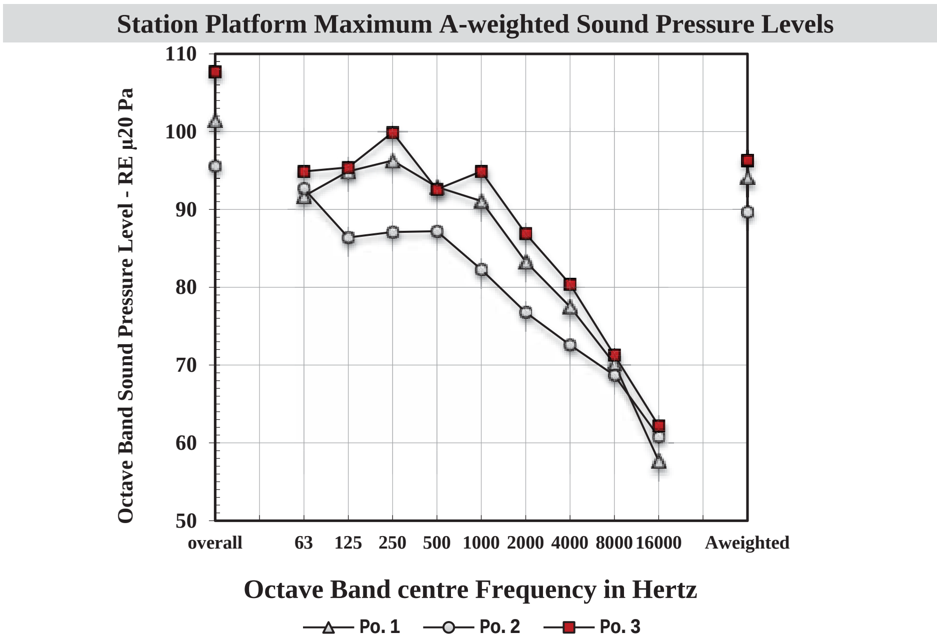


Figure 3-12: Maximum Sound pressure level Measured on Station Platform with Train Entering and Leaving on Near Track. Sadat Station*

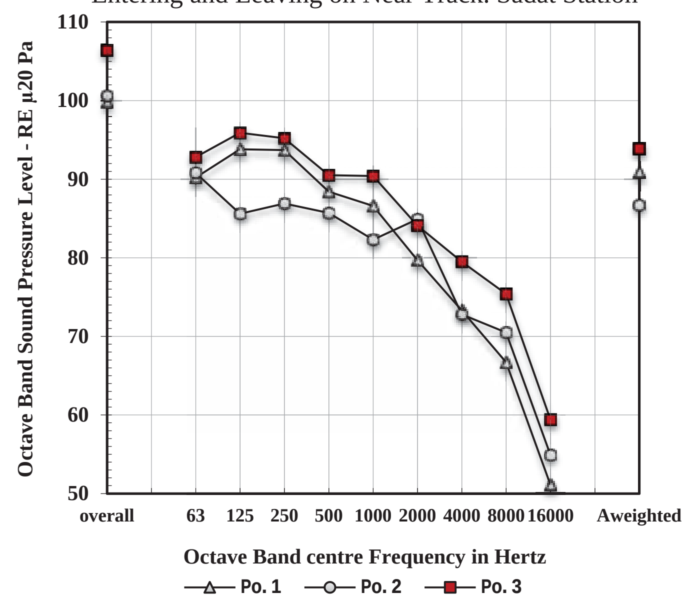


Figure 3-13: Maximum Sound Pressure Level Measured on Station Platform with Train Entering And Leaving on Near Track. Mubarak Station

*Measurements of Noise levels were conducted after permission from the National Authority for Tunnels by the author.

3.5. Conclusion

- Reverberation Time measurements lied within the recommended criteria for allowing moderately fair listening conditions between passengers and for the public address broadcast, and this is attributed to the current ceiling acoustic treatment with the mineral wool based coating
- Platform Background Noise Levels exceed the balanced noise criterion (**NCB)** rating curve at 55 dB due to the loud broadcasting from internal TV circuit and public address system as well as crowds' noise at peak hours.
- Platform A-weighted Maximum SPLs exceeds the limits set by **NAT** specifications and the APTA guidelines by 10 dB (approximately).
- Platform noise levels increase at both of the platforms ends than platform middle section due to:
    - Reflection of coming train noise on tunnel walls
    - Generated train noise increase with the train speed:
        - The speed of a coming train, whilst entering the station, is relatively higher at the platform end than the speed at the platform middle section and obviously at the platform front when it comes to rest due to train deceleration.
        - The speed of a leaving train, whilst leaving the station, is relatively higher at the platform front than the speed at the platform middle section and obviously at the platform end due to train acceleration.
- The current acoustic treatment applied to the station ceiling maintain reverberation time on the platform area to recommended values for speech intelligibility, yet platform noise levels exceeds acceptable limits.
- There is a need to apply some acoustic treatments near excess noise sources inside the platform area to reduce noise levels to acceptable limits.

Part 2: Assessment of the Acoustical Environment inside the Greater Cairo Underground Stations.

4. Chapter 4: Underground Station Noise Control

4.1. General Approaches to Noise Control

Three approaches to noise control should be considered for solving any noise problem: [27]

1. Modifying noise at the source.
2. Blocking or reducing noise along the path from source to receiver.
3. Isolation of sound from the receiver by means of barriers, operator location, or hearing protection.

The four basic principles employed to achieve these approaches are:

- isolation
- Absorption
- vibration isolation
- vibration damping

Some types of noise control systems used to fulfill these basic principles include: [27]

1. Sound barriers.
2. Sound absorbers.
3. Vibration damping.
4. Vibration isolation.
5. Baffles.
6. Machine redesign, process modification, or noise source elimination.

Using any one or a combination of these principles is not actually superior to another. The most effective solution to a noise problem can be developed at a minimum cost if each principle is understood. [28] Each proposed noise control design must be reviewed to ensure suitability to the application for which it is intended, and to establish production feasibility. Non-acoustical consideration related to any design include:[27]

1. Employee safety and hygiene
2. Fire code compliance
3. Operational integrity:
    a. accessibility to equipment
    b. maintenance serviceability assurance
    c. product quality assurance
4. Machine system compatibility:
    d. Service life
    e. ventilation and cooling

The optimum control approach for any operation must be determined based on acoustical effectiveness, production compatibility and economics. The first step in reducing noise is to define specifically how the acoustic energy is being generated.

All mechanical noise sources generate sound by one of the following two mechanisms:

1. Acoustical radiation from a vibrating surface.
2. Aerodynamic turbulence (accounted for moving source with velocity not less than 200km/h). [22]

Figure 4-1 summarizes general concerns and requirements used to solve acoustical questions. The matrix shows decision to be made in determining feasibility of acoustical design.

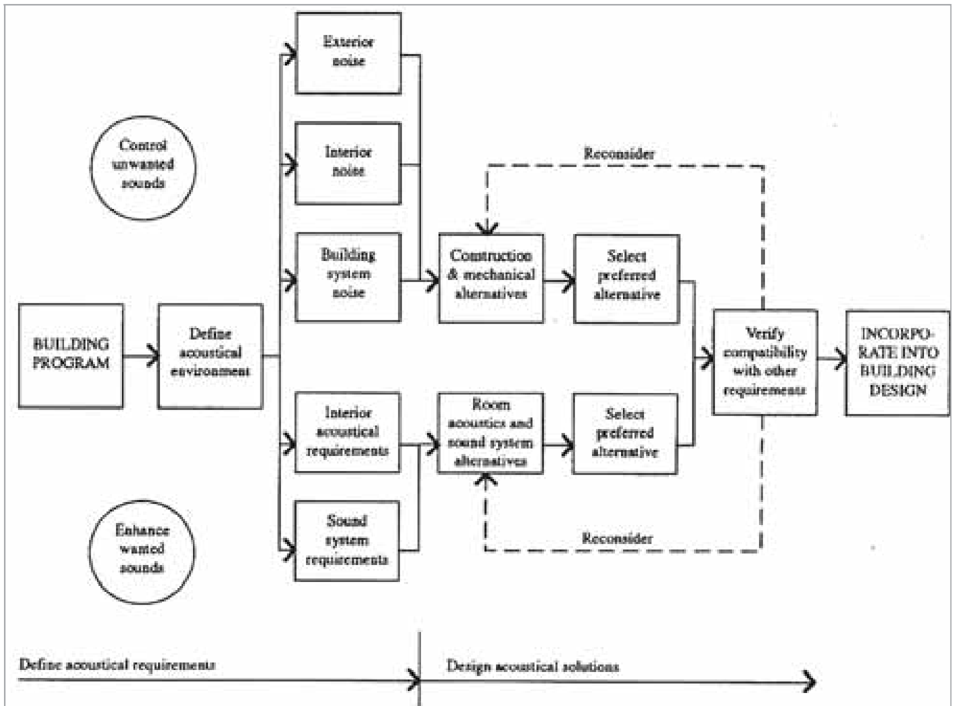


Figure 4-1: Steps used to solve acoustical questions.*

*Croker, M.J. (1997) Encyclopedia of Acoustics. Vol. 3. New York: John Wiley & Sons, Inc. p.1006

4.1.1. Sound Absorption

According to Cox[24] "***Both absorbers and diffusers have a role to play in good acoustic design. They have a complementary function, which means when they are used appropriately, better acoustics can be achieved***". The rate at which sound is absorbed in a room is a prime factor in reducing noise and controlling reverberation. All materials used in the construction of building absorb some sound, but proper acoustical control often requires the use of materials that have been especially designed to function primarily as sound absorbers. Such materials are popularly known as "acoustical materials". [29]

Reverberation is most audible in large spaces with hard surfaces, where the sound echoes around long after the sound was emitted from the source. In small spaces, with plenty of soft, acoustically absorbent materials, the absorbent materials quickly absorb the sound energy, and the sound dies away rapidly. The amount of reverberation in a space depends on the size of the room and the amount of sound absorption. The solution to the reverberant space is to add acoustic absorbers. This will reduce the reflected sound energy in the room and so reduce the reverberance and sound level. [24]

Sound absorption in enclosures occurs when sound waves strike objects in the enclosure and the enclosure boundaries as well during propagation through the acoustic medium (air) that fills the enclosing space. The boundary absorption may be described in terms of a sound absorption coefficient (α) that is the ratio of energy absorbed to the energy incident. Sound absorption in enclosures plays an important part in determination of sound pressure levels resulting from the operation of sound sources of known sound power output as well as in determining the amount of reverberation of the enclosure, which is quantified in terms of its reverberation times. [26]

Whenever a noise source is operated within an enclosed space, sound levels increases to some extent due to reverberation. When this reverberant sound level increase becomes significant, it is appropriate to install sound absorbing materials on specific locations in order to control noise. [27]

To some extent, absorption occurs in all materials. Sound absorption takes place when sound waves enter a material and a portion of the energy is converted to heat. Absorbing Materials commonly used are fibrous, lightweight and porous.

The extent to which acoustical energy is absorbed is denoted by the material's absorption coefficient. The absorption coefficient (α) of a surface is the ratio of the energy absorbed by the surface to the energy incident. It typically lies between 0 and 1, which represent non-absorbing and totally absorbing surfaces, respectively. Values greater than 1 are often found in random incidence measurements, although theoretically impossible. This usually occurs due to diffraction/edge effects.[28]The following section will discuss noise control procedures used for railway noise mitigation.

4.2. Railway Noise Control

Transit system designers have often used acoustically reflective materials in transit stations, such as painted concrete or ceramic tile, on all surfaces of train platform areas for durability, abuse resistance, and ease of cleaning. With these materials, train noise is not dissipated resulting in a reverberant and noisy space. Wheel/rail noise control at the source and minimizing the buildup of reflected (reverberant) airborne noise by sound absorptive treatments are the key to a successfully acoustic treatment.[18]

According to the recommended values for background noise levels and reverberation time in underground stations that are presented in chapter 2, the designer have to select an appropriate control solution from a range of alternatives on the basis of familiarity with the noise problem requirements and site conditions. Railway noise treatment generally falls into one of the following categories:

1. Track-work treatments
2. On-Board treatments
3. Wayside treatments

Track-work treatments are applied to the most dominant railway noise source that is generated from the wheel\rail interaction during train operation. While On-Board treatments are applied to the vehicle either to control noise generated from the train equipments, as in using vehicle skirts, or to control noise from going into the passenger's car, as in insulating the car body. Wayside treatments are applied away of the track and the vehicle to include treating the train way (tunnel) and the station either in a surface station or in an underground one. Each of the three categories of treating railway noise will be discussed in brief as follows:

4.2.1. Track work Treatments

Track-work treatments provide noise control at the track-bed where noise is generated from wheel and rail interaction. It includes sound absorption at the track level between the rails, rail vibration absorbers, and low-height barriers between tracks. Other measures that would be applied directly to the track include rail grinding, wayside lubrication and rail joint welding as continuous welded rail is effective in reducing or eliminating rail-related impact noise. Other treatments include, vibration-damping systems, certain types of resilient fasteners. [18] Track-work treatments are classified as shown in the following figure:

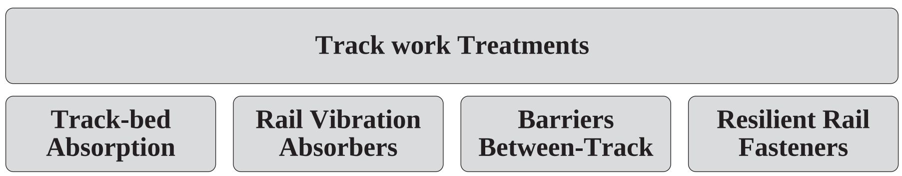


Figure 4-2: Track-Work Treatments in Surface and Underground Stations

4.2.1.1. Track-bed Absorption

Track-bed absorption is effective for direct fixation track with concrete inverts or slabs. Noise levels at ballast-and-tie track are normally 4 to 5 dB lower than a similar station with un-ballasted track. There may be substantial maintenance problems associated with sound absorption treatments positioned beneath the train in exposed situations. Such problems may involve the ability to inspect and maintain track components. The absorption must be protected from tunnel washing machines and other maintenance equipment that might damage the treatment. Candidate treatments include Ballast, Encased Fiberglass board and Spray-on cementitious sound absorption, yet ballast is easier for maintenance.

a) ballast

Most emitted railway noise sources are beneath the train car, in the confined space between the car and the track-bed, so it is normal and appropriate to assume that with an absorptive track-bed the amount of sound energy radiated to the reverberant sound field will be reduced. Reduction will be relative to the amount of sound energy absorbed at the first reflection from the track-bed. This then implies that the amount of sound energy available for the reverberant sound field should be reduced by an amount equivalent to the absorption coefficient of the ballast. [20] Sound absorption provided by ballasted track has an acoustic advantage over many other acoustical treatments because of the stone ballast the stone ballast is close to the sources of noise. Furthermore, ballast is not damaged by workers or their equipments.

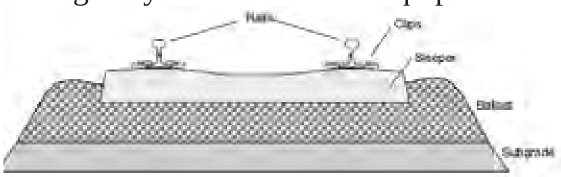


Figure 4-3: Left - Typical Track Construction Showing Rails, Sleepers And Ballast.[*]
Figure 4-4:Right - Ballast At Track Bed[†]

4.2.1.2. Rail Vibration Absorbers

Rail vibration absorbers are spring-mass systems with damping incorporated into the spring to absorb and dissipate vibration energy. They are attached to the rail with clamps, without contacting the invert or ballast. Vibration absorbers may be tuned by the absorber manufacturer to optimize dissipation of rail vibration energy into heat over a particular range of frequencies and may be particularly desirable at locations where a sound barrier would be impractical and the needed noise reduction is about a few decibels.

4.2.1.3. Between-Track Barriers

Barriers positioned between tracks can reduce platform noise levels. Both sides of the barrier should be lined with sound absorbing material, such as 2 inch of fiberglass. Cementitious panels with sound absorbing properties may be proposed for acoustical treatments. Barrier height should extend to the floor level of the train car. There is a safety issue concerning entrapment of track inspection personnel or patrons caught in the train way.

Figure 4-5: Platform And Noise-Absorbent Baffles Between Tracks And On Sidewalls Of The Under-Platform At Magenta Station Paris, France.[‡]

[*]Thomson, D. (2009) Railway noise and vibration: mechanisms, modelling and means. Great Britain: Elsevier Ltd. p.29
[†] Ibid.p.16
‡http://www.arep.fr

4.2.1.4. Resilient Rail Fasteners

Resilient fasteners are not usually considered a treatment for wheel/rail noise. They are designed to reduce low-frequency ground-borne or structure-borne noise above about 30 Hz and can be effective in reducing wayside noise radiated from steel elevated structures and aerial structures with steel box girders.

4.2.2. On-Board Treatments

On-board treatments are applied to the vehicle either by enclosing noise radiated from it by vehicle skirts or by insulation the vehicle body to prevent noise from going into the passenger's car. On-board treatment options available for controlling normal rolling noise are limited primarily to vehicle skirts, under-car sound absorption, and enhancement of car body sound transmission loss. Damped wheels are not considered effective because the maximum A-weighted noise reduction observed for typical transit application has been about 0 to 1 dB(A). On-Board treatments are classified as follows:

4.2.2.1. Vehicle Skirts

Vehicle skirts that are located about the train may reduce wayside noise by up to 2 dB if combined with sound absorption treatment applied to the interior surfaces of the skirts. The skirts must deflect and absorb wheel-radiated noise and may be most effective in controlling squeal as opposed to rolling noise. Skirts should be less effective on ballast-and-tie track than on direct fixation track because of the absorption provided by the ballast. Skirts are likely to be ineffective in reducing noise radiated by the rails.

4.2.2.2. Under-car Absorption

Under-car sound absorption may provide limited interior and exterior noise reductions, about 2 to 3 dB, if applied to the underside of the floor over the train. Attractive features of under-car sound absorption are the fact that:

1. it is reasonably inexpensive
2. it would be effective system wide

However, there may not be sufficient free area under the car to treat, and the treatment may interfere with vehicle maintenance.

4.2.2.3. Car Body Sound Insulation

Car body sound insulation is controlled by the car body shell, floor, windows, doors and, connections between the trucks and the vehicle body. Effective car body designs include a composite double layer shell and liner with fiberglass sound absorption, a composite floor with a resilient floor covering, acoustically rated glass windows, and effective door seals.

4.2.3. Wayside Treatments

Wayside treatments are applied separately of the mechanical treatments of the track and the vehicle. Treatments in surface and underground stations take two different approaches. In surface stations, treatments include control at the source-receiver path (i.e. sound barriers, earth berms and depressed grades are used to reduce noise radiated from the rail and the vehicle) and control at the receiver (i.e. applied on buildings complaining from railway noise, using fenestration treatments and weather stripping). While in underground stations, treatments are limited to the station boundaries: under-platform, walls and ceiling. Table 4-1 shows the difference between wayside treatments applied to the surface and underground stations.

Wayside treatments	
Surface stations	**Underground stations**
Sound barrier walls	Under-platform treatment
Absorptive barriers	wall and ceiling treatment
Earth Berms	Fan and Vent acoustical absorption
Depressed Grades	Tunnel treatments
Receiver treatment	

Table 4-1:Wayside noise treatments in surface and underground stations .*

Noise problem should be defined properly by determining the most dominant noise source in order to specify an appropriate and affordable noise treatment. Table 4-2 lists treatments for railway noise applied to surface and underground stations with the corresponding achieved noise reduction.

*Nelson, J.T., (1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. COUNCIL, Editor. Federal Transit Administration in Cooperation with the Transit Development Corporation.

Wayside Treatments with the Corresponding Noise Reduction				
Noise Source	**Treatment option**		**Noise reduction dB**	**Site specific limitations**
Normal rolling noise	**Surface station**	Sound Barriers	5 to 10	Adverse to visual characteristics
		Absorptive barriers	7 to 12	Less effective for tie and ballast track
		Earth Berms	7 to 12	Attractive for landscaping
		Depressed grade	5 to 10	
		Receiver treatment	8 to 10	May require forced ventilation, May encounter structural deficiencies, code violations, and pest damage.
		Enclosure	10	Impact on fire control, and ventilation
	Underground station	Tunnel wall treatment	3	
		Station treatment	5 to 10	Wall, ceiling, and under-platform treatment
		Fan and vent shaft acoustical absorption	5 to 15	
Excessive rolling noise	Treatments listed for normal rolling noise			
Impact Noise	Treatments listed for normal rolling noise			
Rail corrugation	Treatments listed for normal rolling noise			
Wheel squeal	**Surface station**	Sound barriers	7 to 10	Does not eliminate squeal
		Absorptive barriers	9 to 12	Does not eliminate squeal
		Berms	10 to 13	Does not eliminate squeal
		Receiver treatment	N/A	Does not eliminate squeal. Noise reduction depends on construction
	Underground station	Tunnel wall treatment	5 to 7	Does not eliminate wheel squeal

Table 4-2:Wayside noise treatments with estimated noise reduction[18]*

*Ibid. p.70, 74, 76, 78, 81.

4.3. Underground Station Acoustic Treatment design guidelines

When an enclosure is designed to contain a noise source, it operates by reflecting the sound back toward the source, causing an increase in the sound pressure level inside the enclosure. There is an increase in the sound pressure at the inner walls of the enclosure compared with the sound pressure resulting from the direct field of the source alone. The buildup of sound energy inside the enclosure can be reduced by placing sound absorbing material on the walls inside the enclosure. [22]

Factors influencing acoustic performance in underground station include control of reverberation time and services noise.[30] Considerable reduction of patron noise exposure can be achieved in the subway station platform areas with the relatively simple, although not necessarily inexpensive, addition of sound absorption treatments. The costs of such modifications depend considerably on the architectural requirements or architectural appearance required of the sound reducing treatment applied.[20]

Noise reductions can be achieved in underground stations by treating the walls and ceiling with sound absorbing materials. Without treatment, the only absorption available is that due to walls, ballast (if existing on the track), or the vehicle where radiation losses up and down the tunnel away from the train. Station with ballasted track would not benefit from wall treatment as much as those with concrete inverts and direct fixation track, because the ballast provides some sound absorption.[18]

Acoustical treatment of the station walls and ceilings prevents excessive build-up of reverberant sound energy, substantially reduces train, ventilation equipment, and crowd noise, and greatly improves the intelligibility of public address systems, an important factor in station design.[18]

The basic procedure for reducing noise in subway station platform areas is the application of sound absorption material for reducing the reflection and reverberation of sound in the space. Two factors are important in the design of the sound absorption treatment:

1. The total area or amount of the sound absorption required
2. The placement of the absorption material.

Noise criteria and limits described in chapter 2 should be targeted during the treatment design process in order to solve noise problems successfully. As long as the noise created by the trains is consistent with

Guidelines for wayside pass-by noise, then following the proposed treatments of walls and ceilings in the platform area will ensure that the design goals for station noise levels are achieved; see Table 4-3.

Minimum Reverberation time	**500 Hz**	**1.5 sec**
Treatment area	Wall and ceiling	35%
	Under Platform wall and overhang	100%
Ceiling and wall treatment properties	Minimum absorption coefficient at 500 Hz	0.6
	NRC	0.6
Under-platform treatment properties: Minimum Absorption coefficient (3 to 4 In. thickness)	250 Hz	0.4
	500 Hz	0.65

Table 4-3:Design Criteria For Acoustical Treatment Of Station Platform Areas To Control Train Noise *

The design guidelines in Table 4-3 are based on an efficient use of materials. The recommended sound absorption treatment will control reverberation and train noise efficiently. Further noise and reverberation control is possible by using greater amounts of treatment, but doubling the amounts would have only a small additional effect on the acoustical environment, and would not justify the added cost. Thus, the use of sound absorbing materials is to some extent governed by the law of diminishing returns; beyond a certain point additional treatment becomes uneconomical and inefficient, and other noise control procedures should be considered. [18]

For the acoustical materials used for treating platform areas it is recommended that the minimum sound absorption coefficient (**α**)is 0.50 at 250 Hz and 0.75 at 500 Hz. For the under-platform acoustical treatment, a material providing a minimum sound absorption coefficient of 0.55 at 250 Hz and 0.75 at 500 Hz is recommended.[20]

4.3.1. Design Calculations

The amount of sound absorption material required to reduce noise determines the amount of reduction of the reverberation time of the space. The sound level from a given noise source is reduced in proportion to the total amount of sound absorption present in the space and is, therefore, proportional to the reduction in reverberation time.[20]

Noise level reduction, the difference between existing noise levels and the recommended levels that can be tolerated by patrons is equivalent to the quantity of sound absorption required to reduce noise levels. On the

* Ibid.p.180

platform or in the tunnel outside the train the noise level reduction for reverberant sound, which is provided by sound absorbing treatment is given by the following equation [17]:

Level reduction = $\mathbf{10\log_{10}\left[\frac{A_a}{A_b}\right]}$ dB .... **Equation 4-1[17]**

$\mathbf{A_a}$: is the total absorption at the specified frequencies after treatment.

$\mathbf{A_b}$: is the total absorption at the specified frequencies before treatment.

This level reduction applies at a given frequency. $\mathbf{A_b}$ and $\mathbf{A_a}$ are the total absorption at the specified frequencies before and after treatment respectively, expressed in metric sabins or in sabins. There is an additional duct-like attenuation of sound with distance along the station or tunnel length not accounted for in Equation **4-1**. The space under the railcar is partially enclosed by the station and tunnel structure, making absorptive treatment near wheels and rails more effective in reducing the level of wheel-rail noise than equation 1 predicts. [17]

The formula above applies to spaces with similar dimensions. Spaces that are long and low (e.g. some factory units) do not allow uniform reverberant field to develop. There is a continual reduction in noise level as the distance from the source increases, and low ceiling can cause absorption of sound at mid frequencies and increased attenuation. Absorbers hanging from or applied to the roof can also increase the sound attenuation with distance from the source.

4.4. Acoustical Materials Selection

There is a wide assortment of acoustically absorbing materials, and the choice of the appropriate material is based on the amount of required absorption, architectural considerations, ability to withstand train movement induced pressure transient loading in stations, resistance to mechanical abuse, safety considerations such as flame resistance, cost, and other considerations. In most cases, Fiberglass products are the most economical treatment. However, there are many other products that should be considered, such as spray on cementitious sound absorption.[18]

Sound absorbing materials used in stations must fulfill certain requirements:

- Light reflective
- Vandal resistant
- Cleanable
- Fire resistant

- Easily maintainable
- Reasonably inexpensive
- Undamaged by water washing and water leaks
- Firm against air currents and overpressures due to train motion Compatible with normal track inspection and maintenance

A review of some common acoustic materials is provided in Table 4-4 with the absorption characteristics in Table 4-5:

	Foam	Fiber Glass	Rigid tiles
Flammability	Can be made self-extinguishing but not generally suitable for architectural purposes.	Good fire resistance	Good fire resistance
Acoustical properties	Excellent absorption in mid-to-high frequencies	Excellent absorption in mid-to-high frequencies	Fair absorption in mid-to-high frequencies
Environmental considerations	Nontoxic, vibration resistant, deteriorates at high temperature	Fiber contamination can be hazardous. Poor vibration resistance. Good high temperature properties.	Nonhazardous. Good high temperature properties. Good vibration properties
Susceptibility to acoustical degradation	Little susceptibility if faced and edge sealed	Little susceptibility if faced and edge sealed	Poor in adverse environment.
Major Applications	Machinery enclosures, floor pads, wall treatments	Machinery enclosures. High temperature environments.	Architectural

Table 4-4:Comparison Of Material Properties For Various Types Of Acoustical Treatments.*

Materials	**Frequency, Hz**					
	125	**250**	**500**	**1000**	**2000**	**4000**
Fibrous glass (4 lb/ft3) hard backing						
1-inch thick	0.07	0.23	0.48	0.83	0.88	0.80
2-inch thick	0.20	0.55	0.89	0.97	0.83	0.79
4-inch thick	0.39	0.91	0.99	0.97	0.94	0.89
Polyurethane foam (open cell)						
1/4- inch thick	0.05	0.07	0.10	0.20	0.45	0.81
1/2- inch thick	0.05	0.12	0.25	0.57	0.89	0.98
1-inch thick	0.14	0.30	0.63	0.91	0.98	0.91
2-inch thick	0.35	0.51	0.82	0.98	0.97	0.95
Hair felt						
1/2- inch thick	0.05	0.07	0.29	0.63	0.83	0.87
1-inch thick	0.06	0.31	0.80	0.88	0.87	0.87

Table 4-5:Sound Absorption Coefficients Of Common Acoustic Materials†

*Cheremisinoff, N.P. (1996) Noise Control In Industry A Practical Guide. USA: Noyes Publications p.33
†Ibid.p.27

General information on the characteristics of sound absorption treatments that can be considered for application in underground stations are given in the following section. For underground stations, it is recommended that a high sound absorption treatment be applied to reduce noise. This requires the installation of a relatively thick acoustical material to minimize the total area of treatment required**. The most flexible and probably the most economical material which can be used for this application is the Fiberglass material.** [20] It can be in one of the following forms:

1. Flexible
2. Semi-rigid
3. Rigid board form [ordinary ventilation duct liner, for example].

4.4.1. Forms Of Acoustical Materials

Most commercially available acoustical materials are included in one of the four following categories:

4.4.1.1. Glass Fibrous Boards And Blankets

Fiberglass is one of the most efficient and inexpensive sound absorbing materials available for the ceilings and walls of the station. Fiberglass boards provide the highest sound absorption coefficient, and, therefore, the highest sound absorption for the amount of area covered.

Fiberglass cannot be used solely without facing because of hygiene and fire resistance issues. Facing cover is needed for Fiberglass protection and it is applied in many forms. Fiberglass installation may include an outer covering of acoustically transparent hardware cloth or expanded metal. Dust or dirt collecting on the surface of the Fiberglass will not significantly affect its sound absorption characteristics, although dust can be a fire or smoke hazard. Water has no permanent degrading effect on the sound absorbing ability of Fiberglass, but absorption is reduced while the material is wet. Over the course of time, the detergents used in tunnel washing may leave an accumulation of residue, the effects of which are not yet known.

Table 4-6 shows the absorption coefficients given for the basic acoustic material mounted on or against the concrete surface without any covering. The sound absorption coefficients are indicated as a function of frequency that can be expected for various thicknesses of Fiberglass sound absorption treatment.

Frequency Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz
1 In. Thick Fiberglass	0.08	0.3	0.65	0.8	0.85
2 In. Thick Fiberglass	0.20	0.55	0.8	0.95	0.9
3 In. Thick Fiberglass	0.45	0.8	0.9	0.95	0.9

Table 4-6:Typical Sound Absorption Coefficients To Be Expected From Fiberglass Sound Absorbing Materials Mounted Directly Against Concrete Surface.*

Because the underground station structures are all concrete and highly reflective at low frequencies, it is essential that the sound absorption treatment have substantial low frequency absorption. 1 inch thick or a thinner treatment cannot supply this low frequency absorption and it is, therefore, essential that at least some of the treatment be made up of 2 inch or 3inch thick Fiberglass blankets or boards.

a) Blankets

Blankets are made up chiefly of mineral fibrous material or wood wool, Fiberglasss and hair felt. Although the thickness of these blankets is generally between 1/2 and 4 inches, blankets of greater thickness are sometimes used in special applications. These materials are more absorptive in low-frequency range, principally because of their greater thickness, than most other types. Blankets sometimes are useful for controlling the acoustical characteristics of studios and auditoriums that requires "balanced" absorption, including a considerable amount at low frequencies.

The absorption coefficient of a blanket mounted against a wall depends on its density and thickness and on the frequency of the incident sound. Increasing the thickness of the blanket increases its absorptivity, principally at low frequencies, slightly at the high frequencies. [29]

b) Fiberglass Material Protection

If it is desired to protect the material from dirt collection and water absorption, it can be covered or surfaced with polyethylene or mylar film of up to 0.1 mm thickness without significantly decreasing the noise reduction provided. If there are fire resistance requirements that preclude the use of plastic film for protective covering and if, in fact, the normal Fiberglass board or blanket with resin binder is prohibited because of fire hazard limitations, there are alternate materials of the same type that will provide the same performance. The selection of plastic film must be based on the life expectancy of the tunnel and the fire resistance of the material.

*Nelson, J.T., (1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. COUNCIL, Editor, Federal Transit Administration in Cooperation with the Transit Development Corporation. P.180

An alternate for the plastic film covering, which gives good protection against water and dust and dirt absorption, is a close weave Fiberglass cloth. Because of surface tension a water spray will generally not penetrate the fiberglass cloth, particularly if it is mounted on a vertical surface. To provide a completely fireproof Fiberglass material it is necessary to use a material without binder.

c) Mounting

For the materials mounted on side walls and ceilings in platform areas it is recommended for the minimum sound absorption coefficient to be 0.50 at 250 Hz and 0.75 at 500 Hz. This implies that the treatment should be of 1-1/2" to 2" thickness on the side walls and/or ceilings.

Some acoustic materials, such as vinyl or neoprene coated Fiberglass or glass cloth faced Fiberglass boards, can be painted or are available with appropriate surfaces so that no further facing is required, particularly for a ceiling application. An alternate arrangement is the use of plainm Fiberglass boards or blankets wrapped in a waterproofing sheet or bag and faced with a perforated sheet metal or other facing. With this latter arrangement the facing material must have at least 30% open area in order to avoid degradation of the sound absorption coefficient.

d) Fixation

There are a number of procedures available for installing Fiberglass boards or blankets directly to concrete surfaces. The most usual procedure for attaching to concrete wall surfaces is a simple mechanical fastening called "Stic Klips". "Stic-Klips are used and attached in the form of large headed nails or a small flat plate and rod assembly fastened to the concrete surface with cement or epoxy such that the shaft or rod sticks straight out from the wall surface. The Fiberglass is pushed over the rod and a friction fit washer is placed over the outside surface to retain the material and any protective coverings such as expanded metal, hardware cloth or plastic sheeting.

There are other procedures such as the use of metal furring strips or studs fastened to the concrete surface and retaining the Fiberglass by a mechanical fastening. Such mountings are convenient when a waterproof covering is to be used. Dust or dirt collecting on the surface of Fiberglass or other absorption material will not significantly affect the sound absorption characteristics.

4.4.1.2. Prefabricated Units

Prefabricated unites are either cast or composed of absorbing material covered with perforated facing. These include:

1. Acoustical tile, which is the principal type of material available for acoustical treatment.
2. Prefabricated panels:
   2.1. Mechanically perforated units backed with absorbent material.
   2.2. Slits and slats system covering absorbent material.

a) Acoustical Tiles

Acoustical tiles have various finishing surface that are used for architectural purposes; see Table 4-7. Tiles can be:[29]

- Cast tiles having a pitted or granular appearing surface
- Tiles having a fissured surface.
- Tiles having a felted fiber surface

The tile is a factory made product; the absorption is relatively uniform from tile to tile of the same kind. In addition, acoustical tile has relatively high absorption as in a factory made product it is possible to control factors as:

1. porosity (including the number and size of pores)
2. flexibility
3. density
4. The punching or drilling of holes.

Such factors are difficult to control in certain types of acoustical plasters. Acoustical tiles often are two or three times more absorptive than acoustical plaster.

<table>
<tr><th colspan="4">Prefabricated Tiles Classification</th></tr>
<tr><th rowspan="8">Type 1</th><th colspan="3">1. Cast Units Having a Pitted or Granular Appearing Surface</th></tr>
<tr><th>Class A</th><th>Class B</th><th>Class C</th></tr>
<tr><td>All mineral units composed of small granules or finely divided particles with Portland cement binder.</td><td>All mineral units composed of small granules or finely divided particles with lime or gypsum binder.</td><td>Units composed of small granules or finely divided particles of mineral with incombustible mineral binder.</td></tr>
<tr><th colspan="3">2. Units Having a Fissured Surface.</th></tr>
<tr><th colspan="3">3. Units Having a Felted Fiber Surface</th></tr>
<tr><th>Class A</th><th>Class B</th><th>Class C</th></tr>
<tr><td>Units composed of long wood fibers</td><td>Units composed of fine felted vegetable fiber or wood pulp</td><td>Units composed of mineral fiber</td></tr>
</table>

Table 4-7:Acoustical Tiles Classification*

*Ibid. P.180

b) Prefabricated Panels

Panels are units having either a perforated surface or a metal or plastic slit-and-slat system which acts as a covering and support for the sound absorbent material. The facing material must be strong and durable and rigid.

With a Fiberglass panel system it would be possible to install sound absorption panels in the running tunnels during service times because the panels could be brought in as prefabricated sections and attached to the subway walls using powder actuated studs or ramsets. The installation of the spray-on material is a more difficult process which would require access for longer periods of time in the subway. [20]

A basic panel system could be designed and arranged to provide the acoustical absorption very simply for ceilings and walls. An exposed panel should be of perforated metal, a slit-and-slat configuration of plastic or metal, or some form of architectural trim, which has at least 30% open area and no bars or sections that are greater than 3.0" in width between openings. Such an arrangement will provide for a completely transparent acoustical face. Acoustical material can be located at 1/2" or larger distance behind the face and could be the simplest and most economical Fiberglass blanket or board, i.e., ventilation duct liner material in 1-1/2" or 2" thickness[18]; see Figure 4-6 through Figure 4-9.

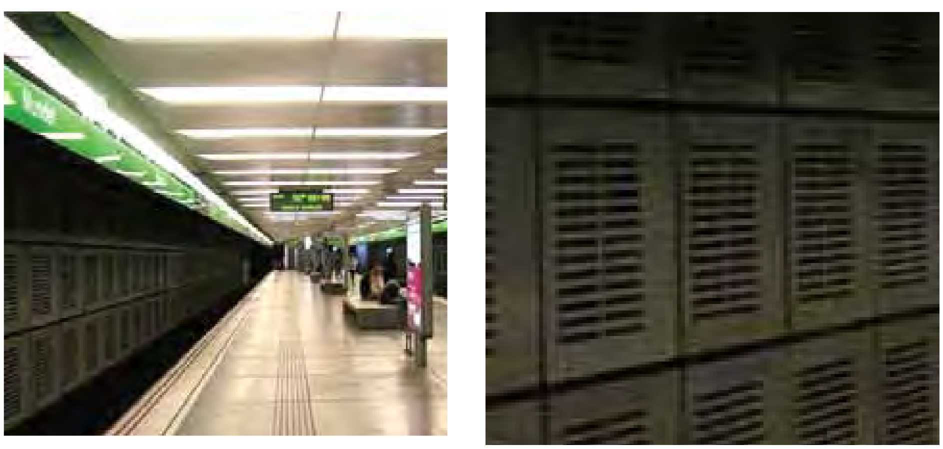


Figure 4-6: Acoustical Perforated Panels Packed With Fiberglass. Station In Barcelona.*

* http://www.trenscat.com/tmb/images/metro/l3/P4060053.jpg

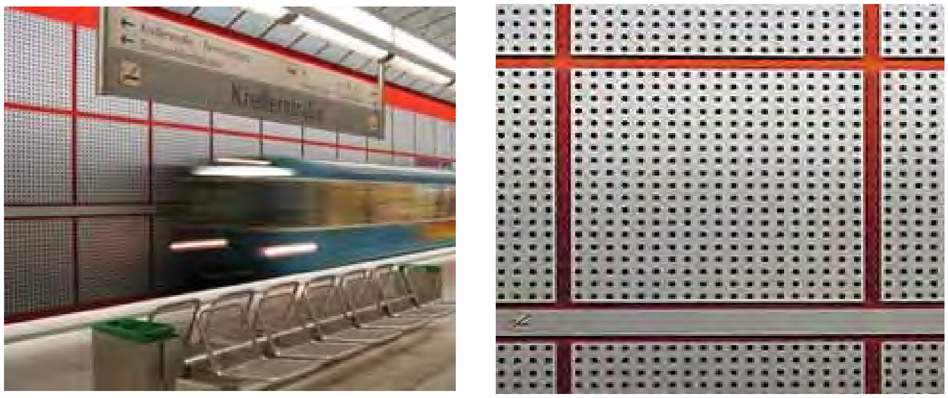


Figure 4-7: Perforated Panels Kreillerstraße Subway Station, Munich.[*]

Figure 4-8: Perforated Panels Kreillerstraße Subway Station, Munich.[†]

Figure 4-9: Acoustical Panels (Slit And Stat System) Heimeranplatz Station, Munich.[‡]

[*] http://en.wikipedia.org/wiki/File:U-Bahnhof_Kreillerstra%C3%9Fe_01.jpg
[†] http://en.wikipedia.org/wiki/File:U-Bahnhof_Kreillerstra%C3%9Fe_01.jpg
[‡] http://upload.wikimedia.org/wikipedia/commons/3/3c/Munich_subway_Heimeranplatz.jpg

a) Paneling With Airspace Behind

In train way areas, air gap between the back of the panels and the concrete backing must be provided around the panel edges or else-where to permit free air flow to the region behind the panel in the case of continuous panel systems or suspended acoustical tile ceiling. If pressure equalization provisions are not provided, the loading due to air pressure transients can eventually cause fatigue failure of the fastenings, allowing the panels to come loose from the mounting surface and fall, possibly injuring personnel and patrons. Train way acoustical treatment in station areas should be designed to withstand air pressure transient loadings.

