Paper's No. BUE-FISC – 146

Methodology for the acoustic performance evaluation of the underground stations

Design considerations learned from the noise simulation in a typical underground station

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ABSTRACT: .
Due to the train high noise levels inside the Greater Cairo underground metro stations, a study has been carried out to reduce the noise at the platform level of the station. Several solutions have been investigated for noise treatment at the sources, which includes treatment of the concrete surface of the railway track or the underplatform walls; and for noise treatment along its route of transmission, which includes creating a noise barrier between the tracks of the railway 1.05m high (the same height of the underplatform walls) or creating platform edge screens 2.5m high. A simulation program which is based on the geometric acoustics has been used to test the effectiveness of each treatment case by case in comparison to the base case before any treatment, in order to get helpful recommendations in preparing an acoustic manual for the acoustic design of both the existing and future stations.

Conference Topic: Integration Issues (economy, society and environment)
Keywords:
NOISE REDUCTION- THE SUGGESTED TREATMENTS- SIMULATION

1. INTRODUCTION.

There are more than fourteen programs that are used in sound prediction, the acoustic simulation software programs depend on the geometric acoustics. Predicting the performance of a sound in a given venue depends on the three dimensions model, the absorption coefficient and the diffusion of the internal surfaces for this venue. Because of the lack of acoustic treatments in the Greater Cairo underground station metro and its high noise levels, one of these fourteen programs are used to perform testing for the suggested treatments in the platform levels to check their acoustic performance.

2. METHODOLOGY.

The effectiveness of the suggested noise treatment in the underground stations has been tested. First, the station to be simulated is selected; its temperature, humidity, the background noise level as well as its surfaces Porosity are determined. Then, the appropriate types for the treatments and their locations are suggested. Next, a suitable simulation software program for testing these treatments and checking the program validation is chosen. Accordingly the experiments have been performed on the platform level of the typical underground station where each treatment is tested individually. Finally, an analysis for the results is made leading to the conclusion of this study.

3. THE SIMULATION ASSUMPTIONS.

3.1 Selecting the station for simulation.

El Behoos station was selected to be the simulated model, as its design is a typical pattern of the underground stations located along the path of the second line representing about 66.7% of their station's total number. Also, 10m of the circular tunnel was simulated at both ends of the station since it is enough for the tunnel diameter (approx.8m).

3.2 The temperature and the humidity of the simulated station.

The temperature and the humidity values actually measured on the underground station are 29^{o}and 51% respectively.

3.3 The background noise level and the base case absorption coefficients of the station model surfaces.

The background noise is generated by the movement and the conversation of the passengers. Table 1 shows the value of background noise according to the actual measurements of the underground station in the absence of the trains. The absorption coefficients of the station surfaces shown in Table 2.

Table 1. The background noise in the station [1]

The background noise value	The background noise at different frequencies						
	125	250	500	1KHz	2KHz	4KHz	8KHz
	46	51	52	52	47.5	41.5	31.5

(1) Ref.= field measurements done by the authors

Table 2. The absorption coefficients of the station surfaces

The name of the surface	The absorption coefficients at different frequencies					
	125	250	500	1KHz	2KHz	4KHz
tunnel and stair openings	0.99	0.99	0.99	0.99	0.99	0.99
ceiling	0.2	0.3	0.48	0.85	0.72	0.68
walls finishing	0.026	0.045	0.045	0.045	0.042	0.023
train surfaces	0.075	0.15	0.15	0.15	0.10	0.03
tunnel and tympan wall	0.01	0.02	0.04	0.06	0.08	0.1

4.THE PROPOSED ACOUSTIC TREATMENTS INSTATION'S PLATFORM LEVEL

Several treatments are suggested to be applied on different locations along the platform level; each suggested treatment will be applied separately in order to study its effect on noise levels fig.(1). These suggested treatments are classified according to the following:

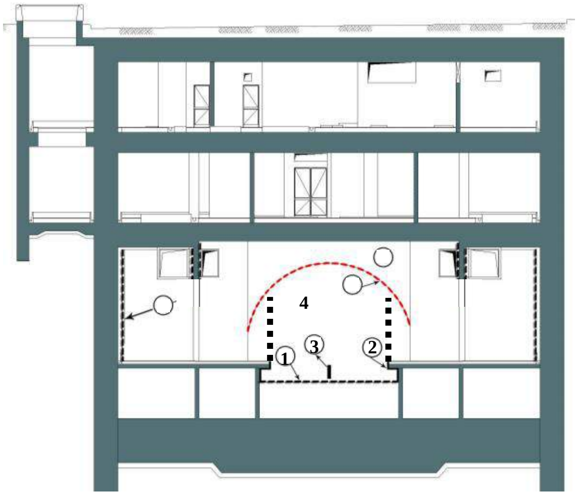

Fig.1: the locations of the treatments indicated on cross station
1.Treatment the surface of the concrete railway track 2.Treatment the Surface of the underplatfrom wall
3.Create a noise barrier of 1.05m height between the two railway tracks
4.Create a protective screen on the edges of the platforms

