Acoustical Effect Evaluation of Balconies' Ceiling Form in Protecting Buildings Facades Against Traffic Noise.

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Acoustical effect evaluation of balconies' ceiling form in protecting buildings facades against traffic noise.
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Abstract

This study presents the evaluation of acoustic performance off tall building facades closed to roadway due to one of its balconies configurations, namely ceiling, with an inclined form in terms of traffic noise reduction. Three inclined angles are tested (5°,10°, and 15°) with different balcony depths (2m, and 3m) by using the Pyramid Tracing model (DISIAPYR) developed by A. Farina and scale model measurements. The results in terms of A-weighted sound pressure level reduction are expressed into the balcony back wall and in free field. The protection level, defined as the difference in noise levels before and after inserting the proposed ceiling form, has been used to assess the reduction offered by that configuration. A maximum reduction due to using these forms is obtained at higher floors.

1. Introduction

A balcony is an extension of an internal floor with access by means of windows or doors to an external environment. It provides view and weather protection and is a familiar element in buildings. Particularly, it can provide an acoustical protection by means of its elements forms.

Most of the previous studies investigated sound levels on balconies by using experimental models as the work of Mohsen, and Oldham (Mohsen and Oldham 1977), numerical models of Hothersall (Hothersall 1996), and Li (Li et al. 2003), and the field measurements analyzed by May (May 1979), Gilbert (Gilbert 1969); and Li (Li et al. 2003). These studies carried out a study of traffic noise reduction in the context of treatment to the sound source, in the path between the sound source and the receiver, and at the reception point.

An alternative approach concerning the self-protecting buildings was discussed by Mohsen and Oldham by means of changing balcony depth (Mohsen and Oldham 1977). Another architectural concept was presented by Hossam El-dien and Woloszyn (Hossam El-dien 2003; Hossam El-dien and Woloszyn 2003; Hossam El-dien and Woloszyn 2004), by using an inclined parapet to increase the shielding effect to protect the balcony back wall from the traffic noise nuisance in a free field.

In the present study, we aim to predict the effect of one of the balcony configurations, namely ceiling, on the traffic noise reduction into building facades.

Inclined ceilings with different angles are tested by 3D numerical model of Pyramid tracing *(DISIPYR)* developed by Farina (Farina and Brero 1996), and in free field conditions. The

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results will be expressed in terms of sound pressure level reduction, in A-weighted scale, into the balcony back wall and for a high rise building.

2. Geometric parameters

Acoustic simulation programs (CITYMAP&DISIAPYR) are used to model the outdoor sound propagation environment within the balcony configurations and in three dimensions. This algorithm allows the simulation of outdoor sound propagation with a complex urban form and the evaluation of sound passing through sound insulating panels, taking into account the edge diffraction over the boundaries and the scattering of sound from the edges of finite surfaces, and the surface diffusion coefficient (Farina and Brero 1996).

As shown in Fig. 1, the simulation has been carried out with the following variables:

1. The horizontal projection depth *(W = 2, and 3 meters).*
2. The balcony's ceiling inclined angle *(Ø = 5°, 10°, and 15°).*

And we have fixed the following parameters:

1. Sound source (infinite line source).
2. Distance to road (8.00 m).
3. Front wall height (1.00m).
4. Balcony's length (5.00m).
5. Number of floors (8 floors).