Panels with perforated metal or slit-and-slat facings (in under-platform, ceiling, and wall installations) should have a dimpled screen placed between the metal facing and the face of the acoustic blanket to establish airspace of about ½ inch. thickness between the perforated facing and the blanket or glass-cloth bag. This airspace serves two purposes:

- It allows the sound waves to diffuse over the entire face of the acoustic material, thereby assuring full efficiency as a sound absorber
- It allows free airflow for pressure equalization, thus preventing loading of the facing by air pressure transients produced by the train.

b) Paneling Flush Against the Ceiling or Walls

In the train way, ceiling and wall treatments should be mounted flush against the ceiling without air gap to avoid stresses induced by dynamic air pressure loading or buffeting as the train enters and leaves the station; see Figure 4-10

Figure 4-10: Acoustical Panels Fixed Directly On Tunnel Walls. Lake Station, Chicago.*

* http://www.chicago-l.org/trains/gallery/images/2600/cta2646.jpg

4.4.1.3. Acoustical plaster and sprayed-on materials

These materials comprise plastic and porous materials applied with a trowel and fibrous materials combined with binder agents that are applied (sprayed-on) with an air gun or blower; see Table 4-8.

The absorption of acoustical plaster is dependent on its thickness and composition. As the thickness is increased, the absorption increases, particularly at low frequencies. However, for plasters of the types applied with a trowel, it is usually uneconomical to increase the thickness beyond 1/2 inch. [29] If too much binder material is used, the plaster is not sufficiently porous. If an insufficient amount of binder is used, the plaster does not set hard and its tensile strength may be less than that required for adequate structural bond.

In selecting an acoustical plastic material it is desirable to consider its adhesive and cohesive properties, its resistance to fire and abrasion, its ease of application, its texture, and its maintenance, as well as its coefficient of sound absorption.

Acoustical Plaster and Sprayed-on Materials
Type 1: Acoustic plaster: composed of a cementitious material such as gypsum, Portland cement, or lime with or without an aggregate
Type 2: Acoustic materials other than acoustic plaster that are applied with a trowel.
Type 3: Fibrous materials combined with a binder agent and are applied being sprayed on with an air gun or blower.
Type 4: Units having a felted fiber surface

Table 4-8:Classification Of The Acoustical Plaster And Sprayed-On Materials According To U.S. Federal Specification SS-A-118-A *

a) Spray-on Cementitious Sound Absorbing Materials

Ceilings and walls can be treated with spray-on cementitious sound absorbing materials which can be applied in an architecturally appealing manner, and substantial experience. The special requirements of the tunnel installation for reasonable mechanical durability, fire resistance, and the ability to withstand water spray for cleaning limits the selection of materials even further. None of the materials described as "acoustic plaster" provide satisfactory sound absorption therefore should not be considered. Some of the materials are mineral fiber and some are

*Knudsen, V.O. and C.M. Harris. (1953) Acoustical designing in architecture. Third edition ed., New York: John Wiley & Sons, Inc.

cellulose fiber. Because the cellulose fiber materials do not retain their chemical fireproofing treatment particularly when washed, they should not be considered.[20]

The following list indicates those mineral fiber materials which have been demonstrated to have the necessary properties in application in underground stations and which should be considered:

Product commercial name	Type and Typical Thickness
Pyrok	3/4" to 1-1/4"
Sound Shield	1/2" to 5/8" Mineral Fiber
Kilnoise	1/2" to 5/8" Mineral Fiber
Pyrospray	3/4" to 1" Mineral Fiber
Edmar	1” Mineral Fiber

Table 4-9: List Of Spray-On Acoustical Absorption Materials To Be Considered For Use In Treatment Of Tunnels.[*]

It is very important to remember in the installation of any spray-on material that the concrete must be thoroughly cleaned of any dirt, residue, oil or other film that may be on the concrete. Any residue or oil can result in poor attachment or release of the spray-on acoustical material. Thus, the application procedure must include cleaning of the concrete before spraying to be sure that the installation will be durable.

Figure 4-11: Spray-On Cementitious Sound Absorbing Material On Station Wall With Attractive Color And Texture. Barcelona Metro Line2 Tetuan Station.[†]

[*]Wilson, G.P., H.K. Ihrig, and A.T. Wright, (1977) Noise Levels From Operations of Cta Rail Transit Trains. Wilson, ihrig & associates, inc.: CHICAGO, ILLINOIS.
[†]http://www.trenscat.com/tmb/images/metro/l2/P050505138.jpg

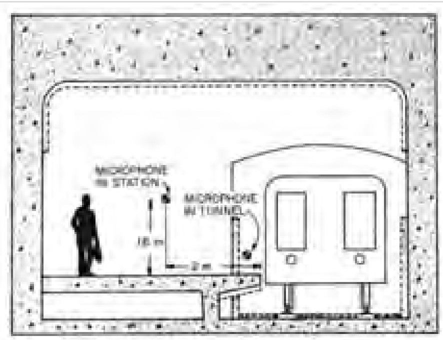
4.5. Acoustical Treatment Locations

One of the factors which should be considered in deriving the optimum location for sound absorbing material in platform areas is the effect of reflective surfaces compared to absorptive surfaces on the amount of sound energy fed to a reverberant space by a sound source. In general, only a portion of the sound energy produced by a source contributes to the reverberant sound in an enclosed space and that portion is the amount of sound energy left in the sound waves after the first reflection from a surface. When the surfaces are highly reflective, the amount of sound energy contributed to the reverberant sound is nearly the total energy radiated by the sound source. When the first surface, encountered by a sound wave as it propagates away from the source, is highly absorbent, then the amount of sound energy fed to the reverberant field is reduced. For example, when the first surface that a sound wave strikes absorbs 50% of the sound energy, i.e., reflects only 50% of the amount of contributed energy when the first surface encountered is highly reflective.[20]

A further consideration in determining the optimum location for the sound absorption material is that it is essential to apply some absorption on both vertical and horizontal surfaces in order to achieve maximum efficient absorption. This is necessary in any enclosed space where acoustical treatment is applied to control noise and reverberation. When 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. [20]

The type and placement of acoustical lining determine acoustical treatment effectiveness. The most effective and efficient location of sound absorption materials in underground station is on the track-bed beneath the transit trains and at each side of the transit cars along the vertical or near-vertical walls beneath the platform level, including the bottom of the platform overhang ledge, if any significant area is available. The next most effective location is on the tunnel side wall opposite the platform and the third most effective location is on the platform and/or tunnel ceilings.[20] Placement of acoustical materials is preferable in enclosed concourse spaces such as fare collection areas, stairs, escalators and corridors. Similarly, enclosed areas of above-grade stations should have ceiling-and wall-mounted absorption treatment to create an attractive acoustic environment for transit patrons. [18]

Noise reduction can reach from 5 to 10 dB in underground station by using acoustical treatments .[18] An absorptive ceiling over the station platform results in a reduction in A-weighted sound level of 5 to 10 dB(A) on the train platform (for otherwise untreated stations).[17] Suitable locations for absorptive treatment are shown in Figure 4-12 for a single track station and in Figure 4-13 for a double track station. Wall treatment heights range in general between 1.8m and 3m.



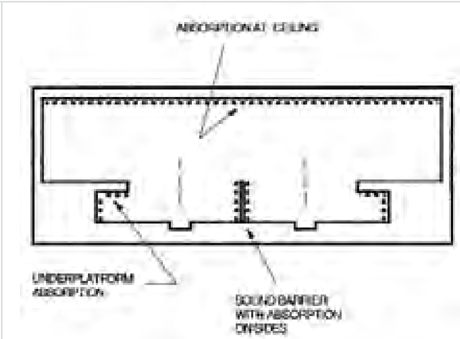


Figure 4-12:Left-Preferred Treatment Locations In Single Track Stations And Tunnels.*
Figure 4-13:Right-Preferred Treatment Locations In Double Track Stations And Tunnels.†

The following section will discuss application of acoustical treatment to under-platform surfaces, station ceilings and station walls.

4.5.1. Under-Platform Treatment

It has been found that efforts to place sound absorption material on top of a concrete track-bed have been unsuccessful. The material tends to become clogged with dirt and presents a maintenance problem. While it is effective when new, it deteriorates rapidly and becomes an ineffective treatment. Therefore, in practical terms the most effective and efficient placement location for sound absorption treatment is on the under-platform vertical surfaces and on the lower portion of the tunnel wall opposite the platform. [20]

*Harris, C.M. (1979) Handbook of Noise Control. 2nd edition ed., New York: McGraw-Hill book Company.p.33-17
† Ibid. P.182.

It is essential to place sound absorption material on the under-platform vertical surfaces and on the lower portion of the tunnel wall opposite the platform in order to reduce effectively the platform noise.[20] Sound absorbing materials located on the walls of the under-platform areas absorb sound energy close to the source effectively, and reduce the level of train noise on the station platform. The under-platform acts as an acoustically lined plenum when the train is in place, and is thus very effective in controlling noise, especially in single –track station. For double track configurations with platforms on both side of the tracks, the plenum noise reduction is only effective for noise produced by the wheels and rails located adjacent to the platform.[18]

4.5.1.1. Under-Platform Acoustical Material Mounting

For the under-platform acoustical treatment, minimum sound absorption coefficient of 0.55 at 250 Hz and 0.75 at 500 Hz is recommended. The best material for this application is 2" or 3" thick Fiberglass boards or blankets with a wrapping for water and dust proofing and with some form of metal mesh covering or enclosure for retention and mechanical protection. A wide range of Fiberglass blanket or board materials will give satisfactory performance. The material may be of 2.0 to 6.0 Ibs/cu ft nominal density and can be of the rigid, semi-rigid or flexible type. A material with or without sprayed vinyl or neoprene protective coating will be satisfactory and appropriate.

Effective under-platform treatments include Fiberglass encased in thin plastic, perforated fiber reinforced plastic sheet or sheet metal, or spray-on cementitious sound absorbing materials. For under-platform overhang treatment, material assembly of 3-in. to 4-in. thickness of non-flammable glass-wool is recommended with an appropriate cover of glass fiber cloth or non-flammable plastic film of not more than 0.004 in. thickness, and a facing of expanded metal or hardware cloth. Cellular glass blocks of 2- to 4-in. thickness are a recommended alternative for under-platform overhang treatment.

If Fiberglass wrapped in glass cloth is used for the under-platform treatment, the panels should be held in place with either an expanded metal facing, hardware cloth facing, or perforated metal facing. For center platform stations, expanded metal or hardware cloth is the most economical material since the material is not visible to patrons.

The sound absorption treatment can be summed up in one of the following manners:[20]

1. Fiberglass boards or blankets mounted directly against the under-platform overhang surfaces. The Fiberglass should be wrapped in a plastic film or glass cloth bag for dirt and water protection and should be provided with an expanded metal or hardware cloth [large mesh screen] cover for mechanical protection and retention.
2. Wrapped Fiberglass blankets or boards with open mesh metal protective facing in no. 1. but with the material mounted with an air space between the back of the treatment and the concrete surfaces.
3. Fiberglass blankets or boards, wrapped in plastic film or glass cloth bags, mounted in and retained by a perforated metal panel [steel or aluminum] and mounted either directly against the concrete surfaces as in no. 1. or mounted on brackets spacing the panels out from the surfaces as in no. 2.
4. Spray-on sound absorption material.

The sound absorption treatment on the under-platform overhang surfaces should be continuous for the full length of the platforms and should provide as complete coverage of the vertical and horizontal surface as can be accommodated. Openings for ventilation duct registers or locations where there must be access panels or hatches would, of course, be points at which the treatment would be omitted. However, in general, the coverage should be as complete as possible.[20] The minimum treatment for the under-platform area is a 75 cm wide strip of continuous treatment on the vertical rear wall surface and complete coverage of the underside of the platform overhang. [18]

For a side platform in double track stations, where the material is visible to patrons on the opposite platform, a better appearance can be obtained with perforated metal facing. Perforated metal or slit-and-slat facings should have open areas of at least 10% (1/8-in. diameter holes at 3/8-in. center-to-center) or, preferably, 20% of the total area. Either expanded or perforated metal facings can be attached to the under-platform surfaces with simple metal brackets. The sound absorbing materials and retention hardware must be able to withstand high pressure wash and other cleaning methods that might be employed in subway environments.

4.5.2. Barriers Between Track Treatments

Barriers may be used between the tracks to block sound from trains passing through stations. This type of treatment has been used in New York, though there are concerns regarding safety.[18] As a rule, this type of treatment would be less needed if the trainway ceiling and station walls were treated with acoustical absorption, and if the rails and wheels were maintained in good condition. Figure 4-14 and Figure 4-15 illustrate the use of a platform height sound barrier to control train noise.

The noise sources of a train are primarily located in the confined space beneath it. Without sound absorption, there would be little reduction of noise. For ballasted track, the ballast provides substantial absorption, and there is no need for absorption to be applied to the barrier. A platform height barrier between the near and far tracks of a side platform station can reduce sound levels on the platform by as much as 10 dB(A) [18]. The actual amount of reduction is dependent on the design of the barrier and the measurement location. The greatest reduction occurs on the far platform, where the wheels and rail would otherwise be in full view of patrons, but there is also some reduction on the near platform.

In double-track station, on side platform, Absorptive sound barriers are used to block noise from far track trains. It only needs to be as high as the platform level to achieve significant reductions of train noise, because wheel/rail noise originates beneath the cars. Sound absorption should be provided on both sides of the barrier where direct fixation track is employed.

Figure 4-14: Left - Barriers Between Tracks. Downtown Crossing Station, Boston.*
Figure 4-15: Right - Treatment Of Under-Platform With Baffles Between Tracks (Haussmann-St-Lazare) Entrances.†

*http://www.flickr.com/photos/jmillerdp/4030500710/
†http://www.arep.fr/

4.5.3. Wall Treatments

4.5.3.1. Fiberglass Boards

For wall treatments application, it is essential in most instances that the Fiberglass material be enclosed in a sheet plastic or plastic film bag or wrapping for durability, hygiene, and fire protection, to prevent the accumulation of dust, and to permit washing of the surface. If fire resistance requirements preclude the use of a plastic film, the covering can be made of a tight weave fiberglass cloth. These coverings slightly decrease the high frequency absorption coefficient and slightly increase the middle and low frequency coefficients but essentially have no effect or a slight benefit in terms of reduction of transit train noise.

4.5.3.2. Slit and Slat Wall Systems

Another alternative is placing slit and slat facing in front of the acoustic materials to preserve it and protect it from fire. Sectioned or continuous panels (consisting of a metal or plastic slit-and-slat) with Fiberglass or cellular glass blocks between the facing and the concrete surface are appropriate for treating flat, continuous surfaces and platform or mezzanine ceiling areas.[20] Preferable wall treatment heights are generally between 1.8m and 3m.

A slit-and-slat configuration of plastic or metal sheet, have some form of architectural trim and has at least 30% open area and no bars or sections that are greater than 7.5cm (3") in width between openings. Thus, acoustic material packed in this system arrangement provides a completely transparent acoustical face. Acoustical material can then be located at 1cm or larger distance behind the face and could be the simplest and most economical Fiberglass blanket or board, i.e., ventilation duct liner material in 1 ½" to 2" thickness.[18] In the following example, holes measure only 1.5 cm^2 and facilitate the absorption of the noise and diffuse it toward the underlying rockwool. In addition, Wall panels measures an average of 2.30 m by 1.80 m, with 20-mm thickness in the solid areas and 15-mm thickness in the perforated areas. The panels are nonflammable, were easy to install and provide highly aesthetic surroundings for the station and its users.

Slit and Slat Wall Panels

Figure 4-16: Acoustical Panels (Slit And Stat System) Monaco Station.[*]

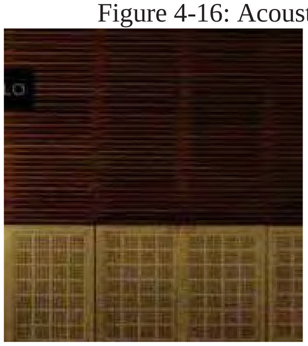


Figure 4-17: Left: Acoustical Panels.[†]

Figure 4-18: Right: Monaco Station With Acoustical Treatment On The Wall Side.[‡]

Figure 4-19: Left: Westendstraße Subway Station, Munich .[§]

Figure 4-20: Right: Arabellapark Subway Station,Munich.[**]

[*] http://en.wikipedia.org/wiki/File:Train_station,_Monaco.jpg
[†] http://en.structurae.de/structures/data/photos.cfm?ID=s0012848
[‡] http://upload.wikimedia.org/wikipedia/commons/1/1d/Train_station%2C_Monaco.jpg
[§] http://www.muenchnerubahn.de/bild/gross/ws_1.jpg
[**] http://www.muenchnerubahn.de/bild/gross/ar_1.jpg

4.5.3.3. Perforated Wall Panels

A possible covering for sidewall treatment in single tracks station is perforated sheet metal or plastic with at least 30% open area. Perforation patterns can be; 15mm (1/16") diameter holes staggered at (25mm) 7/64" centers, 1/8" diameter holes at 45mm (3/16") centers, and 45mm 3/16" diameter holes at 30mm (5/16") centers provide adequate open area. There are, of course, other combinations of equivalent performance; see Figure 4-21 to Figure 4-26.

Perforated Wall Panels

Figure 4-21: Westminster Underground Station, London.[*]

Figure 4-22::Left-Detail, The Angled Platform Walls, Openwork Cement-Glass Composite Panels Are Used In Conjunction With Rockwool(Valence TGV)[†]

Figure 4-23: Right-The Angled Platform Walls, Openwork GRC Panels Are Used In Conjunction With Rockwool (Valence TGV) [‡]

[*] http://www.flickr.com/photos/andymcgowan/3201308037/
†http://www.arep.fr/
‡Ibid

Perforated Wall Panels

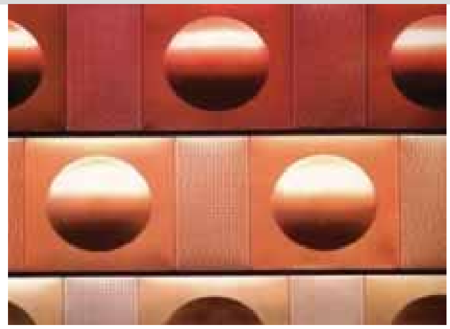


Figure 4-24:Left - Hradčanská Station, Line A Prague Metro
Figure 4-25:Right - Museum Station, Prague Metro. *

Figure 4-26: Metro Station Malostranská, Line A.†

4.5.3.4. Spray-on Cementitious Materials

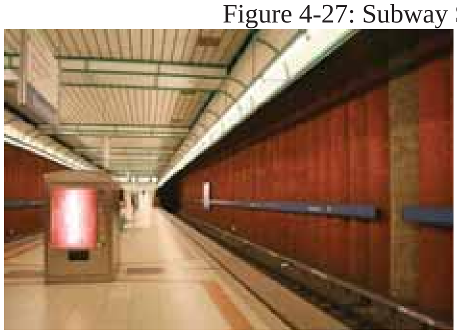
Spray-on materials are the easiest to install, and may be cheaper than Fiberglass materials. The number of satisfactory spray-on products is much more limited than Fiberglass blanket or board materials. Spray-On materials have similar absorption characteristics when applied in thicknesses of 1.5cm to 2cm in. When properly installed, all are durable enough to withstand repeated cleaning or washing with water spray. The installation procedures must be clearly defined and monitored to ensure a durable application. Improper installation may result in inadequate acoustical performance and poor adhesion to surfaces.

Mangfallplatz is a terminus station in Munich on the U1 line of the Munich U-Bahn system. The walls at the **Mangfallplatz** station consist of inclined bored piles that are coated with spray-on cementitious acoustic materials; see Figure 4-27. The same treatment is applied in Obersendling station on the U3 line of the Munich U-Bahn system; see Figure 4-28.

*http://commons.wikimedia.org/wiki/File:Prague_metro_Hradcanska_station_01
†http://commons.wikimedia.org/wiki/File:Praha,_Malostransk%C3%A1,_vlak

Acoustic Spray-on Cementitious Materials

Figure 4-27: Subway Station, Munich (U1)[*]



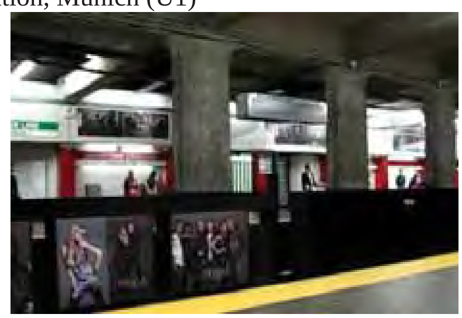


Figure 4-28: Left- Obersendling Subway Station, Munich (U3) †

Figure 4-29: Right - Red Line Train At Downtown Crossing Showing Cementitious Sound Absorption On Ceiling And Walls ‡

4.5.4. Ceiling Treatments

4.5.4.1. Acoustical Ceiling Tiles

One type of sound absorption treatment that could be used at the platform island, in case of two way tracks on each side of the platform, is the suspended acoustical tile type of ceiling treatment. A suspended acoustical tile ceiling with an air space between the tile and structural ceiling above can provide adequate low frequency sound absorption to provide equivalent results to a 5cm (2") or 7.5cm (3") thick surface mounted treatment. Such an assembly may be desirable both

[*] http://commons.wikimedia.org/wiki/File:Munich_subway_Mangfallplatz.jpg
[†] http://en.wikipedia.org/wiki/File:U-Bahnhof_Obersendling_01.jpg
[‡] http://www.flickr.com/photos/crash575/2930562036/in/photostream/

economically and architecturally for ceiling treatment in platform areas.

This type of treatment is also appropriate for concourse and corridor areas and should be given consideration as a possible treatment for such areas. For platform areas, however, this type of sound absorption assembly requires special consideration because of the static pressure changes that occur during train operations into and through the station platform areas. The piston action of the trains can cause large air flows and large air pressure forces on suspended acoustical tile ceiling assemblies (i.e. any assembly which has an enclosed air space behind the facing material).

If a suspended acoustical tile ceiling system is considered for sound absorption treatment in a platform area, the assembly must include adequate opening for airflow and pressure equalization between the main platform space and the enclosed air space behind the acoustical treatment. In fact, the need for providing gaps for pressure equalization should be considered in all acoustical material applications in underground station platform areas. With proper provision for air flow and pressure equalization, the suspended acoustical tile assembly is a design which can provide adequate and appropriate sound absorption for platform areas.

The preferred minimum recommended thickness of acoustical tile is 3/4" and 1" thickness. If the assembly selected is a perforated metal pan system then the acoustical material behind the facing should be at least 1" thick Fiberglass blankets with appropriate covering to minimize dust and water absorption. Also, because of the static pressure and air flow problem, the acoustical material for metal pan systems should be spaced back from the perforated metal facing by at least 3/8" to 1/2", using a dimpled screen or other support, to provide an air space between the bag enclosing the material and the perforated face.

Acoustical material applications on ceilings, between structural members on ceilings or in middle platform areas could be of pre-formed perforated metal panels with Fiberglass behind and with this assembly suspended from or applied directly against the face of the concrete as in Figure 4-30 and Figure 4-31.

Acoustical Ceiling Tiles

Figure 4-30:Above Left -Bethnal Green Tube Station, Central Line Of The London Underground.[*]
Figure 4-31:Above-Right-City Railway Station Bundesrechnungshof Germany.[†]
Figure 4-32: Left- Heussallee / Museumsmeile City Railway Station In Bonn[‡]

Figure 4-33: Left-Magenta Station With Acoustical Ceiling Treatment And Noise-Absorbent Baffles Between Tracks Magenta Station.
Figure 4-34: Right-Acoustical Ceiling Panel.[§]

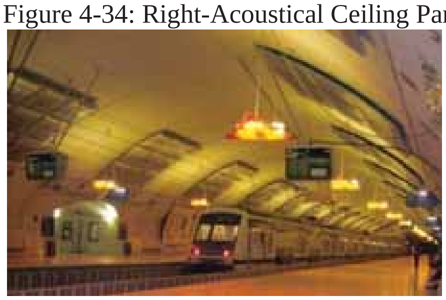


Figure 4-35: Left-Acoustical Absorbing Tiles (Magenta Station). [**]
Figure 4-36: Right-Acoustical Absorbing Tiles Haussmann-St.Lazare.*

[*]http://en.wikipedia.org/wiki/File:Bethnal_Green_stn_eastbound_look_east.JPG
[†] http://upload.wikimedia.org/wikipedia/commons/e/e7/Bonn_Bundesrechnungshof.jpg
[‡] http://commons.wikimedia.org/wiki/File:Bonn_Heussallee_2283.jpg
§ http://www.arep.fr/arep.php?langue=2&id_type_menu=2&id_menu=4#2-2-4-13
** http://en.wikipedia.org/wiki/File:RER-E-station-Magenta.jpg

4.5.4.2. Spray-on Cementitious Materials

Acoustic spray-on materials are the easiest to install on station ceiling as well as station walls as mentioned previously. It is more efficient in spaces subjected to air pressure resulting from moving trains and spaces where maintenance will be difficult for panel construction.

4.5.5. Tunnel Wall Treatment

When a train is in the tunnel, Underground station noise can be reduced by a strongly absorbent section near the tunnel entrance using diffusely reflecting boundaries, absorbent end walls, etc.[31]

In the tunnel, ceiling and wall treatments should be mounted flush against the ceiling without air gap to avoid stresses induced by dynamic air pressure loading. Ceilings and walls also may be treated with spray-on cementitious sound absorbing materials. The spray-on cementitious treatments can be applied in an architecturally appealing manner, and substantial experience has been gained with the application of these treatments. Costs for station treatment are difficult to assess.

Tunnel wall treatments reduce noise in tunnel, inside the vehicle, as well as the station platform noise levels caused by approaching trains and subway ventilation fans. Ballast provides substantial sound absorption; therefore, the addition of tunnel wall and ceiling absorption in tunnels with ballasted track will have much less effect than in tunnels with direct fixation track.

In underground stations with direct fixation track, treating the upper half of the tunnel walls and the entire ceiling with sound absorbing materials will reduce car interior noise. The treatment is especially desirable where vehicle windows are often left open for ventilation or where there is substantial sound transmission through the car body or doors. Car interior noise reductions would also be obtained with tunnel wall treatment.

Curves beginning at the end of station platforms may cause considerable squeal which transmits to the station platform area and may be uncomfortable to patrons or interfere with conversation. In this case, sound absorption applied to the upper portion of tunnel walls and the ceiling in the curved track section may be effective in reducing squeal noise transmission to the station platform area.

Wheel squeal noise can be easily transmitted to the interior of the vehicle, where it may actually be painful to patrons, so sound absorption

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* http://en.wikipedia.org/wiki/File:Haussmann-St.Lazare.jpg

placed against the tunnel wall from floor to ceiling and extending throughout the curve would be particularly effective in controlling this transmission path, even with ballasted track where ballast normally provides some sound absorption. Cementitious spray-on sound absorbing materials are particularly attractive for this purpose, although the most effective treatment would be 2-in.-thick 3-pcf Fiberglass board encased in Tedlar plastic and protected with perforated powder coated metal.

Tunnel wall treatments consisting of spray-on cementitious sound absorbing treatment are practical and effective. An example of extensive tunnel wall treatment with cementitious sound absorption includes the MBTA stations. Subway wall treatments consisting of spray-on cementitious sound absorbing treatment are practical and effective. Alternative treatments include certain spray-on materials of mineral fibers which are suitable for use on tunnel walls or Fiberglass board protected by plastic film with a perforated sheet metal or fiberboard cover.

Figure 4-37: Spray-On Cementitous Treatment On Walls. MBTA Red Line Outbound Train Approaching South Station Viewed From Inbound Platform*

*http://upload.wikimedia.org/wikipedia/commons/7/75/RedOutSouthStation.jpg

4.6. Effect of Acoustical Treatments on Noise Reduction

The following section will describe some of the acoustical treatments used in underground stations around the world to improve the acoustical environment.

4.6.1. <u>Ceiling and Under-Platform Treatments</u>

4.6.1.1. <u>Vehicle Interior Noise</u>

Noise measurements inside WMATA Metro cars indicate that acoustical treatment of underground stations can substantially reduce car interior noise levels [18].

Figure 4-38 shows the measurements results in a box structure station with no sound absorption treatment, the interior noise level for a 2-car (train operating at 40 mph 65 km/h) was 79 dB(A), whereas in passing through an acoustically treated station the interior level was 68 dB(A). The same type of measurement indicated 64 dB(A) for at-grade ballast-and-tie stations, where no reflective sound impinges on the transit car.

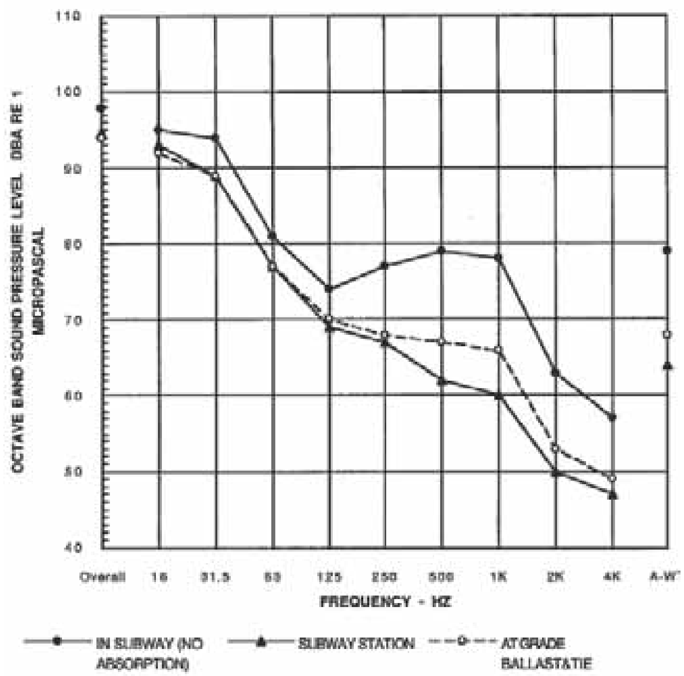

Figure 4-38: WMATA Car Interior Noise Levels, 2 Car Train At 40 MPH (65 Km/H).*

*Nelson, J.T., (1997) <u>Wheel/Rail Noise Control Manual</u>, T.R.B.N.R. COUNCIL, Editor., Federal Transit Administration in Cooperation with the Transit Development Corporation. p.185.

4.6.1.2. Reverberation Time

Figure 4-39 indicates reverberation times measured in WMATA Metro and BART underground stations, before and after installation of acoustical treatment on ceiling and under-platform overhang surfaces.

Reverberation times measured in treated BART and WMATA stations are typically 1.3 to 1.5 sec at 500 Hz, as compared with 7 to 9 sec for untreated stations. Train noise levels in acoustically treated stations are much more acceptable than those found in older systems with completely untreated, highly reverberant stations.

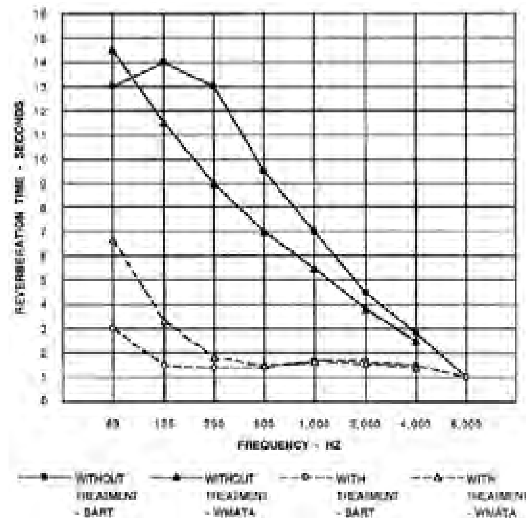

Figure 4-39: Reverberation Times For Treated And Untreated Stations *

4.6.1.3. Maximum platform noise levels

Figure 4-40 presents typical noise levels, measured in TTC tunnel stations having sound absorption treatment on the under-platform overhang surfaces only (an insufficient amount to control reverberation and allow intelligibility of the public address system), and in a station in which the entire ceiling, as well as the under-platform, has been treated. The range shows the typical maximum levels that occur on the station platforms as trains arrive and depart. The sound absorption on the ceiling in this case is

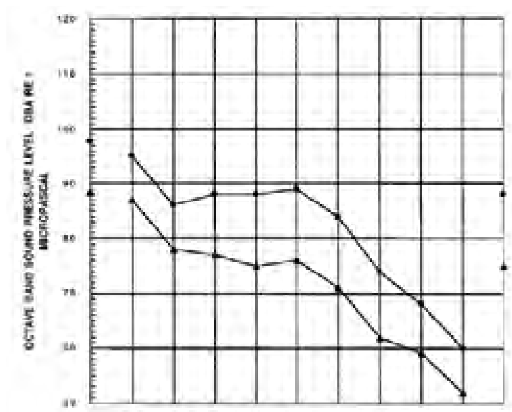

Figure 4-40: Typical Maximum Platform Noise Levels Of TTC Tunnel Stations With Trains Entering And Leaving†

*Ibid. P.183

†Ibid. p.186

provided mainly by a suspended acoustical tile ceiling, an arrangement that gives nearly uniform absorption and noise reduction over the entire frequency range relevant to wheel/rail noise. The effective noise reduction is very dramatic—about 13 dB(A).

Figure 4-43 presents data obtained on station platforms at the two BART system stations which both have extensive ceiling acoustical absorption and comparable, short reverberation times while one station lacks under-platform sound absorption treatment. The result was considerably less control of train noise in the station without the under-platform treatment, even though the reverberation time in the two stations and the total amount of acoustical absorption per unit volume was about the same for both. The charts on Figure 4-43 show the large effect of treatment of the relatively small area placed under the platform. In the station where the under-platform treatment was omitted the average noise level was about 5 dB(A) greater and in the mid- and low frequencies. The difference in noise level was 5 to 8 decibels. This result points out the importance of proper placement of the sound absorbing material. [20]

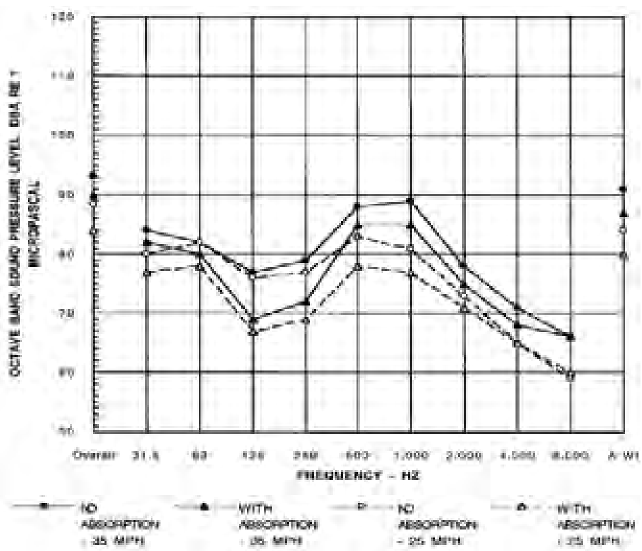

Figure 4-41: Left- Above -The Lake Merritt BART Station. Downtown Oakland.*
Figure 4-42: Left – Below-The 19th Street BART Station. Downtown Oakland.†
Figure 4-43: Right -Noise Levels On Acoustically Treated 2 Bart Subway Stations.‡

*http://en.wikipedia.org/wiki/File:Lake_Merritt_station.jpg
† http://en.wikipedia.org/wiki/19th_Street/Oakland_(BART_station)
‡Nelson, J.T., (1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. COUNCIL, Editor., Federal Transit Administration in Cooperation with the Transit Development Corporation. p.186

4.6.2. Track-Bed Area Treatments

4.6.2.1. A-weighted sound pressure level

Figure 4-44 shows noise levels on platforms for trains passing by at 40 mph (65 km/h) at several subway stations having concrete track-bed and Ballast and tie tracks. The noise levels at BART and WMATA platforms ranges of 87 to 89 dB(A). Noise levels in untreated Chicago CTA stations, under similar operating conditions and using similar trains, are as high as 108 dB(A) on the platform of stations with concrete track-bed and 93 dB(A) on the platform of stations with ballast-and-tie tracks.

The 15 dB(A) difference due to the ballast confirms that the ballast provides a significant amount of sound absorption which both absorbs sound at the source and reduces the reverberant sound energy build-up.

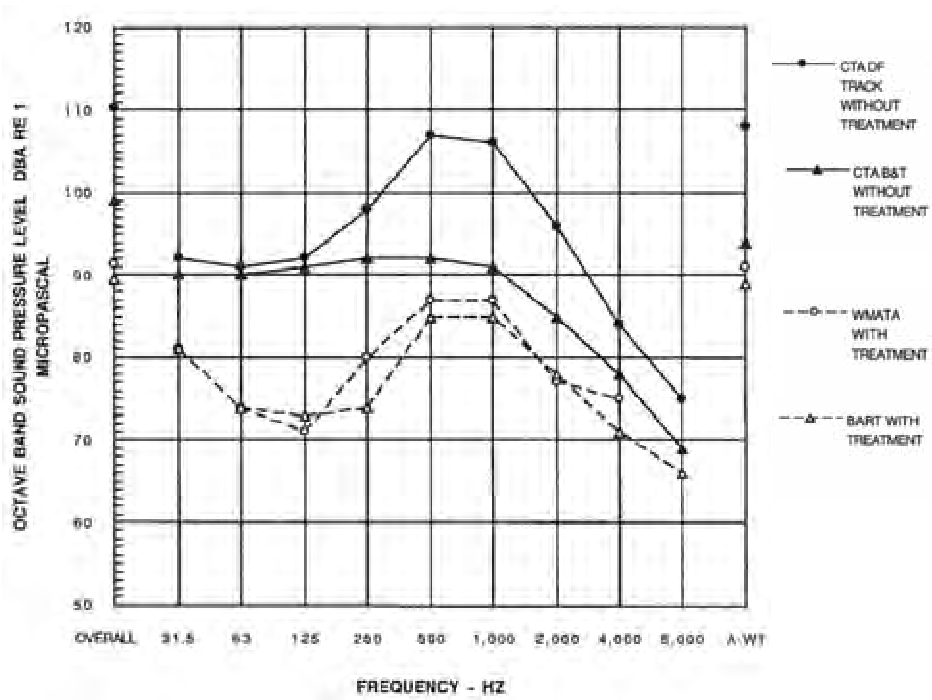

Figure 4-44: Subway Station Platform Noise Levels With Train Passing Through At 40 MPH (65 Km/H)*

*Ibid. P.184.

4.7. Examples of a Typical Station Treatments

An extensive study by the Chicago Transit Authority was conducted for the generated noise of the operating transit vehicles noise of various types of way structures of the CTA rail transit system. The measurements have included evaluation of car interior noise levels, station platform noise levels, and wayside noise levels for transit train operations on elevated structure, on ballast and tie track, and in tunnels. The objective of the study was to provide for evaluation of the noise and vibration characteristics of the CTA vehicles and facilities and to determine possible procedures for reducing the noise exposure for patrons and wayside neighbors of the system.[20]

4.7.1. Noise Measurement Procedures

The general procedure used for measuring the noise of the CTA transit trains consisted of taking multiple readings in all cases of train operation either in terms of repeat runs in opposite directions or by multiple readings for the same condition. This was done to obtain average results and to minimize the effects of non-typical operating conditions or other irregular effects that influence individual readings. Measurements were taken for the following noise sources[20]:

- Car equipment wayside noise
- Ballast and Tie track wayside noise
- Elevated structure wayside noise
- Tunnel structure wayside noise
- Underground station platform noise
- Car interior noise

The following photos present the noise measurement setup for evaluation of subway noise inside the car, tunnel, and station platform.