4.1 Noise mitigation around the sources.

a) For the concrete railway track

Using a layer of broken stones and gravels of 15 cm thickness above the concrete of the railway track, its absorption coefficients at frequencies of 125: 4 kHz are 0.15-0.30-0.80-0.42-0.61-0.72, respectively.

b) The underplatfrom wall

Using a layer of sprayed cellulose fiber of thickness 3.2 cm "1.25 inches" - treated with one of the boric acid salts " to be fire and pests resistant " and Portland cement to be a bond material; the absorption coefficients of this treatment at frequencies of 125: 4 kHz are 0.10 -0.30 - 0.73 -0.92 -0.98 -0.98 respectively.

4.1.2 Noise mitigation along the route of noise transmission.

a) Creating a noise barrier of 1.05m high between the two railway tracks

Noise can be reduced by Creating a noise barrier between the two tracks of the railway. The height of this barrier is 1.05 m and its length is equal to the platform length; its surfaces are treated with a layer of sprayed cellulose fiber of thickness 3.2 cm "1.25 inches"; and its absorption coefficients at frequencies of 125: 4 kHz are 0.10 -0.30 - 0.73 -0.92 -0.98 -0.98 respectively.

b) Creating a protective screen on the edges of the platforms

Noise can be reduced by using a platform edge screen of the transparent poly carbonate sheet and aluminum sections on the edge of the two platforms. The height of this screen is 2.5 m and thickness 2.1 cm; its absorption coefficients at frequencies of 125: 4 kHz are 0.18 - 0.06 - 0.04 -0.03 - 0.02 - 0.02, respectively.

5. THE ACOUSTIC SOFTWARE USED IN THE SIMULATION.

CATT[2] is a room acoustic software application based on the randomized tail-corrected cone-tracing and late part ray-trace (instead of RTC) for special cases, it simulate till 260 sources and 100 receivers and used to simulate many projects, it is chosen because of two reasons; it has been chosen by the international round robin on room acoustical computer simulation as one of only three programs out of total 14 that can be assumed to give an accurate results [3], and it has been tested by many researcher and educational societies as Acoustic Associates.

5.1 The assumptions concerning the representation of train noise in the station.

Since the study deals with the main source of the noise inside stations which is the trains, the following have been assumed, see table 3 for spectrum-sound power-directivity values.

- Thirty two omni sources are used to simulate the noise sources from the train eight cars at the wheel/rail position (where each car has 4 wheels), the sound intensity generated by all cars are equaled except the first car " the driving car" which produces more noise than the others.
- The simulation is based on the extreme case of noise inside the station, where both trains are supposed to be entirely inside the station and both are braking.

Table 3. SPL at 1m on the source axis 125 Hz to 4 kHz

spectrum-sound power-directivity from	SPL at 1m on the source axis					
	125 Hz	**250 Hz**	**500 Hz**	**1KHz**	**2KHz**	**4KHz**
the 1st car	**91.8**	**100.3**	**99.2**	**102.4**	**96.6**	**91**
other cars	**86.8**	**95.3**	**94.2**	**97.4**	**91.6**	**86**

5.2 The assumptions concerning the receivers on station platform.

It is suggested that there are three groups of receivers along the platform where each group has two receivers; the first group stands at the front of platform and takes the symbols "(F-c) - (F-b)[4]", the second group stands in front of the alcoves and takes the symbols "(C-c) - (C-b) " while the last group stands at the middle of the platform and takes the symbols" (M-c)-(M-a) " Fig.(2).

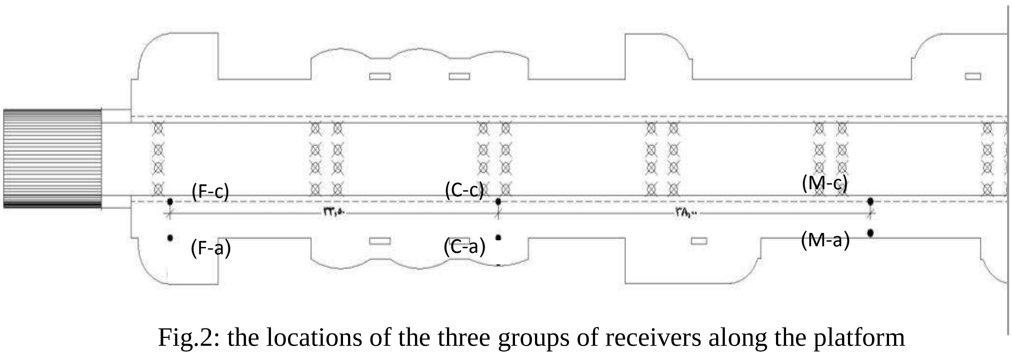

Fig.2: the locations of the three groups of receivers along the platform

[2] CATT= Computer-Aided Test Tool

[3] El Khateeb, 2002

[4] The symbol **C** refers to the receivers stand at the edge of platform while the symbol **b** refers to the receivers stand at the middle of platform width and the symbol **a** refers to the receivers stand at the end of platform width