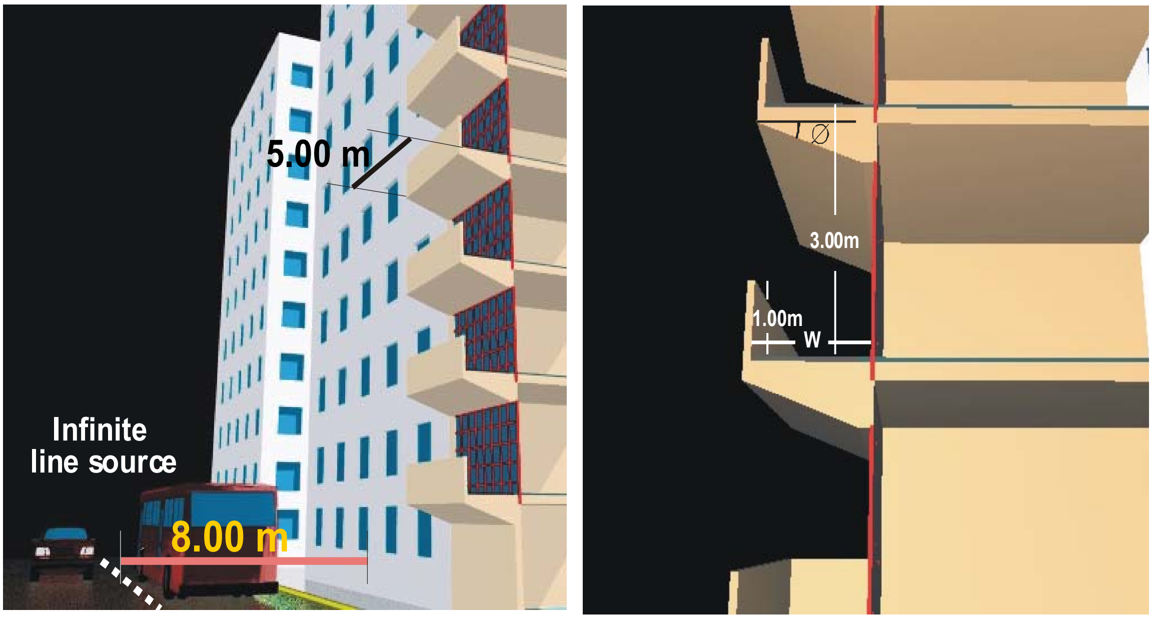

Fig. 1. Geometric parameters.

3. Prediction Methodology

In three dimensions, the model is equivalent to an infinite coherent line source parallel to the building facade. All the surfaces in the model are initially defined as specular surfaces (concrete with absorption coefficient 0.07 at 1K.Hz). The acoustic performance of the balcony ceiling with an inclined shape has been assessed by means of a numerical simulation. Three inclined angles have been tested (5°, 10°, and 15°).

The basic concept of inclining the balcony ceiling is to decrease the power of reflection and diffuse energy components by changing the direction of reflected rays away from the openings located at the balcony back wall as shown in Fig. 2. In the case of the inclined ceiling, we can notice that the protected surface over the balcony back wall increases by comparison of the protected surface gained from the classical form as a consequence of ceiling reflected area.

Firstly, the sound pressure reference level (SPL_{ref}), was calculated over the balcony back wall with an inclined angle **Ø** equals to 0°.

The protection level is defined as the difference in noise level at an assessment point with and without changing ceiling inclined angle, and is calculated according to the following equation:

$$L_p = SPL_{ref} - SPL_{\emptyset} \quad dB(A)$$

Where SPL_{ref} is the reference level and $SPL_{\emptyset}$ is the sound pressure level calculated for a given ceiling angle at the same point.

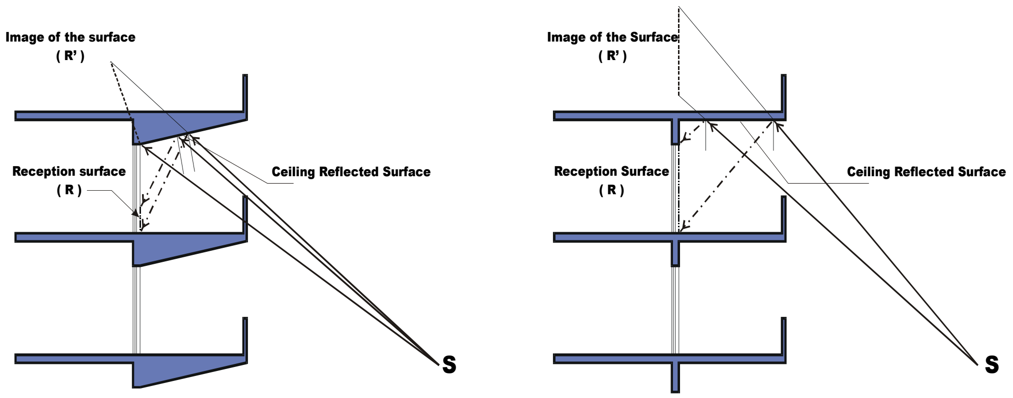

Fig. 2. Schematic representation of the reception surface and its image before and after changing balcony ceiling form