Figure 4-45: 1&2-Two Views Of The Sound Level Meter Set Up On The Tunnel Walkway.[*]
Figure 4-46: 3 - Sound Level Meter On State Street Station Platform[†]
Figure 4-47: 4 - Measurements Inside The Train Car.[*]

[*]Wilson, G.P., H.K. Ihrig, and A.T. Wright, (1977) Noise Levels From Operations of Cta Rail Transit Trains. Wilson, ihrig & associates, inc.: CHICAGO, ILLINOIS. P.18
[†]Ibid. p.19

In octave band analysis, the average for the overall sound pressure level and the A-weighted sound level were demonstrated for of each measurement. For underground station platform and tunnel noise the data were averaged for several pass-bys of transit trains of each type. For the car equipment noise with the cars stationary or on jacks, the levels were averaged over several seconds of operation at constant conditions.

4.7.2. Noise Measurements Results

The following section presents the results and discussions of the conducted noise measurements.[20]

4.7.2.1. Car Equipment Wayside Noise

The measurements of the car equipment wayside noise provide basic data on the sound levels produced by the transit car propulsion systems and auxiliary equipment. These data provide a basis for determining the degree to which equipment noise affects or contributes to the wayside noise for operation of the transit trains on the various way structures.[20]

During normal operations with the motors and gears loaded there may be some additional contribution to the total noise due to gearbox noise, however, in most cases it has been found that the gearbox noise is less than, or at most comparable to, the noise from the propulsion motors; see Figure 4-48 and Figure 4-49.

4.7.2.2. Tunnel Wayside Noise

Measurements of the reverberation time are conducted in the tunnels, on the walkway at three locations for a variety of lengths of trains and types of cars. Figure 4-45 presents photographs of the test setup in tunnels.

Figure 4-50 presents octave band analyses of the average results for wayside noise in the tunnels sections considering both tunnels with concrete track-bed and the tunnel or box section with ballast and tie track-bed. It is apparent from the charts that the noise level is considerably reduced outside the cars in the tunnel with ballast and tie track.

In order to determine the effective sound absorption coefficient (α) of the ballasted track-bed, reverberation time measurements are taken in the Tunnel. Such measurements provide means for calculating the absorption of the ballast. Table 4-10 and Table 4-11 indicate the measured reverberation time in the three types of tunnels: horseshoe tunnel with concrete track-bed, horseshoe tunnel with ballasted track, and box tunnel, along with the calculated absorption coefficients of the ballast.

[*] Ibid. p.19

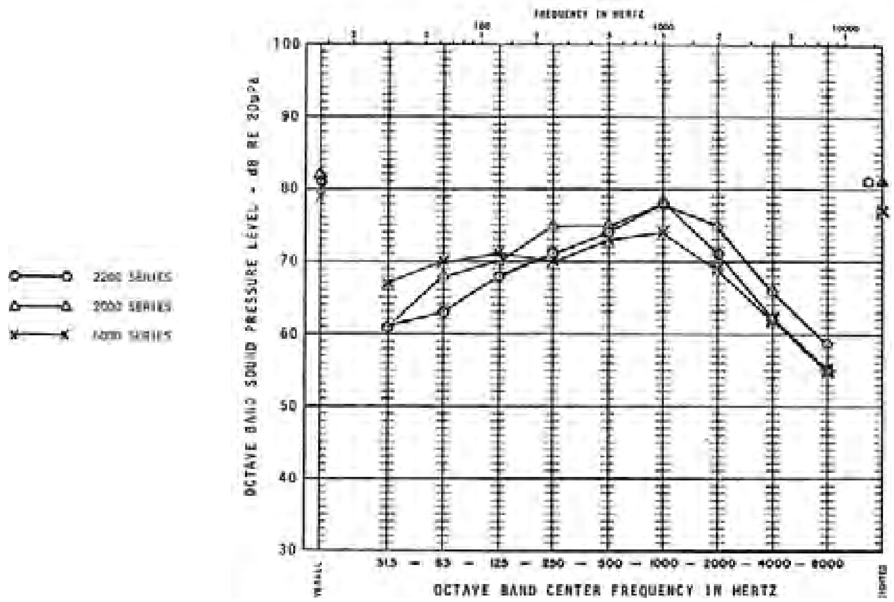

Figure 4-48: Propulsion Equipment Wayside Noise Normalized To 15 M From Track Centerline For 40 Mph Operation On Ballast And Tie Track.[*]

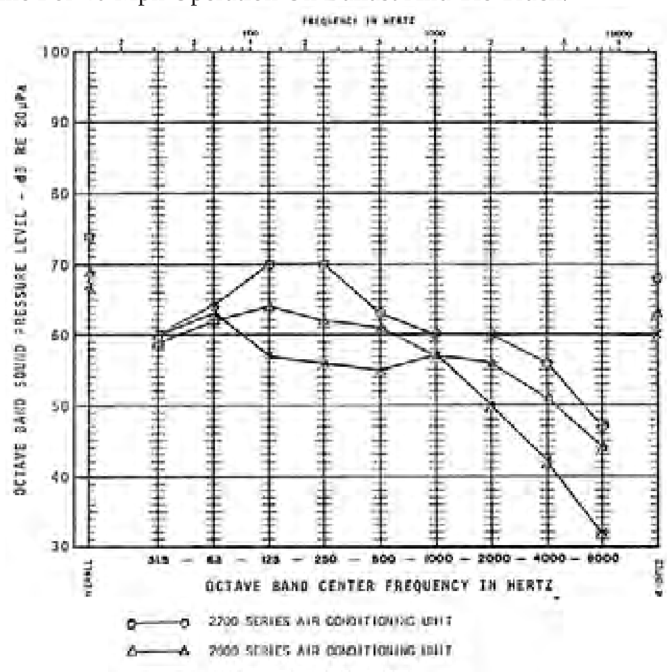

Figure 4-49:Typical Auxiliary Equipment Wayside Noise At 15 M For Ballast And Tie Track[†]

[*]Ibid. P.29
[†]Ibid. P.30

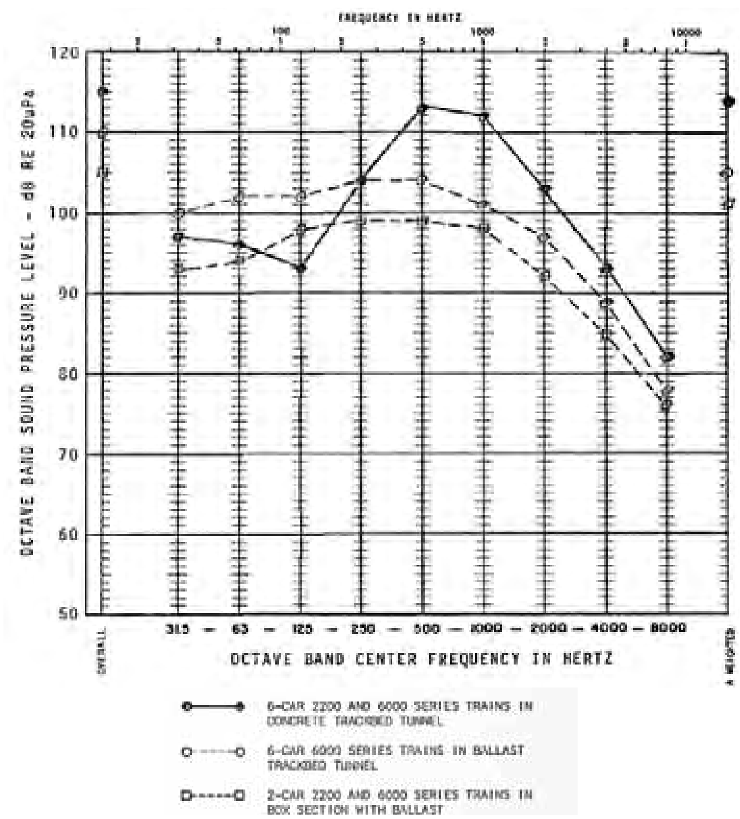

Figure 4-50: Average Tunnel Wayside Noise Levels For 30-40 Mph.*

Reverberation time						
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**
Concrete Track-bed Tunnel	6.3	5.4	4.5	3.6	2.1	1.7
Ballast Track-bed Tunnel	1.1	1.4	1.05	1.35	1.2	1.0
Ballast Track-bed Box	0.90	0.95	0.85	1.1	1.0	0.95

Table 4-10: Reverberation Time Measured In Tunnels.†

Absorption coefficients						
Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**
Concrete Tunnel Surfaces	0.03	0.35	0.043	0.053	0.091	0.113
Tunnel Ballast	0.68	0.52	0.68	0.46	0.46	0.47
Box Section Ballast	0.67	0.60	0.67	0.49	0.4	0.37

Table 4-11: Calculated Ballast Absorption In Tunnels.‡

*Wilson, G.P., H.K. Ihrig, and A.T. Wright, (1977) Noise Levels From Operations of Cta Rail Transit Trains. Wilson, ihrig & associates, inc.: CHICAGO, ILLINOIS. P.50
†Ibid.p.49
‡Ibid.p.49

4.7.2.3. Platform Noise Levels

Noise measurements on underground station platforms are taken by setting up the sound level meter microphone at 1.35 to 1.5 m height, approximately standing head height, and 1.5 m from the edge of the platform. This position is chosen for representing a typical location for patrons waiting on the platforms. All train operation noise level data on the station platforms are obtained for trains passing through or stopping in the stations and thus the data were for a variety of car types and lengths of train for the speeds characteristic of operations in and out and through the stations.[20]

The results of the noise measurements show that the noise levels experienced in the CTA transit vehicles, on the underground station platforms and at the wayside cover a wide range of levels. The actual sound levels experienced and the noise exposure of patrons are highly dependent on the type and design of the way structure and are somewhat dependent on the type and configuration of the transit cars; see Figure 4-51.[20]

The highest noise levels are experienced by CTA patrons are typically in the range of 105 to 110 dB(A) at underground stations of concrete track-bed. In addition, the highest noise levels are found also at the platforms for the round tunnel stations besides concrete track-bed. The same transit vehicles operating in stations with ballast and tie track, either tunnel stations or box section stations, produce noise levels on about 15 dB(A) less, i.e., in the range of 90 to 95 dB(A) as a maximum noise level. The latter is a considerably reduced noise level demonstrating the potential for reduction of platform noise levels that can be achieved by sound absorption treatment applications.[20]

Measurements in the underground stations with concrete track-bed indicated a relatively short reverberation time, considering that the spaces have no sound absorption treatment present; see Figure 4-52. Columns or the relatively complex shape of the CTA round tunnel stations, indicate short reverberation apparently due to the presence of the columns and the relatively complex shape [islands on the platform, arched ceilings, etc.] that lead to sufficient sound diffusion where sound energy is absorbed at a higher rate than normally expected for a space that is completely untreated. This result tends to indicate and confirm that application of sound absorption material to the stations will give substantial noise reduction. The detailed octave band analysis charts of platform noise levels due to the trains are given in Figure 4-53 to Figure 4-55.[20]

Effect of Ballast Absorption on Maximum Noise Levels

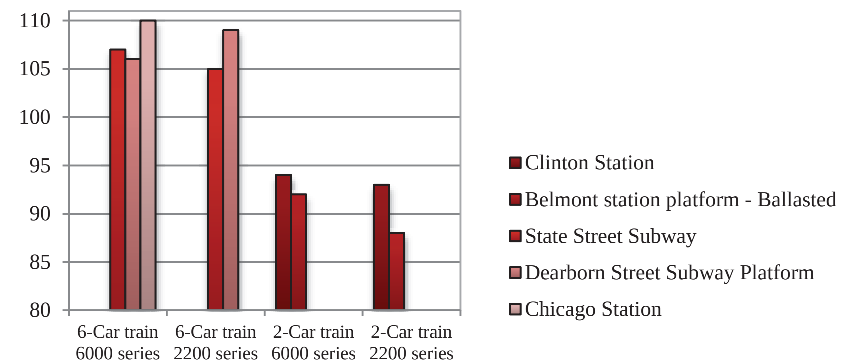

Figure 4-51: Maximum Noise Levels Measured In The Ballast Treated And Untreated Station Platform Areas.*

Effect of Ballast Absorption on Reverberation Time

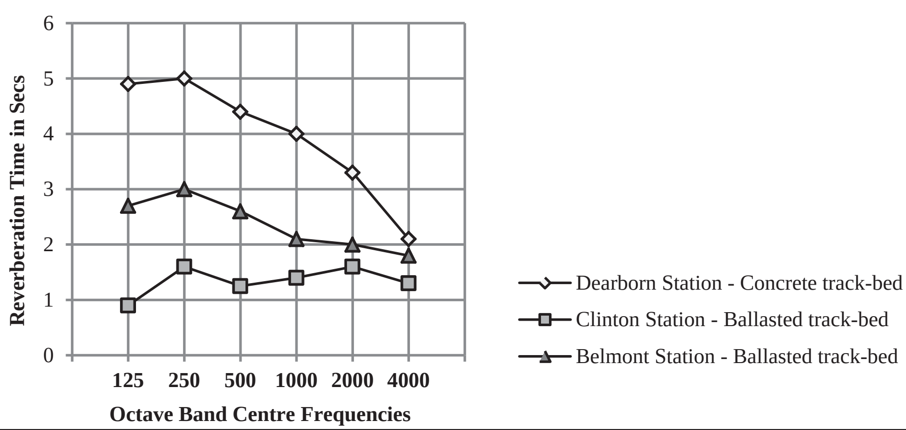

Figure 4-52: The Reverberation Times Measured In The Ballast Treated And Untreated Station Platform Areas.†

Reverberation time in sec						
Station - Frequency	**125**	**250**	**500**	**1000**	**2000**	**4000**
Dearborn Station - Concrete track-bed	4.9	5.0	4.4	4.0	3.3	2.1
Clinton Station - Ballasted track-bed	0.9	1.6	1.25	1.4	1.6	1.3
Belmont Station - Ballasted track-bed	2.7	3.0	2.6	2.1	2.0	1.8

Table 4-12: The Reverberation Times Measured In The Ballast Treated And Untreated Station Platform Areas.‡

*Ibid.P.54- Generated by the Author
†Ibid.P.54 Generated by the Author
‡Ibid.P.54

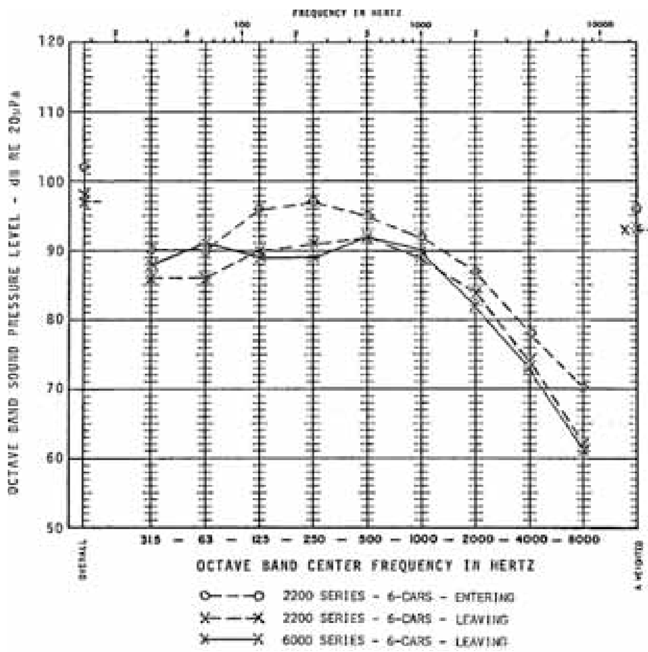

Figure 4-53:Average Platform Noise Levels In Underground Station With Ballasted Track-Bed With Train Entering And Leaving On Far Track- Clinton Station.*

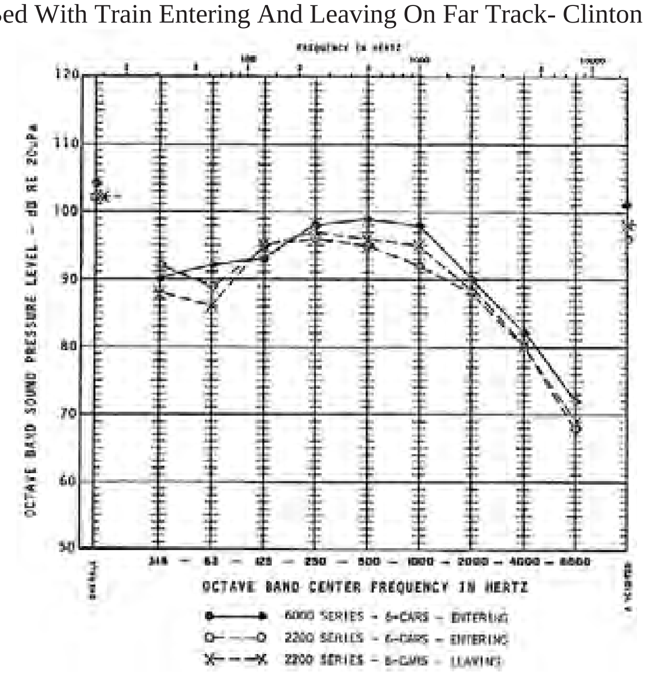

Figure 4-54: Average Platform Noise Levels In Underground Station With Concrete Track-Bed With Train Entering And Leaving On Near Track- Clinton Station

*Ibid. P.235, P.236.

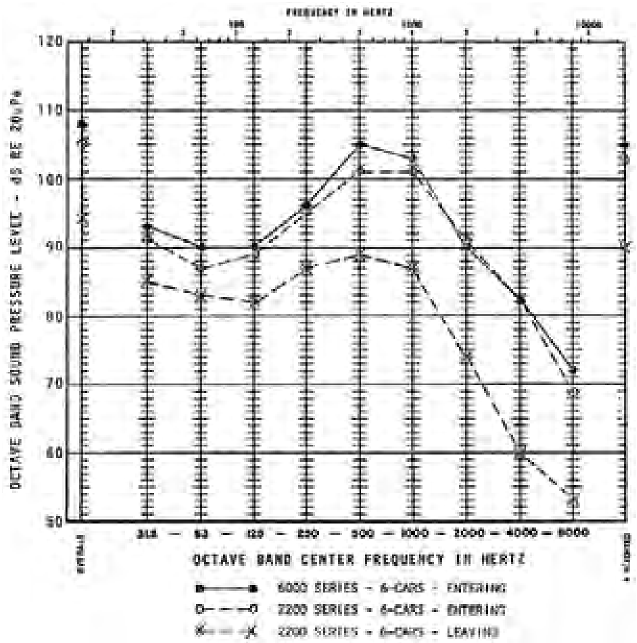

Figure 4-55: Average Platform Noise Levels In Underground Station With Concrete Track-Bed With Train Entering And Leaving On Near Track- Chicago Station

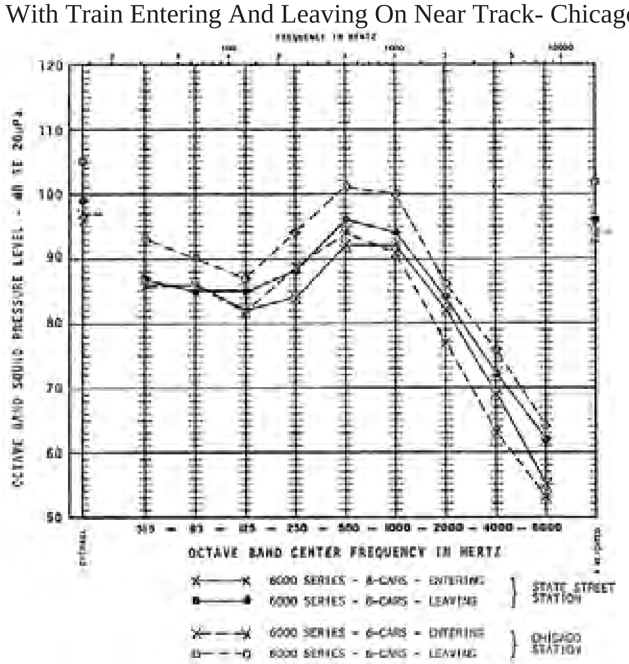

Figure 4-56: Average Platform Noise Levels In Underground Stations With Concrete Track-Bed With Train Entering And Leaving On Far Track- State Street And Chicago Stations*

*Ibid. P.233, P.234.

4.7.3. Discussion

The most intense noise levels observed after investigating several types of trains operations were found to be the noise levels on underground station platforms of the rounded tunnel section with concrete track-bed. Following this in intensity and exposure to patrons are the noise levels in the cars operating in the smooth bore tunnels with concrete track-bed. [20]

Comparison of the sound levels in the underground stations that have sound absorption treatment in the form of ballasted track-bed with stations that are not treated show a substantially reduced noise exposure level in the stations with the ballast for absorption; see Figure 4-51 and Figure 4-52 It may be assumed by some that the reduced noise level is due to reduced generation of noise at the source. However, the measurements show that most of the reduction can be explained in terms of the absorption provided by the ballast. In fact, the noise power generated at the source is probably very similar in the two types of stations and most of the difference in noise level is due to the sound absorptive effect of the ballast.[20]

The actual measured relative values of the typical station noise levels were 14 to 16 dB(A) lower noise levels in the ballasted track-bed stations compared to the concrete track-bed tunnel stations. This type of result certainly shows the potential for improved performance in the subway stations without acoustical treatment by application of acoustical absorptive treatment.[20]

In addition, since the ballasted stations have no acoustical treatment on the walls and ceilings, it is likely that the noise could be even further reduced in these stations through the application of an absorbing material covering at least the ceilings over the platform areas. Such acoustical treatment would have the added benefit of reducing crowd noise and machinery noise by a larger increment than these noises are reduced with just the absorption of the ballast.[20]

According to the acoustical investigation in several underground stations, the results discussed above show that substantial noise reductions can be achieved in the CTA, about 15 dB(A), by acoustic treatment of the station platform areas. Such a reduction is equivalent to reducing the noise to between 1/3 and 1/4 of the original loudness.[20]

4.7.4. Procedure for Noise Reduction

The following discussions specify recommended procedures for noise reduction to be considered for application in areas where the noise levels are high .

4.7.4.1. Acoustical Treatment Materials

For the treatment of the CTA round tunnels or horseshoe tunnels with concrete track-bed, It was recommended to apply either:

a) Spray-on Material

One type of material recommended for consideration for use in the tunnels is spray-on mineral fiber applied at a thickness of 2.5 -3cm (1" ± 1/4"). This form of material has been demonstrated to give adequate fire resistance, durability and cleanability in existing underground installations and the sound absorption data, calculations and results with existing installations indicate that good noise reduction can be obtained. It is applied continuously along both sides of the tunnels for a height of 2.4m to 3m, starting from the invert or walkway and extending up the sidewalls.

b) Fiberglass Blankets

The second type of material to be considered is the Fiberglass blanket with a waterproof or impervious covering and expanded metal or hardware cloth cover for mechanical protection. Either of these types of materials will give satisfactory results. In case of Fiberglass blankets, the area of coverage can be somewhat less since the absorption coefficients are greater. A width of treatment of 1.5m to 1.8m should be sufficient using a 2.5-3cm (1" or 1-1/2") Fiberglass blanket.

4.7.4.2. Tunnel Acoustic Treatment

Patrons are subjected to the greatest noise levels, for the longest periods, inside smooth bore concrete track-bed tunnels. Therefore, it is appropriate to consider acoustic absorption treatment for reduction of the roar noise in the tunnels. The use of absorption in the tunnels can result in substantial reduction, on the order of 8 to 10 dB(A) reduction, for car interior noise in the running tunnels with concrete track-bed. To obtain further improvement after rail smoothing, the best procedure for reducing the noise in the smooth bore tunnels with concrete track-bed is the application of sound absorbing material to the tunnel walls. The three basic factors to be considered in the design of running tunnel sound absorption are:

1. The location for placement of the material
2. The type of material to be used
3. The extent or coverage of the material.

The most effective location for the material is the lower part of the sidewalls. Application of sound absorbing material at these locations can accomplish:

1. Reduction of reverberation in the underground station.

2. Minimizing the reflection of sound generated from the vehicle beneath the car, because all the noise sources on a transit vehicle are in the space beneath the car

Placing the sound absorbing material on the track-bed presents problems of maintenance and durability and, therefore, the recommended location for the sound absorbing material is the lower parts of side walls. The requirements for fire resistance, mechanical durability and cleanability of the sound absorption material to be used in tunnels place considerable limitations on the choice of materials; however, there are a number of types of materials which have satisfactory properties.[20]

One further factor that should be considered in acoustic treatment is the noise transmitted from running tunnels to platforms or from adjacent untreated areas in the long platform stations. <u>To avoid higher noise levels at the ends of a platform than would be experienced at the center, sound absorption treatment should be included for a distance of at least 60 m beyond each end of a treated platform. In the running tunnels beyond each end of a platform this treatment could consist of a spray-on material or it could be panels similar to the under-platform surface treatment.</u>[20]

4.7.4.3. Platform Area Acoustic Treatment

To determine the appropriate acoustical treatment to be applied to the underground stations, calculations have been done to determine the natural absorption present due to the interior surface materials and configuration and to determine the added absorption necessary to give certain degrees of noise reduction. In general terms, it was found that the minimum recommended acoustical treatment to be added to the stations is 14 sabins per linear foot and the desirable treatment is 25 sabins per linear foot of platform. Taking into account the size of the CTA tunnel stations, for optimum results the reverberation time of the platform areas should be <u>reduced to the range of 1.0 to 1.4 seconds for the mid frequency range.</u>[20]

The priorities for location of sound absorption treatment in the platform areas should be as follows:

1. Under-platform edge surfaces
2. On sidewalls opposite platform, from invert to platform level
3. On platform area ceilings in the central arch area
4. On the running tunnel ceiling outboard of the tunnel centerline
5. On the tunnel side walls opposite the platform from platform height to about 3m above the platform

Another effective procedure for reducing noise transmitted from transit trains to the platform area is the inclusion of a platform or ledge on the opposite side of the track from the passenger platform to provide a "channel" which restricts the sound from the wheel and rail and propulsion equipment to the space beneath the car and the platform; see Figure 4-63 and Figure 4-65.[20]

1. All arrangements considered include acoustical absorption treatment on or in the arched ceiling area over the center platform in addition to sound absorption material applied to the lower sidewalls and under the edge of the platform.[20]

2. All acoustical treatments discussed should be continuous for the entire length of the subway stations.

Center platform ceiling treatment would have to be omitted in those areas where there are escalators, storage rooms or other islands that obstruct the center platform space.[20]

4.7.5. Expected Results from the Acoustical Treatments

The various alternates shown on Figure 4-60 to Figure 4-65 indicate the recommended configurations for the acoustical treatment with a predicted noise reduction result for each case.[20]

In Figure 4-60, the basic treatment will provide about 8 to 10 dB reduction. This is less than the reduction provided by ballast and tie track-bed such as used in the Clinton Station structure. The treatment consists of:[20]

1. Sound absorption treatment for the central arch
2. Sound absorption treatment for the under-platform treatment on the platform side
3. A 120 cm wide band of treatment above the existing walkway on the side of the tunnel opposite from the platform.

Further treatments are applied in Figure 4-61 as follows:

1. Sound absorption on the ceiling over the center of the platform between the column lines.
2. Sound absorption treatment under the platform.
3. Bands of sound absorption treatment in the running tunnels.

In Figure 4-62, the tunnel wall treatment may all be located on the lower sidewalls or a combination of lower sidewall and tunnel ceiling. This treatment will provide 12 to 14 dB(A) reduction of the noise, which is comparable to the reduction provided by the ballast and tie track-bed in the Clinton Station structure and will subjectively reduce the sound level to less than half its present value.[20]

Other three suggested configurations include a modification of the walkway to provide a confined space beneath the car and thus minimize the noise transmission to the platform area. This arrangement is a preferred arrangement acoustically; however, it would probably be expensive to provide the modification of the walkway.[20]

In the running tunnels with concrete track-bed the application of sound absorbing material panels or spray-on sound absorbing material to the lower side walls can give reductions of at least 6 to 8 dB(A) for the car interior noise. With sound absorption treatments which can be applied to the under-platform surfaces, the side walls of the running tunnels, and ceilings of the station platform areas, it is possible to reduce the platform noise levels in the subway stations to much more acceptable levels, at least 12 to 15 dB(A) less than now experienced, making the platform noise levels much nearer the levels experienced at newer facilities which had acoustical absorption material installed at the time of construction.

The subjective effect of noise reduction in a reverberant space is always a little greater than predicted by comparing of sound levels alone that can be done out-of-doors in an open space. This is because when the reverberation is reduced the sound tends to come predominantly from one direction, Whereas when the reverberation is great the sound tends to Impinge on the observer from all directions, giving it an "overwhelming" quality in comparison to the same sound level in a less reverberant or non-reverberant space.[20]

The following figures shows acoustical treatments applied on to the CTA underground stations to reduce platform noise with signage and decorative ceiling tiles.[20]

Figure 4-57:Untreated Underground Station In Chicago Transit System

Figure 4-58:Left –Acoustical Treatments In Lake Station. Blue Line, Chicago, USA.

Figure 4-59: Acoustical Treatments In Jackson Station. Red Line, Chicago, USA.*

*http://www.chicago-l.org/trains/gallery/

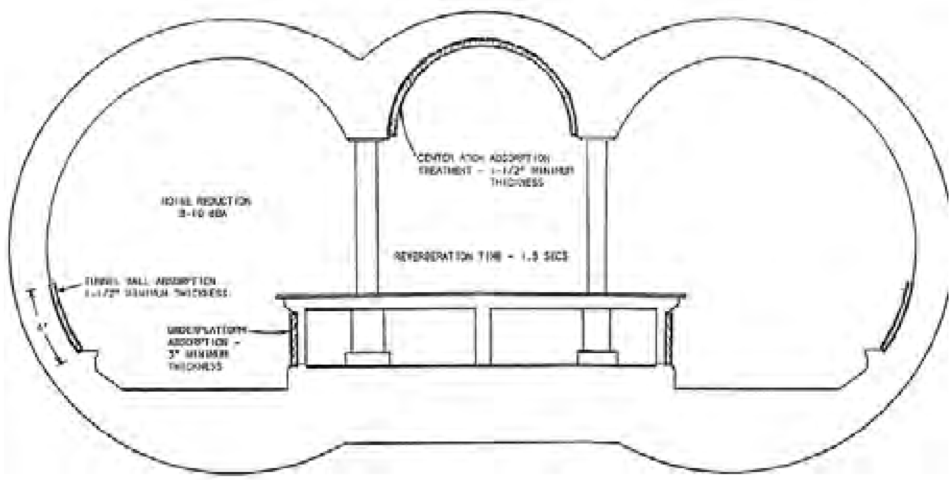

Figure 4-60 :Basic Absorption For Tunnel Station With Concrete Track-Bed – Will Reduce Noise From 8 – 10dba.[*]

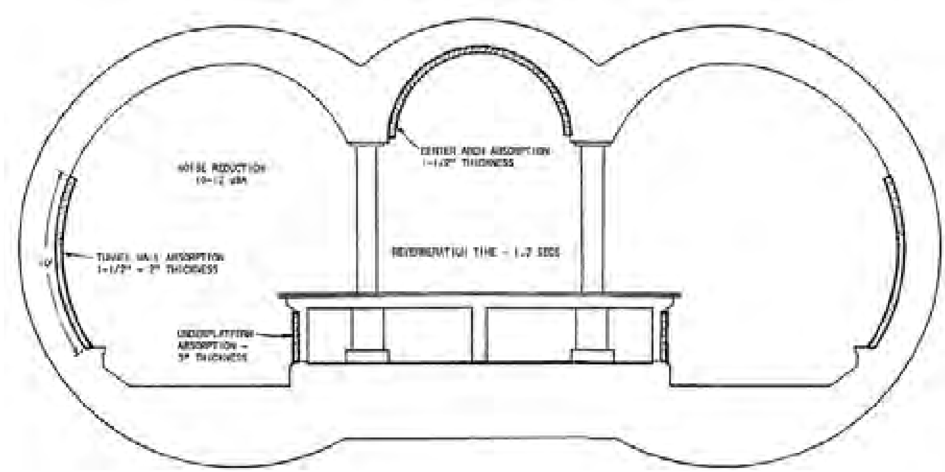

Figure 4-61 :Minimum Recommended Absorption Treatment For Noise Reduction In Tunnel Station With Concrete Track-Bed- Will Reduce Train Noise 10 – 12 Db(A).[†]

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[*]Wilson, G.P., H.K. Ihrig, and A.T. Wright, (1977) Noise Levels From Operations of Cta Rail Transit Trains. Wilson, ihrig & associates, inc.: CHICAGO, ILLINOIS. P.116
[†]Ibid. P.117

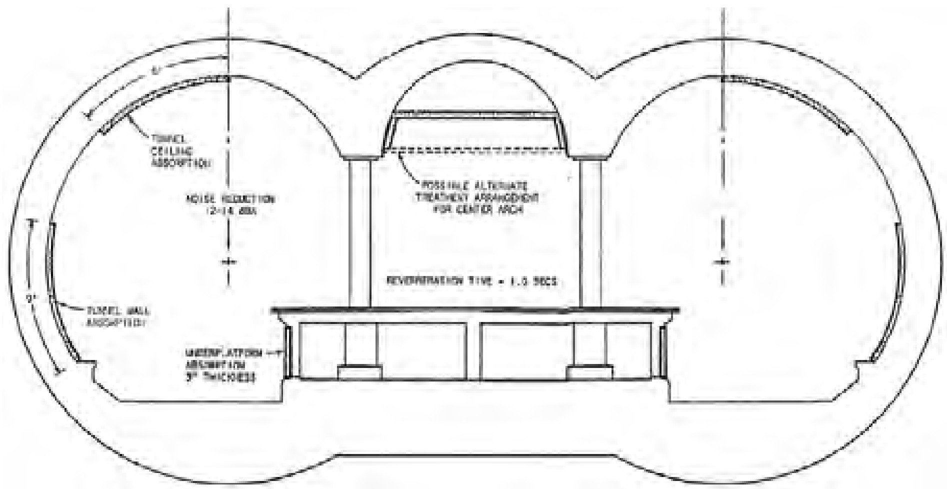


Figure 4-62 :Recommended Absorption Treatment Configuration For Reduction Of Train Noise In Tunnel Station With Concrete Track-Bed – Will Achieve 12 To 14 Db(A)*

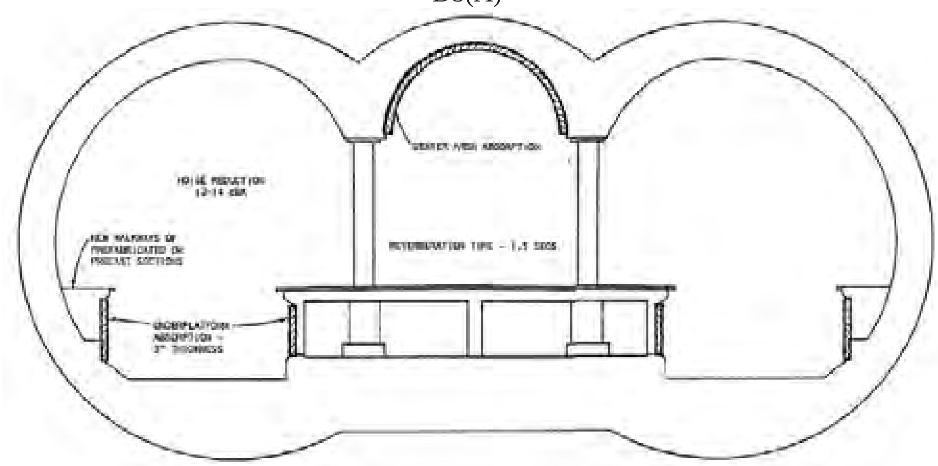


Figure 4-63 :Minimum Sound Absorption Treatment Recommended With Added Walkway Ledge For Confining Noise Beneath The Transit Cars – 12 To 14 Db(A) Reduction Of Train Noise On Platform†

*Ibid. P.118
†Ibid. P.119

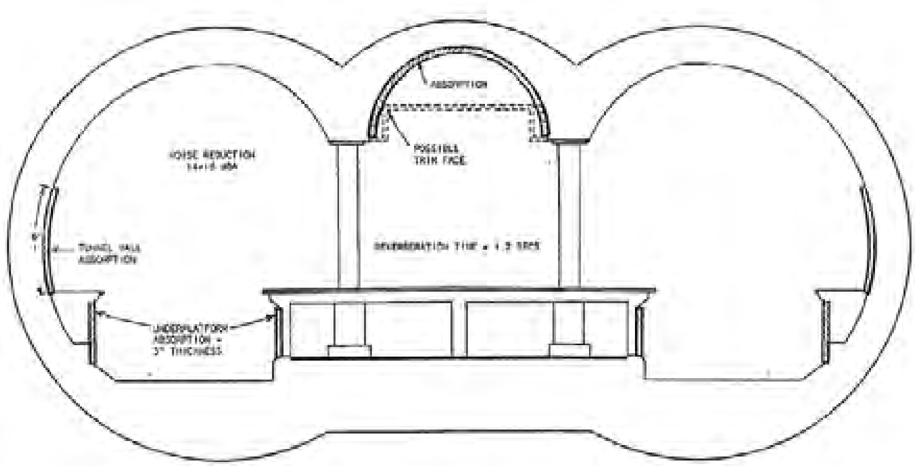


Figure 4-64 : Recommended Arrangement Of Station Treatment With Modified Walkway – 14 To 16 Db(A) Reduction Of Train Noise On Platform.[*]

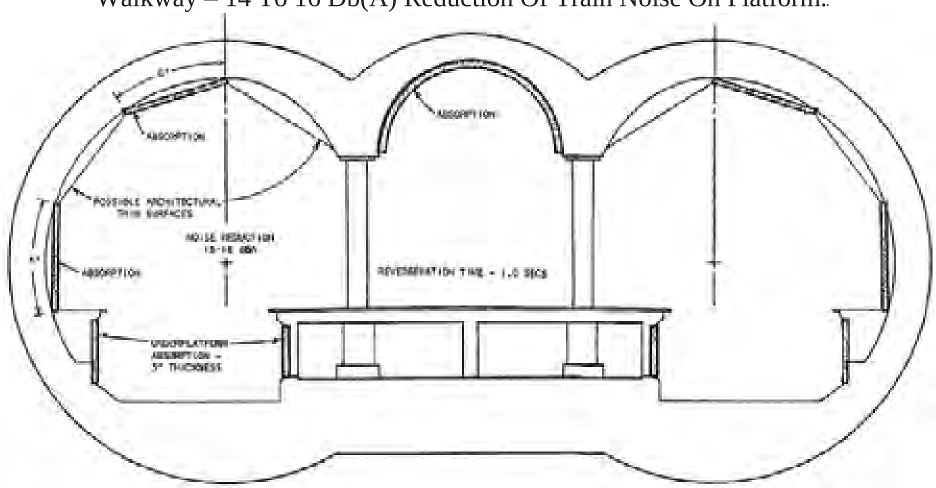


Figure 4-65 : Absorption And Modifications That Will Gives The Maximum Noise Reduction Which Can Be Achieved By Application Of Absorption To Wall And Ceiling Surfaces.[†]

[*]Ibid. P.120
[†]Ibid. P.121

4.8. Conclusion

Noise reduction can reach from 5 to 15 dB(A) by means of appropriate and economical application of sound absorbing material in the underground station platform area. For noise reduction in underground stations, considerations and recommendations for acoustic treatments can be summarized as follows:

- For Track-Bed Absorption:
  - The added effect of sound absorption treatment on the ceiling in the ballasted track stations would probably result in a total further reduction of the train noise by 2 to 4 dB(A) and reduction of crowd noise and stationary mechanical equipment noise by 5 to 7 dB(A).[20]
- For Under-Platform area:
  - Sound absorption treatment on under-platform overhang surfaces should consist of complete coverage of the surfaces with (5-7.5cm) 2" to 3" thick Fiberglass boards with a plastic or glass cloth bag for dirt and water protection and an expanded metal, perforated metal or other facing for mechanical protection. Alternately a (2-3cm) 1-1/2" thick application of spray-on absorption material could be used.
  - In Single Tracks station, Sound absorption on the under-platform and the lower part of the side walls is the most important part of the treatment but must be accompanied by ceiling and possibly wall treatment to give good overall sound control in the platform areas.
  - In double Tracks stations, Barriers may be used between the tracks to block sound from trains passing through stations. As a rule, this type of treatment would be less needed if the trainway ceiling and station walls and ceiling were treated with acoustical absorption, and if the rails and wheels were maintained in good condition.
- For wall and ceiling Treatments:
  - In Sidewall and ceiling applications, the sound absorption treatment should be of (2.5-5cm) 1-1/2" to 2" thickness Fiberglass material with protective and architectural trim facing.