6. THE PROGRAM VALIDATION.

Comparison and validation analysis are made for the program results and the actual measurements. The reverberation time "RT" is chosen to be the comparative Parameter. The RT results from the program and from the field measurement (at El Behoos station platform when it is completely free from people after the end of the operation) are very close.
Table 4 shows the average values of the reverberation time resulting from the simulation and from the field measurement at El Behoos station.

Table 4. The average values of the reverberation time resulting from the simulation and the field measurement on the station platform

Freq. Hz	125	250	500	1000	2000	4000
Meas./sec.	3.3	2.26	1.71	1.29	1.3	1.14
Simul./sec.	3.01	2.32	1.76	1.31	1.4	1.4

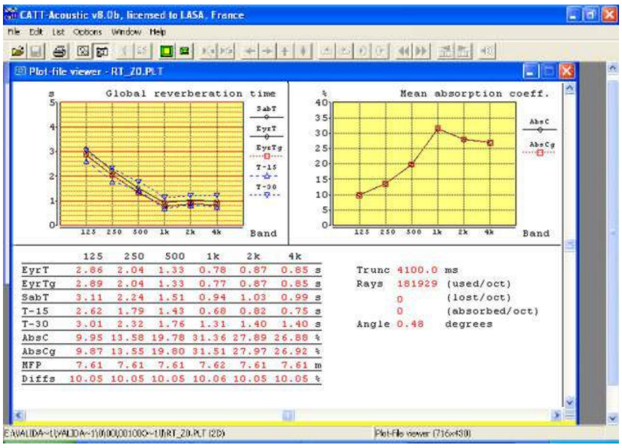

Fig.3: the values of the RT resulting from the simulation

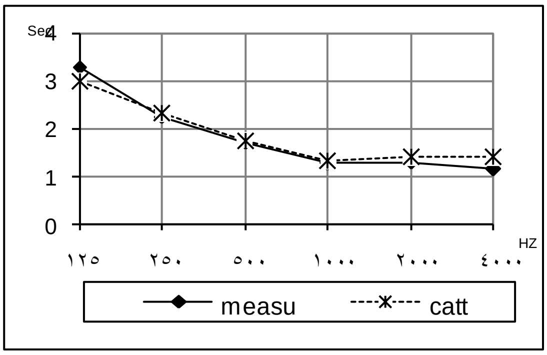

Fig.4: the RT values at the different frequencies resulting from the simulation and the field measurement at the station platform

7 THE RESULTS ANALYSIS OF VARIOUS PROPOSED TREATMENT FOR THE NOISE LEVELS INSIDE THE STATION PLATFORM.

7.1 The Effect of treatment applied to the concrete railway track on the noise levels.

Table 5 below shows the reduction values of the noise level at all receivers and Figures 5 & 6 show the results of the simulation due to this treatment.

Table (5): the amount of the resulting reduction in decibels at each due to this treatment

Receivers	R (F-c)	R (F-b)	R (C-c)	R (C-b)	R (M-c)	R (M-a)
Reduction value/dB	6.9	4	6.1	5.7	7.1	6

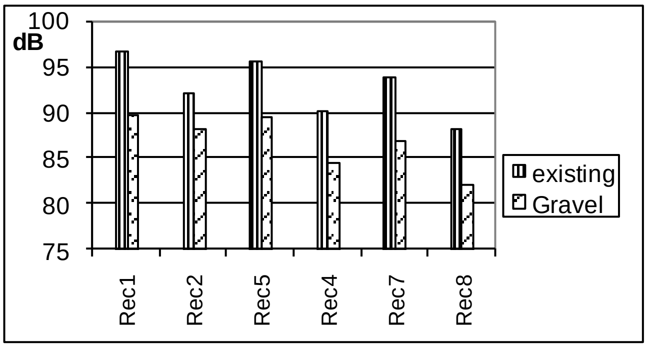

Fig.5: comparative between the SPL before and after the treatment of the track surface

