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Assessment of Fences as Noise Barriers: A Case Study in New Cairo, Egypt

Heidy A. Mohamed[a*], Sherif Ezzeldin[b], Mostafa R. Ismail[c]

[a]Department of Architectural Engineering, College of Engineering, British University in Egypt, Egypt
[b]Architectural Engineering & Environmental Design Department, Arab Academy for Science, Technology and Maritime Transport (AASTMT), Cairo Campus, Egypt
[c]Department of Architecture Engineering, Faculty of Engineering, Ain Shams University, Egypt
[a]Email: h_heidy16@hotmail.com , [b]Email: sheriff.ezzeldin@aast.edu
[c]Email: mostafa_ismail@eng.asu.edu.eg

Abstract

Noise levels in Egypt exceed acceptable thresholds due to high population and lack of mandatory sound regulations. According to noise measurements done by “The National Network for Noise Level Measurement in Greater Cairo” most of the areas examined (main squares, industrial areas, main roads, residential areas, commercial and administrative areas in Cairo governorate) had shown that noise levels exceeded the standard permissible levels that are identified by the Environmental Law 4/1994 and its executive regulations. Noise levels reached up to 75-85 decibels (dB), which is considered unacceptable as noise levels should not exceed 65 dB during daytime and 55 dB during night due to law number 4/1994. On the other hand, fences are considered a common feature within the Egyptian urban context and are mainly constructed for safety and privacy reasons. This research assesses the effectiveness of existing fences as noise barriers and specifies factors that reduce noise levels. Site measurements and photographs were taken for the fence of a residential compound in new Cairo, where noises arising from surrounding places cause annoyance. MEP services were the main sources of disturbing continuous noise along with social activities and traffic noises. Measurements were performed using TM-102 digital sound level meter. Readings were recorded at various time intervals in front and behind of the fence and noise reduction levels were calculated. Measurements revealed that the fence acts as a good noise barrier and that combined configuration of the fence resulted in the attenuation of noise to acceptable levels.

Keywords: Noise Barriers; Noise Level Reduction; Fence; Egypt.

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* Corresponding author.

1. Introduction

Noise in objective terms is defined as “random vibrations with no regular pattern” [1]. Studies revealed that being exposed to noise levels above 90 dB (decibels) for several years can cause anxious and tension which may lead to permanent hearing loss [2]. Community noise, also known as environmental noise or domestic noise is the noise their main source involve air, rail and road traffic, construction and public work, industries, MEP services, social activities, familiar domestic sources and neighborhood [3, 4]. In In the Egyptian context we usually see that gates and barriers or fences is one of the fixed elements of any land or private home; and this is done most of the times also for safety and privacy reasons [5]. Despite the safety and privacy use, the use of fences as a noise barrier or screen is one of the ways that may help in reducing noise levels, as the line of sight between the source and the receiver is interrupted allowing reflection, absorption and diffraction of noise to takes place, thus the energy of sound becomes reduced and its effect on the receiver will then be decreased [6]. The aim of this study is to assess the effectiveness of fences as noise barriers and the factors affecting noise level reduction. This will provide an understanding of the impact of a fence on reducing noise levels and how essential barrier factors would be. According to the Egyptian Environmental Law 4/1994 and its regulations, table 1 below shows the maximum allowed noise levels for various regions, thresholds during the day (L_{day}) - which is the corresponding continuous sound pressure level during a particular period of time “the day” - and during the night (L_{night}) - the corresponding continuous sound pressure level during a particular period of time “the night” [7, 8].

Table 1: Maximum allowed noise levels in decibels in Egypt [8]

Region type	Maximum allowed noise levels (*LAeq*) in decibels (*dB*)	
	L_{day} (7-10 AM) dBA	L_{night} (7-10 PM) dBA
Noise sensitive areas (schools, hospitals, libraries, etc..)	50	40
Residential areas along with trading areas	60	50
Residential areas facing a street width less than 12m with social, administrative and trade activities	65	55
Areas facing a street width over 12m with industrial areas	70	60
Industrial areas with heavy industrial activities	70	80

2. Noise Sources and Its Measures

The measure of the vibrations of air that form sound is the classified as sound pressure. As human ears can detect a very wide range of sound pressures, these sound pressure levels are measured in units of decibels (dB) on a logarithmic scale. Accordingly, these levels cannot be arithmetically added or averaged. Moreover, most noises’ sound levels vary with time, so when calculating sound pressure levels, the pressure fluctuations should be incorporated over a number of time intervals [3]. Environmental sounds are mostly consisting of a compound mix of lots of different frequencies. Frequency is the number of air vibrations per second where sound is transmitting and is measured in Hertz (Hz). The range of audible frequency that is considered to be normal for listeners with unimpaired hearing is from 20-20000 Hz. The most common weighting that is used in noise measurement is A-Weighting. Similar to the human ear, this successfully cuts off the lower and higher frequencies that the average individual cannot hear. A-weighted measurements are identified as dBA or dB(A) [3].