  - For the platform islands ceiling, a suspended acoustical tile ceiling could be used but requires appropriate considerations for air pressure relief.

- For tunnel treatments:
  - Sound absorption treatment should be extended at least 60m along the tunnels to each side of a treated platform to obtain full benefit from the platform area treatment.
  - The recommended location for the sound absorbing material in tunnels is the lower parts of sidewalls. The requirements for fire resistance, mechanical durability and cleanability of the sound absorption material to be used in tunnels place considerable limitations on the choice of materials; however, there are a number of types of materials that have satisfactory properties.

- Acoustic Material Mounting:
  - A possible covering for Fiberglass boards or blankets is perforated sheet metal or plastic with at least 30% open area. Perforation patterns can be:
    - 15mm (1/16") diameter holes staggered at (25mm) 7/64" centers
    - (30 mm) 1/8" diameter holes at 45mm (3/16") centers
    - 45mm 3/16" diameter holes at 30mm (5/16") centers

    There are, of course, other combinations of equivalent performance.

- Acoustic Material Fixation:
  - Metal furring strips or studs fastened to the concrete surface are used to retain the Fiberglass by mechanical fastening. Such mountings are convenient when a waterproof covering is to be used.

The Following tables sums up some data about absorption and noise reduction in underground stations.

Acoustical Treatment Design Guidelines		
Treatment Area	**Area of Treatment**	**Expected Noise Reduction**
Wall and Ceiling	35%	5 to 10 [18] 10 to 15 [20]
Under Platform Sidewalls	100%	
Tunnel Wall Treatment	Lower Parts of the Sidewalls	5 to 7 [18] 8 to 10[20]

Expected Noise Reduction From Acoustic Treatments*

Fiberglass Absorption Coefficients					
Frequency in Hz	**125**	**250**	**500**	**1000**	**2000**
1 In. Thick Fiberglass	0.08	0.3	0.65	0.8	0.85
2 In. Thick Fiberglass	0.20	0.55	0.8	0.95	0.9
3 In. Thick Fiberglass	0.45	0.8	0.9	0.95	0.9

Typical Sound Absorption Coefficients To Be Expected From Fiberglass Sound Absorbing Materials Mounted Directly Against Concrete Surface.†

Absorption Coefficients of Underground Station Architectural Components						
Frequency in Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**
Concrete Tunnel Surfaces	0.03	0.35	0.04	0.05	0.09	0.11
Rounded Tunnel Ballast	0.68	0.52	0.68	0.46	0.46	0.47
Box Section Ballast	0.67	0.60	0.67	0.49	0.4	0.37

Calculated Ballast Absorption In Tunnels‡

*Nelson, J.T., (1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. COUNCIL, Editor, Federal Transit Administration in Cooperation with the Transit Development Corporation

†Ibid. P.180

‡Wilson, G.P., H.K. Ihrig, and A.T. Wright, (1977) Noise Levels From Operations of Cta Rail Transit Trains. Wilson, ihrig & associates, inc.: CHICAGO, ILLINOIS. p.49

Part 2: Assessment of the Acoustic Environment inside the Greater Cairo Underground Stations.

5. Chapter 5: Acoustical Treatments of the Selected Underground Stations

5.1. Selection of the Underground Stations

At the present time, the GCM Network consists of two constructed lines 1&2. Twenty underground stations are present in the GCM second line and they are all standardized to have the same finishing materials and the same space design. Noise levels recorded in Line2 are higher than those in Line1[15], [13], [14], so Line2 underground stations are selected for the acoustical investigation. The GCM Stations are classified into three categories: terminal, intermediate and central stations. This classification is according to station location in the network; see Figure 5-1.

<u>Mubarak</u> and **<u>Sadat</u>** underground stations are selected for acoustical investigation from line2 underground stations as they both share maximum noise levels recorded on their platform[15], [14] and have the same finishing materials and volume as the rest of underground stations. High platform overall noise levels are attributed to train wheel/rail noise interaction, passengers' crowd noise and operation of Closed TV circuits and internal public address system.

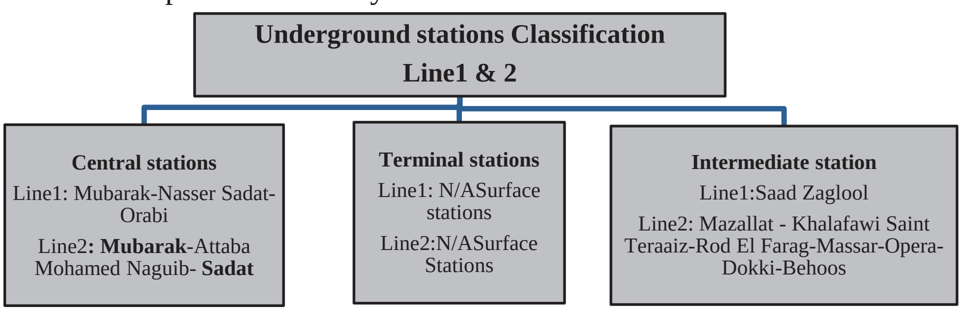


Figure 5-1: Classification Of The Underground Stations*

5.1.1. <u>Mubarak Station</u>

This station is located in Ramses square beside the Egyptian Railway station where thousands of passengers ride daily. Several entries of Mubarak underground station are distributed all around Ramses square.

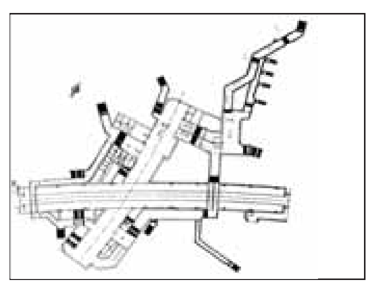


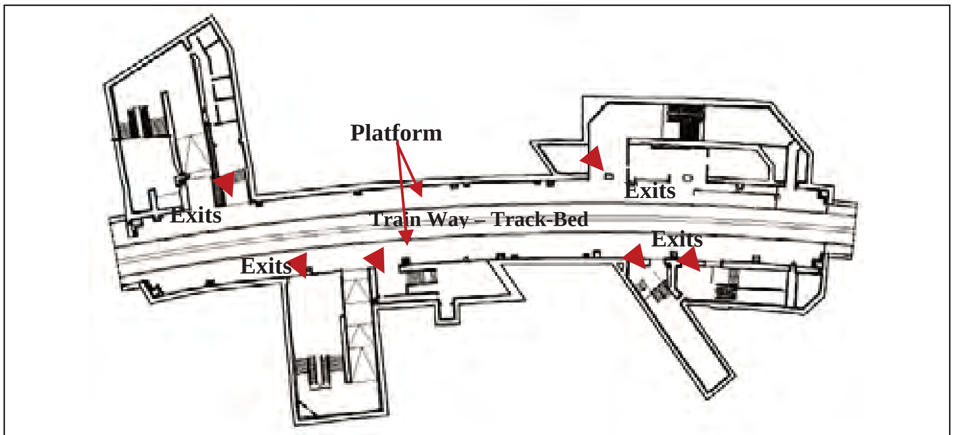
Figure 5-2:Ticket Level, Mubarak Station

The station connects both Metro lines 1&2 and is composed of two underground levels. Line 1 the upper level whose area is 13000m2 while Line 2 passes through the lower level whose area is 2350m2.

*Mohamed Abdo El Fayoumi,(2002).The Interaction between transportation networks and urban development in Great Cairo Region. Masters degree.p.157

The upper level comprises two ticket halls on both sides of Line1 railway with ancillary rooms for services purpose. Four groups of stairs and escalators connect both underground levels, two groups on each platform. According to design criteria, the station is expected to receive over 30,000 passengers per hour by other mean 600 passenger/train/Direction so its platform is 5m wide.

The station is 144 m long and 16 m wide. Line2 station ceiling has two levels as line1 passes over line2, the ceiling height measured from platform level is 3 and 5 m. The platform width is 4.7 m from wall to the platform edge. There are two exits from the platform on each side of the railway line that leads to a group of stairs and escalators as shown in Figure 5-3.



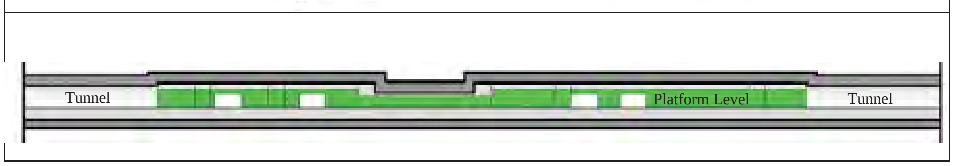


Figure 5-3: Top-Platform Level Plan, Mubarak Station.
Figure 5-4: Bottom- Section At Mubarak Station Underground Station.

5.1.1.1. <u>Architectural and Statistical Data</u>

Station Platform Dimensions and Area										
Platform					**Railway Line**				**Area and Volume**	
L	**W**		**H min**	**H max**	**L**	**W**	**H**	**Hc**	**Area m2**	**Volume m3**
144	16	14.5	3.1	5.1	144	6.3	2.7	7.8	2288	13522

Finishing Materials						
Platform				**Railway Line**		
Floor	**Walls**	**Plinth**	**Ceiling**	**Floor**	**Sidewall**	**Ceilin g**
Granite Tiles Plain concrete 5 cm	Designed pattern Ceramic Panels Ceramic tiles on masonry Trowel Cement plaster on masonry	Ceramic tile 30 cm height under panels on wall	Acoustic Paint Lighting fixture AC ducts	Smooth Concrete	Smooth Concrete	Acoust ic Paint

Statistical Data					
Maximum Passengers capacity	**Area /person m2**	**Volume/person m2**	**RT optimum @500Hz in Sec**	**Environmental conditions(Average)**	
				RH%	Temp.C°
600 per platform	0.5	16.03	1.0-1.4	52	27.9

Table 5-1: Architectural And Statistical Data, Mubarak Platform Level, Line2.

5.1.2. Sadat Station:

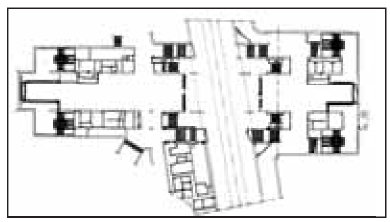
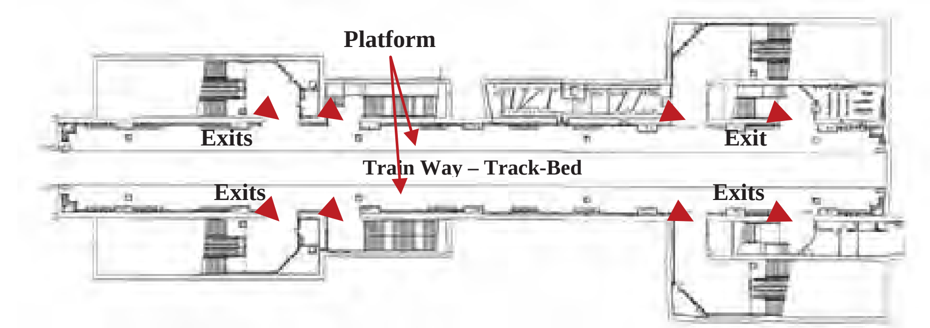


Figure 5-5:Ticket Level, Sadat Station

This station is located in the Tahrir square. Which is the hub of the Cairo City where all the city main traffic arteries meet. Several entries of Sadat Station are distributed around Tahrir square. The station connects the two lines 1&2. The station is composed of two underground levels with total area 13700 m^2. Line1 passes through the upper level while Line2 is in the lower level. The upper level contains two ticket halls on both sides of Line1 railway with ancillary services rooms. Four groups of stairs and escalators connect the two lines, two groups on each platform. According to design criteria, the station is expected to receive over 30,000 passengers per hour by other mean 600 passenger/train/Direction so its platform width is 5m.

The platform is 150 m long and 16 m wide. The ceiling height measured from platform level is 3 for the whole platform except for the part where line1passes over the platform; the height is 5 m. The platform is 4.5 m wide from wall to the platform edge and 144 m long. There are two exits from the platform on each side of the railway line that leads to a group of stairs and escalators as shown in Figure 5-7.



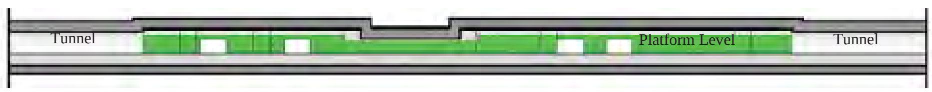


Figure 5-6:Top – Platform Level Plan, Sadat Station.*
Figure 5-7: Bottom - at Sadat Station Underground Station

5.1.2.1. Architectural and Statistical Data

Station Platform Dimensions

Platform					Railway Line						
L	**W**		**Hmin**	**Hmax**	**L**	**W**	**H**	**Hc**	**Area m2**	**Volume m3**	**Per. m**
144	16	14.5	3.5	5.5	144	6.0	2.7	7.8	2285	19170	400

Finishing Materials

Platform				Railway Line		
Floor	**Walls**	**Plinth**	**Ceiling**	**Floor**	**Sidewall**	**Ceiling**
Granite Tiles Plain concrete 5 cm	Designed pattern Ceramic Panels Ceramic tiles on masonry Trowel Cement plaster on masonry	Ceramic tile 30 cm height under panels on wall	Acoustic Paint Lighting fixture AC ducts	Smooth Concrete	Smooth Concrete	Acoustic Paint

Statistical Data

Maximum capacity	Area /person m2	Volume/person m2	RToptimum@500Hz Sec	Environmental conditions(Average)	
				RH%	Temp.Cº
400 per platform	0.5	16.03	1.0	45.5	28.5

Table 5-2: Architectural and Statistical Data, Sadat Platform Level, Line2.

*Ibid

5.2. The Acoustical Analysis

In the following section, the effect of acoustical treatments will be investigated in two selected underground stations; **Mubarak** and **Sadat** stations. Two noise prediction models are set up using **ODEON 4.2** software for the two stations. A simulation process is carried out for two entering trains from both ends of the platform in order to imitate the station noisiest case. Sound absorbing materials will be placed at several locations in both stations to be investigated for the corresponding noise reduction at each alternative. Noise prediction model consists of the following setup:

- Line source for characterization of railway line.
- Characterization of ground, wall and ceiling acoustical absorbance information.
- Receiver points for predicted indicators.

The acoustical analysis is performed using **ODEON4.2**. Air absorption are taken into account by entering temperature and relative humidity readings at measurements time. Field Reverberation time measurements are compared with the corresponding **ODEON4.2** results to validate the acoustical models. The Underground Stations Modeling Procedure

The selected stations: **Mubarak** and **Sadat** are 3D modeled using CAD program where station walls, ceilings, and floors are modeled as planes and the curved walls are subdivided into sectional planes; see Figure 5-8. AC ducts in the platform area and lighting fixtures are ignored in modeling as many surfaces in the model make it visually complex, and increase the probability of the acoustical analysis errors.

In simulation process, the train noise is modeled as a line source. The receiver positions are at eight different locations at each platform. All surfaces in the platform level are acoustically defined in the model with their absorption and diffusion characteristics as shown in Table 5-5. The calculation details used in the acoustical analyses are listed in Table 5-3.

<table>
<tr><th colspan="9">Acoustical Analysis Input Information</th></tr>
<tr><td colspan="2">Number of rays</td><td colspan="7">35200</td></tr>
<tr><td colspan="2">Max. number of reflections</td><td colspan="7">2000</td></tr>
<tr><td colspan="2">Impulse response length</td><td colspan="7">2500 ms</td></tr>
<tr><td colspan="2">Number of receivers</td><td colspan="7">16</td></tr>
<tr><td rowspan="3">Background noise level</td><td>Station name</td><td>125</td><td>250</td><td>500</td><td>1000</td><td>2000</td><td>4000</td><td>8000</td></tr>
<tr><td>Mubarak station</td><td>61.3</td><td>68.5</td><td>62.1</td><td>60.5</td><td>53.7</td><td>45.3</td><td>34.2</td></tr>
<tr><td>Sadat Station</td><td>63.5</td><td>68.7</td><td>67.2</td><td>65.0</td><td>60.2</td><td>53.2</td><td>44.9</td></tr>
</table>

Table 5-3: The Detail Of The Calculation Used In The ODEON Software

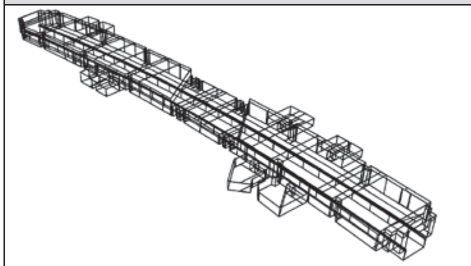
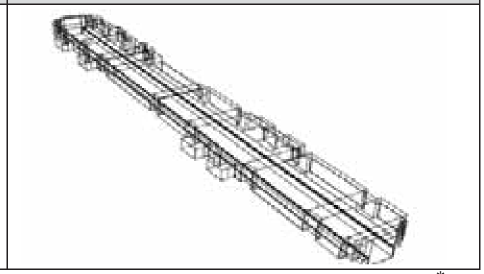
Mubarak station	Sadat station
	

Figure 5-8: CAD Generated 3Dimentional Models, Mubarak And Sadat Stations.*

5.2.1.1. Train Noise Source

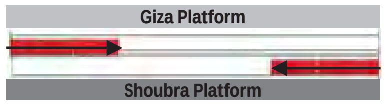


Figure 5-9: Train Noise Modeled During Arrival Of Trains From Both Directions.

Two line source are aligned at the centre line of both tracks at a height 1.5 from the track-bed; see Figure 5-9. Train noise sound power level assigned to the acoustical model is derived from the Mean value of the A-weighted sound power level per unit length for railway noise during pass-by of rail vehicles.[8] A-weighted sound power level per unit length for a subway electric powered train is 95 dB(A) per unit length and 90 dB(A) per unit length for passengers' train as indicated in Table 5-4. The average relative spectrum for electrically powered passenger railcars used in the model is shown in Figure 5-10. The line source in model generates noise levels in the acoustical model relative to the maximum noise levels measured in stations. These maximum levels are used as reference levels to measure the acoustical treatment changes effect in both platforms. Maximum noise level reaches 95 dB(A) at platform ends; while in platform middle section noise levels reach 87 dB(A) because the train noise decrease with the train deceleration and due to the lower ceiling covered with acoustic paint.

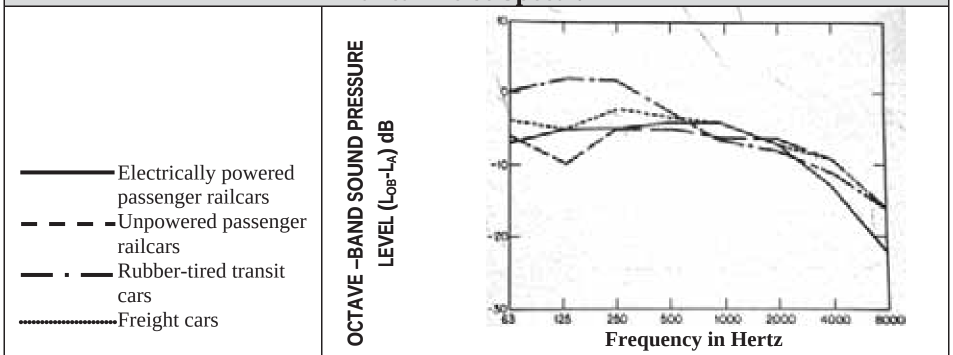
Type of vehicle	LW'A,100km/h dB(A)
E-powered vehicles	
Disc braked	95
Cast iron tread braked	104

Type of vehicle	LW'A,100km/h dB(A)
Passenger vehicles	90-96
Cast iron tread braked	108

Table 5-4: Mean Value Of The A-Weighted Sound Power Level Per Unit Length During Pass-By Of Rail Vehicles.†

*Generated by the Author.
†Kurze, U.J., R.J. Diehl, And W. Weibenberger. (2000) Sound Emission Limits For Rail Vehicles. Journal of Sound and vibration 231(3). P.500.

Railcar Noise Spectrum



63	125	250	500	1000	2000	4000	8000
-7	-5	-5	-4	-4	-7	-13	-22

Figure 5-10:Average Relative Octave-Band Spectrum For Railcars In The Open[17]

5.2.1.2. Receivers

All receiver points are distributed evenly over the platform area. Eight receivers are distributed at 18-m intervals on each platform in the middle of every car, 1.5 m from the platform edge, and at a height of 1.50 m above the platform floor, which is typically the ear height of the passengers; see Figure 5-11.

Receiver Points Locations

Mubarak Station	Sadat Station

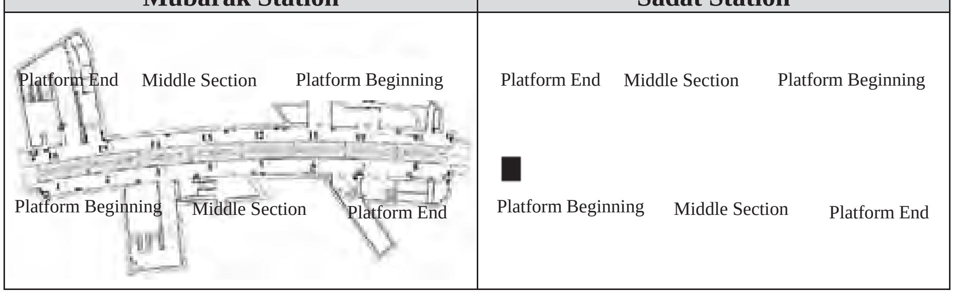


Figure 5-11: Receivers Positions In Mubarak And Sadat Stations.

5.2.1.3. Absorption Data

The station floor is finished with Granite tiles with a safety strip at the platform edge finished in fair faced concrete. The two ends of the tunnels are both open while the station walls are lined with ceramic panels of height that ranges from 3 to 3.6m. Vertical ventilation ducts along the platform are enclosed in masonry ducts that are lined with ceramic tiles. The station ceiling is acoustically treated with mineral wool based coating. Finishing materials of the platforms level in all line2 underground stations are listed in the following table:

Absorption Data									
Space	**Finishing material**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Floor	**Platform floor - Granite**	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
	Platform Edge - Smooth unpainted concrete [32]	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.05
	Tunnel floor - concrete track-bed	0.01	0.03	0.35	0.043	0.053	0.091	0.113	0.20
Wall	**Ceramic panel**	0.10	0.22	0.29	0.50	0.80	0.75	0.60	0.60
	Ceramic on masonry - Ceramic tiles with smooth surface	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Ceilin g	**Mineral Wool Based Coating**	0.01	0.05	0.2	0.6	0.8	0.62	0.6	0.5
People	**standing adults 2 person per m2**	0.26	0.46	0.87	0.99	0.99	0.99	0.99	0.26

Table 5-5: Absorption And Diffusion Coefficients Of The Station Finishing Materials.

5.2.1.4. People Absorption

In fully occupied stations, passengers contribute in sound absorption in the station space. In considering the effect of passengers on the total sound absorption, an effective absorption coefficient is attributed to the area occupied by the expected passengers. This procedure has been shown to give accurate results in acoustical analysis procedures. [26]

People present at the station platform either arriving, departing, or waiting for the coming train absorb part of the sound energy emitted from the train by their body and cloth. In central stations, number of people estimated entering and leaving is over 30,000 per hour during peak hours by another mean 600 passenger/Train/Direction. [7] According to design criteria, platform width in **Mubarak** and **Sadat** station is about 5m in order to accommodate all this number of people. Every single person occupy 0.5 m along the platform length and every two persons occupy area of $1m^2$ starting after the driver cabin to the last train at the end of the platform.

Both platforms are not occupied at the same time by the same people capacity. As peak hours on both directions does not occur at the same time. In Simulation model both platforms were considered to have full occupancy in order to calculate the actual required noise reduction on each side in the station and avoid excess absorbing materials required to assess noise as people will absorb part of the emitted noise on the platform.

In the acoustic model, the sound absorption of people waiting in the station is replaced by a plane that has the same sound absorption characteristics of standing people (2 persons per 1 m^2). Waiting zone starts from the end of the driver's cab to the end of the last car. The waiting zones in the selected underground stations are shown in Figure 5-12.

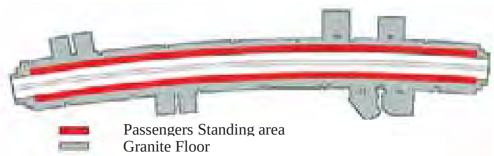
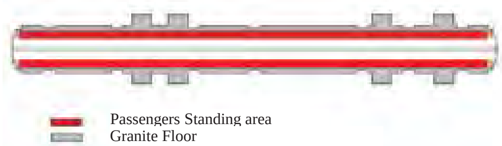
Mubarak Station		
Platform length	144 m	
Platform width	4.5 to 5m	
Estimated occupancy on each platform (Full occupancy during peak hours)	600 pers.	
Passenger's waiting area on each platform	300 m^2	
Sadat Station		
Platform length	144 m	
Platform width	4.5 m	
Estimated occupancy on each platform (Full occupancy during peak hours)	400 pers.	
Passenger's waiting area on each platform	200 m^2	

Figure 5-12: Passengers' Waiting Zones In Mubarak And Sadat Stations.

5.2.2. <u>Acoustical Model Validation</u>

5.2.2.1. <u>Measured Acoustical Indicators Versus Prediction Results</u>

Validation is the process of comparing results from the implemented model or simulation with an appropriate reference related to it in reality to demonstrate that the model or simulation can in fact support the intended use[33].The 3D models built for the selected underground stations are validated by comparing the field measured Reverberation time in the selected unoccupied stations with the simulation generated reverberation time. Figure 5-13 and Figure 5-14 shows the Measured reverberation T20 values versus simulation output in **<u>Mubarak</u>** and **<u>Sadat</u>** Stations.

a) Reverberation Time

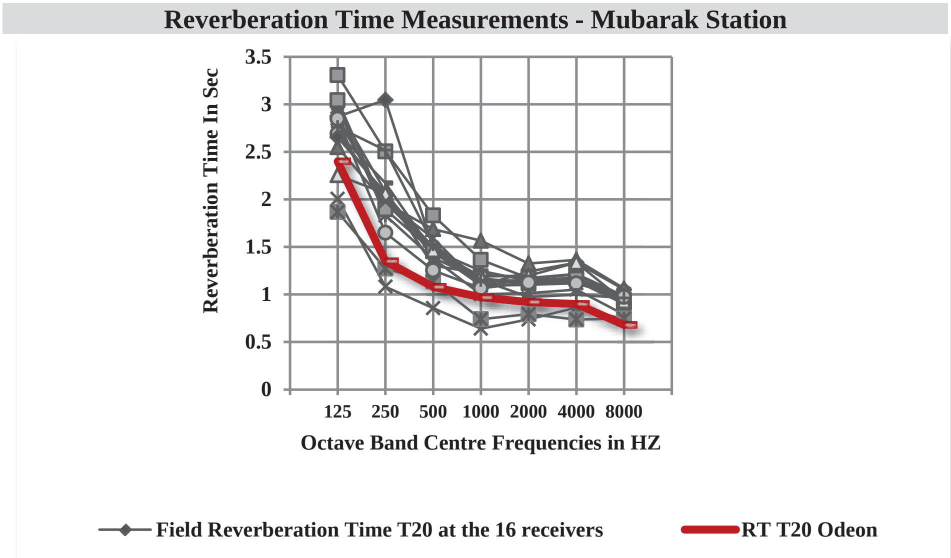


Figure 5-13: Measured T20 Values Versus Simulation Output In Mubarak Station

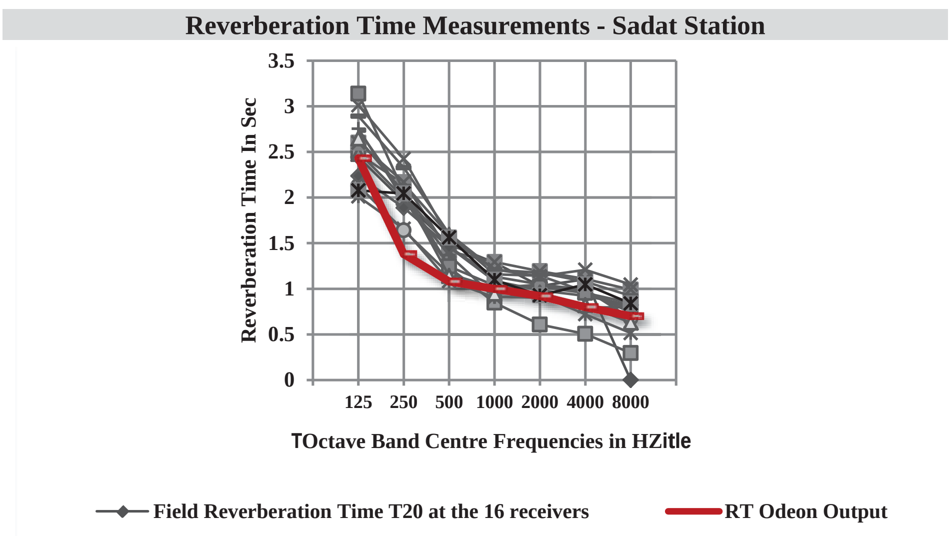


Figure 5-14: Measured T20 Values Versus Simulation Output In Sadat Station

5.3. Acoustic Treatments in the Selected Underground Stations

The most effective procedure for reducing excessive noise in an underground station is the application of sound absorbing material to some locations in order to absorb sound in reverberant tunnels and station platform. The priorities for placing sound absorbing materials in station platform areas should be as arranged as follows:[20]

1. Under-platform edge surfaces
2. Barriers Between track
3. On ceiling
4. On ceiling and walls

The highest priority for placing acoustic treatment is on under-platform. There is another option to place barriers between tracks in order to surround train noise at the source .The next priority is the platform ceiling then walls. The reason that running tunnel ceiling and tunnel sidewalls are not included as a high priority in acoustical treatment is that there must be some distribution of the sound absorbing material in the station space in order to achieve good results. Acoustical materials located under the platform edge are not in the optimum location for reducing reverberation in the main part of the platform space nor is it in the optimum location for reducing noise from other sources such as the crowd noise or station equipment noise. [20]

If the amount of treatment which can be applied is limited for some reason, either architectural, maintenance or economic, it is most important to place the absorbing material on the under-platform overhang surfaces, the lower sidewalls and the ceiling area. [20]

To compare noise control solutions in the station, 31 design alternatives are introduced to reduce platform noise levels. These solutions include under-platform area treatment (under-platform sidewalls, barrier wall with absorbing material on its surfaces, ballast mats under the rail track), ceiling and wall treatments with porous absorbers.

Various combinations of the sound absorbing materials are applied in different locations to achieve the best acoustic conditions on platform.

Table 5-6 shows the combination of Acoustic treatment solutions, including sound absorbing material on the station under-platform, track-bed, barrier between tracks, walls, and ceiling. As a reference, simulation number S4-C1 is the condition with the current ceiling acoustic treatment; see Figure 5-15 to Figure 5-19.

Classification of Treatments Alternatives

Treatment Location	No.	Ceiling								Wall	Under-Platform		
		Acoustic Paint	Porous Absorbers							Porous Absorbers	Porous Absorbers		Ballast
		Existing Treatment	Fiber Glass Boards			Acoustic panels on False Ceiling			Baffles	Acoustic perforated panels	Sidewalls	Barriers	Track-bed-Ballast
		C1	C2 30%	C3 60%	C4 80%	C5 100%	C6 70%	C7 100%	C8	W1	U1	U2	U3
Under-Platform	S1-C1U1	•									•		
	S2-C1U2	•									•	•	
	S3-C1U3	•											•
Current Ceiling treatment	S4-C1	•											
Ceiling	S5-C2	•	•										
	S6-C3	•		•									
	S7-C4	•			•								
	S8-C5					•							
	S9-C6	•					•						
	S10-C7							•					
	S11-C8	•							•				
Ceiling and Under-Platform treatment	S12-C2U1	•	•								•		
	S13-C3U1	•		•							•		
	S14-C4U1	•			•						•		
	S15-C5U1					•					•		
	S16-C6U1	•					•				•		
	S17-C7U1							•			•		
	S18-C8U1	•							•		•		
Ceiling and Wall Treatment	S19-C1W1	•								•			
	S20-C2W1	•	•							•			
	S21-C3W1	•		•						•			
	S22-C4W1	•			•					•			
	S23-C5W1					•				•			
	S24-C6W1	•					•			•			
	S25-C7W1							•		•			
	S26-C8W1								•				
Ceiling, Wall and Under-Platform Treatment	S27-C1W1U1	•								•	•		
	S28-C2W1U1	•	•							•	•		
	S29-C3W1U1	•		•						•	•		
	S30-C4W1U1	•			•					•	•		
	S31-C5W1U1					•				•	•		
	S31-C6W1U1	•					•			•	•		
	S32-C7W1U1							•		•	•		
	S33-C8W1U1	•							•	•	•		

Table 5-6: Acoustic Treatment Options.

5.3.1.1. Under-platform Treatments

Acoustic treatment located on the under-platform sidewalls absorb sound energy close to the source effectively and reduce train noise levels on platform. For double track configurations with platforms on both sides, Under-platform acoustic treatment is efficient in reducing noise produced by the wheels and rails located adjacent to the platform.

In the first alternative under-platform sidewalls are treated with Fiberglass boards, in the second alternative, Barrier is placed between tracks and is treated with Sound absorbing in addition to under-platform sidewalls treatment. Finally, track-bed is treated with Ballast; see Figure 5-15.

a) Acoustical Material and Mounting

3 inches thick Fiberglass boards or blankets with a wrapping for water and dust proofing are applied for under-platform acoustical sidewalls and barrier treatment. Fiberglass boards are mounted in and retained by a perforated metal panel [steel or aluminum] and mounted directly against the concrete surfaces where the material is visible to patrons on the opposite platform.

Perforated metal facings should have open areas of at least 10% (1/8 inches (30mm). diameter holes at 3/8inches (90mm). center-to-center) or, preferably, 20% of the total area. Either expanded or perforated metal facings can be attached to the under-platform surfaces with simple metal brackets. The sound absorbing materials and retention hardware must be able to withstand high-pressure wash and other cleaning methods that might be employed in underground stations environments.

The acoustical treatment on the under-platform surfaces must be applied continuously for the full length of the platforms and provides complete coverage of the vertical and horizontal surface as can be accommodated. Sound absorption coefficients for the Fiberglass boards and the ballast used in the acoustical treatments are listed in the following table. [18]

Acoustical Treatments Absorption Coefficients							
Frequency Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
3 Inches Fiberglass Boards	0.45	0.8	0.9	0.95	0.9	1	1
Box Section Ballast	0.67	0.60	0.67	0.49	0.4	0.37	-

Table 5-7: Sound Absorption Coefficients For The Treatment Materials.*

*Wilson, G.P., H.K. Ihrig, and A.T. Wright, (1977) Noise Levels From Operations of Cta Rail Transit Trains. Wilson, ihrig & associates, inc.: CHICAGO, ILLINOIS.

5.3.1.2. Ceiling Treatments

All underground stations in line2 are acoustically treated with mineral wool based coating whose absorption data are listed in Table 5-8.* Further ceiling treatments will be investigated for more sound absorption and noise reduction on platform.

Ceiling treatments are applied directly to the platform ceilings in a number of treatment alternatives and are applied to a false ceiling above passengers' waiting area in other alternatives; see Figure 5-16. False ceiling can covers A/C ducts and ancillary facilities. Several simulations are carried out in order to investigate the effect of applying different amounts of acoustical materials on the station ceiling. All proposed ceiling treatments are arranged according to Kang(2002)[34] arrangements on underground station experimental scale models.

Acoustical material applications on the platform ceiling are composed of Fiberglass boards with perforated metal facing whose specifications are as discussed. This assembly is applied directly against the face of the current treatment.
Sound absorption data for the current ceiling treatment and the proposed acoustical materials for the ceiling treatments are listed in the following table:

Acoustical Treatments Absorption Coefficients							
Frequency Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Mineral Wool Based Coating (Current Treatment).†	0.02	0.2	0.6	0.8	0.68	0.62	0.6
1 Inches Thick Fiberglass mounted directly against concrete surface	0.08	0.3	0.65	0.8	0.85	0.80	0.85
2 Inches Thick Fiberglass mounted directly against concrete surface	0.20	0.55	0.8	0.95	0.9	0.79	0.85
3 Inches Thick Fiberglass mounted directly against concrete surface	0.45	0.8	0.9	0.95	0.9	0.89	0.9

Table 5-8: Typical Sound Absorption Coefficients Expected From Glass-Fiber Sound Absorbing Materials For Ceiling Acoustical Treatments.‡

5.3.1.3. Wall Treatments

In double tracks stations, wall treatments do not come in the first priorities for acoustic treatments as they provide low noise reduction besides, treatments must be accompanied by ceiling treatment to give

*National Authority for Tunnels Specifications.
†National Authority for Tunnels specification from. FIBROFEU Brochure.
‡Nelson, J.T(1997) Wheel/Rail Noise Control Manual, T.R.B.N.R. COUNCIL, Editor., Federal Transit Administration in Cooperation with the Transit Development Corporation. P.180

good overall sound control in the platform areas; see Figure 5-18.

Fiberglass boards placed should be at least 1inch thick with appropriate covering to minimize dust and water absorption.

A possible covering for sidewall treatment is perforated sheet metal with at least 30% open area. Perforation patterns such as (1/16 inches) (15mm) diameter holes staggered at (7/64 inches) (25mm) centers, (1/8inches) (30 mm) diameter holes at (3/16inches) (50mm) centers, and (3/16inches) (50mm) diameter holes at (5/16 inches) (80mm) centers provide adequate open area.

5.4. Conclusion

- The main objective in the acoustic treatment design is maintaining noise levels on platforms in the permissible ranges with an even distribution of sound levels over the platform when the train arrives or departs.
- All acoustic treatments under investigation are intended to control noise at the path throughout sound absorbing porous materials applied on the platform under-platform area, ceiling and walls in several combinations.
- Acoustical treatments proposed for investigation are based on Kang(2002) [34] experimental arrangements of porous absorbers on underground station ceiling and walls.
- Under-platform Treatments include:
    - Under-platform sidewalls treatments
    - Barrier between tracks and Under-platform sidewalls treatments
    - Track-Bed Absorption – Ballast
- Barrier between tracks treatment is not combed with proposed ceiling treatments, as this type of treatment would be less needed if the train way ceiling and station walls were treated with acoustical absorption, and if the rails and wheels were maintained in good condition.
- Ceiling treatments are distributed over the platform ceiling by applying Fiberglass boards in the following amounts:
    - 30% of Ceiling Area

    - 60% of Ceiling Area
    - 80% of Ceiling Area
    - 100% of Ceiling Area (Replacing the current treatment)

- False Ceiling treatments are distributed over the platform ceiling by applying Fiberglass boards in the following amounts:
    - 80% of Ceiling Area
    - 100% of Ceiling Area(Replacing the current treatment)

- Hanging acoustical baffles are distributed over the platform ceiling by applying vertical hanged Fiberglass boards with area equivalent to 60% of the ceiling area.

- Under-platform, ceiling, wall treatments are investigated in several combinations to measure the effect of each on noise reduction.