4. Experimental system

4.1. Scale model

A 1:10 scale model of building façade with 2.50m height and 1.60m length (Fig. 3) was carried out. Building façade was simulated by varnished wood (absorption coefficient 0.06 at 1K.Hz). in order to satisfy the laws of acoustic similarity for the sound absorption by the building façade.

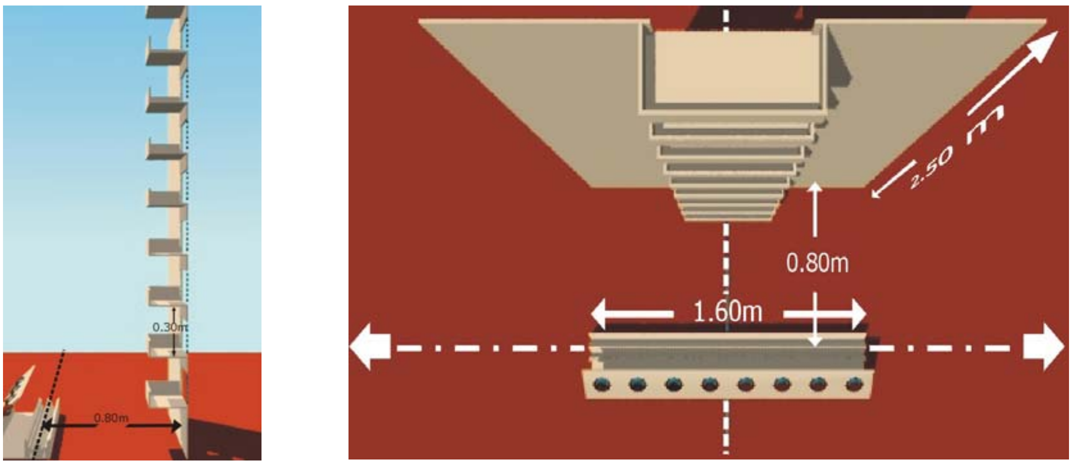

Fig. 3. Scale model dimensions.

4.2. Acquisition system

The experimental results were obtained using a measurement exploiting maximum-length sequence stimulus *(MLS).* The A-weighted sound pressure levels are measured with a 1\2 inch free field microphone *(G.R.A.S – type 40 AE)* connected to a MLSSA card via a preamplifier *(01dB - PRE12S).* The reception points and the microphone position are presented in Fig. 4.

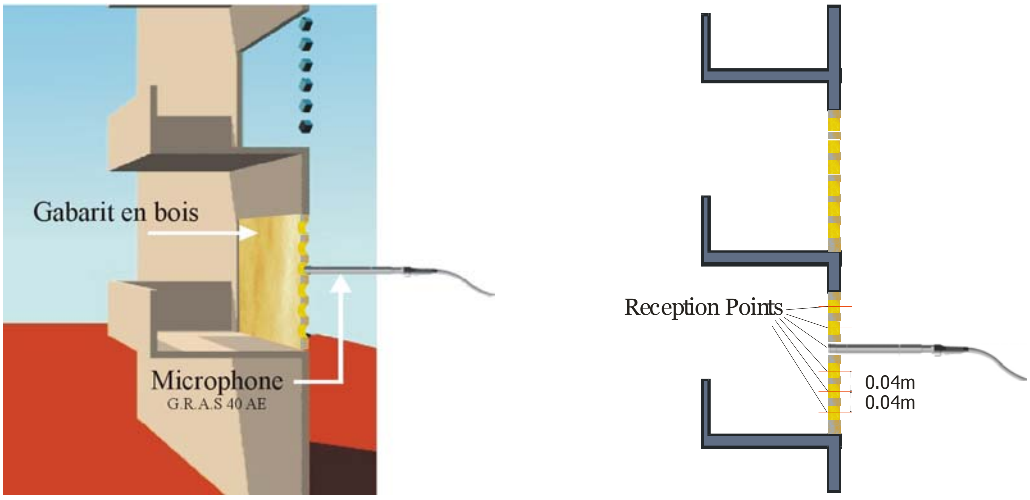

Fig. 4. Reception points (6 reception points at the centre of the facade) and microphone position.