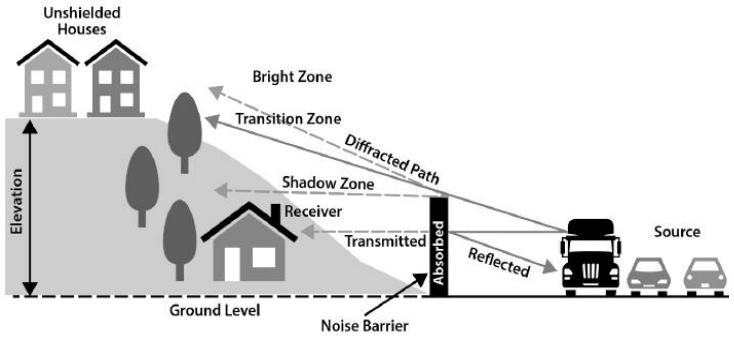

Figure 1: Absorption, reflection, transmission and diffraction of noise barriers

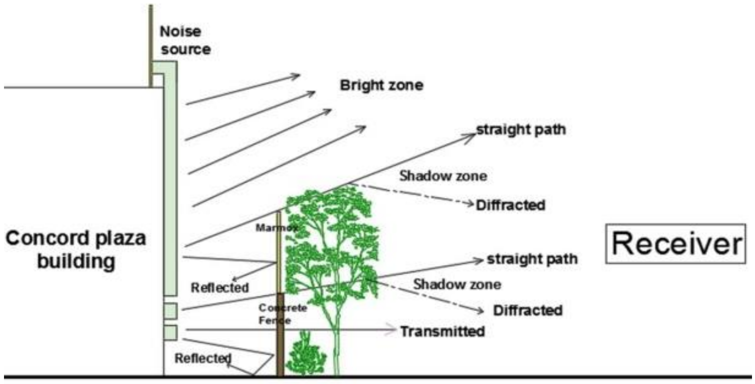

Figure 2: Absorption, reflection, transmission and diffraction of noise in researcher's field study (by researcher)

Sound is a sequence of pressure waves that propagates through a compressed media, such as air, water or solid. Therefore, the propagation of sound is the transmission of acoustic energy through a medium by the use of a sound wave. During this propagation, those waves can be refracted, reflected or attenuated by that medium [9]. In air, sound is transmitted by pressure variations from its source to the surroundings. As the sound gets further and further away from its source, this will make the sound level decrease. Consequently, distance plays a more important role in the reduction of noise during transmission. This sound or noise reduction is called Attenuation. The type of noise sources has an influence on distance attenuation [10]. Figure 1 is an illustration of sound wave that has been reflected absorbed and diffracted creating a shadow zone and a bright zone [11]. Figure 2 is an illustration for the study field showing how sound waves was reflected as the concrete fence is a reflective barrier and the rest of these waves became absorbed and transmitted through that barrier. The marmox boards added to the barrier height causing also come reflection of waves. The rest of the sound waves became diffracting due to high trees creating a shadow zone.

3. Fences as Sound Barriers

Noise barriers are typically vertical masonry or concrete walls that require less space but may have height restrictions because of cost considerations, structural requirements, and aesthetic considerations. Noise barriers can be comprised of wood, stucco, concrete, masonry, metal, and other materials. Some states also include aesthetic requirements for color and texture applications on noise barriers to improve their appearance. Noise barriers or sound walls are the most common form of barriers used for reduction of noise. Usually, noise barriers come in the form of: Earth berms, high vertical barriers called noise or sound walls, a combination of both earth berms and noise walls and vegetated noise barriers [11]. Barriers should be conducted of non-porous, solid materials for high efficiency and should have a minimum density of 20kg/m2 [12]. All barriers are classified as either absorptive or reflective [13, 14]. The most common materials used in reflective barriers are: concrete as precast panels and masonry blocks, lightweight concrete as fibrous cement, metal sheeting, plastic, glass, wood and other materials or combination of materials example as metal sheets and glass. On the other hand, absorptive barriers are not widely used as reflective barriers and they include: composites such as porous concrete and perforated plastic, ceramics, sintered metal, cement-bonded wood-wool or wooden chips and aerated concrete [15]. Noise barriers act only as a noise reducing tool but they cannot completely block the noise and annoyance [16]. Noise barriers are used in order to help reduce noises from the roadside and this is by absorbing or reflecting the noise caused by traffic or other activities. These barriers block the straight-line path from noise source to the receiver. The effectiveness of a noise barrier can be determined by its insertion loss, which is the reduction in the noise levels achieved between the source of noise and its receiver [17]. There are several ways for determining a barrier's insertion loss. First, it is done using a direct study where before and after scenario is conducted, noise levels measurements are taken for an existing noise barrier at receiver's position; then a barrier is constructed and noise levels are again measured at same points. If all conditions remain constant, therefore the insertion loss is the calculated difference between before and after the barrier is constructed [15, 18]. The second insertion loss method is the indirect method, where the barrier already exists and no before scenario is available. In that case an alternative site needs to be used under the same conditions for measurements and recordings or a computer simulation needs to be done for a before barrier situation [18]. The third insertion loss method is in case of an existing barrier; insertion loss can be obtained by difference in sound levels of an existing barrier and free-field conditions [19]. An insertion loss experiment was conducted on 3 different scenarios on a busy street segment in Dallas. First scenario was without the presence of the noise barrier, second was with the presence of a green buffer barrier and third with a combined plastic sound wall and a green buffer barrier. A GPS tracking recorder was used for GIS data collection, transportation records and delivery services. Also a digital sound pressure level meter (Koolertron-TM) was used for measuring the sound levels. Results revealed that with the presence of the green buffer barrier alone, noise level was decreased by 0.81 dB, and with the combined scenario it was decreased by 0.86 dB. Therefore the combination of both the plastic sound wall and the green buffer acted very well in decreasing traffic noise levels with a calculated reduction in insertion loss of 8.06 dB, the difference between both scenarios [20]. Another insertion loss process involved an existing barrier; insertion loss was obtained by difference in sound levels of an existing barrier and free-field conditions [21]. A noise barrier of height of 4m, thickness of 25cm and a length of 132m was built at a primary school for screening the traffic noise from a Highway was studied. Observations of traffic volume were taken for 24 hours for 7 days. The height is 4m with thickness of 25cm and length 132 m while the distance of the barrier. Readings were taken using a sound level meter (SLM) placed 1.5m from ground at 5 points along barrier length (P1-P5) at distances 0.5m and 6m respectively behind the barrier, 15 minutes each. Moreover, readings at 0.5 m in front of the barrier were also taken to obtain the noise reduction level of barrier. For the free-field condition, readings were taken at 2 points, one 17 m from noise wall and the other is double the distance which is 34m from wall. The doubling distance is used to determine the characteristic of noise source propagation from the road with and without barrier. Results revealed that the barrier is effective at reducing noise at 6m behind noise wall as the insertion loss is was 5 to 12 dBA, therefore reduction of transportation noise is effective when the distance behind the wall is more than 3.5m [21]. According to the previous studies done on insertion loss, it was hard to apply the direct and indirect methods due to difficulties of each to apply in the studied field; therefore in this research a linear sound source logarithmic propagation equation was used to measure the sound pressure levels in decibels at a specific distance from source in a free field condition - an area in space where sound may propagate freely from any form of obstacle or barrier [22, 23] as examined earlier by the authors of [21], but with the use of the linear source propagation equation instead of simulation. Below is Equation 1 used for measuring free-field propagation:

$$SPL = SPL1 - 20\log(r) - 5 \qquad (1)$$

4. Fences Configurations Affecting Sound Effectiveness

4.1 Fence Height

The effective height of barrier symbolizes the distance between the top of the barrier and the straight line drawn between the receiver of the noise and the source of noise. The larger the effective height of a barrier, the greater the noise-reduction effect it has. Noise screening will usually has a noise reducing effect that could cover up to the second level or perhaps the third level of a building depending on the height of the barrier or wall and how close it is placed to the road [24]. The authors in [16] stated that environmental noise barriers depend on their design and height in reducing the A-weighted noise levels. If the density of the barrier surface exceeds 20 kg/m2, this achieves a reduction of 5 dB(A) by having a barrier that is tall enough to break the line of sight from the roadway to the receiver, moreover an additional 1.5 dB(A) noise reduction can be reached for each additional meter of height [16]. The authors in [25] tested the effect of barrier surface mass on the noise reduction which was also studied; and barriers with various heights (3m, 5m and 7 m) were placed at various distances to the road (1m, 3m, 5m and 7 m). Results showed that noise barrier construction was necessary and 3 m tall barrier could not perform the desired noise reduction at all distances while the 5 m and 7 m tall barriers could achieve that [25]. This shows that the fence height is directly linked to the distance from source; as the distance increases the barrier height need to be also increased for effective results. Therefore it is important to consider the barrier height along with the distance from the noise source in designing noise barriers or readjusting them.

4.2 Fence Length

The length of a noise barrier affects its performance. The barrier should be long enough in order for only a little sound or noise can diffract around its edges. If the noise barrier is not long enough as it should be, a degradation of 5 dB (A) of barrier performance will take place near the barrier ends. The best way for noise not being diffracted along edges is to ensure that the distance between the receiver and the barrier end is at least four times the perpendicular distance obtained from the receiver of noise and barrier along the line between the receiver and the noise source. Another way to rephrase that is that the angle subtended from the receiver to the noise barrier end has to be at least "80 degrees" which is measured from the perpendicular line of receiver to the noise source [26] as shown in figure 3 or covering a horizontal angle of 160 degrees from the receiver [27] as shown in figure 4, these two measuring distances along the fence edge differ according site differences and receiver's location.