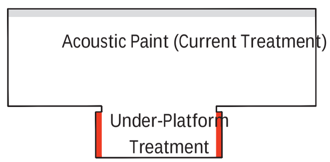
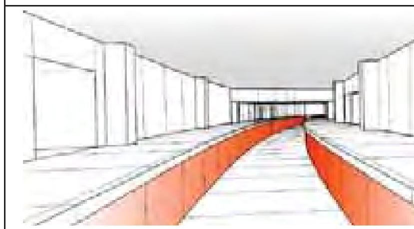
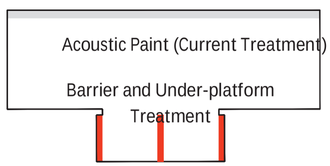
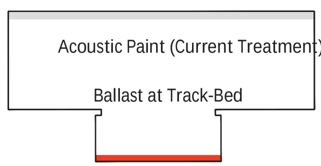
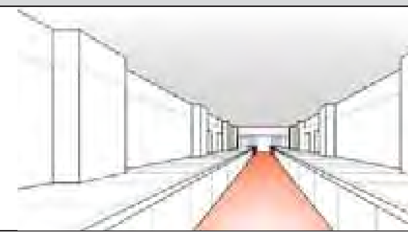
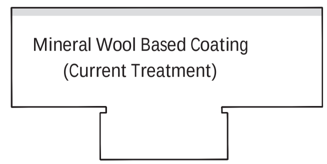
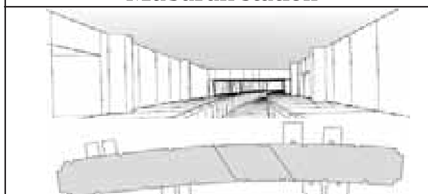
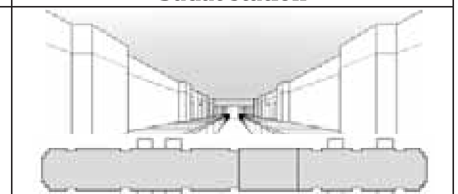
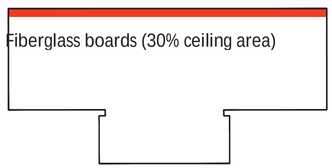
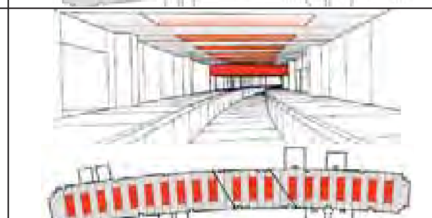
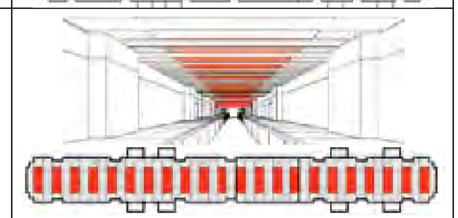
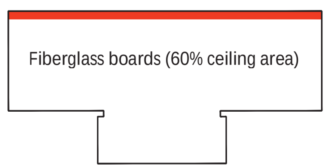
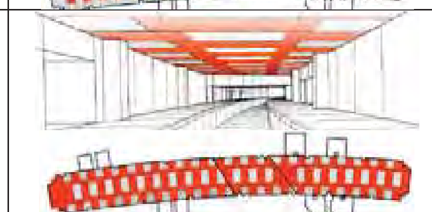
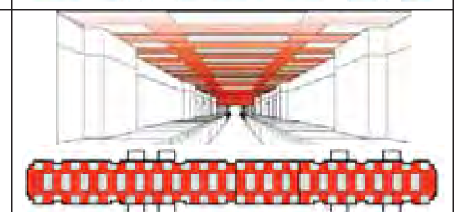
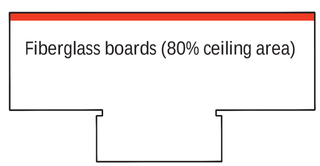
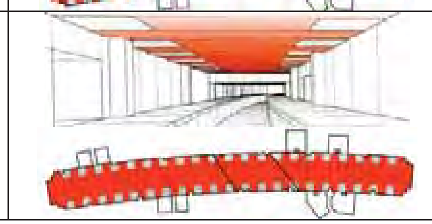
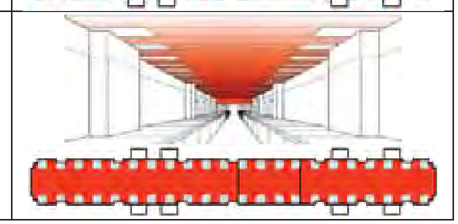
1-Under-Platform Treatment Alternatives			
		Mubarak station	**Sadat station**
U1-Under-Platform walls Treatment			
U2- Under-Platform walls and Barriers between Tracks Treatment			
U3- Track- Bed Treatment			

Figure 5-15: Under-Platform Treatment Alternatives.

2-Ceiling Treatment Alternatives			
		Mubarak station	**Sadat station**
C1 Existing Acoustic Paint Treatment – Current station state			
C2 Acoustic Treatment -30% of Ceiling Area			
C3 Acoustic Treatment -60% of Ceiling Area			
C4 Acoustic Treatment -80% of Ceiling Area			

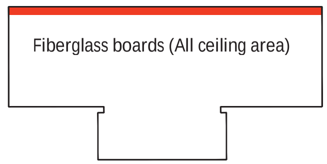
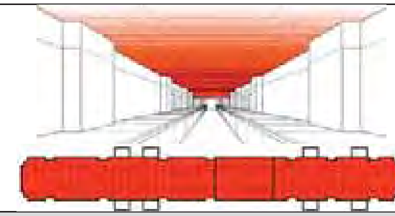
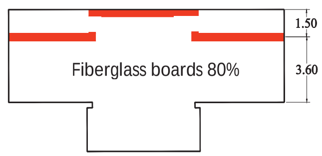
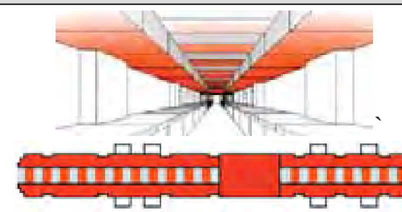
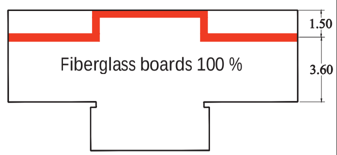
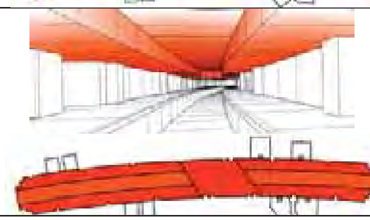
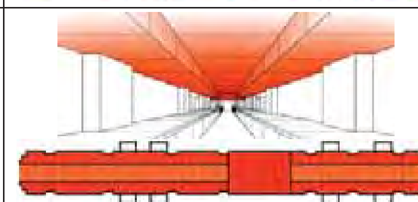
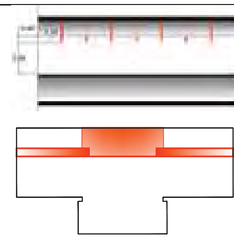
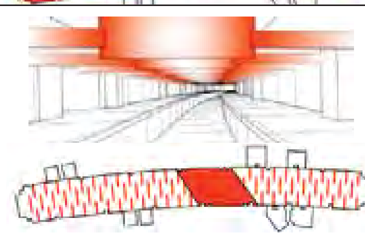
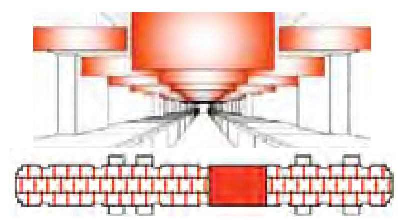
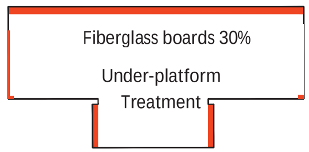
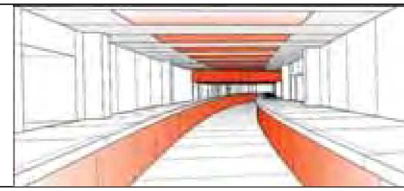
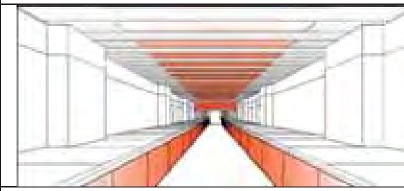
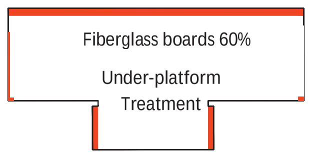
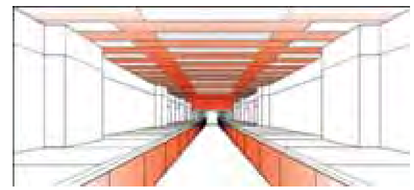
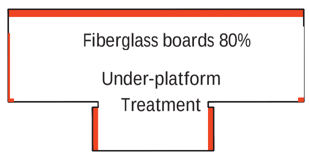
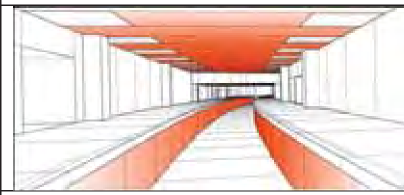
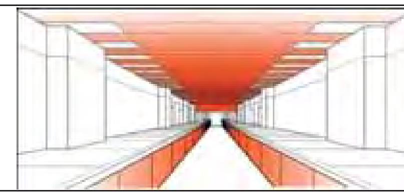
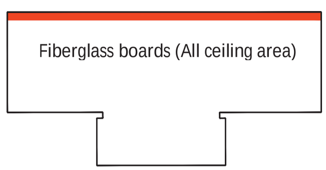
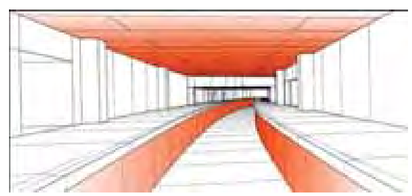
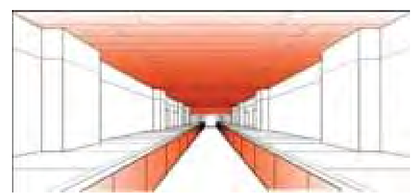
C5 Acoustic Treatment -100% of Ceiling Area	 		
Cont.-False Ceiling - Treatment Alternatives			
C6 False Ceiling Above Platform -70% of Ceiling Area	 		
C7 False Ceiling Above Platform -100% of Ceiling Area	 		
C8 Hanged Absorbers-60% of Ceiling Area			

Figure 5-16: Ceiling Treatment Alternatives.

3-Ceiling and Under-platform Treatment Alternatives			
		Mubarak station	**Sadat station**
C2 W1 30% of Ceiling Area and Wall Panels treatments			
C3 W1 60% of Ceiling Area and Wall Panels treatments			
C4 W1 80% of Ceiling Area and Wall Panels treatments			
S16- C5 W1 100% of Ceiling Area and Wall Panels treatments			

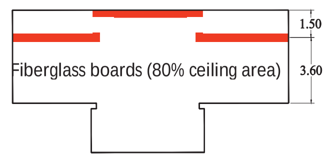
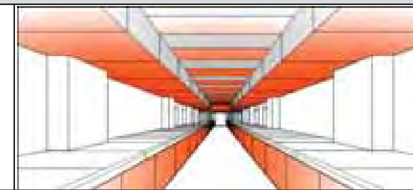
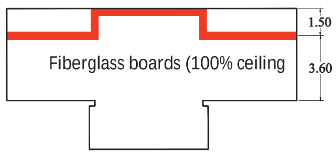
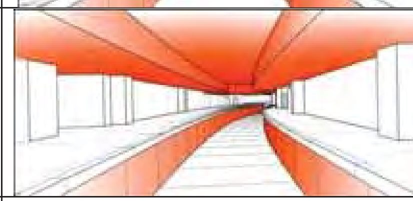
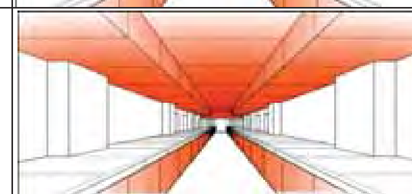
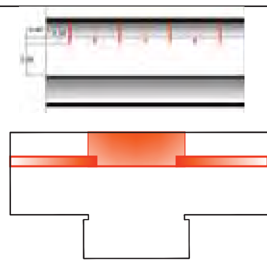
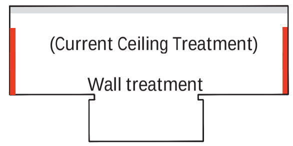
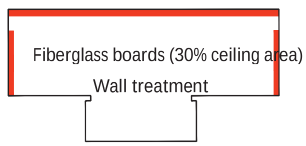
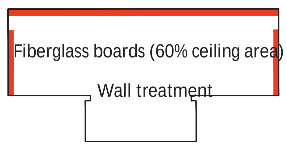
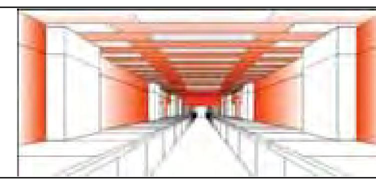
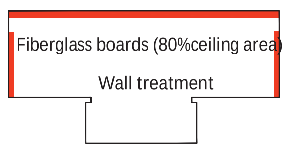
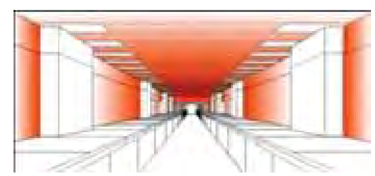
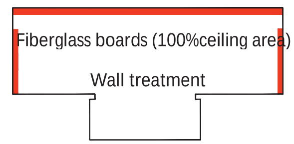
Cont-False Ceiling and Under-platform Treatment Alternatives			
S17- C6 W1 **70% of Ceiling Area and Wall Panels treatments**			
S18-C7 W1 **False Ceiling -100% of Ceiling Area and Wall treatments**			
S19-C7 W1 **Hanged Absorbers-60% of Ceiling Area and Wall treatments**			

Figure 5-17: Ceiling And Under-Platform Treatment Alternatives.

4-Ceiling and Wall Treatment Alternatives

		Mubarak station	Sadat station
C1 W1 **Existing Acoustic Paint Treatment and Wall Panels treatments**			
C2 W1 **30% of Ceiling Area and Wall Panels treatments**			
C3 W1 **60% of Ceiling Area and Wall Panels treatments**			
C4 W1 **80% of Ceiling Area and Wall Panels treatments**			

Cont. Ceiling and Wall Treatment Alternatives			
S16- C5 W1 100% of Ceiling Area and Wall Panels treatments			

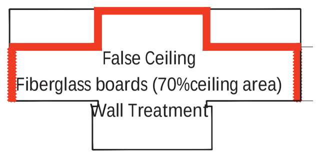
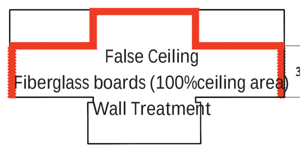
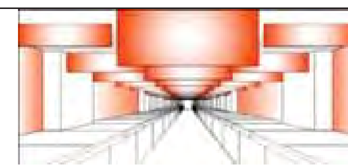
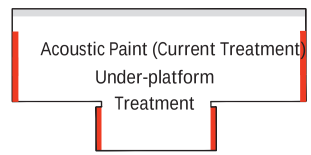
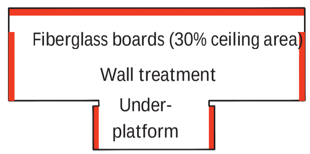
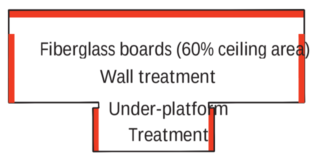
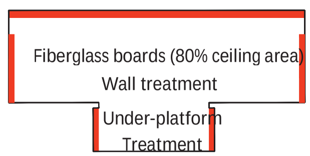
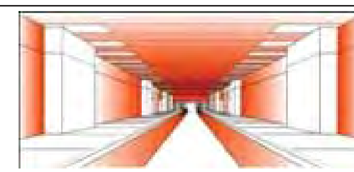
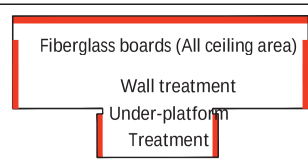
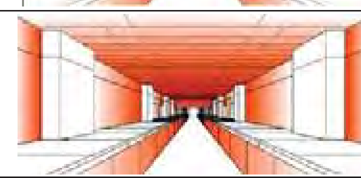
Cont. False Ceiling and Wall Treatment Alternatives			
S17- C6 W1 70% of Ceiling Area and Wall Panels treatments			
S18-C7 W1 False Ceiling -100% of Ceiling Area and Wall treatments			
S19-C7 W1 Hanged Acoustical Baffles-60% of Ceiling Area and Wall treatments			

Figure 5-18: Ceiling And Wall Treatment Alternatives.

5-Ceiling, Wall, and Under-platform Treatment Alternatives			
S20-C1 W1 U1 Existing Acoustic Paint Treatment, Wall Panels and Under-Platform treatments			
S21-C2 W1 U1 30% of Ceiling Area, Wall Panels and Under-Platform treatments			
S22- C3 W1 U1 60% of Ceiling Area, Wall Panels and Under-Platform treatments			
S23-C4 W1 U1 80% of Ceiling Area, Wall Panels and Under-Platform treatments			
S24- C5 W1 U1 100% of Ceiling Area, Wall Panels and Under-Platform treatments			

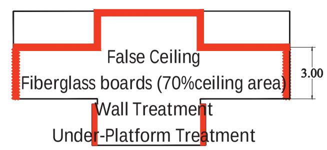
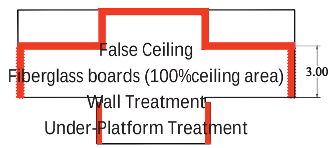
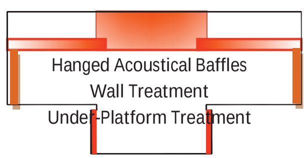
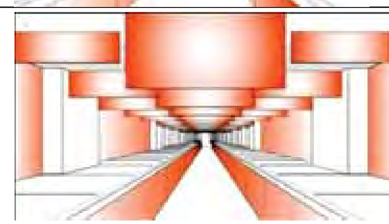
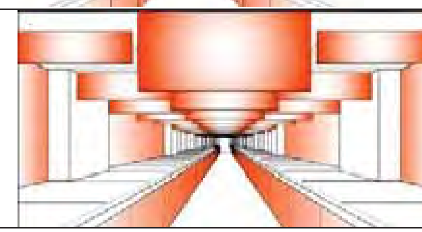
Cont. -False Ceiling, Wall, and Under-platform Treatment Solutions			
S25- C6 W1 U1 70% of Ceiling Area, Wall Panels and Under-Platform treatments			
S26- C7 W1 U1 70% of Ceiling Area, Wall Panels and Under-Platform treatments			
S27- C8 W1 U1 Hanged Absorbers-60% of Ceiling Area, Wall and Under-Platform treatments			

Figure 5-19: Ceiling, Wall And Under-Platform Treatment Alternatives.

Part 2: Assessment of the Acoustic Environment inside the Greater Cairo Underground Stations.

6. Chapter 6: Acoustical Simulation Results and Discussion

6.1. The Current Ceiling Treament Effect

Acoustic treatments alternatives are investigated using computer simulation to determine the appropriate treatments that achieve the most noise reduction with least absorbing materials. A-weighted sound pressure levels on platform are predicted using **ODEON 4.2** software after applying the proposed treatments, then compared with the reference simulation model corresponding A-weighted SPL values; see Table 5-6. That reference simulation model S4-C1 presents the current state of the platform treated with mineral wool based coating on the ceiling.

In the acoustic model, the two line sources generates sound inside platform space equivelant to the measured maximum noise levles. A-weighted SPL values are observed at 16 receiver; 8 receivers on each platform distributed all over the station platform in the middle of each train-car, Figure 6-1 shows the reference A-weighted SPL values taken on both **Mubarak** and **Sadat** platforms. The highest observed A-weighted SPL is recorded at both platform ends due to arrival of train with high speed; see Figure 6-1.

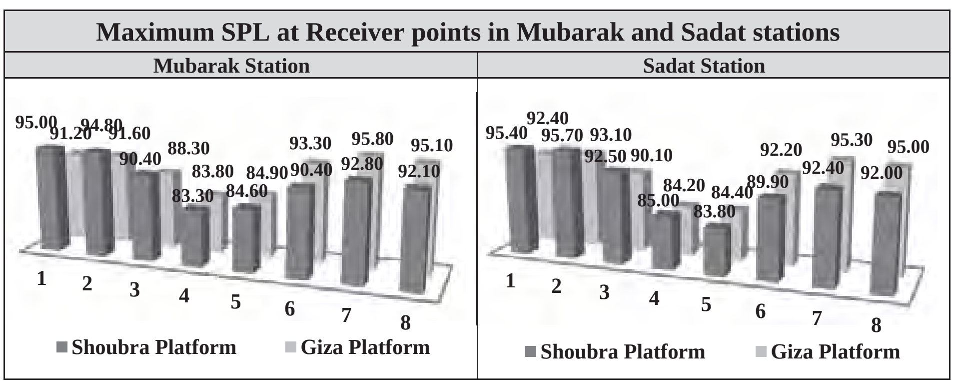


Figure 6-1: Reference Noise Levels Used To Measure Acoustic Treatments Effects In Mubarak And Sadat Stations.

Noise reduction resulting from of the current ceiling treatment with acoustic paint is explored first before investigating any proposed acoustic treatments. Simulations is processed for two cases; Station without ceiling treatment (fair face concrete) and station with treated ceiling (acoustic paint) . Figure 6-2 shows the level reduction achieved after replacing the mineral wool based coating treatmed with fair faced concrete.

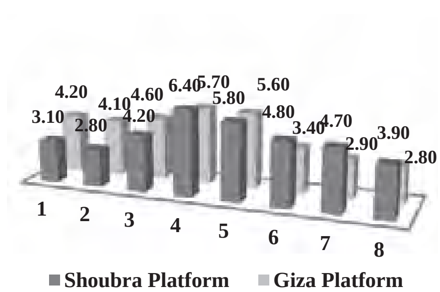
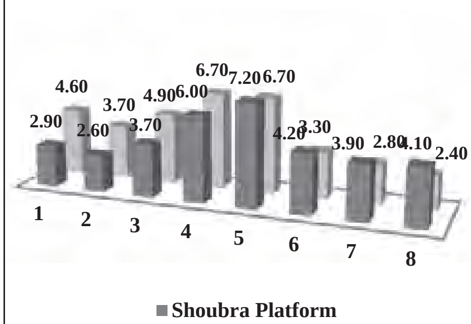
<table>
<tr><th colspan="2">Noise Reduction of The Current Ceiling Treatment
with (Mineral Wool Based coating) S4 – C1
A-weighted Sound Pressure Level Reduction</th></tr>
<tr><th>Mubarak Station</th><th>Sadat Station</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Most Noise Reduction at both Platform middle sections due to low ceiling height
Average NR = 4.3 dB(A)
Maximum NR=6.4 dB(A)</td><td>Most Noise Reduction at both Platform middle sections due to low ceiling height
Average NR = 4.3 dB(A)
Maximum NR=7.2 dB(A)</td></tr>
</table>

Figure 6-2: A-Weighted Sound Pressure Level Noise Reduction Due To Acoustic Paint Treatment At The 16 Receiver Points On Both Sadat Station Platforms.

Acoustical simulation results will be discussed according to treatment location as follows:

6.2. Under-Platform Treatments Results

Noise reduction achieved from applying acoustic treatments to Under-Platform area is relatively high. Under-Platform treatments included sidewalls, barriers, and track-bed absorption. These treatment locations are the nearest to train noise source resulting to direct absorption of railway noise.

6.2.1.1. <u>Sound level Distribution</u>

The frequency contents for train noise on platform front, middle section and end are illustrated for under-platform treatment alternatives at three receiver points 1, 5 and 8 in Figure 6-4. Under-Platform treatments include applying absorbing materials to sidewalls, to barriers between tracks and applying Ballast for track-bed absorption. Comparing the three Under-Platform treatments, the greatest difference in level among platform receivers is about 10 dB at mid frequencies after applying absorbing materials to barriers between tracks with the treated under-Platform sidewalls.

A-weighted SPL reduced due to under-platform sidewalls treatment ranges from 2 to 5 dB(A) which is clearly noticeable and from 5 to 10 dB(A), which is half as loud, with further addition of absorbing materials on a barrier between tracks. While in the third alternative, Ballast applied to the railway track-Bed reduce noise from 1 to 3 dB(A), which is barely perceptible; see Figure 6-3.

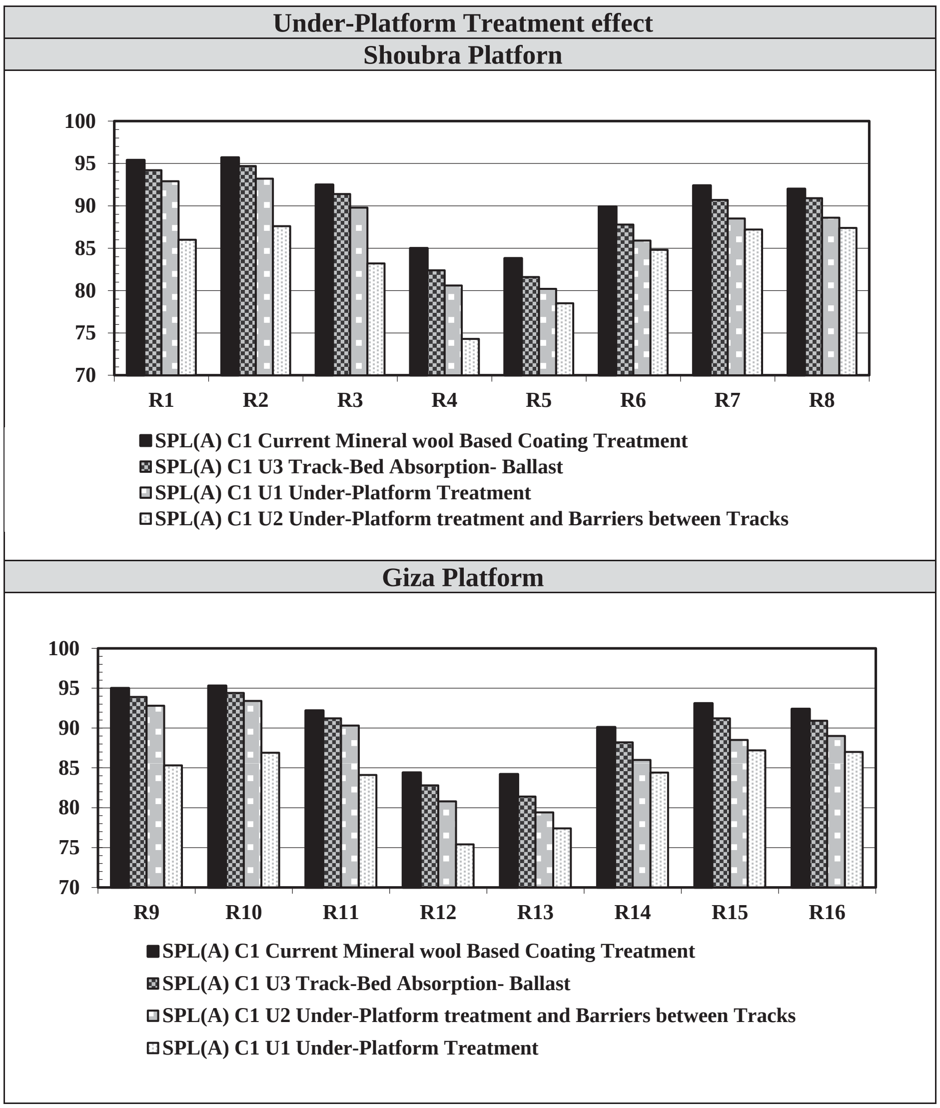
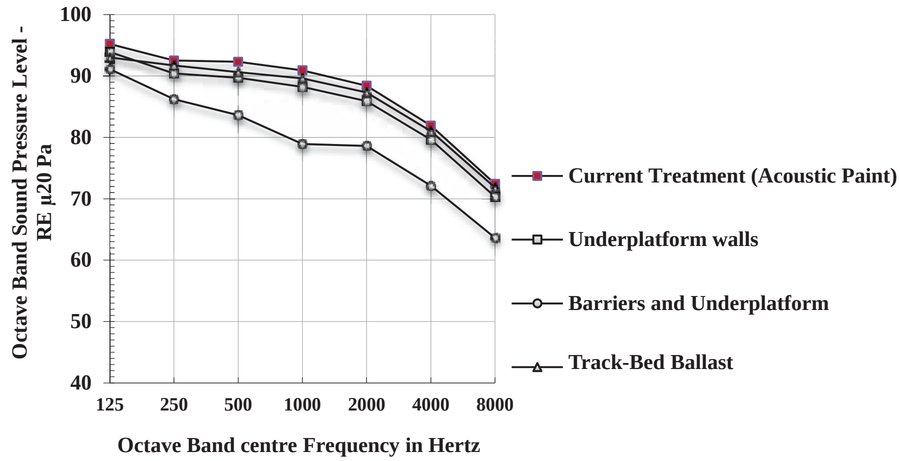
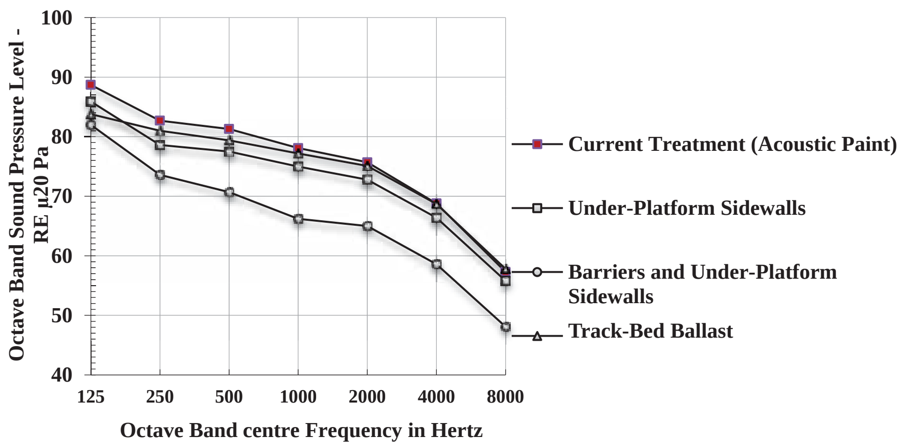


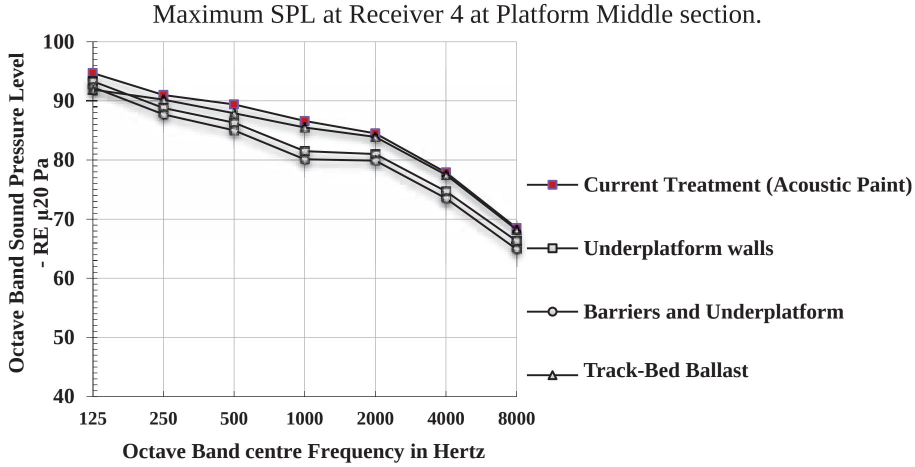
Figure 6-3:Left- Maximum A-Weighted SPL On Both Station Platforms For Under-Platform Treatment



Maximum SPL at Receiver 1 at Platform Front.



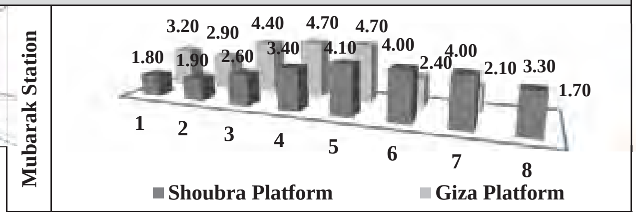
Maximum SPL at Receiver 4 at Platform Middle section.



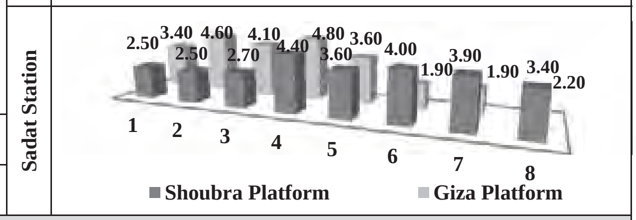
Maximum SPL At Receiver 8 At Platform End.

Figure 6-4:Maximum SPL At The Station Front, Middle Section And End With Under-Platform Treatments

C1-U1 - Under-Platform Sidewalls Noise Reduction

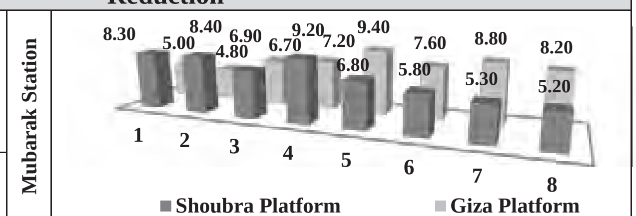


Noise reduction decrease gradualy along Train direction
Mubarak: Average NR=3.2dBA
Maximum NR=4.7 dB(A)
Sadat: Average NR=3.4dBA
Maximum NR=4.8 dB(A)

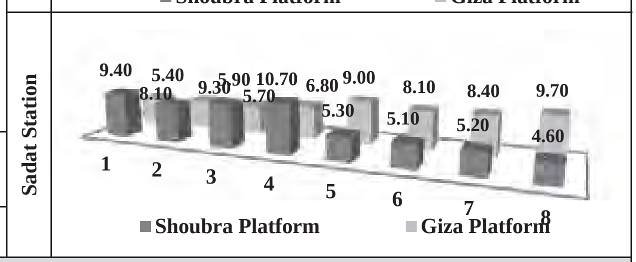


Noise Reduction approximated to the nearest 0.5dB	
Average 3.5 dB(A)	Maximum 5 dB(A)

C1 –U2 - Under-Platform Sidewalls and Barriers between Tracks Noise Reduction

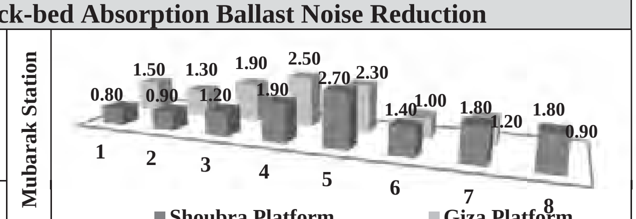


Most Noise reduction is on opposite platform when train enters the station
Mubarak: Average NR=7.1dBA
Maximum NR=9.4 dB(A)
Sadat: Average NR=7.3dBA
Maximum NR=10.7 dB(A)

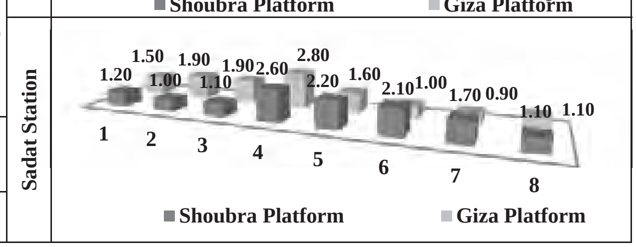


Noise Reduction approximated to the nearest 0.5dB	
Average 7 dB(A)	Maximum 10.5 dB(A)

C1 - U3 - Track-bed Absorption Ballast Noise Reduction



No significant reduction exept for Platform Middle section
Mubarak: Average NR=1.6 dB(A)
Maximum NR=2.7 dB(A)
Sadat: Average NR=1.6 dB(A)
Maximum NR=2.8 dB(A)



Noise Reduction approximated to the nearest 0.5dB	
Average 1.5 dB(A)	Maximum 3 dB(A)

Figure 6-5: A-Weighted SPL Noise Reduction After Under-Platform Treatment At Receiver Points On Both Mubarak And Sadat Station Platforms.

6.3. Ceiling Treatments Results

Noise reduction achieved after applying further acoustic treatments to the platform ceiling is not significant compared to the current acoustic mineral wool based coating. Maximum noise reduced when the platform ceiling is totally covered with fiberglass boards is 3 dB(A), which is barely perceptible.

6.3.1.1. Sound level Distribution

The frequency contents for train noise on platform front, middle section and end are illustrated for ceiling treatment alternatives at three receiver points 1, 5 and 8; see Figure 6-7. Acoustic treatments introduced to the platform ceiling include Fiberglass boards distributed over the platform ceiling in four alternatives to cover 30%, 60%, 80% and 100% of ceiling total area. Two other alternatives include installing false ceiling over both platforms to be covered with fiberglass boards. In the last alternative, Hanging acoustical baffles are attached to the platform false ceiling with a spacing 2.5 m.

Comparing ceiling treatments alternatives, the greatest difference in level among platform receivers is about 3 dB at mid frequencies after replacing the current treatment with Fiberglass boards or using hanged acoustical baffles. The A-weighted SPL reduced due to ceiling treatments ranged from 0.5 to 3 dB(A) along the platform which is considered barely perceptible.

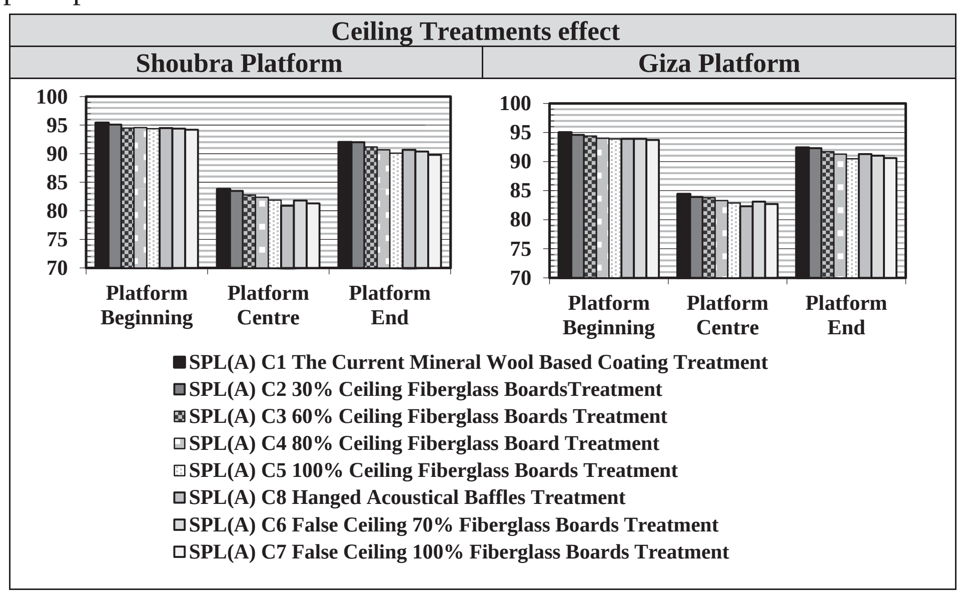
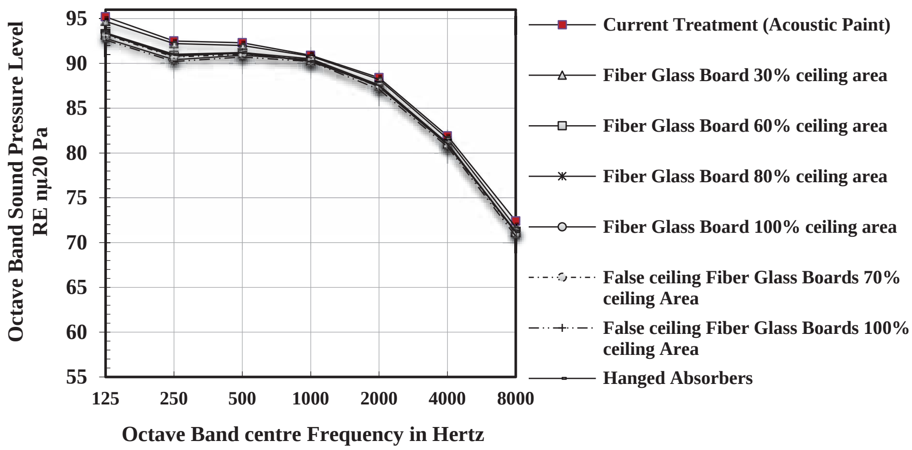
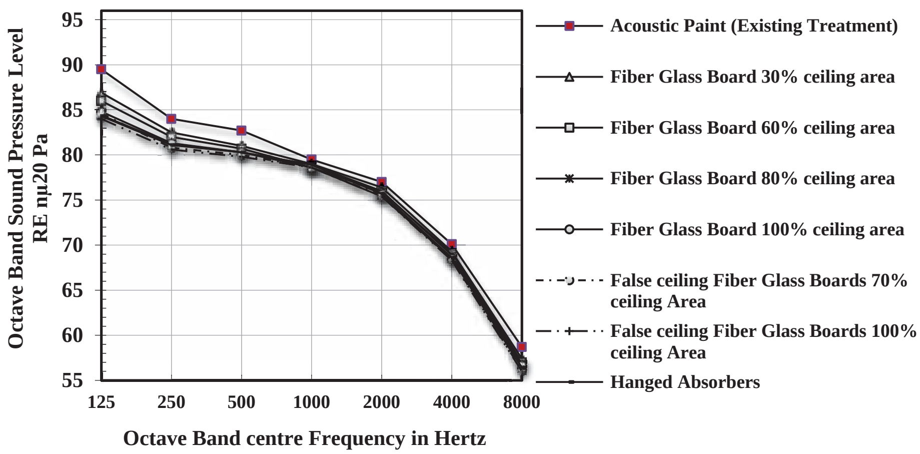


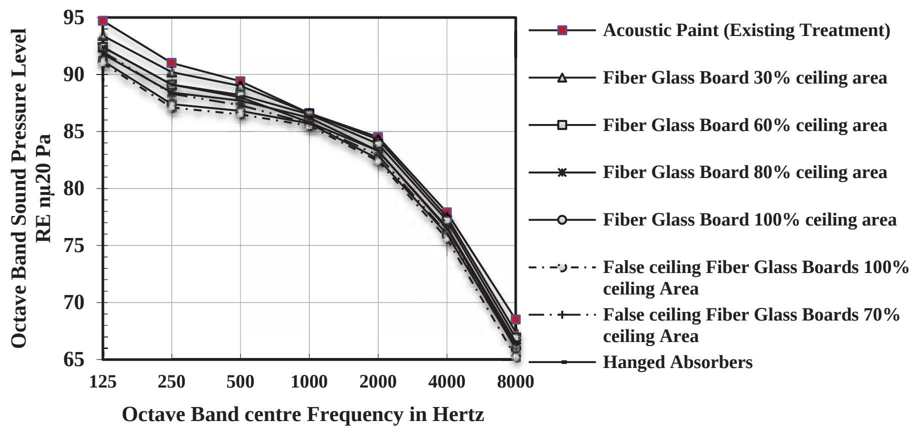
Figure 6-6:A-Weighted SPL At Both Station Platform Front, Middle Section And End After Ceiling Treatments



Maximum SPL at Receiver 1 at Platform Front.



