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The Effect of Design Efficiency of the Wall Barrier (Screen) On Traffic Noise Attenuation

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Abstract

This research evaluates the sound performance of screen models exposed to linear finite-length sound source as a mean of traffic noise attenuation to prevent sound waves penetration through the wall barrier (screen) gaps and sound diffraction around its edges which affect the sound shadow area in front of the building behind the screen which act as a noise barrier.
A theoretical background of the acoustical performance of screens that act as a noise barrier between the source (vehicles) and the receiver environment is presented.
Mathematical models are used to analyze the proposed case studies, and to test the effect of different type of screen design on geometrical spreading of direct and diffracted sound waves around the screen reaching the front facade of buildings facing traffic noise.
The objective of the research is to study

1. The effect of screen design and their geometrical configuration on noise penetration to the acoustical shadow zone behind the screen in aligned buildings.
2. The effect of the design variables of the barrier wall on the value of the visual angles at reception point.

Keywords: *Acoustical barriers; Façade environmental design; Noise wall barrier; Screen design; Traffic noise attenuation.*

1. Introduction

One of the main factors affecting noise attenuation in urban environment exposed to traffic noise is building envelop design, in particular, front façade elements such as screens, curtain walls and sun breakers, which act as a noise barrier placed between sound source and front elevation.

The Research Methodology of the paper consists of a brief theoretical background to indicate the effect of barrier walls such as screens in front of building façades as a noise barrier on traffic noise attenuation in the urban environment.

A hypothesis is set to study the impact of the geometrical configuration of screens on the ratio of protected area of front facade by screen to the exposed area which affects the traffic noise attenuation to the area behind these screens.

A mathematical model is applied to test the validity of the given hypothesis using different types of screen models. Prediction method analysis of defined variables and mathematical equations are used to estimate the resultant noise attenuation values and their relation to the design variables.

The outcomes expected from the current study are of special interest to architects who are mainly concerned with the geometrical configuration and orientation of screens acting as traffic noise barriers, especially for those who have no choice but to be close to the traffic, so as to reduce the negative impacts on the urban area behind these screens.

Results of this study indicate that the screen design and its orientation, affect the noise level at the reception point of building façade which in turn affects traffic noise attenuation values.

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1.1. Hypothesis:

The geometrical configuration of screens exposed to the linear finite-length sound source (traffic noise) affects the ratio of protected to exposed area of front façade behind these screens which accordingly will affect the noise attenuation value.

2. Finite Length Screen (Partial Screen)

When a noise barrier (screen) is placed between the source (vehicle) and receiver, the original straight line path from the source to the receiver is interrupted by the noise barrier depending on the noise barrier material and surface treatment. A portion of the original noise energy is reflected or scattered back towards the source. Other portions are either absorbed by the material of the noise barrier, transmitted through the noise barrier, or diffracted at the top edge of the noise barrier. See Figure1. *[1]*

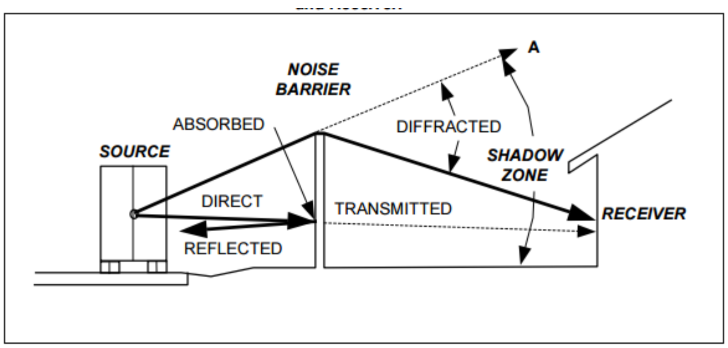


Fig. 1 Sound waves behavior due to barrier properties *[1]*

Without a screen, the sound propagates directly between the source and the receiver. When screen is placed between source and receiver, the space behind screen is divided into two: an illuminated zone and a shadow zone. *[2]*. A receiver in the illuminated zone receives the noise directly from the source while receivers in the shadow zone are acoustically protected.
All observation points in the shadow zone perceive a reduction of the sound level while those in the illuminated zone get very little advantage from the barrier, see Figure 2. *[3]*

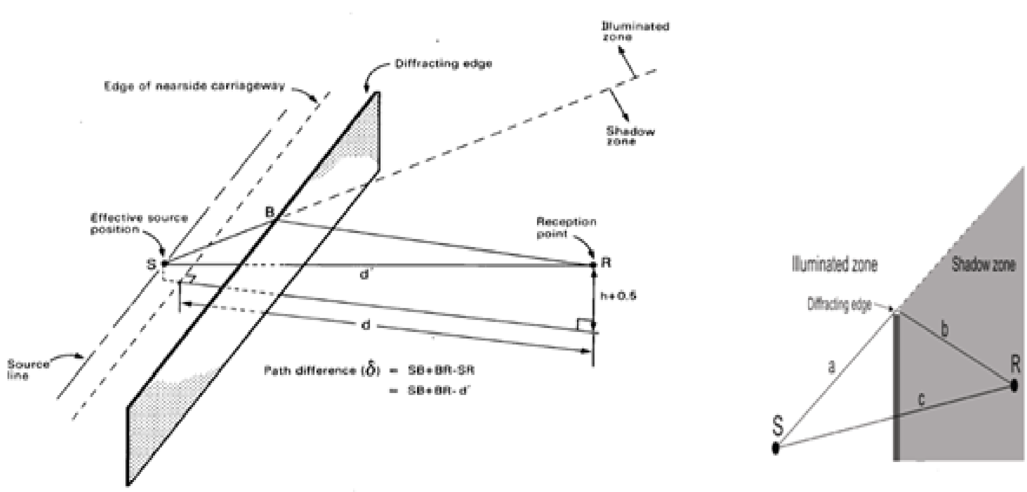


Fig. 2 Sound wave diffraction due to screening *[3], [2]*

Figure 2. Shows how a screen changes the sound path length from a source (S) to a receiver (R). The path length difference is **δ = a + b - c**.
The noise reduction in the shadow zone depends on the difference between the direct path length (c) and the indirect path length (a + b). *[3]*

The Transmission Loss (TL) of a barrier is the attenuation of sound passing through a material. It depends on:-

- The barrier material (mainly its weight).
- The frequency spectrum of the noise source. *[4]*

All materials permit sound energy to pass through although in varying degrees depending on the material and the frequency of sound. For a barrier to be fully effective, the amount of sound energy passing through it must be significantly less than that passing over the top (or around the edge). *[1]*

The transmitted noise is not the only noise from the source reaching the receiver. Originally, the effect of a barrier is to diffract the original straight path of sound wave (a – in Figure 2) and to force it to follow path (b) downward towards the receiver. This process also results in a "loss" of acoustical energy. *[3]*

The receiver is thus exposed to both transmitted and diffracted noise. Whereas the transmitted noise only depends on barrier material properties [4], the diffracted noise depends on the location, shape, and dimensions of the barriers. The sound wave diffraction is not equal to all frequencies. Low frequency waves diffracted more than medium and high frequencies. *[5]*
The screen should be too small compared to the wavelengths of sound waves, as shown in Figure 3. *[6]*