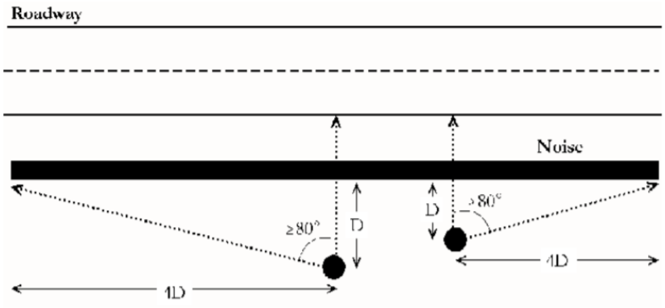

Figure 3: Noise Barrier Length [26]

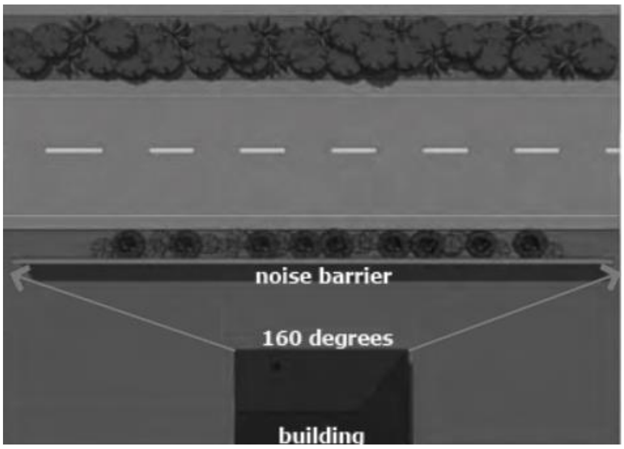

Figure 4: Noise barrier Length at horizontal angle of 160 degrees [27]

4.3 Fence Thickness

If a noise barrier is thicker than 1-2 m (3 to 6.5 ft), its noise reducing effect will be increased in relation to a thin barrier with a thickness of between 5 and 50 cm (2 to 20 inches). This means that in some cases increased noise reduction can be obtained through the use of thick barrier or barrier buildings. The effective barrier height marks the distance [24]. Due to the diffraction theory, the sound attenuation of a noise barrier can be calculated using the path length difference, which is the further distance where sound is enforced to travel due to barrier existence [28]. In the case where there is no barrier, sound travels directly from the sound source to the receiver showing a distance (d). On the other hand, when barriers are present, they are classified into thin and thick barriers. For thin barriers, sound should travel from the sound source to the barrier top which is referred to (distance a) and then from barrier top to the receiver which is referred to (distance b), giving a total distance of (a + b) [28] . Therefore, the path length difference (PLD) is obtained using Equation 2:

$$PLD = (a + b) - d \qquad (2)$$

According to thick barriers, the path length difference can be used to indicate sound reduction: where barrier thickness is defined as (T), the PLD is calculated as follows in Equation 3:

$$PLD = a + b + T - d \qquad (3)$$

The sound attenuation of a barrier can now be calculated using the wavelength of sound or sound frequency by first calculating a *Fresnel Number* (*N*) [21] as shown in Equation 4 where,

$$N = \frac{2\delta}{\lambda} \qquad (4)$$

Where λ is the wavelength of sound, and δ is the path length difference.

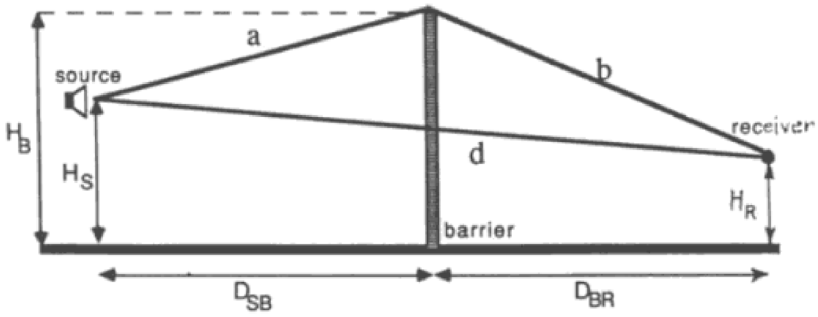

Figure 5: Path-Length Difference [28]

4.4 Distance between Noise Source, Barrier and Receiver

The ideal noise-reduction effect is attained when the screening is positioned either as close to the possible to the roadway or as close as possible to the housing or outdoor areas that need protection against noise. If a noise barrier is placed midway between the road and the noise-sensitive areas, the effect of noise reduction will be remarkably less than with the previously mentioned optimal placing. The effect of a noise barrier with a given height that is placed close to the road may help reduce noise. Also by placing a noise barrier along the middle centerline of a highway can help in noise reduction levels in addition to barriers that are just placed outside the roadway [24].

4.5 Fence Perforation

According to literature, a leak usually occurs at the gaps between the noise barrier components, between acoustic panels for example. As the height of the barrier increases, leakage has a major effect; on the other hand they widely reduced along the distance from the noise barrier. In this case the receiver's position relative to the barrier is a significant factor. It is really essential that a barrier should be entirely solid, and that the type of material chosen will not form cracks or any other type of leakage due to for example weathering. Even the presence of small gaps in a noise barrier will lead to a substantial reduction of the noise-reducing effect. It is for that reason important that the noise barriers are assembled in a way that makes allows them to be completely flush and even with the surface of the ground or with the base on which they stand [24, 29].