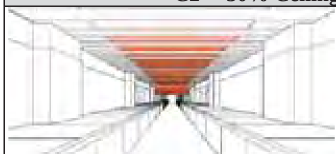
Maximum SPL at Receiver 4 at Platform Middle section.



Maximum SPL At Receiver 8 At Platform End.

Figure 6-7:Maximum SPL At The Station Front, Middle Section And End With Ceiling Treatments

C2 – 30% Ceiling Fiberglass Boards Treatment Noise Reduction

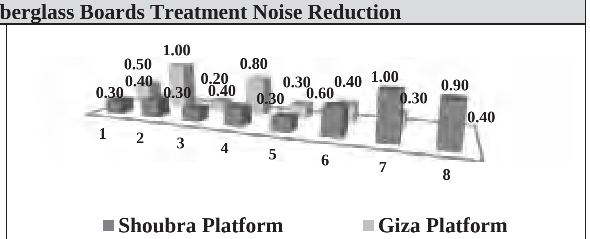


Low Noise Reduction along the station platforms
Mubarak: Average NR=0.5 dB(A)
Maximum NR=1 dB(A)
Sadat: Average NR=0.5 dB(A)
Maximum NR=1 dB(A)

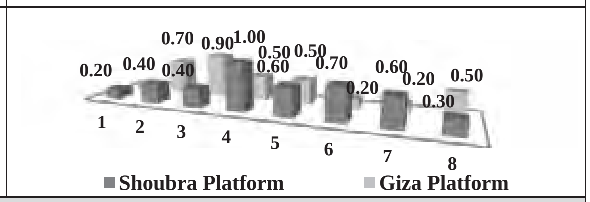
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
0.5 dB(A)	1 dB(A)

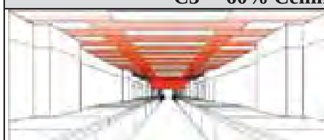
Mubarak Station



Sadat Station



C3 – 60% Ceiling Fiberglass Boards Treatment Noise Reduction

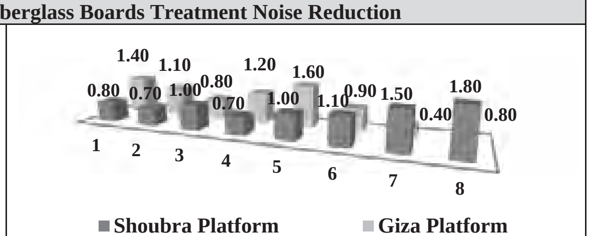


Low Noise Reduction along the station platforms
Mubarak: Average NR=1.1 dB(A)
Maximum NR=1.8 dB(A)
Sadat: Average NR=1 dB(A)
Maximum NR=1.6 dB(A)

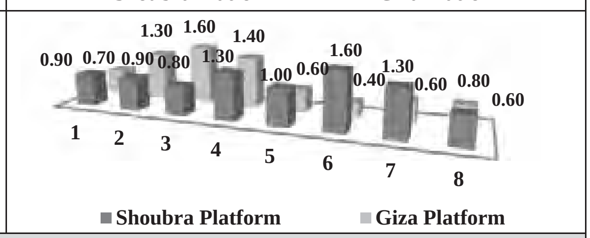
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
1 dB(A)	2 dB(A)

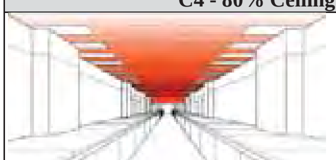
Mubarak Station



Sadat Station



C4 - 80% Ceiling Fiberglass Boards Treatment Noise Reduction

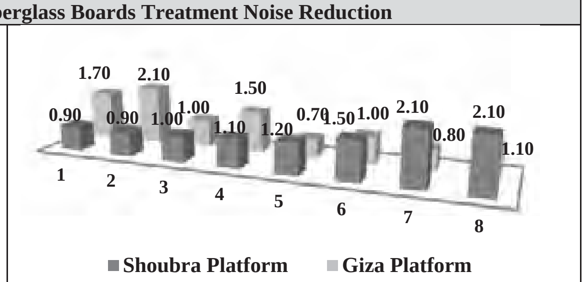


Noise reduction decrease gradualy along Train direction
Mubarak: Average NR=1.3 dB(A)
Maximum NR=2.1 dB(A)
Sadat: Average NR=1.3 dB(A)
Maximum NR=1.8 dB(A)

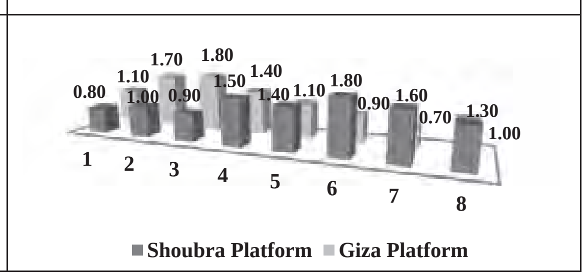
Noise Reduction approximated to the nearest 0.5dB

Average	Maximum
1.5 dB(A)	2 dB(A)

Mubarak Station

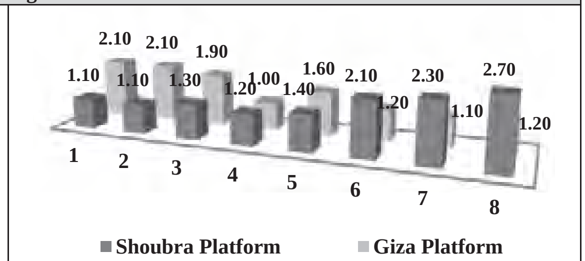


Sadat Station

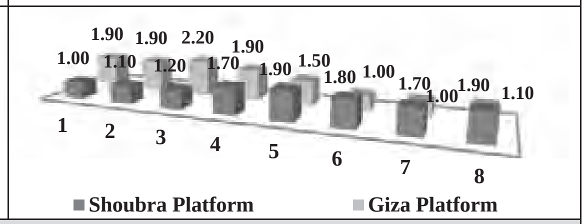


C5 - 100% Ceiling Fiberglass Boards Treatment Noise Reduction

Mubarak Station



Sadat Station

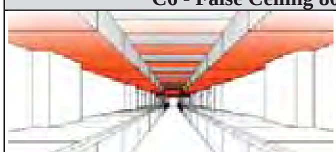


Noise reduction decrease gradualy along Train direction
Mubarak: Average NR=1.6 dB(A)
Maximum NR=2.7 dB(A)
Sadat: Average NR=1.6 dB(A)
Maximum NR=2.2 dB(A)

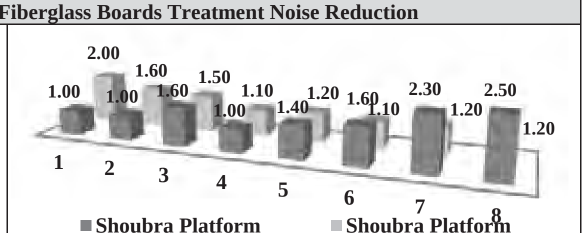
Noise Reduction approximated to the nearest 0.5 dB

Average	**Maximum**
1.5 dB(A)	**3 dB(A)**

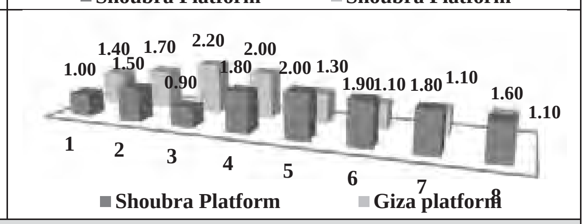
C6 - False Ceiling 80% Fiberglass Boards Treatment Noise Reduction



Mubarak Station



Sadat Station

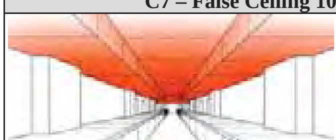


Noise reduction decrease gradualy along Train direction
Mubarak: Average NR=1.3 dB(A)
Maximum NR=2.1 dB(A)
Sadat: Average NR=1.3 dB(A)
Maximum NR=1.8 dB(A)

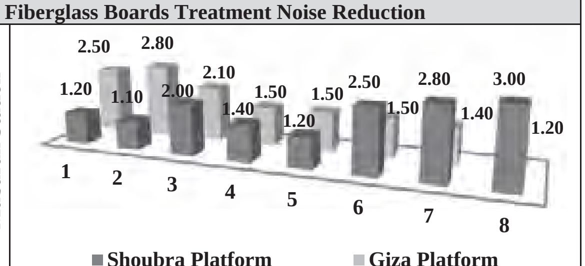
Noise Reduction approximated to the nearest 0.5 dB

Average	**Average**
1.5 dB(A)	**2 dB(A)**

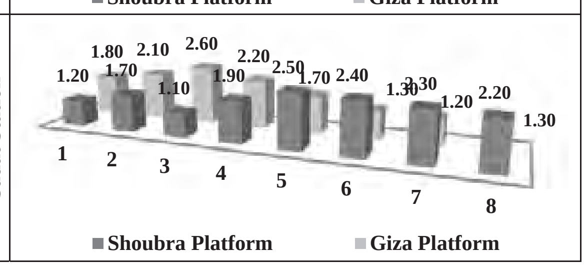
C7 – False Ceiling 100% Fiberglass Boards Treatment Noise Reduction



Mubarak Station



Sadat Station

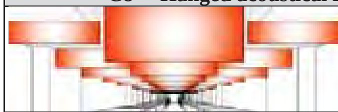


Noise reduction decrease gradualy along Train direction
Mubarak: Average NR=1.6 dB(A)
Maximum NR=2.7 dB(A)
Sadat: Average NR=1.6 dB(A)
Maximum NR=2.2 dB(A)

Noise Reduction approximated to the nearest 0.5 dB

Average	**Maximum**
1.5 dB(A)	**3 dB(A)**

C8 – Hanged acoustical Baffles 60% of ceiling area Treatment Noise Reduction

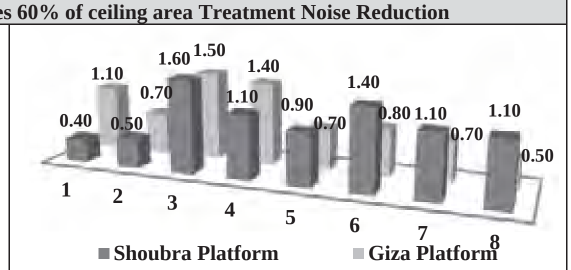


Gradual Increase in Noise Reduced with more Hanged Absorbers in Train Direction
Mubarak: Average NR=1.1 dB(A)
Maximum NR=1.8 dB(A)
Sadat: Average NR=1 dB(A)
Maximum NR=1.6 dB(A)

Noise Reduction approximated to the nearest 0.5 dB

Average 1 dB(A)	Average 2 dB(A)

Mubarak Station



Sadat Station

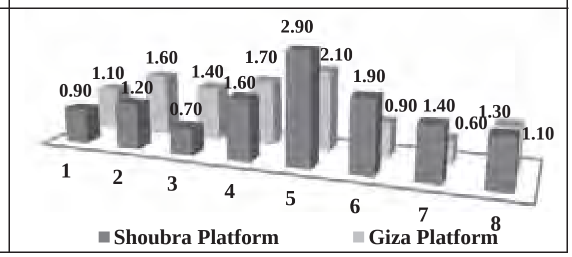


Figure 6-8: A-Weighted SPL Noise Reduction After Ceiling Treatment At Receiver Points On Both Mubarak And Sadat Station Platforms.

6.4. Ceiling and Under-Platform Sidewalls Treatments Results

Noise reduction achieved after applying acoustic treatments to the under-platform area in addition to ceiling treatments provided considerable noise reduction. Maximum noise reduction is achieved when barrier and under-platform sidewalls are totally covered with fiberglass boards to provide 10 dB(A), which is half as loud as noise source.

6.4.1.1. <u>Sound level Distribution</u>

The frequency contents for train noise on the platform front, middle section and end are illustrated for ceiling and under-platform sidewalls treatments at three receiver points 1, 5 and 8; see Figure 6-10. Acoustic treatments introduced to the station under-platform sidewalls

The greatest difference in sound pressure levels among platform receivers is about 10 dB at mid frequencies for totally treated ceiling with under-platform sidewalls treatment.

Average and Maximum noise reduction due to ceiling acoustical treatments ranges from 0.5 to 1.5 dB(A) and from 1 to 3 dB(A) respectively. With further application of absorbing materials on under-platform sidewalls noise reduction gets to 4.5 to 6 dB(A) and 6.5 to 10 dB(A).

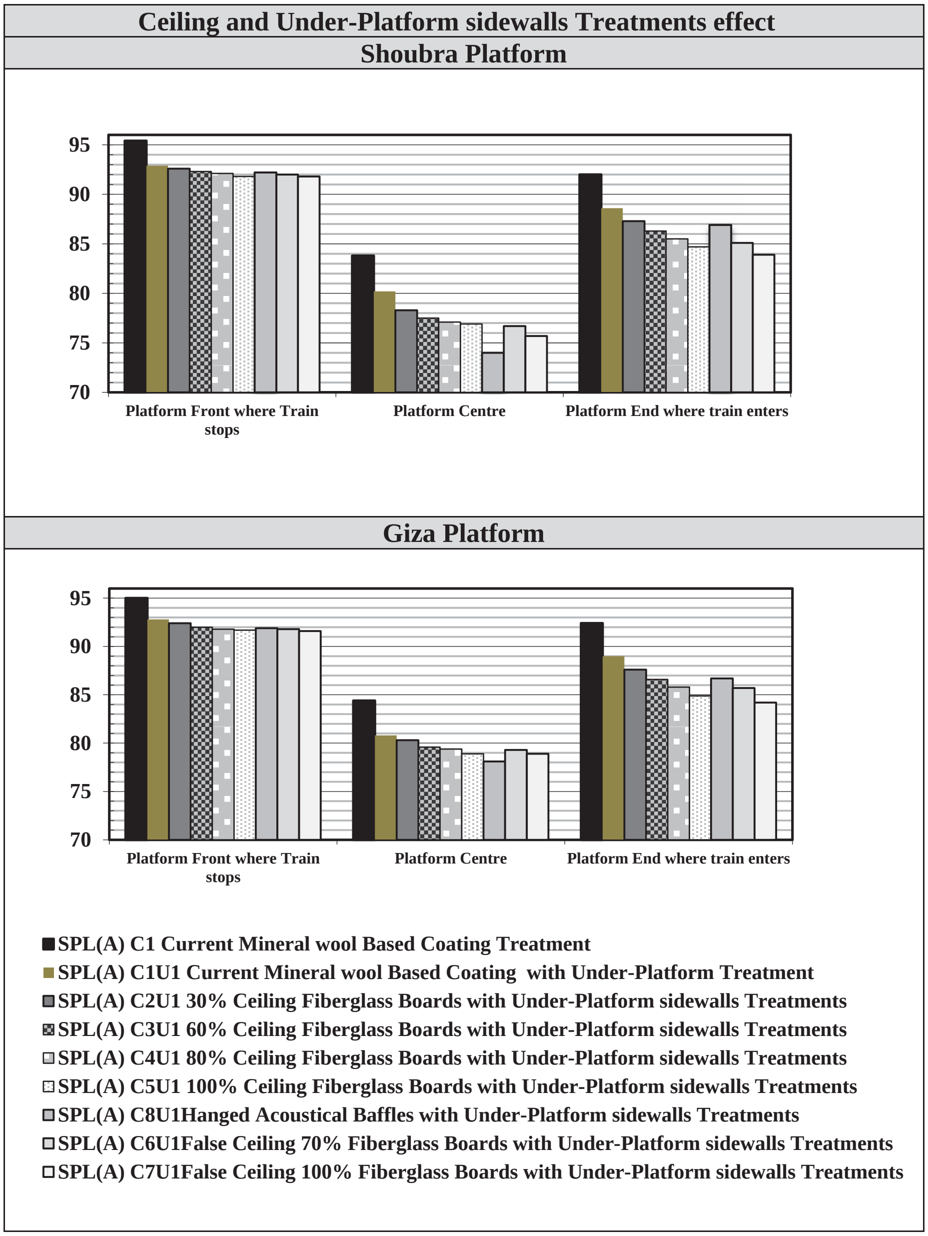
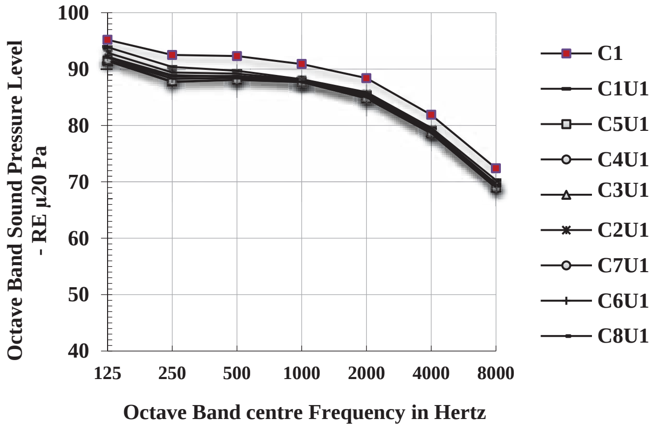
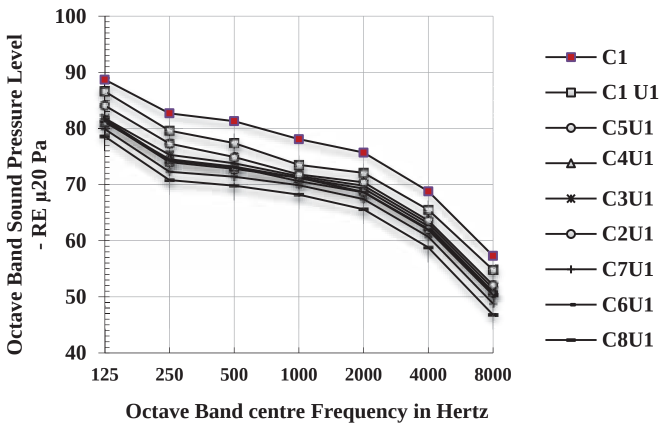


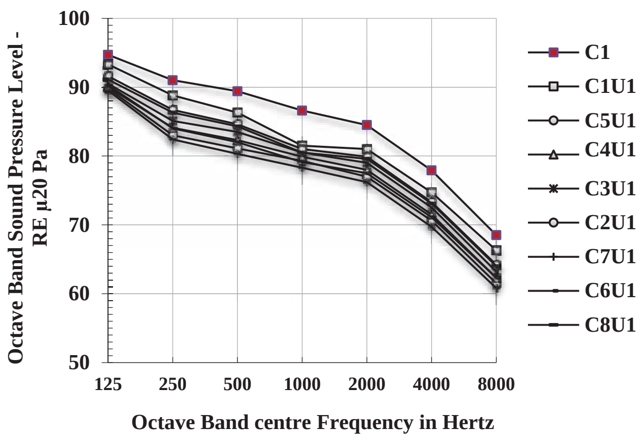
Figure 6-9:A-Weighted SPL At Both Station Platform Front, Middle Section And End After Ceiling And Under-Platform Sidewalls Treatment



Maximum SPL at Receiver 1 at Platform Front.



Maximum SPL at Receiver 5 at Platform Middle section.

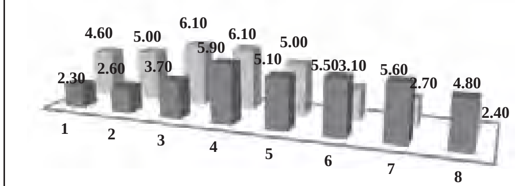


Maximum SPL At Receiver 8 At Platform End.

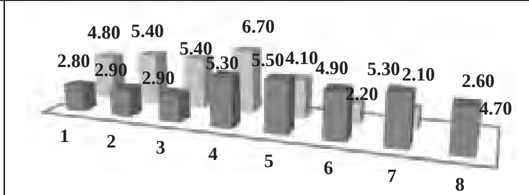
Figure 6-10:Maximum SPL At The Station Front, Middle Section And End With Ceiling And Under-Platform Treatments

C2U1 – 30% Ceiling Fiberglass Boards with Under-Platform Treatment Noise Reduction

Mubarak Station



Sadat Station

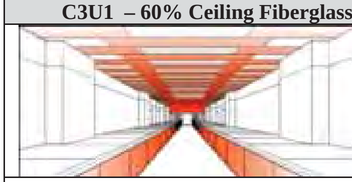


Low Noise reduction along the station platforms
Mubarak: Average NR=4.4 dB(A)
Maximum NR=6.1 dB(A)
Sadat: Average NR=4.2 dB(A)
Maximum NR=6.7 dB(A)

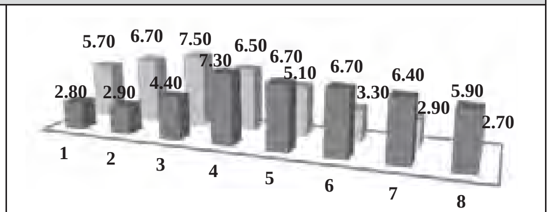
Noise Reduction approximated to the nearest 0.5 dB

Average	**Maximum**
4.5 dB(A)	**6.5 dB(A)**

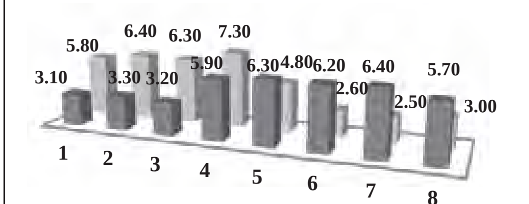
C3U1 – 60% Ceiling Fiberglass Boards with Under-Platform Treatment Noise Reduction



Mubarak Station



Sadat Station

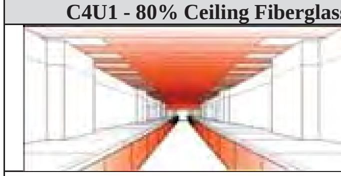


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=5.2 dB(A)
Maximum NR=7.5 dB(A)
Sadat: Average NR=4.9 dB(A)
Maximum NR=7.3 dB(A)

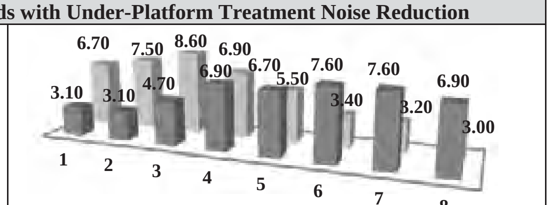
Noise Reduction approximated to the nearest 0.5 dB

Average	**Maximum**
5 dB(A)	**7.5 dB(A)**

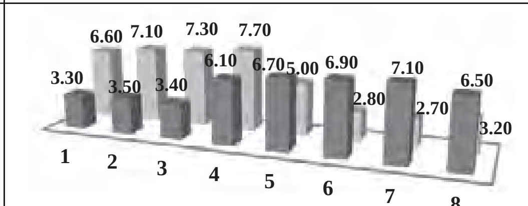
C4U1 - 80% Ceiling Fiberglass Boards with Under-Platform Treatment Noise Reduction



Mubarak Station



Sadat Station

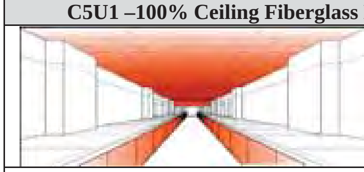


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=5.7 dB(A)
Maximum NR=8.6 dB(A)
Sadat: Average NR=5.4 dB(A)
Maximum NR=7.7 dB(A)

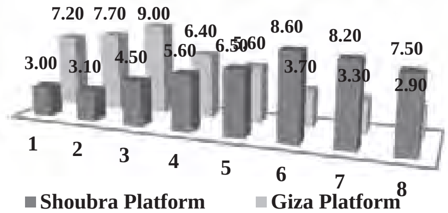
Noise Reduction approximated to the nearest 0.5dB

Average	**Maximum**
5.5 dB(A)	**8.5 dB(A)**

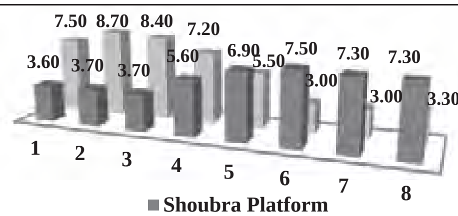
C5U1 –100% Ceiling Fiberglass Boards with Under-Platform Treatment Noise Reduction



Mubarak Station



Sadat Station

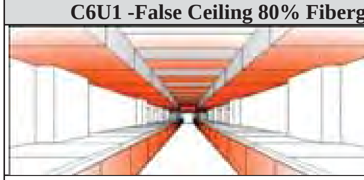


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=5.8 dB(A)
Maximum NR=9 dB(A)
Sadat: Average NR=5.7 dB(A)
Maximum NR=8.7 dB(A)

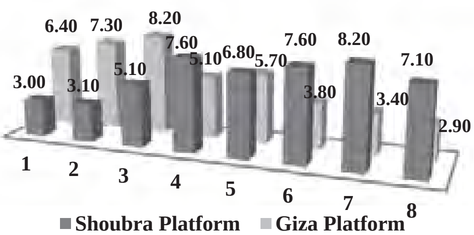
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
6 dB(A)	**9 dB(A)**

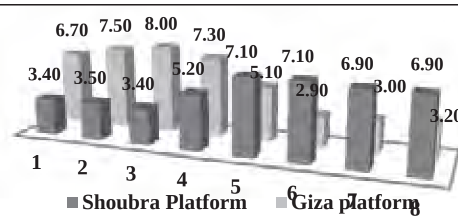
C6U1 -False Ceiling 80% Fiberglass Boards with Under-Platform Treatment Noise Reduction



Mubarak Station



Sadat Station

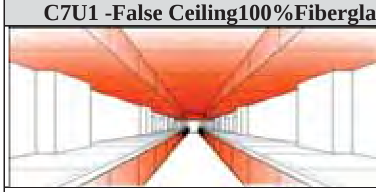


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=5.7 dB(A)
Maximum NR=8.2 dB(A)
Sadat: Average NR=5.5 dB(A)
Maximum NR=8 dB(A)

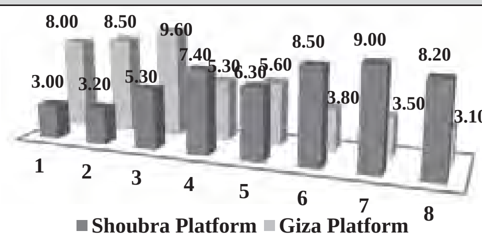
Noise Reduction approximated to the nearest 0.5 dB

Average	Average
5.5 dB(A)	**8 dB(A)**

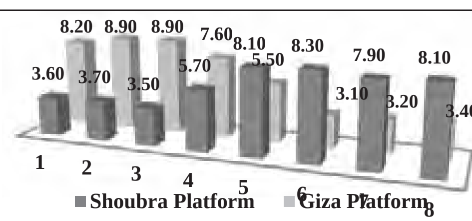
C7U1 -False Ceiling100%Fiberglass Boards with Under-Platform Treatment Noise Reductior



Mubarak Station



Sadat Station

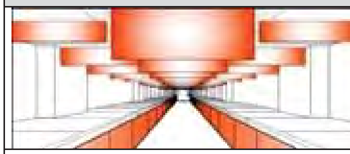


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=6.1 dB(A)
Maximum NR=9.6 dB(A)
Sadat: Average NR=6.1 dB(A)
Maximum NR=8.9 dB(A)

Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
6 dB(A)	**9.5 dB(A)**

C8U1 –Hanged Acoustical Baffles 60% of ceiling area with Perforated Wall Panels Noise Reduction



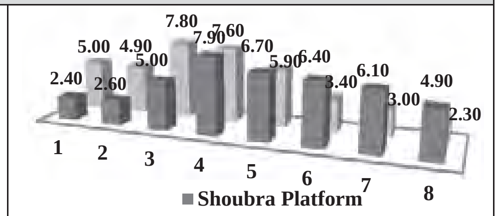
Gradual Increase in Noise Reduced with more Hanged Absorbers in Train Direction

Mubarak: Average NR=5.1 dB(A)
Maximum NR=7.9 dB(A)
Sadat: Average NR=5.3 dB(A)
Maximum NR=9.8 dB(A)

Noise Reduction approximated to the nearest 0.5 dB

Average 5 dB(A)	Average 10 dB(A)

Mubarak Station



Sadat Station

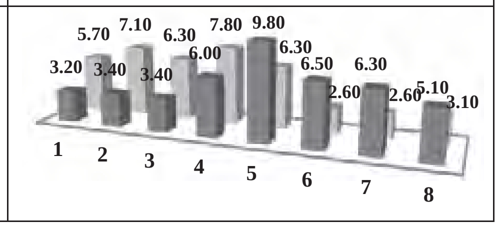


Figure 6-11: A-Weighted SPL Noise Reduction After Ceiling And Under-Platform Treatment At Receiver Points On Both Mubarak And Sadat Platforms.

6.5. Ceiling and Wall treatments

Noise reduction achieved after applying acoustic treatments to the platform walls is relatively low. Wall treatments applied with the current ceiling treatment and the other proposed ones had no significant noise reduction in the selected stations being double track stations with walls away from the train noise. Highest noise reduction achieved from ceiling and wall treatments was 2 dB(A) by totally covering ceiling with fiberglass boards in addition to the wall treatment.

6.5.1.1. <u>Sound level Distribution</u>

The frequency contents for train noise on the station platform front, middle section and end are demonstrated for treatment alternatives applied to the station at three receiver points 1, 5 and 8; see Figure 6-7.

Comparing ceiling and wall alternatives, the greatest difference in level among platform receivers is about 4 dB at mid frequencies and is attributed to the ceiling treatment; see Figure 6-14.

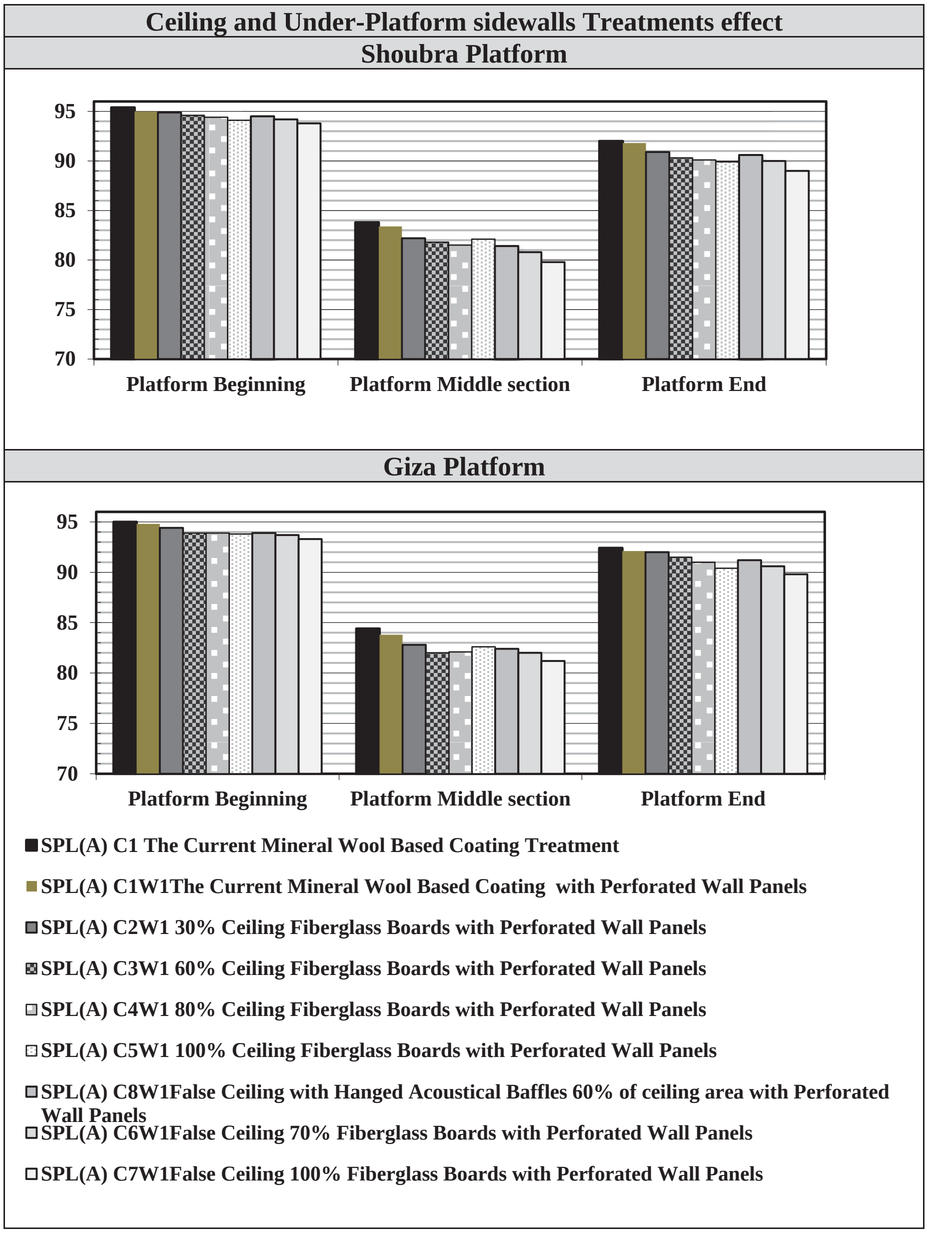
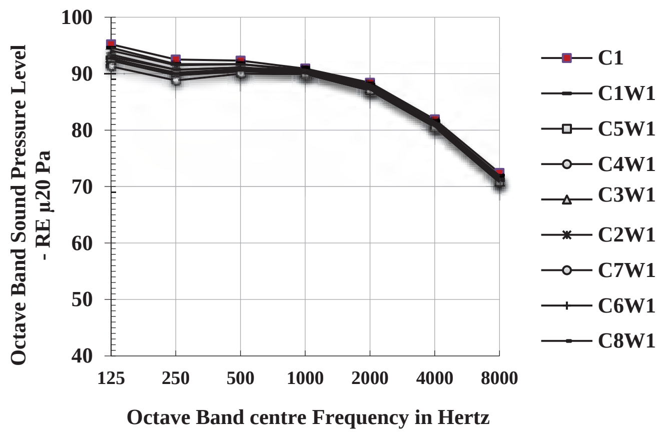
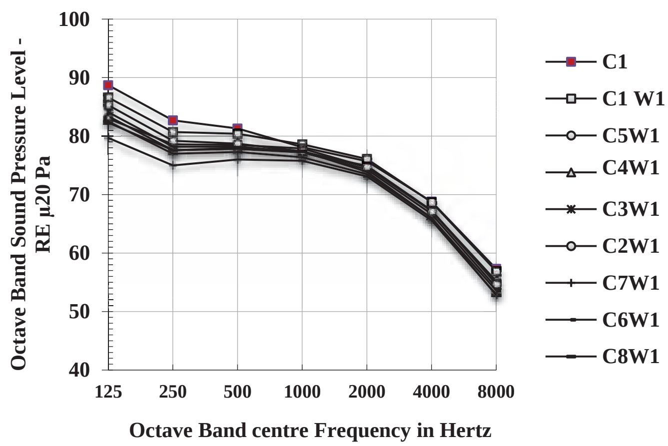


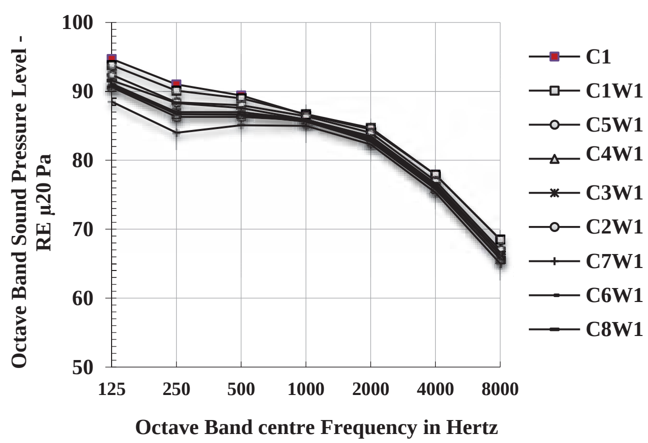
Figure 6-12:A-Weighted SPL At Both Station Platform Front, Middle Section And End After Ceiling And Under-Platform Sidewalls Treatment



Maximum SPL at Receiver 1 at Platform Front.



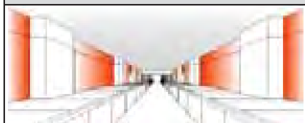
Maximum SPL at Receiver 5 at Platform Middle section.



Maximum SPL At Receiver 8 At Platform End.