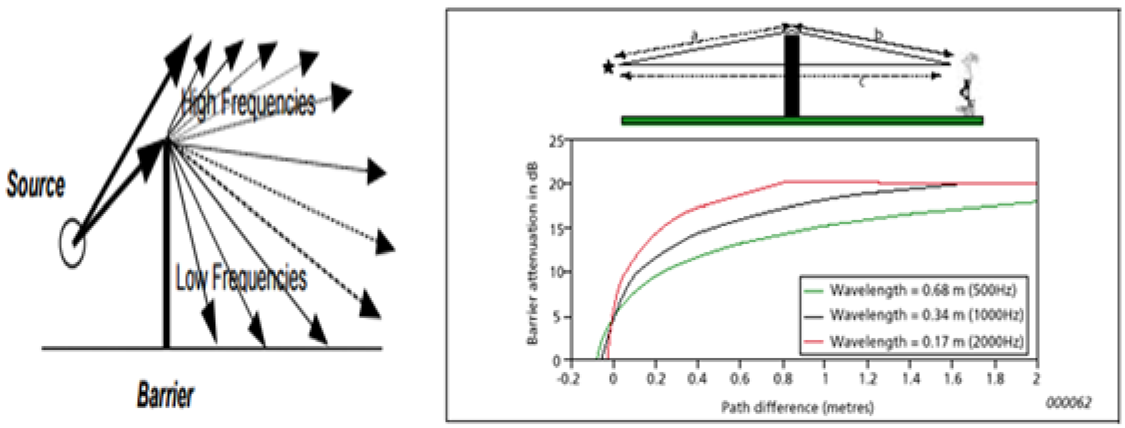


Fig. 3 [Different degree of sound wave diffraction depending on its frequency] *[6]*

3. Screen Acoustical Design Considerations

3-1. Noise Shadow behind Screen

Screen between noise source and the recipient will reduce the noise depending on:-

- the angle of noise shadow
- The effective height of the barrier above the line connecting the noise source with the recipient. *[7]*

The traffic noise reduction of screen (barrier wall) will improve with increasing angle of noise shadow (β) and screen effective height (H) above the line connecting the noise source with the recipient, as shown in Figure 4. *[8]*

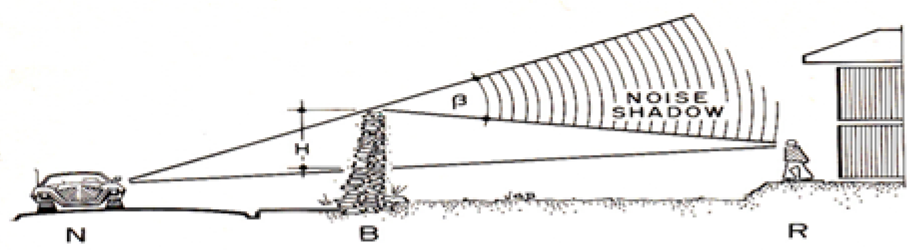
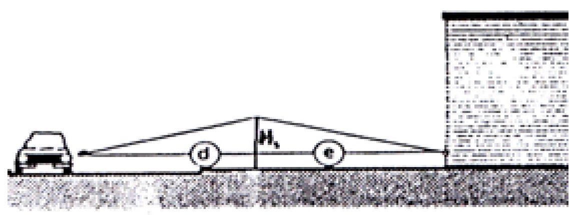


Fig.4 Relation between the height of the barrier and the noise reduction *[8]*

For a screen to be acoustically effective, it must be close either to the noise source or to the recipient to be protected against the noise.

3-2. Screening Factor (SF)

All of effective screen height and distance from the source and the receiving point variables affect the value of the screening factor as in the following equation *[4]*.



$$S.F = H^2 \left(\frac{1}{d} + \frac{1}{e} \right)$$

Where
H= effective height
d = distance between screen and sound source
e = distance between screen and reception point
S.F = screening Factor

The degree of screening depends on:-

1. The relative positions of the source **S,** the reception point R, and the diffracting edge along the top of the screen that cuts the vertical plane, containing both **S** and R.
2. The zone between the screen and the reception point is divided into an illuminated zone and a shadow zone. *[4]*

The screening factor has the same value for all the models that has been analyzed in the practical part of the study. This is due to fixed value of the height of the screens and of the distance between the source and receiver point.

3-3. Barrier Solidity & Continuity

Reduction in noise screen performance due to Holes, Slits or Gaps affect noise level value at reception point, solid screen will block direct line of sight, reducing impact of noise on internal living spaces, sometimes low height solid screen provides acoustic buffer while still maintaining sight lines and 'active' facade**.**
Sound "leaks", due to holes, slits cracks or gaps through or beneath a noise barrier, can seriously reduce the barrier performance, and should be avoided. Any gaps represent segments of the barrier with zero Transmission Loss; (i.e. the gap can transmit 100% of the incident energy). Therefore, extra efforts should be done at design and construction stages to avoid holes, slots or gaps. *[1]*

3-4. Surface Density

The increase in mass of the measured surface barrier (kg / m²) increases the attenuation values. Material used in the barrier must have a surface density of at least 20kg/m2, so that the barrier material should be dense enough to reduce the transmitted sound by at least (15) db.

3-5. Visual Angles

The limited length barriers obscure part of the source line (street) from vision creating angles of view hidden from the source (θ_2) (protected angle), and angles of view visible to the source (visual angle) on both sides of the limited length barriers (θ_1), (θ_3) . *[6]*

As shown in Figure 5, the total sum of the viewing angles (visible and blocked) is (180 °) at the reception point. The attenuation increases with the values of (θ_2) (protected angle) which in turn increases with the length and depth of the barrier. *[2]*

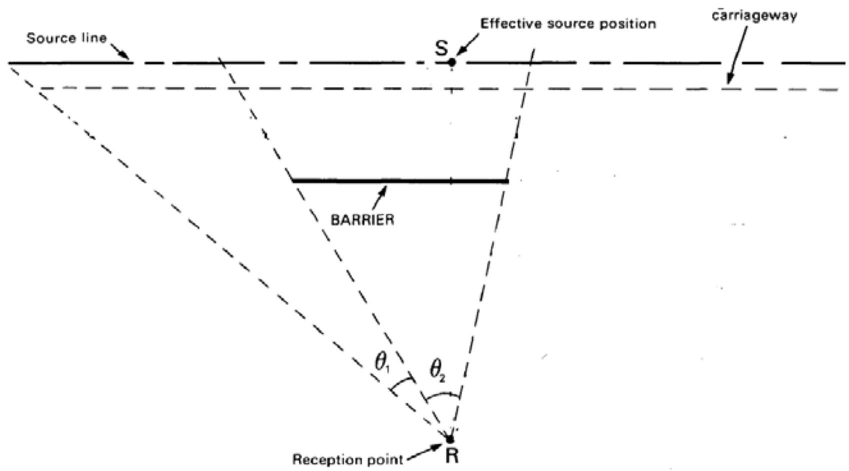


Fig. 5 Visual and protected angles behind screen *[2]*

3-6. Visual & Architectural Impact

Screen walls as acoustical barriers would affect the aesthetic perception of road users and people living there. The principle is to design barriers with appropriate scale and character compatible with the local environment. If it is not possible to design a barrier that blends into the local environment, the aim should be to reflect some of its features such as materials, colors, textures and shapes, in a form of barriers which has aesthetic aspects, without being dominant in the field of view. Sometimes, transparent panels may be used to lighten the overall impact, either to create "windows" which partially restore views, or along the top section of a barriers to reduce its apparent height.