4.6 Material of Fences

Most conventional wall materials (such as concrete, steel, masonry, and wood) can be used in the thicknesses sufficient to block noise. For all materials except perhaps wood, the thickness that would normally be used in barriers or sound walls to achieve structural performance and durability, is adequate to block sound, and consequently to fulfill acoustical requirement [17]. Each material has its own characteristics apart from its acoustical performance. There are different ranges of traditional building materials that are mainly used for noise barriers. These materials can be basic, innovative, proprietary products, or developed for specific applications. All of these barriers are categorized as reflective or absorptive [15]. Researches discovered that since the 1970, more than 2,947 km of noise barriers in the US have been built. The concrete material is one of the most materials used for noise barriers in comparison to other materials. Percentages showed that 44.5 % of traffic noise barriers was made out of concrete, then block material follows by 27.5 % and wood by 9.8 %. Berm, brick and metal account for around 6% of the total. Moreover, studied showed that barriers combining earth berms and wall together showed a 12.3% of all barriers. Only 0.9 % of barriers were constructed of other materials such as plastic and recycled products, and 1.4 % with absorptive materials.

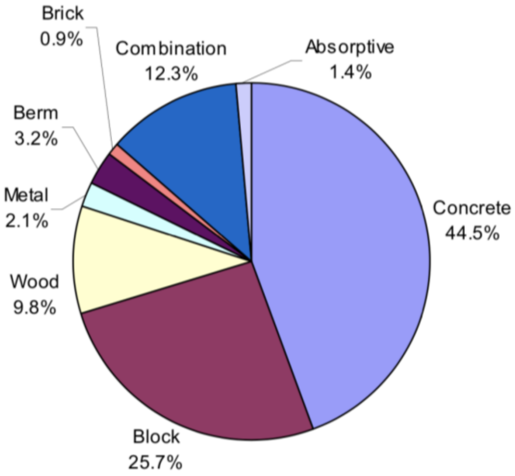

Figure 6: Percentage of noise barriers used according to material type [30]

Regarding the height of barriers 94% of these barriers had height ranges between 2 m to 6.9 m tall, 4 % were higher than 6.9 m and only 2 % were less than 2 m high [30]. This indicates that concrete comes on top of the list for most constructed, durable and reflective material which allows reflection of noise that strikes to the opposite site. Figure 6 below illustrates the previous percentage of material types.

5. Research Method

Measurements will be done using Tenmars TM-102 digital sound level meter (A-Weighted) on fast mode and this will show the effectiveness of the fences as noise barriers and how different factors have an effect on noise level reduction. Field measurements were tested by measuring the noise levels in front and behind a compound fence in New Cairo, Egypt. The studied part of the continuous fence is approximately 176m long, and is subdivided into 5 different parts named (F1 to F4) with different specifications:

F1: A concrete fence only 3m high with small shrubs, F2: consists of 2 parts: first part is a concrete fence 3m high along with vegetation and second is a concrete fence 3 m high plus marmox boards attached above with different heights giving a total height range of (4.5-6m) with different height of vegetation, F3: A concrete fence 4m high plus slight vegetation and F4: A concrete fence 4 m high plus dense vegetation. This study will help reveal the efficiency of fence on the noise levels reduction and how these factors affect the effectiveness. Measurements will be taken on week-days (day, evening and night measures). The duration of each measurement should not exceed an hour according to the sound level meter (SLM) regulations; therefore each measurement will range from 30seconds-15minutes maximum. As it was very difficult to apply insertion loss methods, a linear sound source logarithmic propagation equation was used to measure and calculate the sound pressure levels (SPL) in decibels at a distance of 4m from source for a free field condition and later compared graphically to measurements taken with presence of fence. Readings of noise level were taken in front of the fence facing the noise source, as close as possible to the barrier, and behind the barrier (4m from fence). This method has its limitations due to difficulties and field limitations; this was one of the closest ways to determine an approximate noise levels reduction. This simple method was done to be able to know if the fence plus its factors have had a difference in reducing noise levels. Readings were taken excluding any other noises as cars passing and loading supplies in the in front area of fence, only during night time it was hard to exclude the side street parking cars, therefore traffic was observed during day and night time and measurements were taken on a static traffic flow. A hand held method was used, and for this case the SLM had to be pointed far up from the holder at a height of about 1.6m high for records. Below (Figure 7) showing a Google image of the study area with the existing fence location presented in yellow line, the red dashed rectangle represents the concord plaza mall and the blue dashed rectangle represents the side street.

Below in figure 8 is the elevation of the specified area along with the measuring points where readings were taken. The distance between each reading point and another was about 4 meters. The concord mall building acts as a noise barrier from the main street traffic noise which blocks main traffic noise from main highway. The most annoying arising noises is from the continuous MEP services found behind the concord plaza building and from the side street along with activity noises on very crowded days or peak hours.