Figure 6-13:Maximum SPL At The Station Front, Middle Section And End With Ceiling And Perforated Wall Panels Treatments

C1W1 – Acoustic Paint with Perforated Wall Panels Noise Reduction

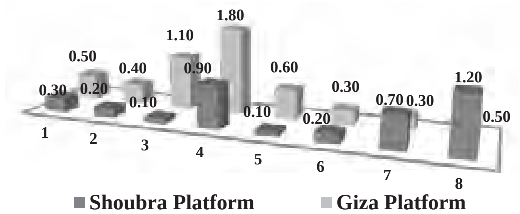


Low Noise reduction along the station platforms
Mubarak: Average NR=0.6 dB(A)
Maximum NR=1.8 dB(A)
Sadat: Average NR=0.5 dB(A)
Maximum NR=1.3 dB(A)

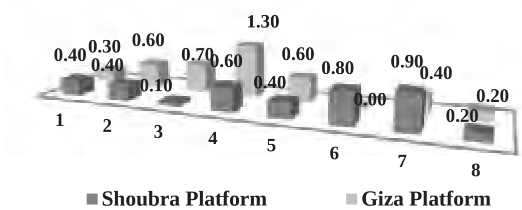
Noise Reduction approximated to the nearest 0.5 dB

Average 0.5 dB(A)	**Maximum 1.5 dB(A)**

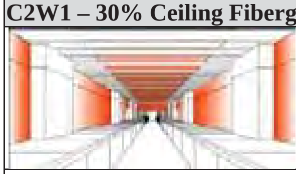
Mubarak Station



Sadat Station



C2W1 – 30% Ceiling Fiberglass Boards with Perforated Wall Panels Noise Reduction

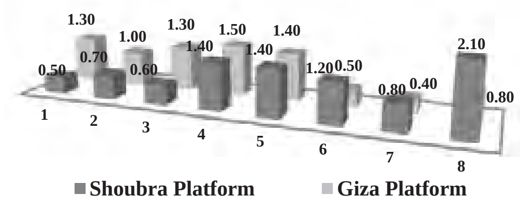


Low Noise reduction along the station platforms
Mubarak: Average NR=1 dB(A)
Maximum NR=2.1 dB(A)
Sadat: Average NR=1 dB(A)
Maximum NR=2.7 dB(A)

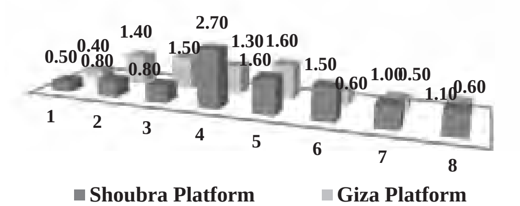
Noise Reduction approximated to the nearest 0.5 dB

Average 0.5 dB(A)	**Maximum 1 dB(A)**

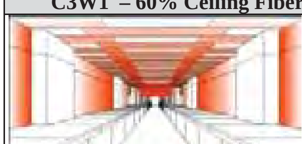
Mubarak Station



Sadat Station



C3W1 – 60% Ceiling Fiberglass Boards with Perforated Wall Panels Noise Reduction

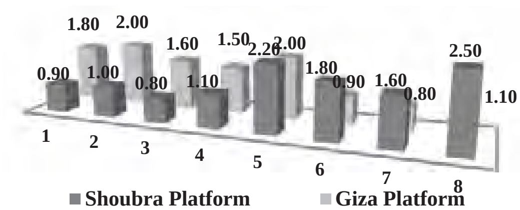


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=1.5 dB(A)
Maximum NR=2.5 dB(A)
Sadat: Average NR=1.6 dB(A)
Maximum NR=3 dB(A)

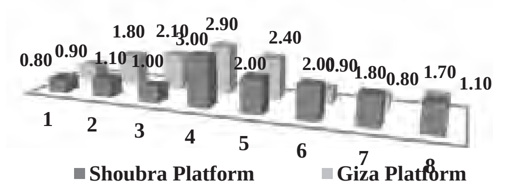
Noise Reduction approximated to the nearest 0.5 dB

Average 1.5 dB(A)	**Maximum 3 dB(A)**

Mubarak Station



Sadat Station



C4W1 - 80% Ceiling Fiberglass Boards with Perforated Wall Panels Noise Reduction

Most Noise Reduction is near the train at the end of Both Platforms

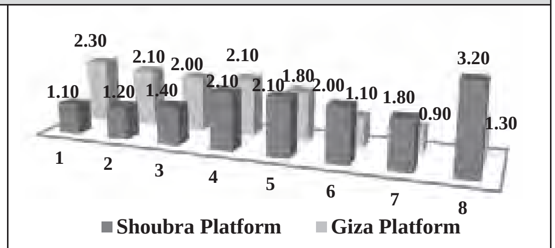
Mubarak: Average NR=1.7 dB(A)
Maximum NR=3.2 dB(A)

Sadat: Average NR=1.8 dB(A)
Maximum NR=3.4 dB(A)

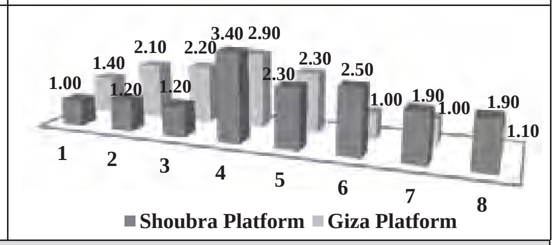
Noise Reduction approximated to the nearest 0.5dB

Average	Maximum
1.5 dB(A)	**3.5 dB(A)**

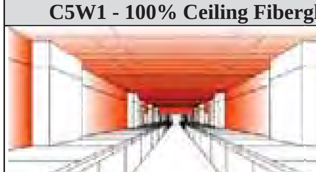
Mubarak Station



Sadat Station



C5W1 - 100% Ceiling Fiberglass Boards with Perforated Wall Panels Noise Reduction



Most Noise Reduction is near the train at the end of Both Platforms

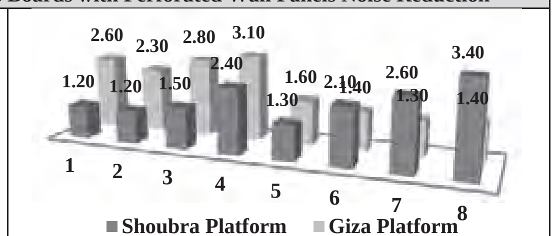
Mubarak: Average NR=2 dB(A)
Maximum NR=3.4 dB(A)

Sadat: Average NR=1.8 dB(A)
Maximum NR=3.7 dB(A)

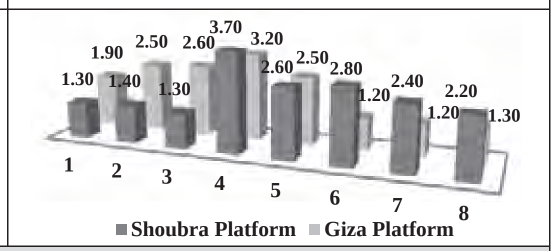
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
2 dB(A)	**3.5 dB(A)**

Mubarak Station



Sadat Station



C6W1 - False Ceiling 80% Fiberglass Boards with Perforated Wall Panels Noise Reduction

Most Noise Reduction is near the train at the end of Both Platforms

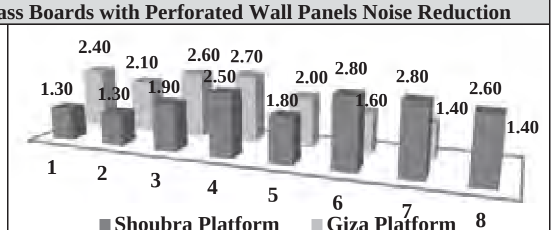
Mubarak: Average NR=2 dB(A)
Maximum NR=2.8 dB(A)

Sadat: Average NR=2 dB(A)
Maximum NR=3 dB(A)

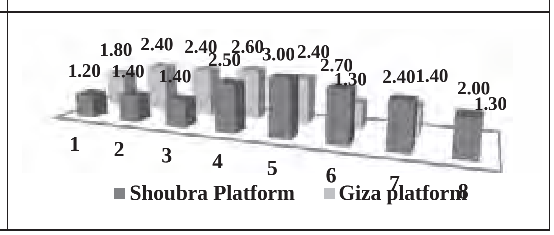
Noise Reduction approximated to the nearest 0.5 dB

Average	Average
2 dB(A)	**3 dB(A)**

Mubarak Station



Sadat Station



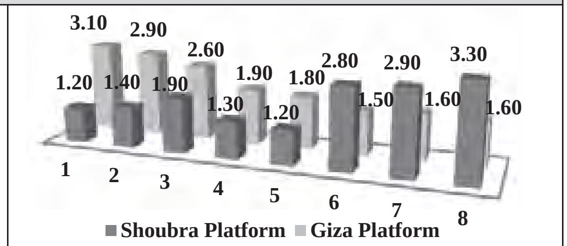
C7W1 – False Ceiling 100% Fiberglass Boards with Perforated Wall Panels Noise Reduction

Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=2 dB(A)
Maximum NR=3.3 dB(A)
Sadat: Average NR=2.7 dB(A)
Maximum NR=4 dB(A)

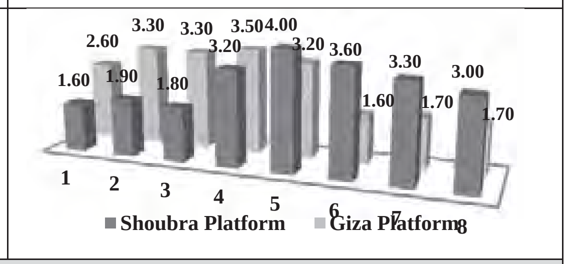
Noise Reduction approximated to the nearest 0.5 dB

Average 2.5 dB(A)	**Maximum 4 dB(A)**

Mubarak Station



Sadat Station



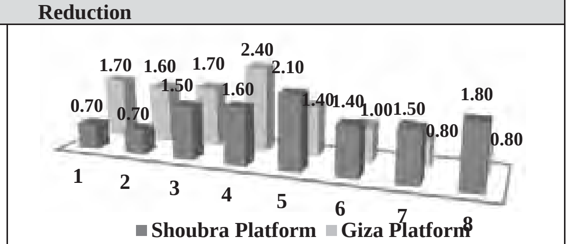
C8W1 –Hanged Absorbers 60% of ceiling area Fiberglass Boards with Perforated Wall Panels Noise Reduction

Gradual Increase in Noise Reduced with more Hanged Absorbers in Train Direction
Mubarak: Average NR=1.4 dB(A)
Maximum NR=2.4dBA
Sadat: Average NR=1.6 dB(A)
Maximum NR=2.8 dB(A)

Noise Reduction approximated to the nearest 0.5 dB

Average 1.5 dB(A)	**Average 3 dB(A)**

Mubarak Station



Sadat Station

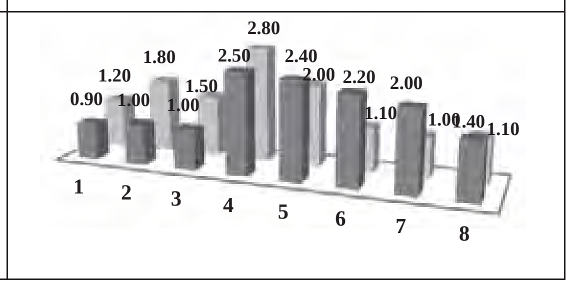


Figure 6-14: A-Weighted SPL Noise Reduction After False Ceiling Treatment At Receiver Points On Both Sadat Station Platforms.

6.6. Ceiling, Wall and Under-Platform treatments

Noise reduction achieved after applying acoustic treatments to ceiling, wall and under-platform sidewalls is very significant, Yet not economically efficient. Highest noise reduction achieved from treatments reached 10.5 dB(A) by total covering of ceiling with Fiberglass boards.

6.6.1.1. <u>Sound level Distribution</u>

The frequency contents for train noise on platform front, middle section and end are illustrated for treatment alternatives at three receiver points 1, 5 and 8; see Figure 6-16.

Comparing the treatments alternatives, the greatest difference in level among platform receivers is about 10 dB at mid frequencies by total covering of ceiling area, part of walls, under-platform sidewalls treated

Average and Maximum A-weighted SPL reduced due to treatment alternatives ranges from 3.5 to 6.5 dB(A) and from 6.5 to 10.5 dB(A) respectively.

Ceiling, wall and Under-Platform sidewalls Treatments effect	
Shoubra Platform	Giza Platform

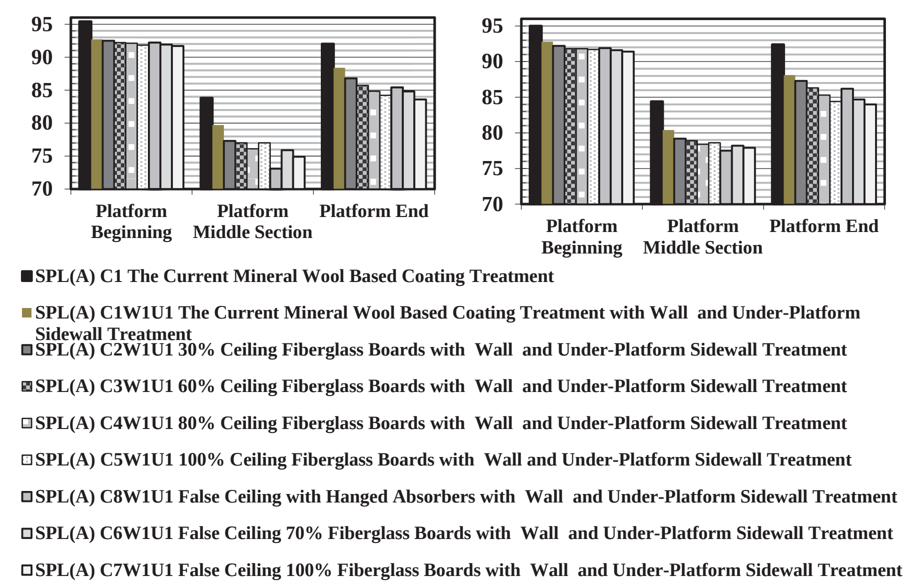
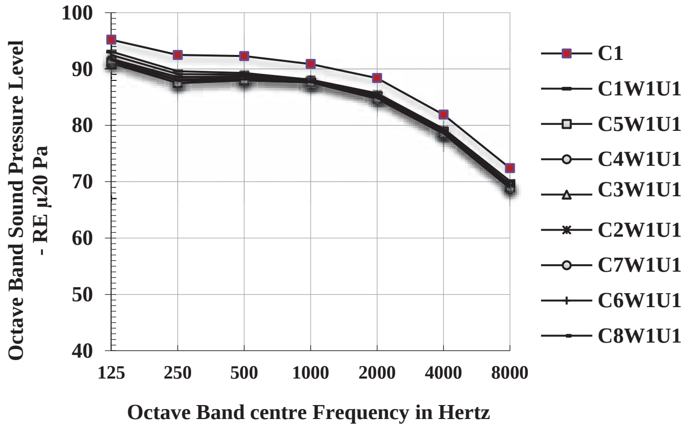
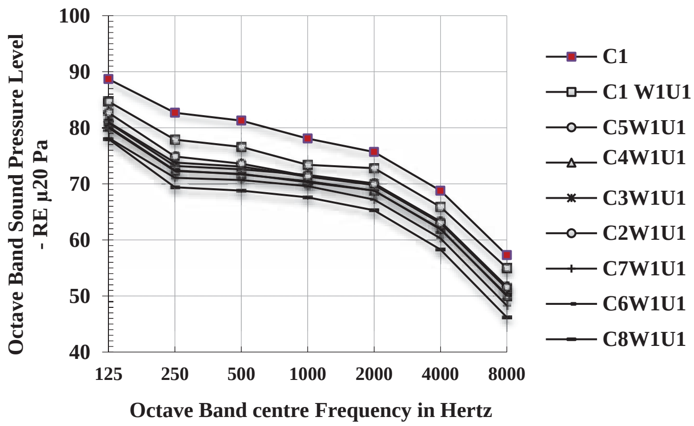


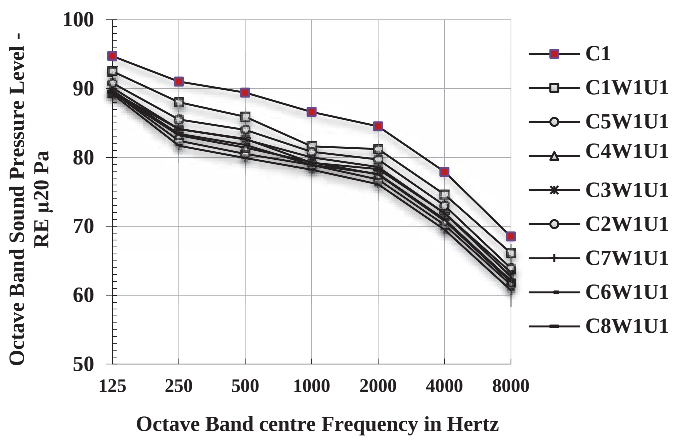
Figure 6-15:A-Weighted SPL At Both Station Platform Front, Middle Section And End After Ceiling And Under-Platform Sidewalls Treatment



Maximum SPL at Receiver 1 at Platform Front.



Maximum SPL at Receiver 5 at Platform Middle section.



Maximum SPL At Receiver 8 At Platform End.

Figure 6-16:Maximum SPL At The Station Front, Middle Section And End With Ceiling And Perforated Wall Panels Treatments

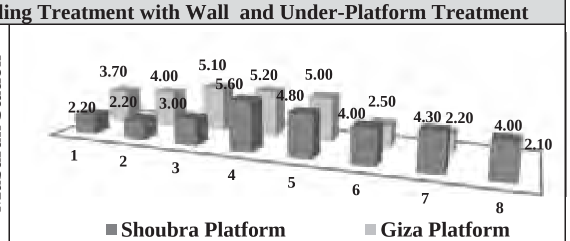
C1W1U1–The Current acoustical Ceiling Treatment with Wall and Under-Platform Treatment

Low Noise reduction along the station platforms
Mubarak: Average NR=3.7 dB(A)
Maximum NR=5.6 dB(A)
Sadat: Average NR=3.8 dB(A)
Maximum NR=7.1 dB(A)

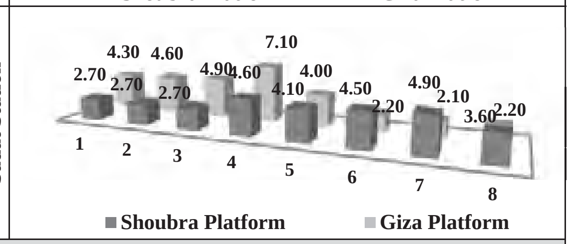
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
3.5 dB(A)	**6.5 dB(A)**

Mubarak Station



Sadat Station



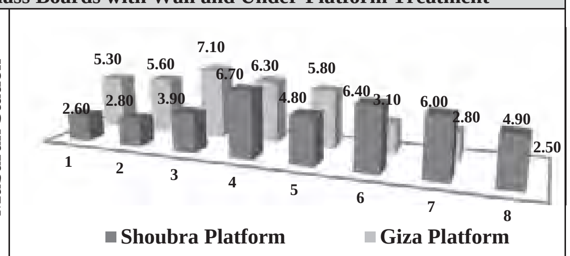
C2W1U1–30% Ceiling Fiberglass Boards with Wall and Under-Platform Treatment

Low Noise reduction along the station platforms
Mubarak: Average NR=4.5 dB(A)
Maximum NR=6.9 dB(A)
Sadat: Average NR=4.8 dB(A)
Maximum NR=7.1 dB(A)

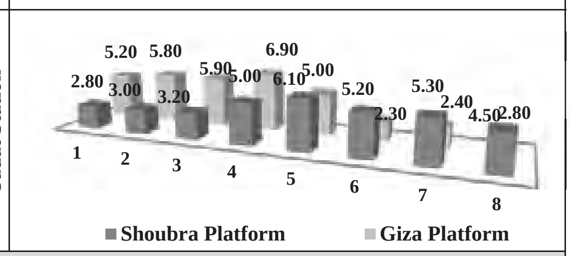
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
4.5 dB(A)	**7 dB(A)**

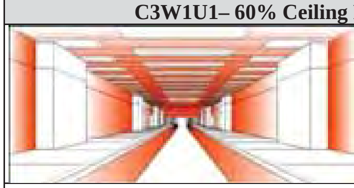
Mubarak Station



Sadat Station



C3W1U1– 60% Ceiling Fiberglass Boards with Wall and Under-Platform

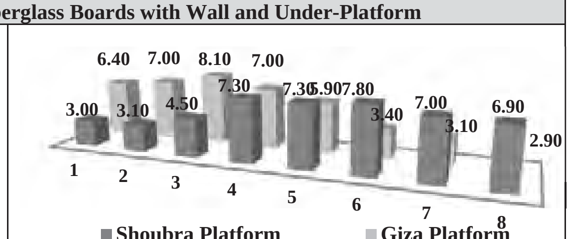


Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=5.7dBA
Maximum NR=8.1 dB(A)
Sadat: Average NR=5.2 dB(A)
Maximum NR=7.8 dB(A)

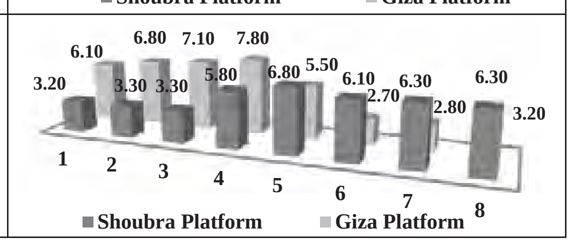
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
5.5 dB(A)	**8 dB(A)**

Mubarak Station



Sadat Station



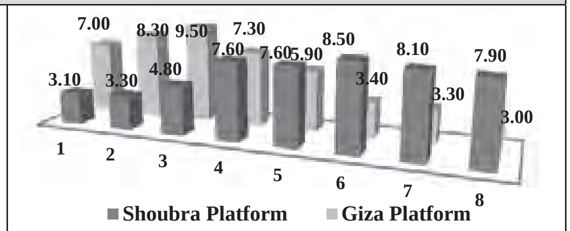
C4W1U1 – 80% Ceiling Fiberglass Boards with Wall and Under-Platform Treatments

Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=6.2 dB(A)
Maximum NR=9.5 dB(A)
Sadat: Average NR=5.7 dB(A)
Maximum NR=8.6 dB(A)

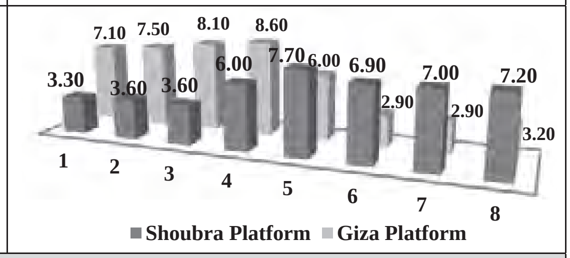
Noise Reduction approximated to the nearest 0.5dB

Average	Maximum
6 dB(A)	**9.5 dB(A)**

Mubarak Station



Sadat Station



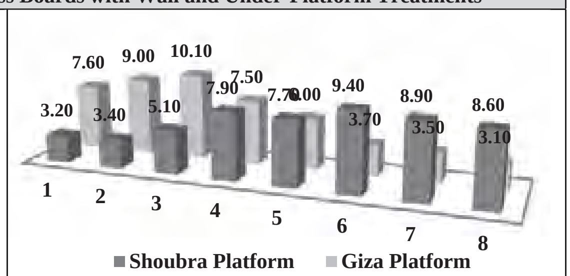
C5W1U1 –100% Ceiling Fiberglass Boards with Wall and Under-Platform Treatments

Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=6.5 dB(A)
Maximum NR=10 dB(A)
Sadat: Average NR=6 dB(A)
Maximum NR=8.9 dB(A)

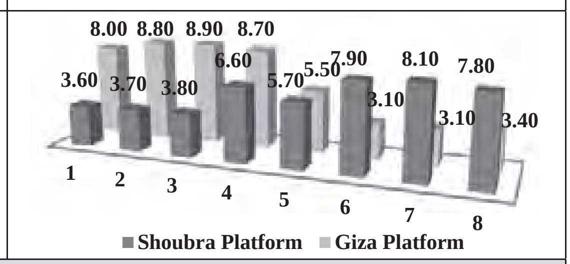
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
6.5 dB(A)	**10 dB(A)**

Mubarak Station



Sadat Station



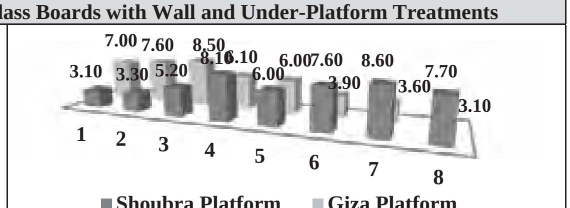
C6W1U1-False Ceiling 80% Fiberglass Boards with Wall and Under-Platform Treatments

Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=6 dB(A)
Maximum NR=8.6 dB(A)
Sadat: Average NR=5.9 dB(A)
Maximum NR=8.4 dB(A)

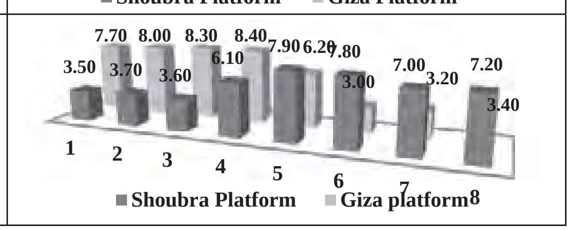
Noise Reduction approximated to the nearest 0.5 dB

Average	Average
6 dB(A)	**8.5 dB(A)**

Mubarak Station



Sadat Station



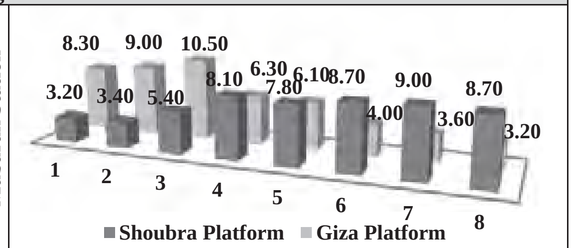
C7W1U1-False Ceiling 100% Fiberglass Boards with Wall and Under-Platform Treatments

Most Noise Reduction is near the train at the end of Both Platforms
Mubarak: Average NR=6.5 dB(A)
Maximum NR=10.5 dB(A)
Sadat: Average NR=6.4 dB(A)
Maximum NR=9.2 dB(A)

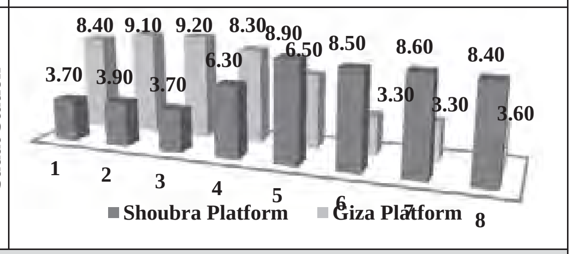
Noise Reduction approximated to the nearest 0.5 dB

Average	Maximum
6.5 dB(A)	10.5 dB(A)

Mubarak Station



Sadat Station



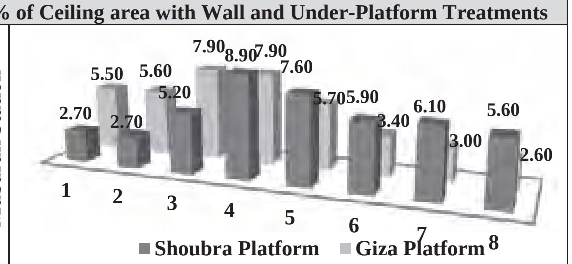
C8W1U1–Hanged Acoustical Baffles 60% of Ceiling area with Wall and Under-Platform Treatments

Gradual Increase in Noise Reduced with more Hanged Absorbers in Train Direction
Mubarak: Average NR=5.4 dB(A)
Maximum NR=8.9 dB(A)
Sadat: Average NR=5.7 dB(A)
Maximum NR=10.7 dB(A)

Noise Reduction approximated to the nearest 0.5 dB

Average	Average
5.5 dB(A)	10.5 dB(A)

Mubarak Station



Sadat Station

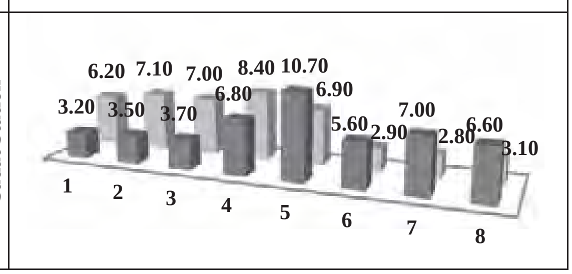


Figure 6-17: A-Weighted SPL Noise Reduction After False Ceiling Treatment At Receiver Points On Both Sadat Station Platforms.

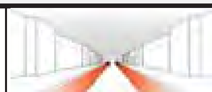
Acoustical Treatments Effect

Under-Platform Sidewalls Treatment

Maximum Noise Reduction | Average Noise Reduction

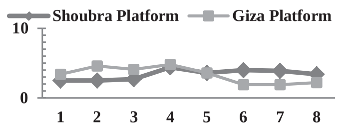
C1U1

Treatment Area = 800 m^2



Average NR:3.5 dB(A) Barely Perceptible Noise Reduction

Max. NR:5 dB(A) Noticeable Noise Reduction

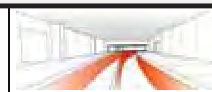


Barrier and Under-Platform Sidewalls Treatment

Maximum Noise Reduction | Average Noise Reduction

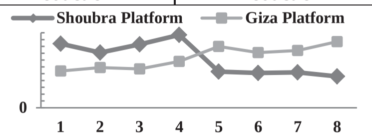
C1U2

Treatment Area = 1530 m^2



Average NR:7 dB(A) Clearly noticeable Noise Reduction

Max. NR:10.5 dB(A) Half as loud Noise Reduction

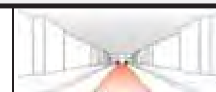


Ballast at Track-Bed Treatment

Maximum Noise Reduction | Average Noise Reduction

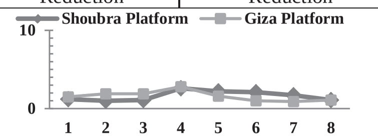
C1U3

Treatment Area = 950 m^2



Average NR:1.5 dB(A) Imperceptible Noise Reduction

Max. NR:3 dB(A) barely perceptible Noise Reduction



Legend

Symbol	Treatment Description
C1	Current Treatment (Acoustic Paint)
C2	30% fiberglass Boards with current treatment
C3	60% fiberglass Boards with current treatment
C4	80% fiberglass Boards with current treatment
C5	100% fiberglass Boards
C6	80% Fiberglass Boards on False Ceiling
C7	100% fiberglass Boards on False Ceiling
C8	Hanged Absorbers
U1	Under-Platform sidewalls treatment
U2	Barrier and under-platform sidewalls treatment
U3	Ballast at track-bed
W1	Perforaterd wall panels packed with 2" Fiberglass

Ceiling Treatment

Average Noise Reduction | Maximum Noise Reduction

Ceiling and Under-Platform Sidewalls Treatment

Average Noise Reduction | Maximum Noise Reduction

Wall Panels and Ceiling Treatment

Average Noise Reduction | Maximum Noise Reduction

Wall Panels, Ceiling and Under-Platform Treatment

Average Noise Reduction | Maximum Noise Reduction

Combination of the Current Ceiling Mineral Wool Based Coating, wall and Under-Platform treatments

C1

Current Treatment area = 2185 m^2

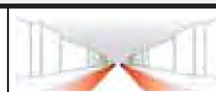
-

-

-

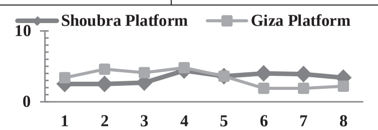
C1 U1

Treatment Area = 800 m^2



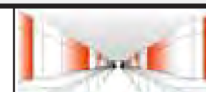
Average NR:3.5 dB(A) Barely Perceptible Noise Reduction

Max. NR:5 dB(A) Noticeable Noise Reduction



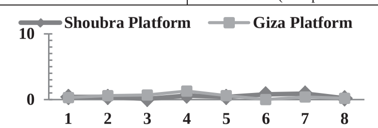
C1 W1

Wall Panels Area = 950 m^2



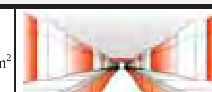
Average NR:0.5 dB Imperceptible Noise Reduction

Max. NR:2 dB Imperceptible Noise Reduction (Except for Tones)



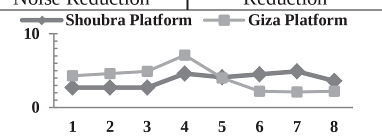
C1 W1 U1

Wall Panels Area = 950
Under-Platform Area = 800 m^2



Average NR:3.5 dB Just barely perceptible Noise Reduction

Max. NR:6.5 dB Clearly noticeable Noise Reduction



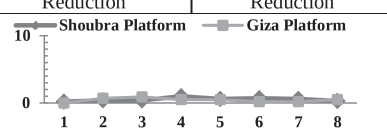
Combination of 30% Fiber Glass Boards on ceiling with the current Treatment, wall and Under-Platform Treatments

C2

30 % Fiber Glass Boards the rest Acoustic paint
Ceiling Area = 870 m^2

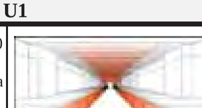
Average NR:0.5 dB Imperceptible Noise Reduction

Max. NR:1 dB Imperceptible Noise Reduction



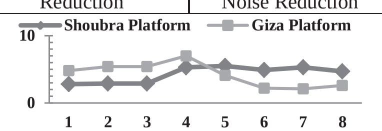
C2 U1

30 % Fiber Glass Boards = 870 m^2 the rest Acoustic paint
Under-Platform Sidewalls Area = 800 m^2



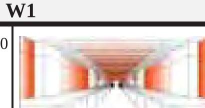
Average NR:4.5 dB(A) perceptible Noise Reduction

Max. NR:6.5 dB(A) Clearly Noticeable Noise Reduction



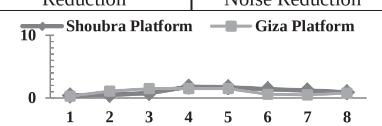
C2 W1

30 % Fiber Glass Boards = 870 m^2
the rest Acoustic paint
Wall Panels Area = 950 m^2



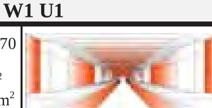
Average NR:1 dB Imperceptible Noise Reduction

Max. NR:3 dB Just barely perceptible Noise Reduction



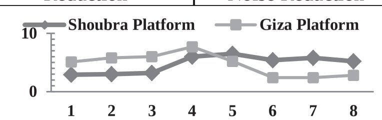
C2 W1 U1

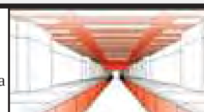
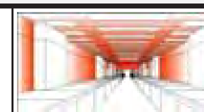
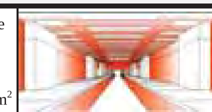
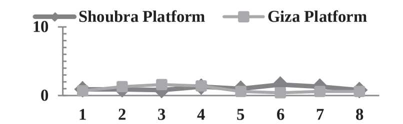
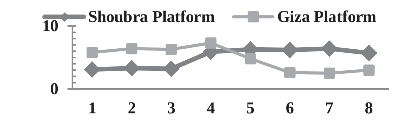
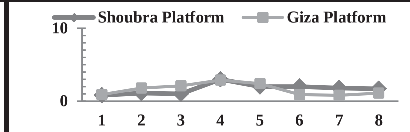
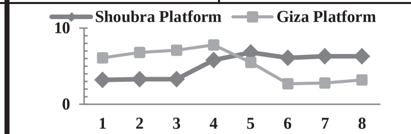
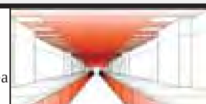
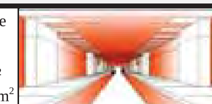
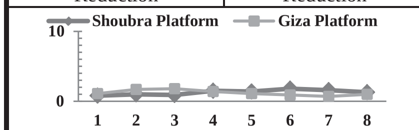
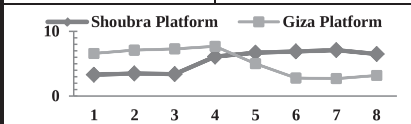
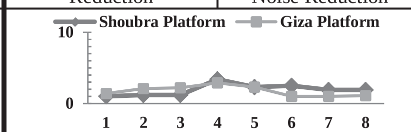
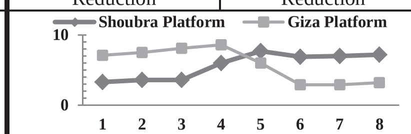
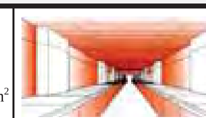
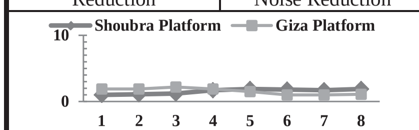
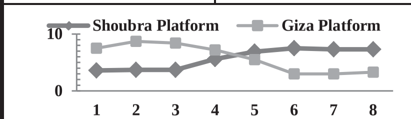
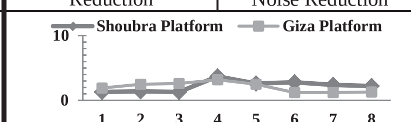
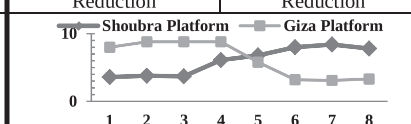
30 % Fiber Glass Boards = 870 m^2 the rest Acoustic paint
Wall Panels Area = 950 m^2
Under-Platform Area = 800 m^2



Average NR:4.5 dB Noticeable Noise Reduction

Max. NR:7 dB Clearly noticeable Noise Reduction



Acoustical Treatments Effect							
Ceiling Treatment		**Ceiling and Under-Platform Sidewalls Treatment**		**Wall Panels and Ceiling Treatment**		**Wall Panels, Ceiling and Under-Platform Treatment**	
Average Noise Reduction	Maximum Noise Reduction	Average Noise Reduction	Maximum Noise Reduction	Average Noise Reduction	Maximum Noise Reduction	Average Noise Reduction	Maximum Noise Reduction
Combination of 60% Fiber Glass Boards on ceiling with the Current Ceiling Treatment, wall and Under-Platform Treatments							
C3		**C3 U1**		**C3 W1**		**C3 W1 U1**	
60 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1300 m^2		60 % Fiber Glass Boards the rest Acoustic paint Ceiling Area = 1300 m^2 Under-Platform Sidewalls Area = 800 m^2		60 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1300 m^2 Wall Panels Area = 950 m^2		60 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1300 m^2 Wall Panels Area = 950 m^2 Under-Platform Area = 800 m^2	
Average NR:1 dB Imperceptible Noise Reduction	**Max. NR:1.8 dB** Imperceptible Noise Reduction	**Average NR:5 dB(A)** Noticeable Noise Reduction	**Max. NR:7.5 dB(A)** Clearly Noticeable Noise Reduction	**Average NR:1.5 dB** Imperceptible Noise Reduction	**Max. NR:3 dB** Just barely perceptible Noise Reduction	**Average NR:5.5 dB** Clearly noticeable Noise Reduction	**Max. NR:8 dB** Clearly noticeable Noise Reduction
							
Combination of 80% Fiber Glass Boards on ceiling with the Current Ceiling Treatment, wall and Under-Platform Treatments							
C4		**C4 U1**		**C4 W1**		**C4 W1 U1**	
80 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1700 m^2		80 % Fiber Glass Boards the rest Acoustic paint Ceiling Area = 1700 m^2 Under-Platform Sidewalls Area = 800 m^2		80 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1700 m^2 Wall Panels Area = 950 m^2		80 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1700 m^2 Wall Panels Area = 950 m^2 Under-Platform Area = 800 m^2	
Average NR:1.5 dB Imperceptible Noise Reduction	**Max. NR:2 dB** Imperceptible Noise Reduction	**Average NR:5.5 dB(A)** Clearly Noticeable Noise Reduction	**Max. NR:8.5 dB(A)** Clearly noticeable Noise Reduction	**Average NR:1.5 dB** Imperceptible Noise Reduction	**Max. NR:3.5 dB** Just barely perceptible Noise Reduction	**Average NR:6 dB** Clearly noticeable Noise Reduction	**Max. NR:9.5 dB** Half as Loud Noise Reduction
							
Combination of 100% Fiber Glass Boards on ceiling with the Current Ceiling Treatment, wall and Under-Platform Treatments							
C5		**C5 U1**		**C5 W1**		**C5 W1 U1**	
100 % Fiber Glass Boards Ceiling Area = 2185 m^2		100 % Fiber Glass Boards Ceiling Area = 2185 m^2 Under-Platform Sidewalls Area = 800 m^2		100 % Fiber Glass Ceiling Area = 2185 m^2 Wall Panels Area = 950 m^2		100 % Fiber Glass Boards Ceiling Area = 2185 m^2 Wall Panels Area = 950 m^2 Under-Platform Area = 800 m^2	
Average NR:1.5 dB Imperceptible Noise Reduction	**Max. NR:3 dB** Just barely perceptible Noise Reduction	**Average NR:6 dB(A)** Clearly Noticeable Noise Reduction	**Max. NR:9 dB(A)** Half as loud Noise Reduction	**Average NR:2 dB** Imperceptible Noise Reduction	**Max. NR:3.5 dB** Just barely perceptible Noise Reduction	**Average NR:6.5 dB** Clearly noticeable Noise Reduction	**Max. NR:10 dB** Half as Loud Noise Reduction
							