To reduce the visual impacts of barriers, some appropriate solutions are considered, such as: *[9]*

- The linear barriers could be broken down using alternative solid and transparent panels for example.
- Using color variations or plantation to soften the sharp edges of barriers.
- Articulated screen forms creating additional noise shields to reduce its visual impact.
- Using acoustic shield wall integrated into front elevation design to provide a buffer to noise sources. *[10]*

The visual quality can be enriched through manipulation of the linear form, such as segmentation, curving and articulation of the surface texture and color. The overall appearance of barriers could be further articulated through applying of architectural concepts such as rhythm, proportion, order, harmony and contrast. The repetition of units can create a sense of order and harmony which is conducive to road safety. *[11]*

To reduce traffic noise for architectural design of building elevations, the path of the sound waves should be considered during building design.

Where noise screens cannot be built to cover the whole facade of a building facing the road, it is often possible to consider shorter local screens to shield noise affecting the openings to the building (i.e. for windows and doors) as shown in Figure 6. This allows natural ventilation with a substantial noise reduction.

Various types of solid fencing that can be effective in reducing traffic noise are shown in Figure 6. Noise barriers are most effective at protecting outdoor areas and ground floor levels of buildings.

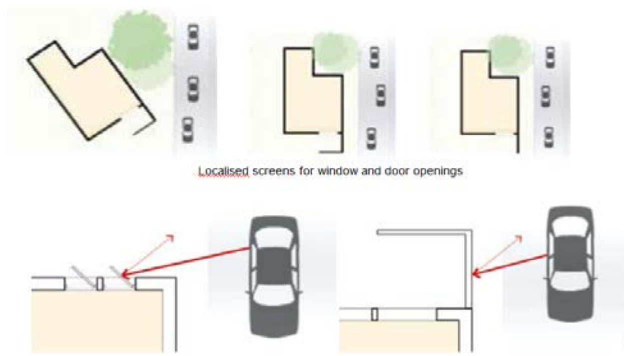


Fig. 6 Localized screens for window and door openings *[9]*

The use of external screen walls can offer an economical alternative for achieving noise reduction and privacy particularly if only a window or a small outdoor living area is in need of shielding. See Figure7. *[12]*

- Some protection may be possible even if certain view or sun penetrations are important. See Figure 7-1.
- If view is not as important as traffic noise, type of partial screen wall affords good protection without excluding too much sun for privacy and wind protection. See Figure 7-2.
- Protection for windows at the side or back is easier and less expensive. See Figure 7-3.
- A small right angle return on the fin wall increases the protection to this side window. See Figure 7-4.

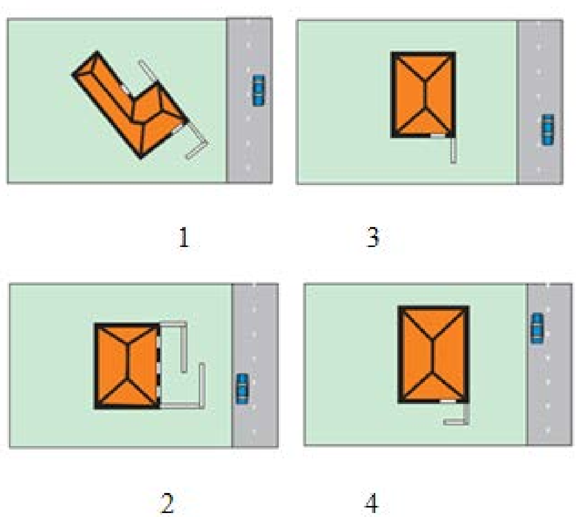


Fig. 7 External screen walls as a noise barrier *[12]*

4. The Prediction Methods For Calculating Traffic Noise Attenuation Due to Sound Waves Diffraction Around Screen.

The prediction method to calculate traffic noise levels (after measuring traffic noise levels from roads), depends on many correction factors to be added to the noise level at the reception point according to many factors, such as, propagation of sound waves, distance, site layout features, reflections from buildings and facades…etc.
This study applies a prediction method to calculate the attenuation values of traffic noise at reception point considering the correction factors of both: sound waves diffracted around screen, and the visual and protected angles of view behind the screen in front of the building facade.
The degree of screening is calculated from the difference between the diffracted path from the screen edges and the direct path depending on whether the reception point is in the illuminated zone or the shadow zone respectively.
The acoustic performance of a noise barrier can be defined in terms of the Fresnel number and is calculated as: *[13]*

Fresnel number* $N = 2\delta / \lambda$

Where **δ** = (The path length difference is $\delta = a + b - c$
λ = the wavelength of the sound in air.

Fresnel Number* N = is a (variable value) that depends on the difference between the direct and diffracted sound paths obtained from the geometrical analysis of the models. *[13]*

The Fresnel number equation above indicate that the lower the frequency is, (i.e. the longer the wavelength), the lower is the Fresnel number (N). In other words, noise barriers are less effective (bring less attenuation) for low frequency noise.
The attenuation value can be calculated depending on Fresnel number (N) using Maekewa equations: *[13]*

$$AT = 10 \log (3+20 N) \qquad N>1$$

Where: AT = sound level attenuation
N = Fresnel number = $\mathbf{2 \delta / \lambda}$

5. Representation of Mathematical Models of Screens.

To test hypothesis, twelve different designs of screen walls are chosen to be subject to a sound source in front of building elevation. The degrees of sound impact are different due to the screen configuration, solidity, continuity, and directivity.

Mathematical models are used to test the twelve case studies which are placed at distance from a finite-length sound source, namely a linear source consisting of a set of point sources equidistant from each other (with constant equal distances between the points of the vehicular traffic that represents a main street sound source at (0.5m) high above the ground level). While the source line represents the (X) axis of the measuring network of the mathematical model, the (Y) axis represents the distance between the building façade and the street line (i.e. the sound source), and the (Z) axis represents the height of reception point from the ground. So the point of reception (P) is determined at the front façade by (X, Y, Z) axes including its height above the ground and its distance from the sound source.

Mathematical models of screens are classified in two types depending on their directivity relative to the level of the front elevation plain of the building.

1. Screens parallel to the flat front facade of building (parallel to the reception point) facing traffic noise, see types (A1-A6) of Figure 8.

2. Screens parallel to the recessed elevation of building (non-parallel to the reception point) facing traffic noise, see types (A7-A12) of Figure 8.