Figure 7: Site location area (Google maps)

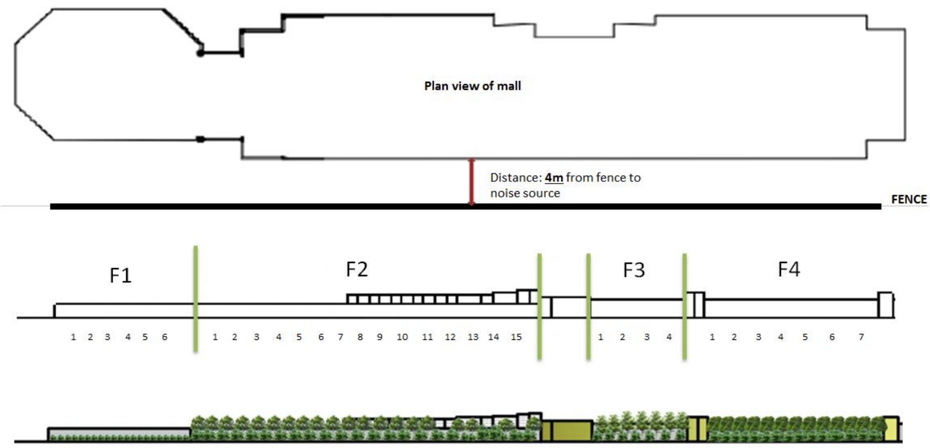

Figure 8: Plan view of mall and fence along the fence elevation (by researcher)

Readings using SLM was divided accordingly, for F1: 6 reading points were taken. For F2: first part 6 reading points, second part: 8 reading points. For F3: 4 reading points were taken. For F4: 7 reading points were taken. Readings were taken on two different weekdays under the same constant conditions from 8-10 AM, 3-5 PM, and 8-10 PM in front of the fence on one day and behind the fence on the other day starting from F1 all way to F4. Table 2 below shows fence configurations along with sample readings taken using SLM.

Referring to Table 1, the studied area applies to the region type “Residential areas facing a street width less than 12m with social, administrative and trade activities”, where the maximum allowed noise levels (L_{day}) is 65 dB and the ($L_{night)}$ is 55 dB. According to that, readings were taken during the day and night from 8 am→ 10 pm for the 4 fence configurations (F1→ F4) and each was presented graphically as shown in the sample below in figures 9 and 10:

Table 2: A sample of readings taken by SLM from 8-10 AM in front and behind the fence (by reseacher)

Fence Configuration	Reading/Measuring points	In front 8-10 am (dB)	Behind 8-10 am (dB)
Concrete wall 3m	1	72.3	69.9
	2	71.5	69.4
	3	70.2	68.4
	4	69.8	67.4
	5	69.9	67
	6	68.7	66.9
Concrete 3m + vegetation	1	69.8	66.7
	2	69.4	66.5
	3	69.3	66
	4	68.4	65.8
	5	68	65.2
	6	67.6	65
Concrete 3m + Marmox boards + vegetation	7	68.2	63
	9	68.5	63.1
	10	68.6	62.8
	11	69	62.5
	12	69.5	62.6
	13	69.2	62.2
	14	68.9	61.8
	15	68.7	61.5
Concrete 4m + slight vegetation	1	68.5	63.9
	2	67.9	64
	3	68	64.1
	4	68.3	64.4
Concrete 4m + Dense vegetation	1	69	64.5
	2	70	64.7
	3	69.9	63.6
	4	69.5	63.4
	5	68.7	63
	6	68.5	62.9
	7	68.8	62.6