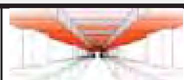
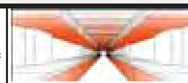
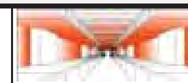
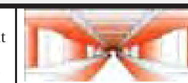
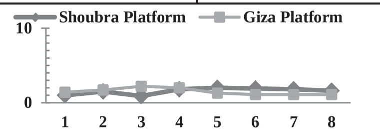
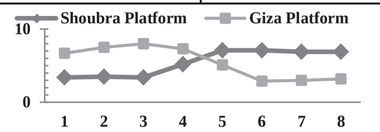
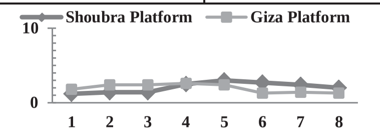
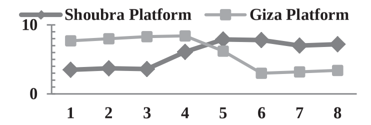
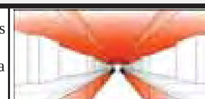
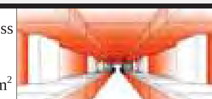
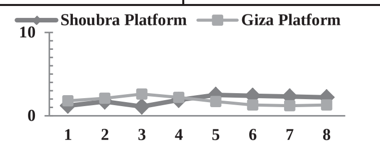
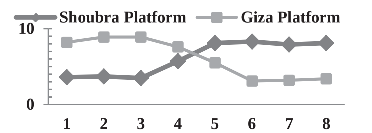
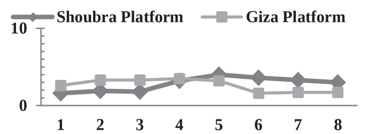
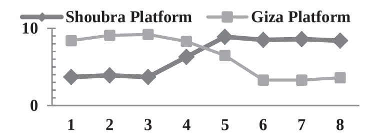
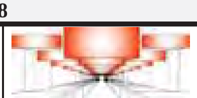
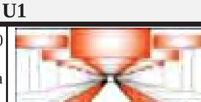
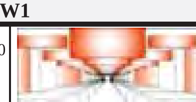
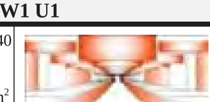
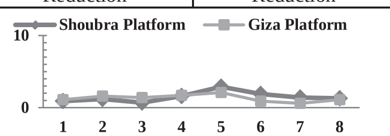
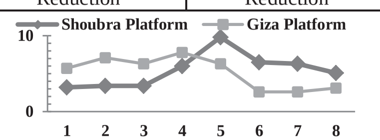
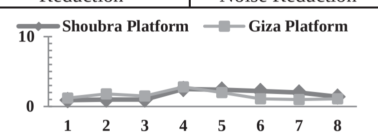
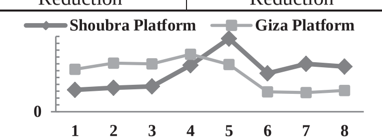
Acoustical Treatments Effect							
Ceiling Treatment		Ceiling and Under-Platform Sidewalls Treatment		Wall Panels and Ceiling Treatment		Wall Panels, Ceiling and Under-Platform Treatment	
Average Noise Reduction	Maximum Noise Reduction	Average Noise Reduction	Maximum Noise Reduction	Average Noise Reduction	Maximum Noise Reduction	Average Noise Reduction	Maximum Noise Reduction
Combination of 80% Fiber Glass Boards on False Ceiling, wall and Under-Platform Treatments							
C6		C6 U1		C6 W1		C6 W1 U1	
False Ceiling 80 % Fiber Glass Boards the rest acoustic paint Ceiling Area = 1783 m^2		False Ceiling80 % Fiber Glass= 1783 m^2 the rest acoustic paint Under-Platform Sidewalls Area = 800 m^2		False Ceiling 80 % Fiber Glass the rest acoustic paint Ceiling Area = 1783 m^2 Wall Panels Area = 950 m^2		False ceiling 80 % Fiber Glass = 1783 m^2 the rest acoustic paint Wall Panels Area = 950 m^2 Under-Platform Area = 800 m^2	
Average NR:1 dB Imperceptible Noise Reduction	**Max. NR:2 dB** Imperceptible Noise Reduction	**Average NR:5.5 dB(A)** Clearly Noticeable Noise Reduction	**Max. NR:8 dB(A)** Clearly Noticeable Noise Reduction	**Average NR:2 dB** Imperceptible Noise Reduction	**Max. NR:3 dB** Just barely perceptible Noise Reduction	**Average NR:6 dB** Clearly noticeable Noise Reduction	**Max. NR:8.5 dB** Clearly noticeable Noise Reduction
							
Combination of False Ceiling with 100% Fiber Glass Boards, wall and Under-Platform Treatments							
C7		C7 U1		C7 W1		C7 W1 U1	
False Ceiling 100 % Fiber Glass Boards Ceiling Area = 2485 m^2		False Ceiling100 % Fiber Glass Ceiling Area = 2485 m^2 Under-Platform Sidewalls Area = 800 m^2		False Ceiling 100 % Fiber Glass Ceiling Area = 2485 m^2 Wall Panels Area = 950 m^2		False ceiling 100% Fiber Glass Ceiling Area = 2485 m^2 Wall Panels Area = 950 m^2 Under-Platform Area = 800 m^2	
Average NR:1.5dB Imperceptible Noise Reduction	**Max. NR:3 dB** Just barely perceptible Noise Reduction	**Average NR:6 dB(A)** Clearly noticeable Noise Reduction	**Max. NR:9.5 dB(A)** Half as loud Noise Reduction	**Average NR:2.5 dB** Just barely perceptible Noise Reduction	**Max. NR:4 dB** Just barely perceptible Noise Reduction	**Average NR:6.5 dB** Clearly noticeable Noise Reduction	**Max. NR:10.5 dB** Half as Loud Noise Reduction
							
Combination of Hanged Acoustical Baffles with the current ceiling Treatment, with wall and Under-Platform Treatments							
C8		C8 U1		C8 W1		C8 W1 U1	
Hanged Absorbers Area = 1640 m2		Hanged Absorbers Area = 1640 m2 Under-Platform Sidewalls Area = 800 m^2		Hanged Absorbers Area = 1640 m2 Wall Panels Area = 950 m^2		Hanged Absorbers Area = 1640 m2 Wall Panels Area = 950 m^2 Under-Platform Area = 800 m^2	
Average NR:1 dB Imperceptible Noise Reduction	**Max. NR:2 dB** Imperceptible Noise Reduction	**Average NR:5 dB(A)** Imperceptible Noise Reduction	**Max. NR:10 dB(A)** Imperceptible Noise Reduction	**Average NR:1.5 dB** Imperceptible Noise Reduction	**Max. NR:3 dB** Just barely perceptible Noise Reduction	**Average NR:5.5 dB** Clearly noticeable Noise Reduction	**Max. NR:10.5 dB** Half as Loud Noise Reduction
							

Table 6-1:Average And Maximum A-Weighted SPL Noise Reduction For All Proposed Acoustic Treatments To The Platforms The Selected Underground Stations.

Conclusion

Conclusion

Noise reduction resulting from applying acoustical treatments to the platform ceiling, walls and station under-platform area reached 10 dB, which is recommended by the acoustical design guidelines. Noise reduction expected from treating the underground station range from 5 to10 dB and 10 to 15 dB according to the APTA association and the Institute for Rapid Transit respectively. [3], [18]

The current ceiling acoustic treatment is efficient in reducing the reverberation time in the platform space, yet platform noise levels exceed allowable limits. Further acoustic treatments applied to the platform ceiling currently treated with the mineral wool based coating in the form of fiberglass boards provided imperceptible noise reduction.

A graph was plotted to show the relation between the area of sound absorbing materials and the corresponding noise reduction; see Figure 6-18 to Figure 6-21. Results showed that Ceiling and under-platform locations were the most appropriate treatment locations that reduce train noise levels in the selected stations. Under-platform area is the nearest location to the noise source thus reduces train noise before reflecting in the platform space. While ceiling treatment reduce the reverberant field and the crowd noises; see Table 6-2.

- Further acoustic treatments applied to the platform ceiling with mineral wool based coating in the form of fiberglass boards provided imperceptible noise reduction. While replacing the current treatment with fiberglass boards over the entire platform ceiling or over false ceiling provided barely perceptible noise reduction of 3 dB(A). Therefore, the current ceiling treatment with the mineral wool based coating is economically the best for reducing reverberation time values and the crowd noise; yet the current platform noise levels reach unacceptable limits and further acoustical treatments are needed.

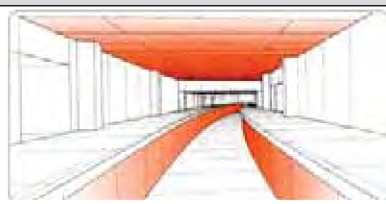
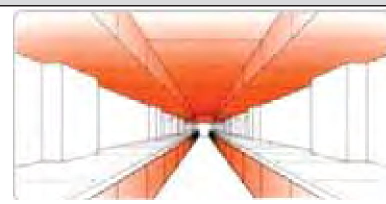
- Wall treatments applied in the platform level with the current ceiling treatment and the other proposed ones had no significant noise reduction in the platform area since wall location is relatively away from the train noise source, besides passenger are subjected to noise directly before it reach the wall treatment location, but it can reduce crowds' noises and reduce reverberation. Highest noise reduction achieved from ceiling and wall treatments acoustical simulation was 2 dB(A) by totally covering ceiling with fiberglass boards in addition to the wall treatment.

- Under-platform treatments provide significant sound absorption directly near the source besides they provide reduction of the reverberant sound energy build-up. Applying sound absorbing material to barrier between tracks and under-platform sidewalls achieved maximum noise reduction among all proposed treatments; yet installing barriers between tracks faces some restrictions concerning track dimensions and train movement. Under-platform sidewalls treatment provided noise reduction that reached 5 dB(A) while Ballast applied to track-bed provided 3 dB(A) noise reduction equivalent to covering the entire ceiling with fiberglass boards.

- The most noise reduction resulting from acoustic treatments combinations is attributed to fully treated ceiling either false or fixed directly to ceiling with wall and under-platform treatment, while a close noise reduction is achieved with the last mentioned treatments except for the wall treatment. (C5, C5W1, C5U1 and C5W1U1) and (C7, C7W1, C7U1 and C7W1U1) are two groups of alternatives that achieved the highest noise level reduction among all proposed treatments. In both groups Fiberglass boards (with perforated facing) covers the entire ceiling, except for C7 fiberglass boards are applied on false ceiling; see Table 6-1. The entire ceiling is acoustically treated with Fiberglass boards (with perforated facing) as in many underground stations like Bonn City railway stations or London Underground Central Line stations, which is rather expensive to recommend in the Egyptian current context.

    - C7 W1 U1 provided 10.5 dB(A) maximum noise reduction which is half as loud as the noise source and 6.5 dB(A) average noise reduction which is clearly noticeable. In this alternative. Sound absorbing materials overall area for all used treatments was 4235 m2; 2485 m2 for ceiling, 950 m2 for wall and 800 m2 for under-platform area. This is not costly-effective as there are some optimum ranges of coverage extent that give the maximum return in terms of noise reduction resulting from the material installed.

    - (C5U1 and C7U1) alternatives provided clearly noticeable noise reduction over both stations platforms with least acoustical materials among all alternatives and also achieved maximum noise reduction that reached 9 dB(A) half as loud as the noise source. Yet covering the entire ceiling with sound absorbing material is not costly-effective. Yet, applying false ceiling over the platform with uniformly distributed sound absorbing tiles can provide acceptable and uniform noise reduction.

C5W1U1	**C7W1U1**
 **100 % Fiber Glass Boards** **Ceiling Area = 2185 m2** **Wall Panels Area = 950 m^2** **Under-Platform Sidewalls Area = 800 m2**	 **100 % Fiber Glass Boards** **Ceiling Area = 2185 m^2** **Wall Panels Area = 950 m^2** **Under-Platform Area = 800 m^2**
C5U1	**C7U1**
 **100 % Fiber Glass Boards** **Ceiling Area = 2185 m2** **Under-Platform Area = 800 m2**	 **False Ceiling100 % Fiber Glass** **Ceiling Area = 2485 m2** **Under-Platform Sidewalls Area = 800 m2**

– The requirements for fire resistance, mechanical durability and cleanability of the sound absorption material to be used in underground station platform and tunnels faces considerable limitations as the sound absorbing materials and their retention hardware must be able to withstand high-pressure wash and other cleaning methods that might be employed in the underground station environments.

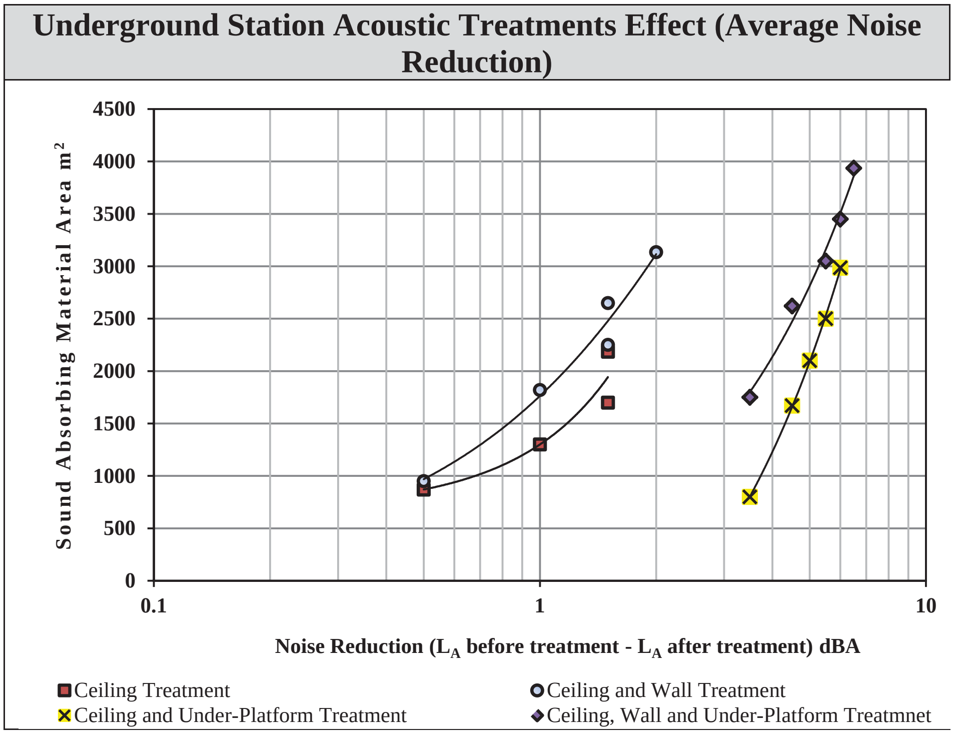


Figure 6-18: Average A-Weighted SPL Noise Reduction After Applying Proposed Acoustic Treatments For The Selected Underground Stations.

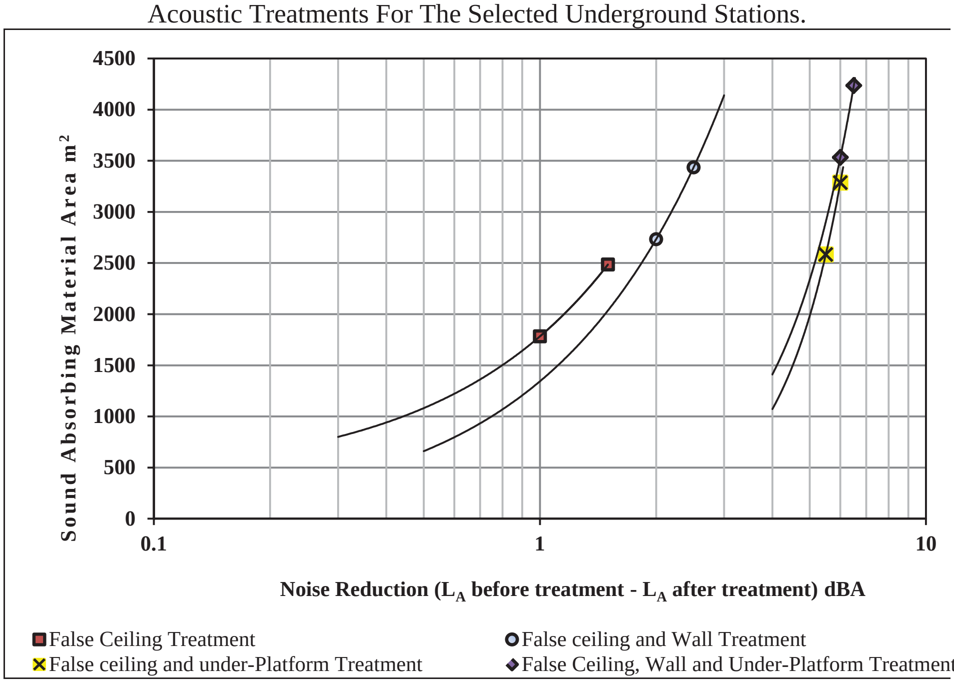


Figure 6-19:Average A-Weighted SPL Noise Reduction After Applying Proposed Acoustic Treatments For The Selected Underground Stations. (False Ceiling)

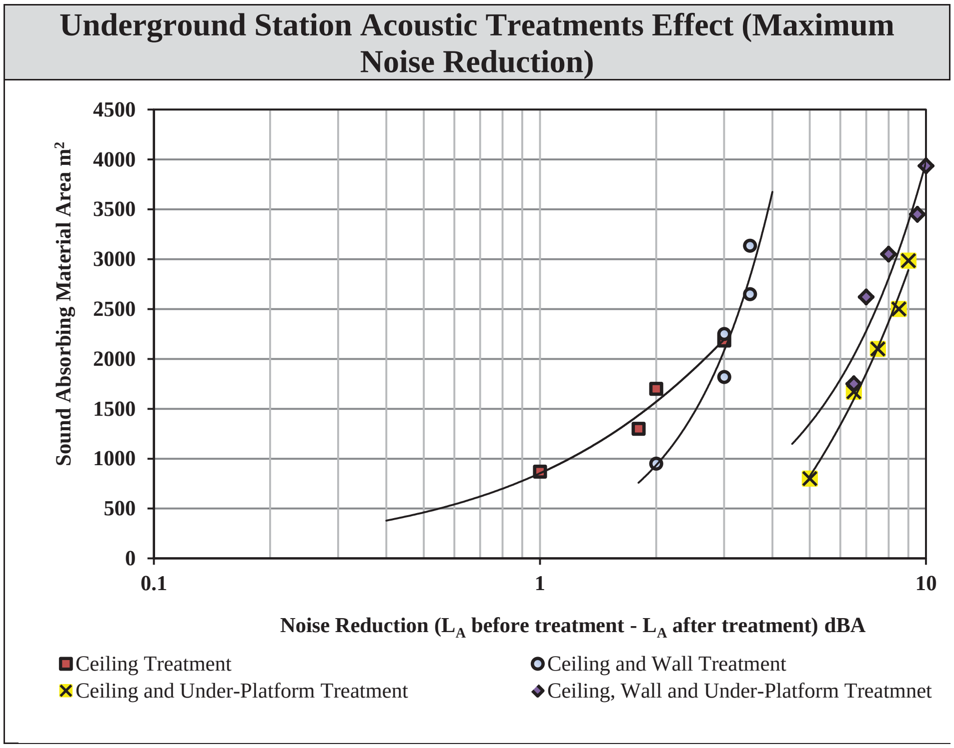


Figure 6-20: Maximum A-Weighted SPL Noise Reduction After Applying Proposed Acoustic Treatments For The Selected Underground Stations.

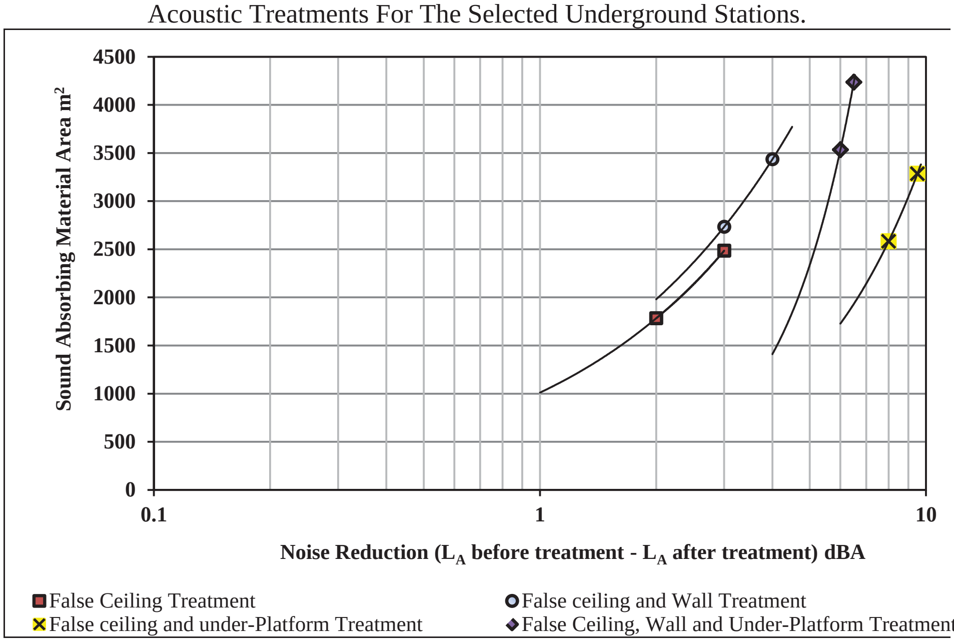


Figure 6-21: Maximum A-Weighted SPL Noise Reduction After Applying Proposed Acoustic Treatments For The Selected Underground Stations. (False Ceiling)

	Treatment applied to Current Ceiling		False Ceiling	Hanged

								Acoustical Baffles
	Ceiling Treatment							
Treatments	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
Ceiling Area	-	30% 870 m2	60% 1300 m2	80% 1700 m2	100% 2185 m2	80% 1783 m2	100% 2485 m2	60% 1640 m2
Average NR dB(A)	-	0.5	1	1.5	1.5	1	1.5	1
Max. NR dB(A)		1	1.8	2	3	2	3	2
	Ceiling and Under-Platform Treatment							
Treatment	**C1 U1**	**C2 U1**	**C3 U1**	**C4 U1**	**C5 U1**	**C6 U1**	**C7 U1**	**C8 U1**
Ceiling Area	-	30% 870 m^2	60% 1300 m^2	80% 1700 m^2	100% 2185 m^2	80% 1783 m^2	100% 2485 m^2	60% 1640 m^2
Under-Platform Sidewalls Area	800m^2	800m2	800m2	800m2	800m2	800m2	800m2	800m2
Average NR dB(A)	3.5	4.5	5	5.5	6	5.5	6	5
Max. NR dB(A)	5	6.5	7.5	8.5	9	8	9.5	10
	Ceiling and Wall Treatment							
Treatment	**C1 W1**	**C2 W1**	**C3 W1**	**C4 W1**	**C5 W1**	**C6 W1**	**C7 W1**	**C8 W1**
Ceiling Area	-	30% 870 m2	60% 1300 m2	80% 1700 m2	100% 2185 m2	80% 1783 m2	100% 2485 m2	60% 1640 m2
Wall Panels Area	950 m2	950 m2	950 m2	950 m2	950 m2	950 m2	950 m2	950 m2
Average NR dB(A)	0.5	1	1.5	1.5	2	2	2.5	1.5
Max. NR dB(A)	2	3	3	3.5	3.5	3	4	3
	Ceiling, Wall and Under-Platform Treatment							
Treatment	**C1 W1U1**	**C2 W1U1**	**C3W1 U1**	**C4U1W1**	**C5W1 U1**	**C6 U1 W1**	**C7 U1 W1**	**C8 U1 W1**
Ceiling Area	-	30% 870 m2	60% 1300 m2	80% 1700 m2	100% 2185 m2	80% 1783 m2	100% 2485 m2	60% 1640 m2
Wall Panels Area	950 m2	950 m2	950 m2	950 m2	950 m2	950 m2	950 m2	950 m^2
Under-Platform Sidewalls Area	800m2	800m2	800m2	800m2	800m2	800m2	800m2	800m^2
Average NR dB(A)	3.5	4.5	5.5	6	6.5	6	6.5	5.5
Max. NR dB(A)	6.5	7	8	9.5	10	6	6.5	5.5

	Under-Platform Treatment		
Ceiling Treatments	**C1U1**	**C1U2**	**C1U3**
Under-Platform Area	800 m2	1530 m2	950 m2
Average NR dB(A)	3.5	7	1.5
Max. NR dB(A)	5	10.5	3

Table 6-2:Average And Maximum A-Weighted SPL Noise Reduction For All Proposed Acoustic Treatments For The Selected Underground Stations.

Recommendations

Recommendations

- Train vehicle noise should be identified and quantified before applying acoustic treatments to underground stations.
- Vehicle noise should be brought first to the design limits assigned by authorities and acoustic design criteria with regular mechanical maintenance.
- Current measured platform maximum noise levels cannot be lowered to acceptable limits by treating the station alone; wheel\rail noise should simultaneously be addressed and reduced to the permissible limits.
- Internal TV circuits and public address systems besides the warning sirens that operate at every single train arrival on each platform should be lowered as they contribute to the overall noise levels that lead to unacceptable noise levels inside underground station.
- Under-platform acoustic treatments should be applied to lower platform noise levels, as applying acoustic materials to barriers between tracks and station under-platform sidewalls provide the highest noise reduction for railway noise that could reach 10 dB(A), while under-platform sidewalls treatment may provide significant noise reduction in the order of 5 dB(A) for railway noise, these treatment combine the advantages of economic use of acoustic materials and minimum interference with the station design.
- Sound absorption treatment should be extended at least 60m along the tunnels lower sidewalls to each side of the treated under-platform area to obtain full benefit from the Under-platform area treatment.

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جامعة عين شمس
كلية الهندسة
قسم الهندسة المعمارية

تأثير المعالجات المعمارية على البيئة الصوتية

دراسة حالة لبعض محطات مترو الانفاق

رسالة مقدمة من:

المهندسة / منار محمد حسن

بكالوريوس الهندسة المعمارية 2004 – جامعة عين شمس

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القاهرة

2010

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كلية الهندسة

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للحصول على درجة الماجستير في الهندسة المعمارية

تاريخ البحث : / / 2010

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أجيزت الرسالة بتاريخ:

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موافقة مجلس الجامعة

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إقــرار

هذا البحث مقدم إلى جامعة عين شمس للحصول على درجة الماجستير في الهندسة ، تم إنجاز هذا البحث بقسم الهندسة المعمارية ، بكلية الهندسة - جامعة عين شمس من عام 2006 إلى 2010.

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و هذا إقرار مني بذلك ،،،

التوقيع :

الاسم : منار محمد حسن حسين

التاريخ : 04 / 05/ 2010

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شكر و تقدير

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الباحثة

جامعة عين شمس
كلية الهندسة
قســـم الهندسة المعمارية

مستخلص الرسالة

رسالة بعنوان
عنوان البحث: تأثير المعالجات المعمارية على البيئة الصوتية
دراسة حالة لبعض محطات مترو الانفاق
للحصول على درجة الماجستير فى العمارة

مقدم من المهندسة / منار محمد حسن
معيدة بقسم العمارة-كلية الهندسة-جامعة عين شمس

تبحث هذه الدراسة تأثير اضافة المعالجات الصوتية داخل محطات نقل الركاب تحت الارض, حيث تم اختيار محطتين بشبكة مترو الانفاق (الخط الثانى) التى تزداد بهما مؤشرات الضوضاء على رصيف المحطة بهدف تحسين البيئة الصوتية من خلال مرحلتين : المرحلة الاولى, تقييم البيئة الصوتية داخل المحطات محل الدراسة عن طريق مجموعة من القياسات الحقلية لكل من مؤشرى زمن الترداد و منسوب ضغط الصوت ومقارنتها بالمعايير القياسية.و ثانيا, تطبيق بعض اساليب التحكم فى الضوضاء عن طريق المسار بالمعالجات الماصة للصوت بالمحطات محل الدراسة باستخدام برنامج المحاكاة (ODEON4.2) لمقارنة تأثير البدائل المختلفة من المعالجات الصوتية على خفض الضوضاء على رصيف المحطة وصولا الى رسم بيانى يوضح العلاقة بين مساحة المادة الماصة للصوت و الخفض المقابل فى الضوضاء داخل المحطات المختارة .أوضحت النتائج ان أفضل الأماكن لتوزيع المواد الماصة للصوت هى منطقة أسفل الرصيف و سقف المحطة نظرا لان منطقة اسفل الرصيف هى أقرب مكان لمصدر الضوضاء مما يؤدى الى خفض الضوضاء قبل الانعكاس على حدود المحطة و أما معالجة السقف فهى تمتص الضوضاء الناجمة عن الركاب بالاضافة الى خفض زمن الترداد.

الكلمات المفتاحية:
التحكم فى الضوضاء, المعالجات الصوتية, المعالجات المعمارية, التحكم فى الترداد, ضوضاء محطات مترو الأنفاق, ضوضاء محطات نقل الركاب السريعة.

ملخص الرسالة

1. المقدمة

تلقى مشكلات الضوضاء مؤخرا اهتمام كبير من قبل الجهات البحثية و المسئولة فى مصرلرصد مشكلات الضوضاء ومعرفة مصادرها. ومن مثل هذه المصادر,الضوضاء الناتجة عن وسائل المواصلات السريعة و خاصة محطات نقل الركاب تحت الارض مما أدى الى اهتمام كثير من الباحثين بدراسة هذه المشكلات وكيفية معالجتها لما يسببه التعرض المستمر للضوضاء من ضرر على صحة الانسان.

تزداد معدلات الضوضاء داخل محطات نقل الركاب تحت الارض عن مثيلاتها فى المحطات السطحية نظرا لانعكاس أصوات القطارعلى جسم النفق و حوائط المحطة.كما تتعدد مصادر الضوضاء داخل المحطات النفقية متمثلة فى أكثر من مصدر كأصوات القطارات المتواصلة ,ألات التنبيه, صافرة الانذار على الرصيف التى تعمل أليا لانذار الركاب عند دخول كل قطار, الدوائر التلفزيونية المغلقة و الإذاعة الداخلية, الضوضاء الناتجة عن أنظمة التكييف والتهوية و أخيرا ضوضاء الركاب . ولكن فى الاغلب تكون الضوضاء الناتجة عن احتكاك اطارات القطار و القضبان هى الغالبة على طبيعة الضوضاء .

كثير من الدراسات اختصت بتقييم البيئة الصوتية داخل محطات مترو الانفاق بمصر ومع ذلك الدراسات الخاصة بالمعالجات المعمارية و الصوتية محدودة جدا. تختص هذه الدراسة بطبيعة انتقال الصوت داخل محطات نقل الركاب تحت الارض و طرق قياس الضوضاء داخلها و كذلك التعرف على البيئة الصوتية الملائمة بها وذلك لحماية المواطنين و العاملين بمحطات المترو من الاعراض الصحية والعصبية الناجمة عن التعرض المباشر والمستمر للضوضاء المتكررة التى قد تزيد فى بعض المحطات عن الحدود القصوى المسموح بها فى المعايير الخاصة بالراحة الصوتية داخل تلك المحطات.

تهدف هذه الرسالة إلى دراسة تأثير المعالجات الصوتية المختلفة على تحسين البيئة الصوتية داخل محطات مترو الأنفاق. وذلك من خلال دراسة البيئة الصوتية داخل فراغات كل من محطتى مبارك و السادات كعينة من محطات مترو الأنفاق بالخط الثانى, التى ترتفع بها القيم القصوى لمنسوب ضغط الصوت على رصيف المحطة مقارنة بالمعايير القياسية.

تبدأ الرسالة بدراسة خصائص فراغ المحطة وبالأخص رصيف انتظار الركاب وطبيعة انتقال الضوضاء به والمعايير القياسية الخاصة بمتغيرات البيئة الصوتية داخله. ثم تنتقل الرسالة لقياس هذه المتغيرات بأجهزة القياس الميدانى فى المحطات المختارة ومقارنتها بالمعايير القياسية بهدف تقييم البيئة الصوتية داخل هذه المحطات.

ثم تنتقل الرسالة بعد تحليل نتائج القياسات الى مرحلة الحلول وتحسين البيئة الصوتية باستخدام المواد الماصة للصوت ودراسة كيفية توزيعها على أسطح الفراغ ومن ثم مقارنة تاثير هذه

المواد على خفض الضوضاء عن طريق المحاكاة بالحاسب الآلى. وتخلص الرسالة الى بعض التوصيات التى تخص أفضل الأماكن لتوزيع المواد الماصة مما يحقق أكبر خفض للضوضاء

2. المشكل البحثي:

ترتفع معدلات الضوضاء فى بعض محطات مترو الانفاق عن الحدود القصوى المسموح بها فى المعايير الخاصة بالراحة الصوتية كما هو مذكور فى بعض الدراسات السابقة وكذلك قياسات الباحث. وترجع هذه الزيادة الى مشكلات ميكانيكية تتعلق بالقطارو القضبان (تخرج عن نطاق الحل فى البحث) , بالاضافة الى طبيعة تشطيب المحطات التى تساعد على زيادة هذه المعدلات. حيث تتسم أغلب مواد التشطيب المستخدمة فى تشطيب الارضيات, الاسقف والحوائط داخل محطات نقل الركاب تحت الارض بالصلابة و التحمل مثل السيراميك, الخرسانة المكشوفة, أرضيات الجيرانيت كما فى محطات مترو الانفاق بمصر.هذه المواد تقوم بعكس الصوت مما يزيد من ترداد الصوت بالفراغ الذى بدوره يزيد من معدلات الضوضاء.

3. الهدف من البحث :

الهدف الرئيسى من الدراسة هو تحقيق بيئة صوتية جيدة بمحطات نقل الركاب تحت الأرض وذلك من خلال الحفاظ على المعايير القياسية للضوضاء داخل المحطة. يتم ذلك من خلال دراسة الطرق اللازمة لخفض الضوضاء عن طريق اللأهداف الاجرائية التالية:

1. تقييم مستويات الضوضاء داخل بعض محطات مترو الانفاق من خلال عمل مجموعة من القياسات الصوتية داخل بعض محطات مترو الانفاق لزمن الترداد و أعلى مستويات ضغط للصوت على رصيف المحطة, يتم مقارنتها بالمعايير الخاصة بالراحة الصوتية بهدف تقييم البيئة الصوتية داخل المحطات.

2. دراسة تأثير المعالجات المعمارية و الصوتية المختلفة على خفض معدلات الضوضاء داخل المحطات محل الدراسة.

4. هيكل الدراسة

الجزء الاول من الدراسة يبدأ بالتعرف على تصميم محطات نقل الركاب تحت الارض بشبكة مترو الانفاق وكيفية انتشار الضوضاء بها مع التعريف بالمؤشرات الصوتية وطرق قياسها, وينتهى بتقييم للبيئة الصوتية داخل المحطات محل الدراسة عن طريق مجموعة من القياسات لبعض المؤشرات الصوتية.
فى الجزء الثانى يتم تناول اساليب وامكانيات تحسين البيئة الصوتية بمحطات نقل الركاب تحت الارض مع تطبيق لهذه الاساليب فى المحطات محل الدراسة.

5. منهج الدراسة

تم اختيار عينة من المحطات للدراسة لتقويم البيئة الصوتية بهم

أولا مرحلة جمع البيانات :

تم قياس المؤشرات الصوتية الاتية داخل المحطات المختارة لتقييم البيئة الصوتية:

1. زمن الترداد RT
2. أقصى منسوب ضغط الصوت **Maximum Sound Pressure** Noise
3. الضوضاء الخلفية على الرصيف عندما لا يوجد قطار بالمحطة **Background Noise Levels**

تم قياس زمن الترداد بنظام **[MLSSA]** . وتمت قياسات منسوب ضغط الصوت حسب المواصفات البريطانية **BS EN ISO 3095:2005.**

ثانيا مرحلة التحليل :

تم استخدام برنامج **ODEON4.2** لتحليل البيانات الصوتية لنموذجي المحطات محل الدراسة التى تم التحقق من كفاءتها باستخام القياسات الحقلية.

ثالثا مرحلة الاستدلال:

تم عمل مقارنة تحليلية لنتائج المحاكاة بهدف الوصول الى أفضل الاماكن و المساحات للمواد الماصة للصوت.

6. مجال وحدود الدراسة:

1- تستهدف المعالجات الصوتية خفض مستويات الضوضاء المرتفعة من ضوضاء القطارو الضوضاء الخلفية عن طريق استخدام المواد الماصة للصوت ولاتقوم الدراسة على معالجة الضوضاء الزائدة نتيجة عيوب ميكانيكية تخص القطار وانما تختص بالمستويات الزائدة على رصيف المحطة بعد توفير الصيانة الدورية والمستمرة للقطارات .

2- تتم المعالجات الصوتية داخل المحطة بدون تغيير أى من خصائص الفراغ التشكيلية وانما تضاف المعالجات بأماكن مثل السقف, الحوائط الجانبية أسفل الرصيف,بعط من وحدات الحوائط (حيث يتم استبدال بعض من وحدات الحوائط بأخرى مجهزة بالمواد ماصة للصوت).

3- لتقييم البيئة الصوتية منصوص عليها من الهيئات المعايير والحدود المستخدمة الخاصة بالنقل عالميا وكذلك مواصفات الهيئة العامة للانفاق بمصر.

7. عينات الدراسة:

ترتفع مناسيب الضوضاء بالخط الثانى عن مثيلاتها بالخط الاول مما دفع الى اختيارعينة محطات الخط الثانى التى تتسم جميع المحطات تحت الارضية به بنفص مواصفات التصميم و التشطيب. تم اختياركل من محطتيى مبارك و السادات لدراسة تأثير المعالجات الصوتية تبعا لموقعهما الجغرافى ومعدلات الاشغال اليومى حيث انهما محطتان تبادليتان تستقبلان ملايين الركاب يوميا.

8. الخلاصة:

تعد المعالجة الحالية لسقف المحطة فعالة فى خفض قيم زمن الترداد على رصيف المحطة, ولكنها غير فعالة فى خفض قيم منسوب ضغط الصوت التى تتجاوز الحدود القياسية. كما ان الاضافات الاخرى من المعالجات الصوتية فى صورة ألواح ماصة للصوت تضاف على المعالجة الموجودة لا تحدث خفض ملحوظ للضوضاء.

من خلال نتائج المحاكاة تم التوصل رسم بيانى يوضح العلاقة بين مساحة المادة الماصة للصوت و الخفض المقابل فى الضوضاء داخل المحطات المختارة. وأوضحت النتائج ان أفضل الأماكن لتوزيع المواد الماصة للصوت هى منطقة أسفل الرصيف و سقف المحطة نظرا لان منطقة اسفل الرصيف هى أقرب مكان لمصدر الضوضاء مما يؤدى الى خفض الضوضاء قبل الانعكاس على حدود المحطة و أما معالجة السقف فهى تمتص الضوضاء الناجمة عن الركاب بالاضافة الى خفض زمن الترداد.

. وتم استنتاج بعض الطرق لتحسين البيئة داخل المحطات المذكورة ومنها:

1- معالجة الحوائط الجانبية أسفل الرصيف بالمواد الماصة للصوت.

2- اضافة حاجز فى منتصف المحطة بين مسارى القطارات معالج بالمواد الماصة للصوت بالاضافة الى منتطقة أسفل الرصيف يحقق أفضل خفض للضواء , ولكن توجد محاذير لاضافة هذا الحاجز تخص أبعاد المسار, حركة القطار و اشتراطات السلامة.

3- معالجة الاجزاء الطرفية من النفق عند أطراف الرصيف لخفض انعكاسات الصوت للقطارات القادمة من النفق.

4- خفض مستويات الصوت لكل من انظمة الاذاعة الداخلية والدوائر التلفزيونية المغلقة التى تساهم فى رفع مستويات الضوضاء