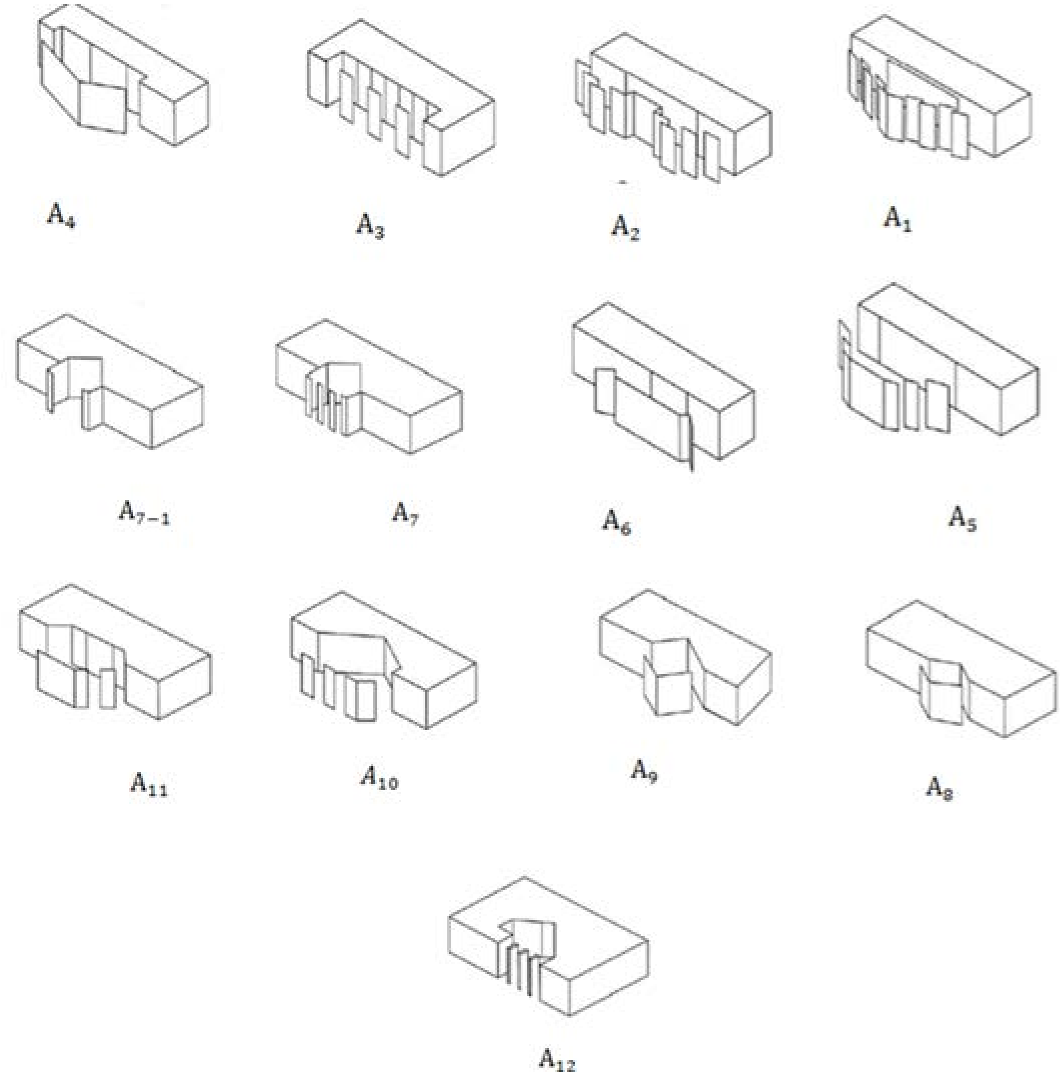


Fig. 8 Mathematical models showing types of screen

6. Geometrical Analysis of Sound Waves Path

It is necessary to calculate the diffracted sound waves paths in regard to the determined diffraction points on the screen edges facing the source. This can be achieved from geometrical analysis of direct and diffracted sound waves paths from visual points of sound source line to the reception point (p). However, the surfaces designs of the exposed screens to the sound source (traffic noise) are considered in order to determine the coordinates of such diffracted point of the sound paths.

It is feasible, thus to calculate lengths of paths received at the screen placed in front of the reception point (P), including the direct and the diffracted paths by these screen as a noise barriers. This geometrical analysis considers the following steps:

- Coordinates of reception points (P), which are located on the center line of the window behind screen.
- Coordinates of point sources that constitute the finite linear source by visual angles at reception point (P).

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- Determine the location of points diffracted incident sound on the side edges of screen or located on both sides of the screen gaps.
- Determine the length of the visual line of the source (street) from receiver locations, to study its impact on the number and length of direct sound paths that affect the degree of traffic noise attenuation.

7. Calculation of Parameter Values Using Geometrical Analysis of Models

1. Calculate the visual angles (θ_1) from reception point (P) to the source line.
2. Calculate the protected angles (θ_2) by screen from reception point (P) to the source line which is located in the sound shadow area, see Figure 9.