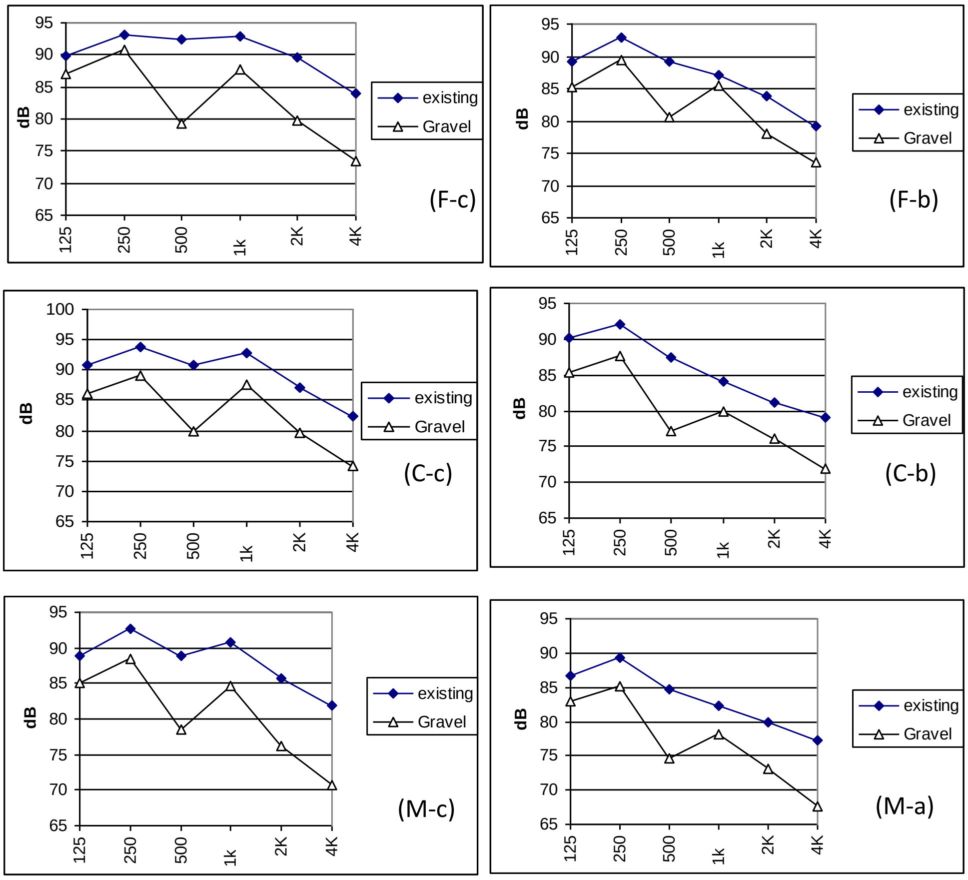

Fig.6: comparative between the SPL before and after the treatment of the track surface on one octave frequency band at all receivers

The analysis Results:

- The noise level has significantly decreased, particularly along the edge of the platform.
- Generally, the peak reduction is at the medium and high frequencies due to the efficiency of the material absorption at these frequencies.
- The value of these reductions is relatively high because the treated surface is adjacent to noise sources, so it absorbed the early reflections, the reduction values vary from 4 to 7.1 dB.
- The least reduction occurred at the receiver (F-b) due to its closeness to the center of the curved wall behind it and due to the intersection of the vertical wall with this curved wall making it a focus area for the noise, and in addition the effect of the untreated tunnel opening near to this receiver, see fig. 2.
- The minimum reduction occurred at frequency 1 kHz due to the inefficiency of this material at this frequency.

7.2 The Effect of treatment applied to the Surface of the underplatform concrete walls on the noise levels.

Table (6) below shows the reduction of the noise level at all receivers and Figures (7) & (8) show the results of the simulation due to this treatment.

Table (6): the amount of the resulting reduction in decibels at each due to this treatment

Receivers	R (F-c)	R (F-b)	R (C-c)	R (C-b)	R (M-c)	R (M-a)
Reduction value/dB	**7.5**	**2.9**	**8.5**	**4.4**	**7.7**	**4.3**

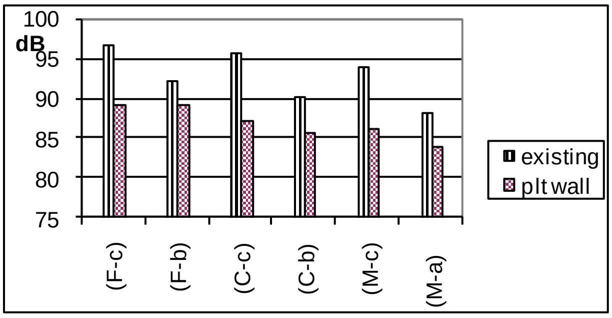

Fig.7: comparative between the SPL before and after the treatment of the UPL walls surfaces