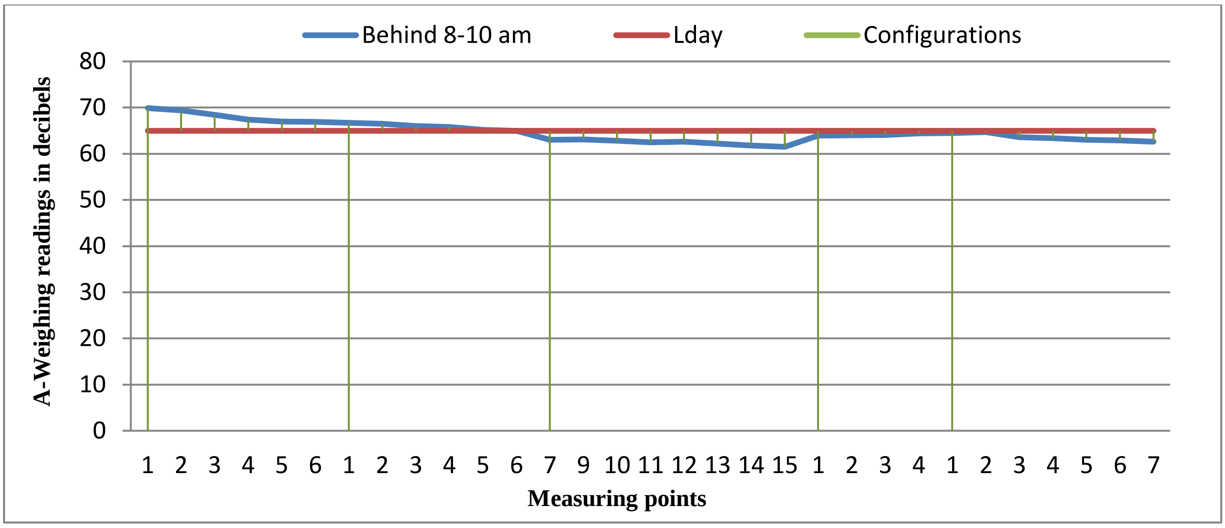

Figure 9: A sample of readings measured from 8-10 AM and compared to day limits

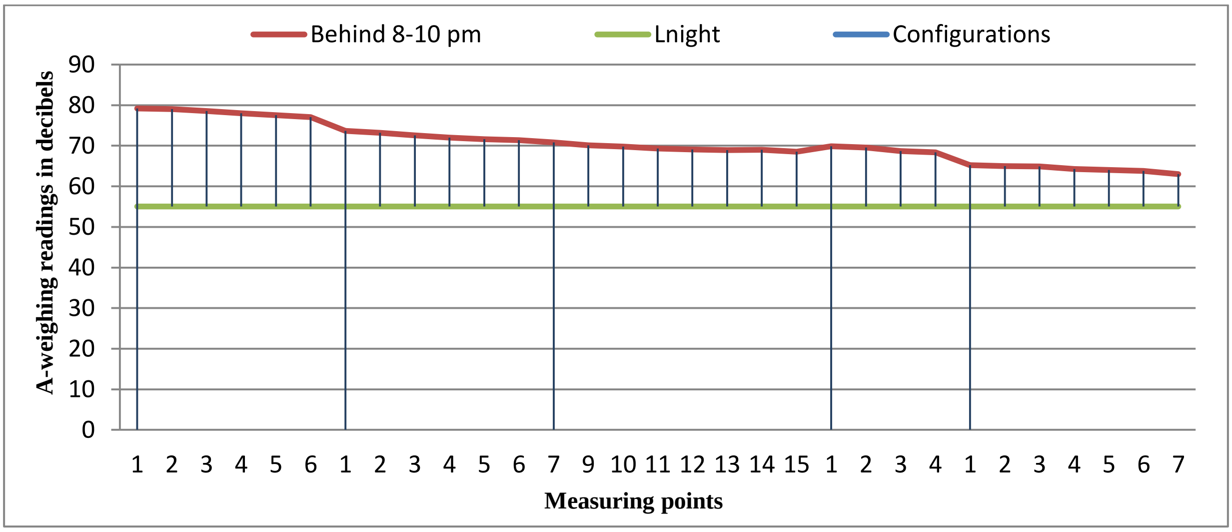

Figure 10: Readings measured from 8-10 pm and compared to night limits

Results showed that readings taken behind the fence from (8-10 AM) were very close in levels compared to maximum allowed noise levels (Lday) in decibels which is 65 dB, which indicates the effectiveness of fence as a barrier. On the other hand, readings taken behind the fence during the night (8-10 pm) showed a slight drop in noise levels compared to the maximum noise levels allowed in Egypt at night which is 55 dB. However, measurements taken at both day and night revealed a drop in noise levels mostly for the (concrete fence + marmox boards) followed by the (concrete fence + dense vegetation) by an average of 5 decibels. Figure 11 below shows a comparison between free field propagation using linear equation and day-evening-night measures with the presence of the fence.

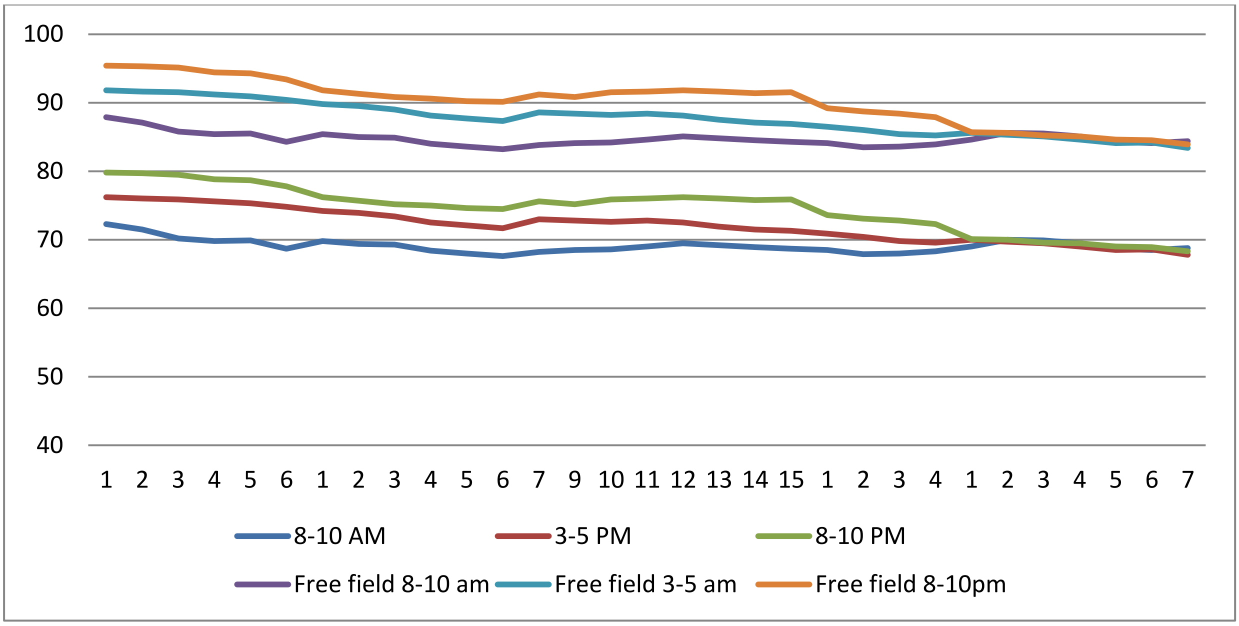

Figure 11: Free field condition in comparison to day-evening-night measures

Using the sound source propagation at a distance of 4 meters, results exposed that sound pressure levels in a free field condition was higher by an average of 15 decibels. This proves that the fence acts as a good barrier for blocking some noise levels and improving the quality of sound.