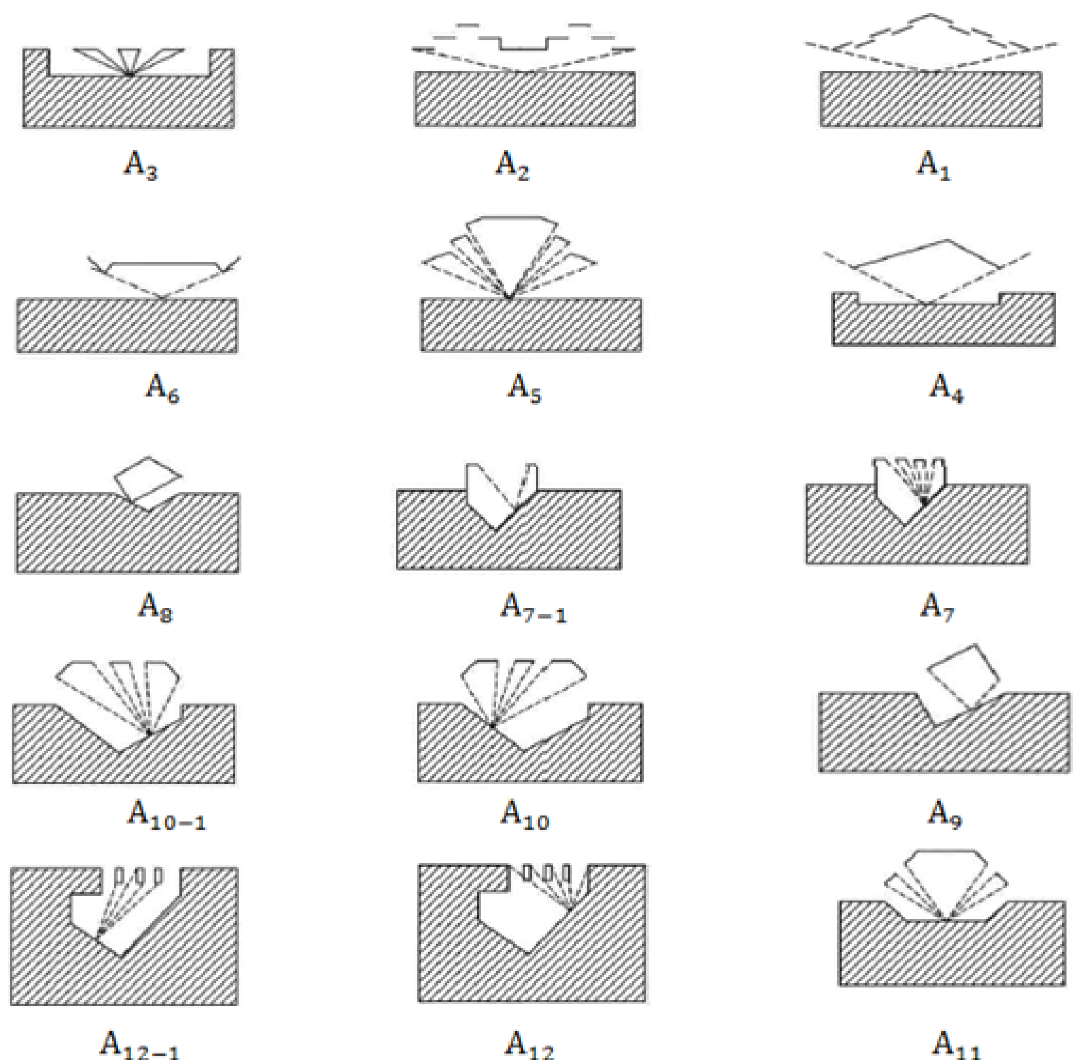

Fig. 9 Types of mathematical models showing protected and visual angles.

The values of visual and protected angles at reception point are shown in table 1.

Table 1 Calculated parameter values (visual and protected values).

Model No	**Visual angles values (θ_1)**						**protected angles values (θ_2)**				
A_1	13	13					154				
A_2	11	11					157				
A_3	7	28	28	7			19	13	44	13	19
A_4	27	27					134				
A_5	22	6	4	4	6	22	15	11	62	11	15
A_6	23	23					134				
A_7	13	12	8				31	13	10	93	
A_{7-1}	56						31	93			
A_8	14	25					41	101			
A_9	21	27					83	49			
A_{10}	15	10	15	21			55	20	12	33	
A_{10-1}	17	13	10	14			15	30	12	20	49
A_{11}	13	12	12	13			18	12	70	12	18
A_{12}	19	16					22	6	116		
A_{12-1}	4	11					95	9	61		

3. Calculate the path difference of the incident direct and diffracted sound paths to the reception point after determining the coordinates of each of them with respect to the point of origin (0, 0), in order to study its impact on noise attenuation, see Figure 10.

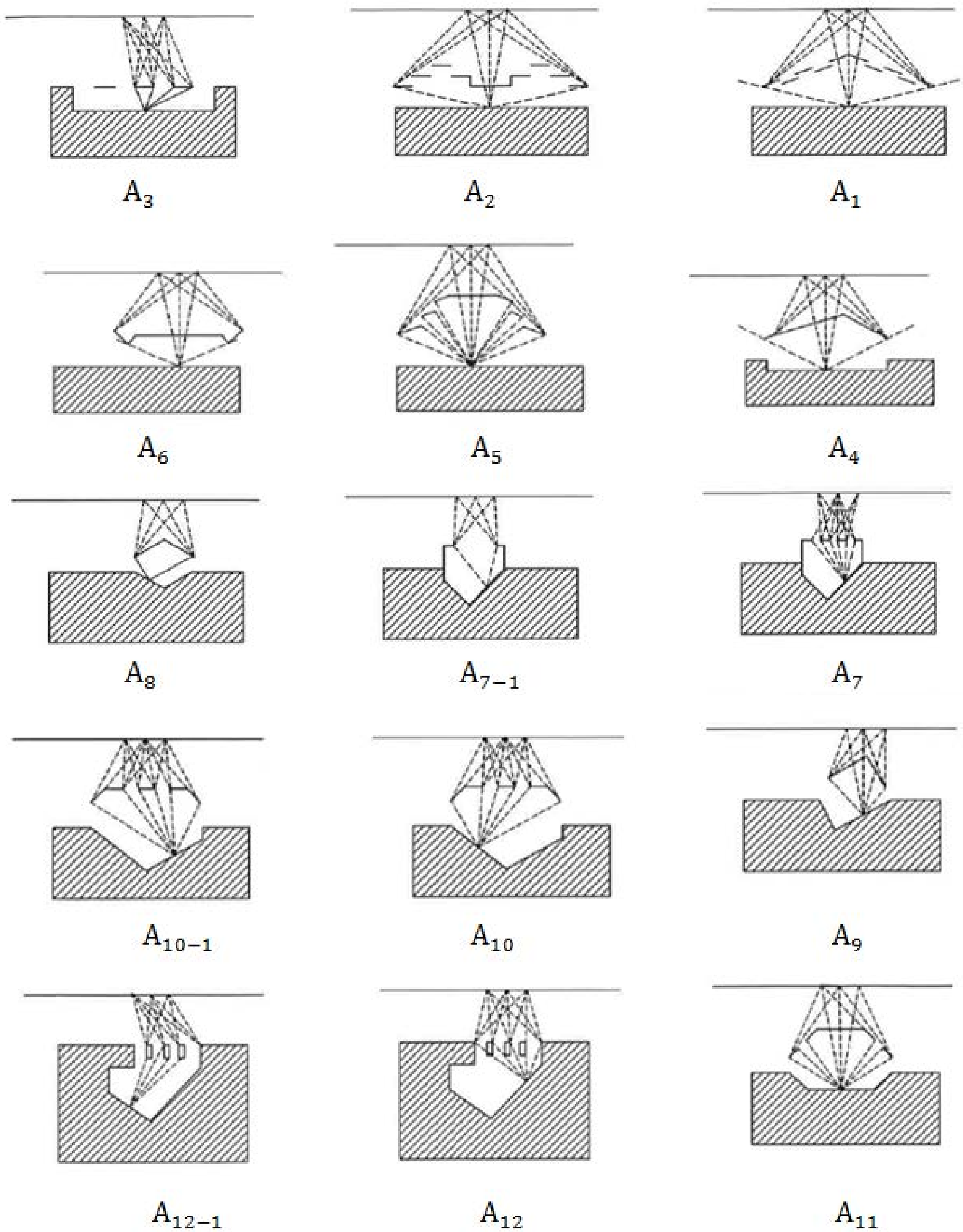

Fig.10. Types of the mathematical models showing direct and diffracted sound waves

7.1. Hypothesis Constants

- Height of reception point (P) from the ground at a constant value of (2 m).
- Sound source height at (0.5 m) above the ground.
- The location of reception point (P) at constant values.
- Linear traffic noise level is assumed to be constant L_p = 75 db
- Coordinates of point sources that constitute the finite linear source.

7.2. Hypothesis variables

- The number and length of direct noise paths from the set of points on the source line.
- The number and length of diffracted noise paths from barrier screen around both sides of the screen.
- Values of path length difference (**δ**) due to its design, articulation and configuration, affected by the difference between direct and diffracted paths.
- Source visual angles (θ1) at reception point (P).
- Source protected angles by screen (θ2) at reception point (P).
- The length of the visual part of the linear source (visual source) according to visual angles at different reception points.

7.3. Application of mathematical equations to find values of defined variables

The Calculated values of parameters extracted from the geometrical analysis of the mathematical models are used as variable values in the following equations to find their resultant impact on noise attenuation applied. See [Table 2].