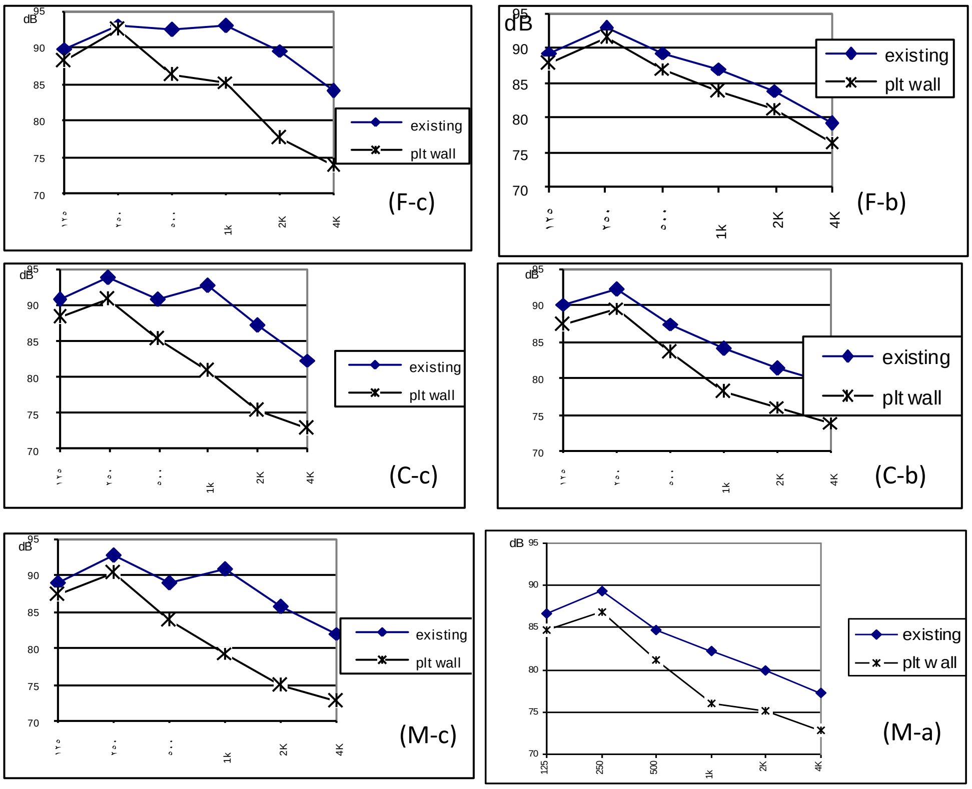

Fig.8: comparative between the SPL before and after the treatment of the UPL walls surfaces on one octave frequency band at all receivers

The analysis Results:

- The treatment absorbed the noise reflections and significantly decreases the noise level, because of the proximity of the underplatform walls to the noise sources and the high absorption coefficients of the proposed finishing material.
- The maximum reduction of the noise level is observed along the edge of the platform (on the receivers stand along the edge of the platform), it varies from 8.5 to 7.5 dB especially.
- The treatment led to the convergence of the noise levels between the receivers in the same group because the reduction at the edge of the platform is much more than the reduction with respect to the depth of the platform
- The peak reduction is at the high frequency from 1:4 kHz, due to the efficiency of material in the absorption of high frequencies (short wavelengths).
- The noise reduction at the depth of platform is much lower than the reduction at the edge of platform as a result of repeated reflections and inefficiency of the absorption material at low frequencies.

- To increase the efficiency of sound reduction at all frequencies, it is suggested to combine the treatment of the concrete railway track with the surface treatment of the underplatform concrete walls.

7.3 The effect of applying surface treatment for both the concrete railway track and the underplatform concrete walls on the noise levels.

Table 7 below shows the reduction of the noise level at all receivers and Figures 9 &10 show the results of the simulation due to this treatment.

Table 7.: the reduction values in decibels at each receivers due to this treatment

Receivers	R (F-c)	R (F-b)	R (C-c)	R (C-b)	R (M-c)	R (M-a)
Reduction value/dB	30.6	22	29.5	22.2	28.2	19.7

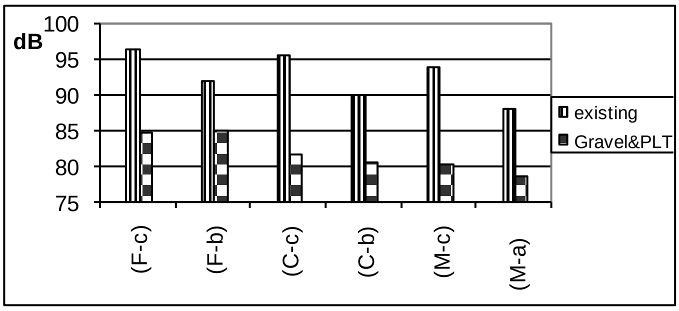

Fig.9: comparative between the SPL before and after after the treatment at all receivers