6. Analysis and Discussion

Results displayed that the fence existence act as an effective noise barrier. First of all the sound pressure levels calculated using the linear source propagation equation in a free-field condition resulted in readings of 15 decibels higher (reaching 95 dB) in comparison with the fence existence where readings did not exceed 79 dB. Concerning the fence’s height, fence number 2 (F2) had marmox boards placed above the concrete fence (3m high) on different heights giving a final height range of (4.5m to 6m high). On a constant measuring distance of 4m from fence, readings revealed that as height increased, noise reduction levels also increased reaching 7 decibels of noise attenuation. This indicates the importance of the effectiveness of height in a noise barrier. Referring to the fence length, the fence is long enough, and it covers an angle of more than 80 degrees from the perpendicular line of receivers to noise source, this helped in great decrease of noise diffracted along its edges. Moreover, the fence thickness could not be obviously studied as the whole concrete fence had the same thickness which is 0.25m thick. Therefore this factor was constant throughout the study showing no changes. Regarding the fence distance factor, distance had to be kept constant throughout the study (all measurements were taken on a 4m distance from existing fence) as the fence had different configurations which would have affected the precision of the results. No gaps or perforations were discovered along the fence. For the material factor, the whole fence is made up of concrete which is a reflective material, therefore not all noise was transmitted and diffracted, and part of that noise was reflected by the concrete fence, and this allowed a greater noise levels reduction. Furthermore, vegetation played an important role in part of the fence as mentioned previously for fence number 4 (F4), trees were high allowing diffraction of noise but on the other hand their interlocking dense feature prevented the pass of noise waves, vegetation was completely dense and interlocking, without any gaps in between which helped in a great noise reduction levels reaching an average of 5 decibels. This factor was found to cause a noticeable reduction in noise levels following the fence height factor. Conversely, for fence number 3 (F3), the vegetation had gaps and was high to allow diffraction and less reduction of noise causing lower noise screening. This research also proved that the combination of factors could help in more effective noise reduction, as previously discussed on the concrete fence part plus the marmox boards that added to the fence’s height, this combination indicated that the addition in height along the original height of the concrete fence allowed high noise reduction levels compared to the concrete fence (3m high) on its own.. Moreover, the concrete fence combined with the dense interlocking vegetation also showed that this combination of factors resulted in more noise level reductions in comparison with the concrete fence alone.

7. Conclusion

The study confirms as stated in the literature that the presence of a barrier is important for noise screening or reducing noise levels. It also highlights the importance of the effectiveness of factors that affect the performance of a barrier. Using the linear source propagation equation for measuring sound pressure levels in free-field condition acted as an alternative for calculating distance attenuation effect without the presence of barrier. Results of the data analysis actually revealed how noise was reduced due to the presence of a barrier or the fence. The assessment of fence factors added to the effectiveness of the fence by specifying how each affected the noise transmission positively and negatively. As mentioned for the addition of marmox boards at (F2), this added to the height of the concrete fence which showed very high reduction of noise levels followed by (F4) where dense interlocking vegetation indicated satisfying reductions.

8. Limitations

The limitations of the study need to be pointed out for more investigation in future research. There was difficulties for taking readings freely and photographs due to safety and security measures which made the process harder. Measurements were taken in summer where the weather was stable, with no wind or high humidity, so readings were limited to this time of the year only; but as the fence external conditions could show changes for different times of the year, readings would display different outcomes. Moreover, the measuring process took a lot of time to cover the length of the fence using hand-held analyzer (SLM) in front and behind the fence without being assisted. Using SLM tripods on specified distances according to the study would have made this process easier and faster, but unfortunately this was not applicable. Fence number 1 (F1)-the concrete 3m high fence- is the closest to the lateral street of concord plaza building, and therefore readings regarding that fence are completely and mostly affected by the traffic on that side of the fence so readings showed higher range of noise levels in comparison to the rest of the fence. Using the linear source propagation equation was an alternative to discovering the noise levels without the presence of any barrier, the free-field condition, which is less in accuracy than the direct method of insertion loss where measurements can be taken before the construction of barrier and after it becomes constructed; but this method was not suitable for this study.

9. Recommendations

In general, the field of noise barriers and community noise in Egypt need to be more highlighted and studied in more researches. The effect of having a fence as a barrier not only for safety and security measures, especially in Egypt, need more in depth studies on how a fence could be constructed to decrease as much noise as possible from surrounding environmental noises as traffic , social activities, MEP services and industrial work places. This study did not have the chance to experiment the effect of the material of the fence in noise attenuation as the fence was made from concrete only. It is recommended for further research to investigate the effect of different materials (absorptive and reflective) on noise reduction levels. In this study the measuring distance had to be kept constant therefore studying the effect of height of fence or barrier on different distances could not be tested. This is recommended for further research studies.

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