1. Calculating the correction factor of visual angles at the reception points. *[2]*

$$C = 10 \log (\theta/180) \qquad (1)$$

Where: C= correction factor
θ = visual angle

2. Calculating the total angles attenuation:

2-1 Visual angles attenuation ($\boldsymbol{F_1}$). *[5]*

$$F_1 = \sum [\ 10^{cu1l10} \ + 10^{cu2l10} \ + 10^{cu3l10} + \text{-------}] \qquad (2)$$

Where: F_1=total visual angle attenuation
Cu=visual angle attenuation for each visual part of source line

2-2. protected angles attenuation ($\boldsymbol{F_2}$) *[5]*

$$F_2 = \sum [\ 10^{cu1l10} \ + 10^{cu2l10} \ + 10^{cu3l10} + \text{-------}] \qquad (3)$$

Where: F_2=total protected angle attenuation
Cu=protect angle attenuation for each protected part of source line

3. Calculating the Attenuation of the sound diffraction around screen. *[13]*

$$AT = 10 \log (3+20\ N) \qquad (4)$$

Where AT= Attenuation of the sound diffraction around screen
N = Fresnel Number explained above.

4. Calculating the noise level at reception point (P) after total attenuation of protected area due to protected angles and sound path diffraction around screen ($\boldsymbol{L_2}$). *[14]*

$$L_2 = L_p - F_2 - AT \qquad (5)$$

Where L_2= noise level after attenuation of protective areas
AT= Attenuation of the sound diffraction around screen

F_2 = total protected angles attenuation
L_p = Traffic noise level = 75 db (constant)

5. Calculating the noise level at reception point (P) after total attenuation of visual areas (L_1) due to visual angles attenuation. *[14]*

$$L_1 = L_p - F_1 \quad (6)$$

Where L_1= noise level after attenuation of visual areas
F_1 = visual angle attenuation

6. Calculating the total noise level (L) after attenuation of visual and protected areas. *[5]*

$$L = 10 \, [\, 10^{L_1/10} + 10^{L_2/10}] \quad (7)$$

7. Calculating the total noise attenuation at reception point (ATT). *[14]*

$$ATT = L_p - L \quad (8)$$

Where ATT= the total noise attenuation

8. Calculating the ratio of protected to exposed area (K) of front facade. *[15]*

$$K = 10^{ATT/10} \quad (9)$$

Since $K = A_s / A_u$ (10)

Where A_s = protected elevation area
A_u = exposed elevation area

Thus

$$A_s / A_u = 10^{ATT/10} \quad (11)$$

The Parameter values are shown in Table 2.

Table 2. [Parameter values calculated from the program]

L (db) = noise level after attenuation

Model No	**ATT(db)**	**F_1(db)**	**F_2(db)**	**AT(db)**	**K**	**L(db)**
A1	8.3	-8.4	-.67	29.1	6.81	51.6
A2	9	-9.1	-.59	26.2	7.98	50.9
A3	3.8	-4.1	-2.2	16	2.44	56.1
A4	5.1	-5.2	-1.2	26.5	3.27	54.8
A5	4.2	-4.5	-1.9	15.5	2.65	55.7
A6	5.8	-5.9	-1.2	24.5	3.83	54.1
A7	7.2	-7.3	-.8	20.2	5.25	52.7
A7-1	4.9	-5.0	-1.6	18.6	3.12	55
A8	6.3	-6.6	-1.0	17.1	4.26	53.6

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A9	5.4	--5.7	-1.3	17.2	3.52	54.5
A10	2.4	-4.7	-1.7	4.8	1.76	57.5
A10-1	1.9	-5.2	-1.5	3.3	1.57	58
A11	5.3	-5.5	-1.4	17.3	3.4	54.6
A12	5.6	-7.1	-.9	10.46	3.71	54.3
A12-1	9.5	-10.8	-0.3	15.5	9.08	50.4

Table 2 above clarifies how the number of direct, diffracted sound paths and visual angles affects the total received sound level at reception points (P) and thus causes a reduction of noise attenuation. It is observed, however, that the smaller the gap's exposure degree to the source line is, the bigger its noise attenuation becomes.
Figures 11 through 18 represent outcomes of the computer analysis, as follows:

7.4. Diagrammatic Representation of Results

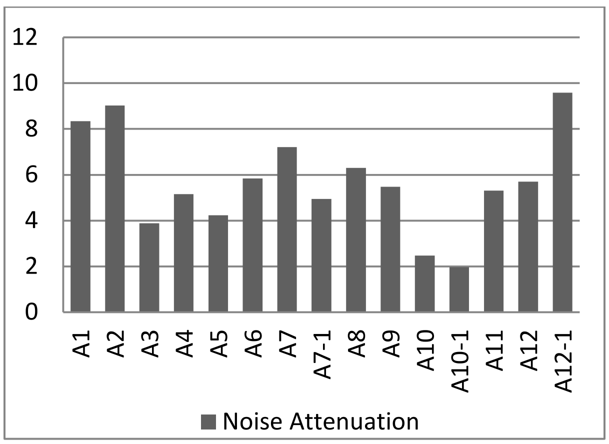

Fig. 11 Comparison between attenuation values exposed for reception points (P) for all types

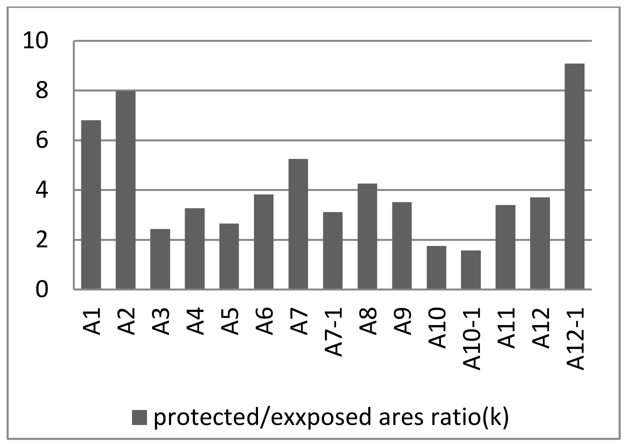

Fig.12 Comparison between protected to ratio of elevation (K) for all types]

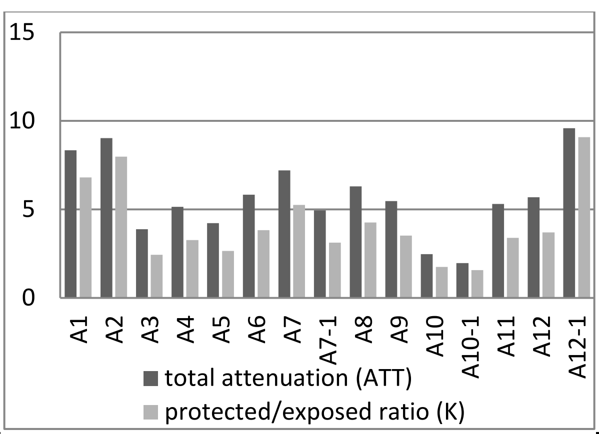

Fig.13 Impact of protected to exposed areas of elevation (K) on attenuation values.