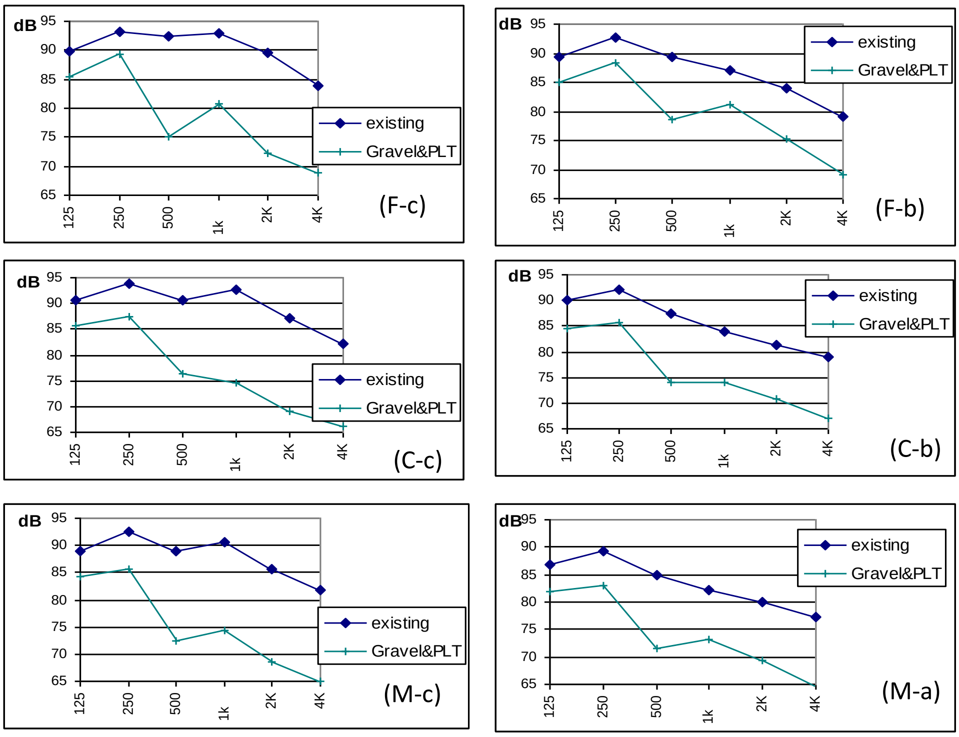

Fig.10: comparative between the SPL before and after the treatment of both the UPL walls surfaces and the track surface on one octave frequency band at all receivers.

The Results analysis:

- Generally the maximum reduction of noise level is observed at all receivers and particularity along the edge of the platform.

- The treatment led to convergence of the noise levels between the receivers in the one group, while the different among the three groups along the platform became limited where the highest level of noise is at the edge of the platform then in front of the curved wall and finally at the middle of the platform.
- The average reduction of noise levels is 11dB.
- The peak reduction occurs at high frequencies, especially at 500 Hz.

7.4 The effect of creating a 1.05m high noise barrier between the two railway tracks.

Table 8 below shows the reduction of the noise level at all receivers and Figures (11) & (12) show the results of the simulation due to this treatment.

Table 8.: the amount of the resulting reduction in decibels at each due to this treatment

Receivers	R (F-c)	R (F-b)	R (C-c)	R (C-b)	R (M-c)	R (M-a)
Reduction value/dB	0.7	2.5	1.3	3.1	1.7	3.6

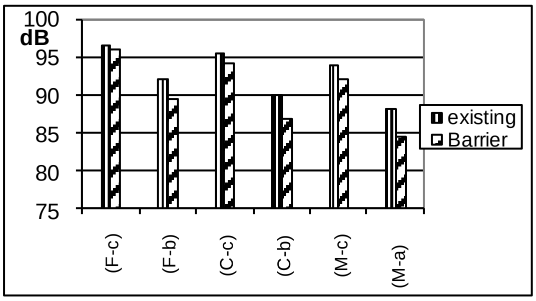

Fig.11: comparative between the SPL before and after the usage of the noise barrier