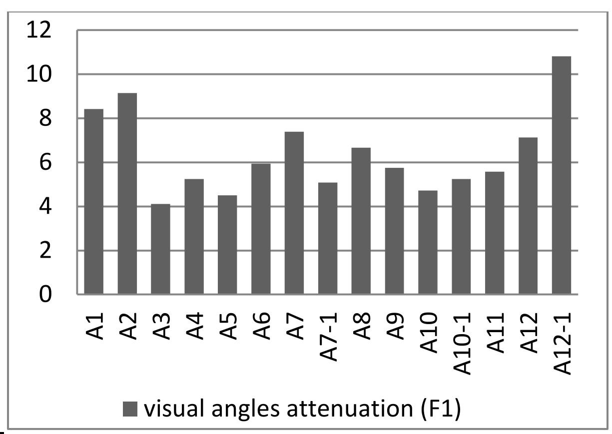

Fig. 14 Comparison between visual angles attenuation values (F1) for reception point (p).

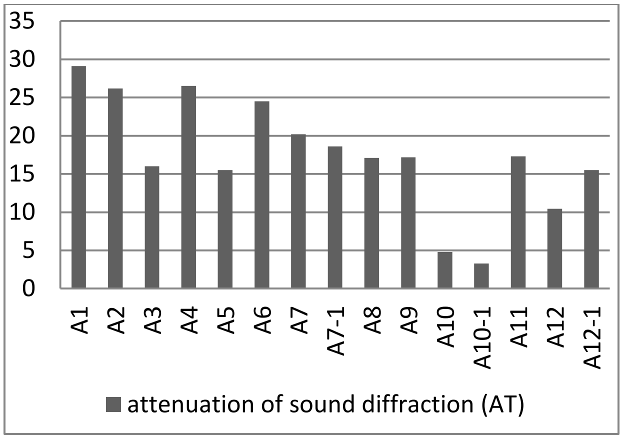

Fig. 15 Comparison between attenuation values of sound diffraction around screen (AT).

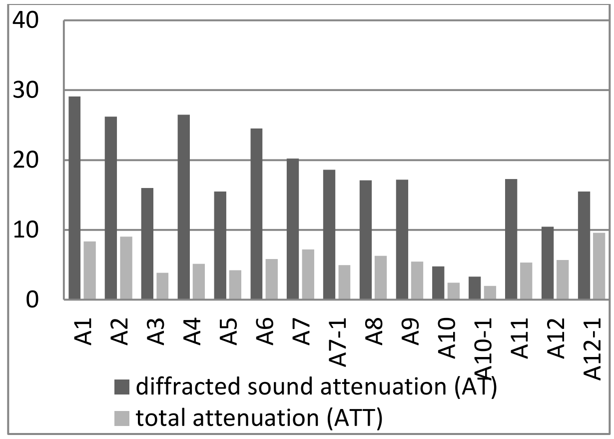

Fig. 16 Impact of diffracted sound attenuation on total attenuation at reception point (ATT).

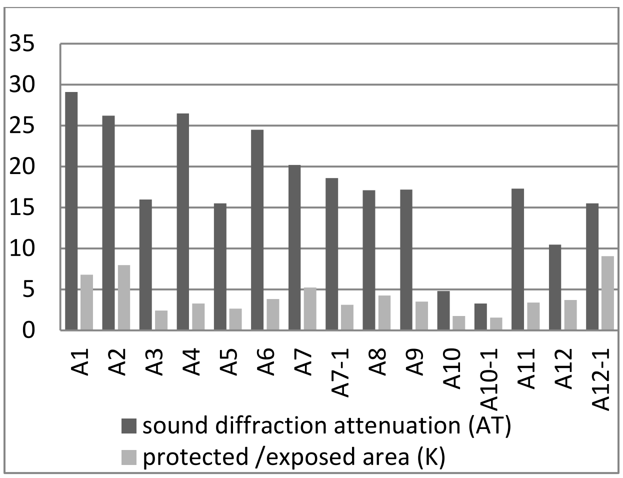

Fig. 17 Impact of sound diffraction attenuation (AT) on protected to exposed area ratio (K).

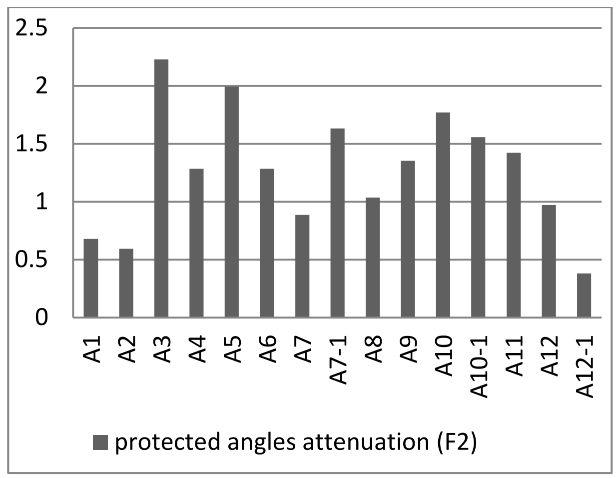

Fig. 18 Comparison between protected angles attenuation values (F2) for all types.

8. Conclusions

The effect of the geometrical configurations of the wall barrier on its acoustical insulation efficiency is found through the study of its effect on the ratio of protected area to the area exposed to noise behind the screen at the reception point at the building facade, and then its impact on the traffic noise attenuation values.

It has been noted that:

1. The amount of attenuation of wall barriers (screen) relies on a set of variables:
   - The shape of the screen
   - Barrier Area Exposed to noise
   - Visual degree of Opening to the source
   - Inclination angle of the building facade to the screen
   - The barrier gaps direction with respect to the source line

2. The best design of the barrier is the one that provides the best attenuation, where one can get the largest protected area from traffic noise at the facade when the barrier wall has no openings (slots). So, it is better to reduce the number of gaps exposed to the source at the barrier keeping in mind that the openings should be on

the side and are not parallel to the source when comparing models (A_1) and (A_2) shown in Figure 10, and Figure 20.

3. The continuous barriers with no slots(holes) parallel to the front facade give more attenuation than if the barrier with slots facing source when comparing models (A_4) and (A_6) with model (A_3), see Figure 11.

4. when the wall barrier contains openings (slots) facing the source with a façade far from the barrier, This allows the arrival of diffracted waves from the sides of the barrier wall and through its slots (holes) to the reception point causing the lowest attenuation, as explained in design model (A_{10}- A_{10-1}), see Figure (11) and Figure 19.

5. The attenuation value increases as the ratio of the protected area to the exposed area of the facade increases, see Figure 13. It has been noted that the lowest ratio was for the design model (A_{10}- A_{10-1}), and the highest ratio was for the design model (A_{12-1}).

6. If the gaps (slots) in the barrier wall were collateral, it gives more attenuation than if they were parallel to the sound source when comparing models (A_{11}) with (A_{10-1}) and (A_{10}). But the greater the number of side/collateral openings, the lower is the attenuation value as in the design model (A_5) compared to the model (A_{11}).

7. When the barrier level is not parallel to the level of the reception point (i.e. at the facades (recessed elevation) where the window is located at the acoustical shadow area), we get the largest protected area from noise as in the design model (A_{12-1}), see Figure 11 and Figure 21. But the larger the side visual angles of the barrier wall the less is its sound attenuation level. This is clear comparing design models (A_4) with (A_8) as in Figure 14, which shows the difference in values of attenuation between patterns depending on the visual angles.

8. The attenuation value of the reception points between parts of the facade of each design varies because some of the reception points are located in the sound shadow zone of the barrier wall, in addition to the attenuation of diffraction from the barrier, which in turn will increase the value of total attenuation. This can be observed comparing model (A_{10}) to model (A_{10-1}), and also in comparing model (A_{12}) to model (A_{12-1}) as shown in Figure 11.

9. The attenuation values vary depending on the source and reception point locations with respect to the edges of the barrier wall sides, which in turn will affect the path difference between the diffracted and direct sounds as in the design model (A_1), which gives a higher diffracted attenuation value from the barrier, as in Figure 15.

10. The multiplicity of protected angles at the reception point and its high values will result in higher attenuation as can be noted in the design model (A_{12-1}) compared with other designs of the barrier. The lowest value of attenuation was found in model (A_3) as shown in Figure 18.

The results of the study suggest the following:

- The side openings (gaps) of the barriers parallel to the source line gives better attenuation than if the slots were parallel to the source. See Figure 20.
- It is preferred to incline the facade from the plain of the barrier and put windows in the sound shadow zone of the barrier. See Figure 21.
- It is better to design a graded (staggered) barrier than a continuous barrier surface as to reduce the barrier exposed area.

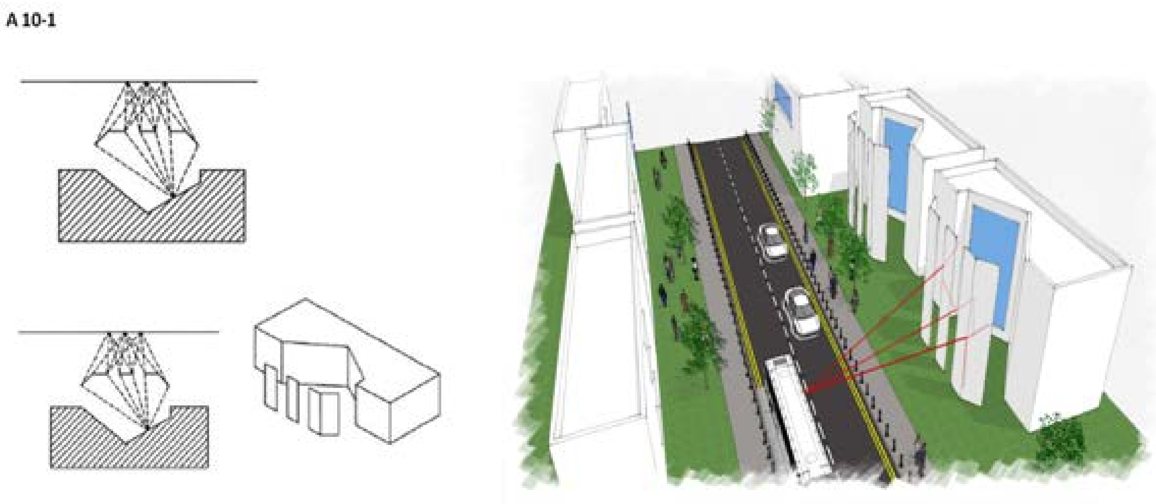

Fig.19 Screen type (A_{10-1}) represent the lower attenuation

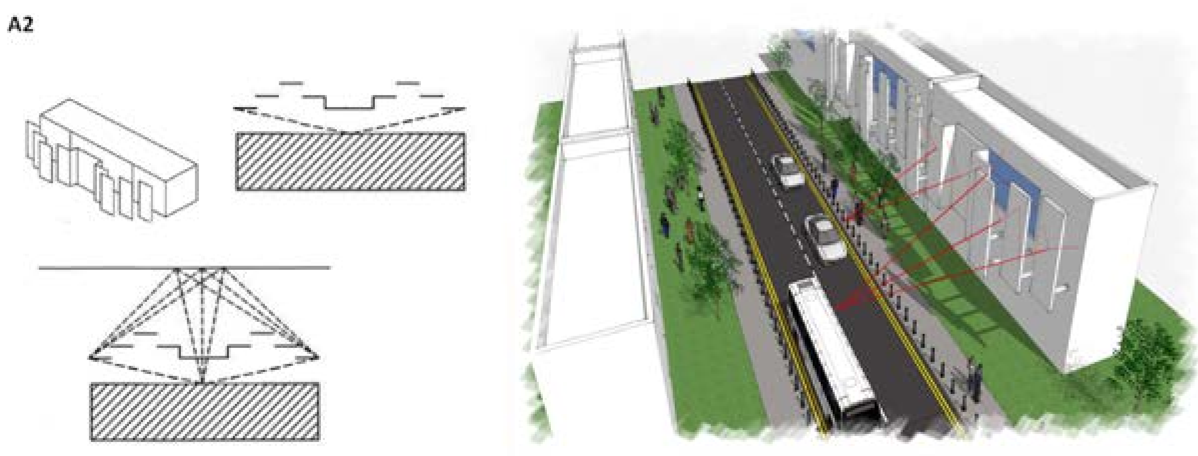

Fig.20 Screen type (A_2) represent best attenuation

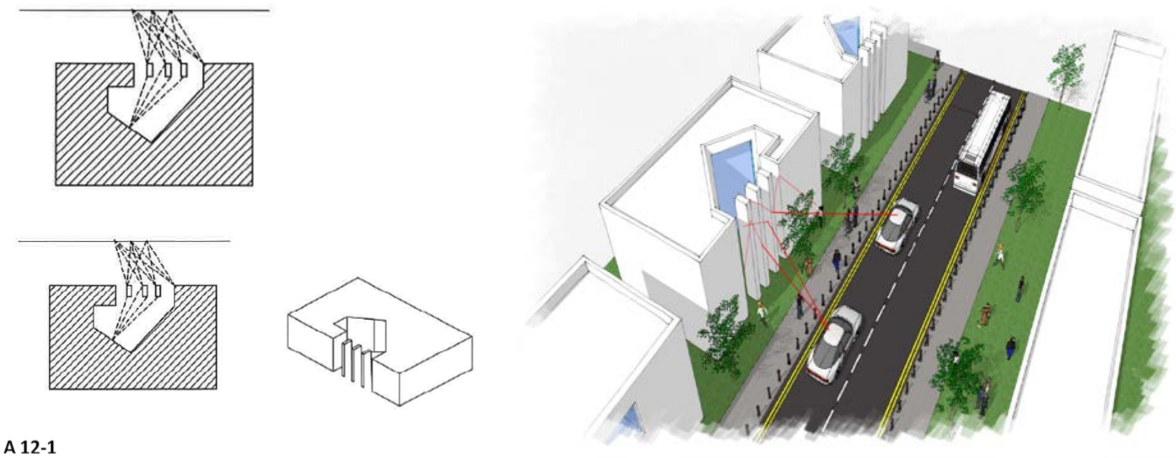

Fig. 21 Screen type (A_{12-1}) represent the best attenuation

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