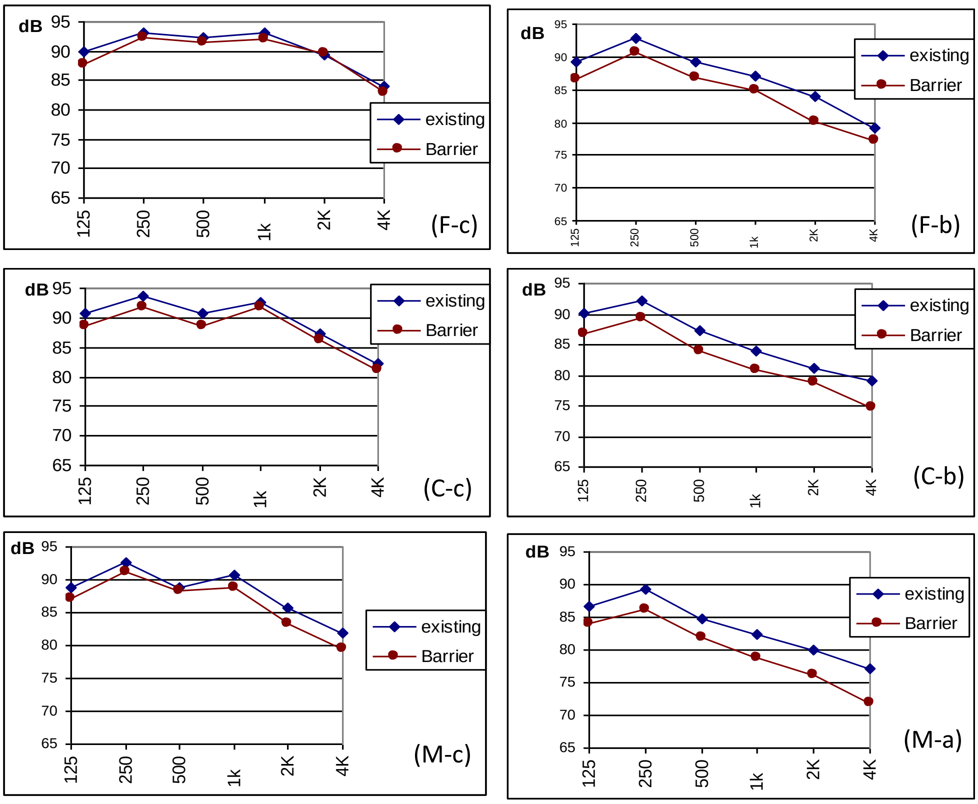

Fig.12: comparative between the SPL before and after the usage of the noise barrier on one octave frequency band at all receivers

The Results analysis:

- Noise reduction is very limited when using noise barrier between the railroad tracks, with height and treatment material similar to the height and treatment material of the underplatform walls
- The maximum reduction in the noise levels is at the depth of platform.
- The maximum values of the noise reduction are at the depth of platform compared to its edge. Generally this is contrary to the results of using the underplatform walls treatment where the maximum reduction values are at the edge of the platform, despite the fact that both the noise barrier and the underplatform walls have the same area and the same characteristics of the treatment material. However, it should be noted that the reduction values at the depth of platform in the both cases are similar.
- The noise reduction at the edge of platform is limited because the barrier is at the side far from the edge of the platform and therefore can not be an obstacle between the noise sources and receivers.
- Due to these results, the noise barrier is an inefficient and uneconomic solution

7.5 The effect of using the platform edge screen 2.50m high on the noise levels.

Table 9 shows the sound transmission index for the material of the platform screen, table 10 below shows the reduction of the noise level at all receivers and Figures 13& 14 show the results of the simulation due to this treatment.

Table 9.: The values of the sound transmission index for the material of the platform screen

Freq./Hz	125	250	500	1000	2000	4000
STC	30	33	36	32	40	50

Table 10.: The reduction values in decibels at each receivers due to this treatment

Receivers	R (F-c)	R (F-b)	R (C-c)	R (C-b)	R (M-c)	R (M-a)
Reduction value/dB	30.6	22	29.5	22.2	28.2	19.7

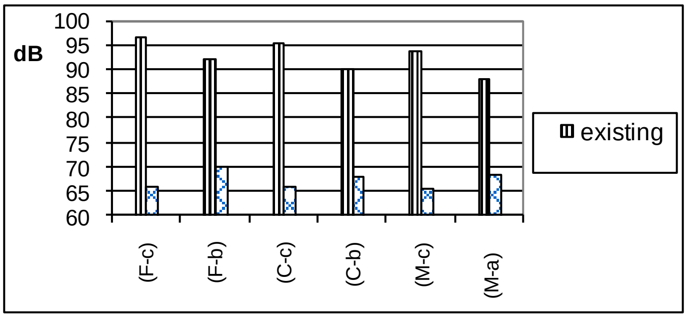

Fig.13: Comparative between the SPL before and after the usage of the PL edge screen

The Results analysis:

- despite its inefficiency in sound absorption. Nevertheless, it is efficient in sound insulation as its sound transmission class is 36dB so a significant reduction in noise levels at all the locations of the platform is generally observed.
- The highest values of the noise reduction occurred at the medium and high-frequency (500: 4 kHz) at all locations of the platform edge.

- The reduction of the noise levels decreases with increasing the distance away from the edge of the platform, where the difference of the noise levels between the edge and the depth of the platform varies from 7.3 to 8.6 dB.
- The noise levels increase in the track zone between the two screens due to the excessive reflections on their surfaces.
- The Less reduction of noise occurs in the middle of the platform because the distance between the edge screen and the walls of the station has the narrowest width, while the highest reduction of the noise occurs in front of the platform where the edge screen extends till the end of the platform and thus separates the receivers from noise sources and the tunnel.

It is expected to increase noise levels inside the trains if their windows are opened as a result of the excessive reflections on the surfaces

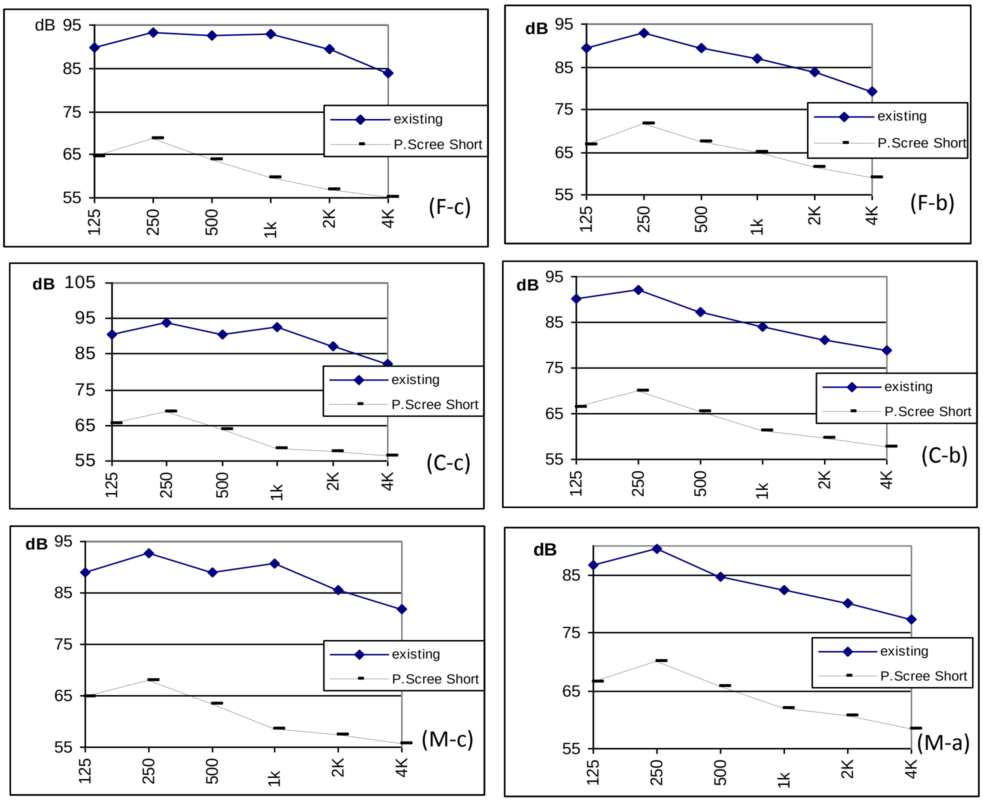

Fig.14 comparative between the SPL before and after the usage of the PL edge screen on one octave frequency band at all receivers

7. CONCLUSION.

7.1 General Findings and Outcomes

- The results of the software simulation are very close to the actual application results, where the difference between the RT values resulting from the actual measurements and those resulting from the software simulation are very minor.
- The simulation results are not accurate at the low frequencies of 125 Hz or lesser.
- The noise sources are invisible due to the different levels between the platform floor and the railway track, accordingly the direct field covers the area in front of the trains and the tunnel while the reverberation field fills the station completely.

- The noise reduction resulting from the different mitigation schemes are not constant at all receivers, where it is influenced by the absorption coefficients of the materials at different frequencies, the walls formations and the location of the receivers related to the location of noise points.
- The noise reduction due to using the same absorption material is affected by its acoustics characteristics, its location, in addition to its area.

7.2 Specific Findings and Outcomes.

- Combination of surface treatment for both the concrete railway track and the underplatform concrete walls results in high reduction of noise levels at all receivers.
- Insignificant noise reduction results from use of the noise barrier (1.05 m height) between the two railway tracks. A change in its height may result in a different result.
- The values of the noise reduction resulting from the platform edge screen are high. This edge screen is not only used as a sound barrier, but also as a protection and security barrier for the passengers. However, it is very expensive and needs highly technical operation and persistent maintenance.

8. RECOMMENDATIONS.

An acoustic manual should be prepared for the design of the underground metro station, to provide adequate noise criteria for both the existing and the future stations. A specialist team work should cooperate to prepare this manual in the light of the following:

- Using the platform edge screen has an efficient role in protecting the passenger from the train accident as well as reducing the noise levels along the station.
- Avoid the forms of curves in the design of walls, especially the curves with small diameter (whose center lies within the platform), where this formation increase the noise levels in front of the wall, especially if it intersect another wall and form a semi closed gap enclosed within two sides thus increasing the noise levels inside it.
- The noise levels inside the station can be reduced by simple procedures, e.g. usage of platform edge screen or the treatment of both the under platform wall and the railway tracks surfaces.
- It is necessary to perform detailed study for the noise levels inside the tunnels to suggest an architectural solution for it, where the tunnels have no acoustic treatment.
- Testing the acoustic materials in different locations through the platform level before their application, where the noise reduction values due to these materials differ with any change in their location or area.

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