4.3. Sound source

Line source was carried out with 8 tweeters AUDAX *(TW 034X0),* filtered for obtaining a frequency response from 1.6 KHz to 25 KHz. As shown in Fig. 5, the tweeters were headed towards a quadratic residue diffuser in order to obtain a quasi quarter-cylindrical propagation form in front of the building facade. By this diffusing system, the line source directivity is made quasi-uniform in the aperture angle which we interest. The sequence of the quadratic residue diffuser is calculated following the Schröder's modulo formula (Schröder.1979).

Fig. 5. Line source with a quadratic residue diffuser.

5. Simulation results

5.1. Balcony with 2m depth

The acoustic performance of inclined ceilings for a closed balcony with 2m depth was tested. Fig. 6 shows the average of sound level reduction obtained by three angles for that configuration. The average reduction obtained at the lower levels is negligible, while it increases at the higher floors. The reduction is negative from the 1st to 5th floor while it increases at the 6th and 7th floors. Generally, the angle equal to 15° has a greater effect at higher levels and allows a protection level from 0.5 to 3 dB (A).

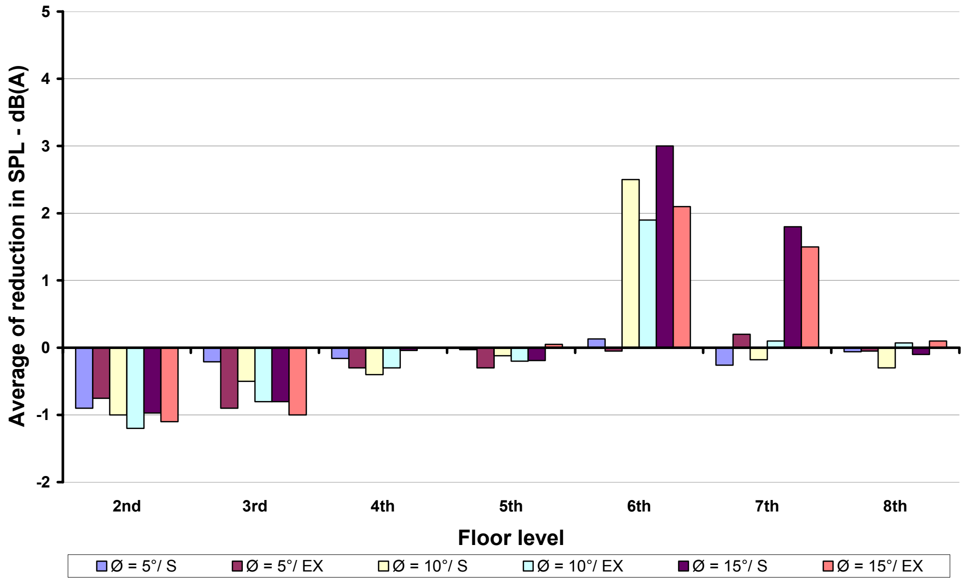

Fig. 6. Average of protection offered by inclined ceilings of a balcony with 2m depth, experimental results (EX) and simulation results (S).

In Fig. 7, we display the results for measurements and predictions of the balcony protection level for a balcony with 2 m depth. We show the comparison results of the balcony with inclined ceiling angle equal to 15°. As demonstrated in the following figure, balconies with that configuration can give better protection on higher floors (Fig. 7 - a) at all the assessment points than those of lower floors (Fig. 7 - c). This reasonable because the path difference of a diffracted ray (diffracted at the parapet or floor of a balcony) and a direct ray increases with the relative height of a balcony to a road. While we notice at the 4th floor (Fig. 7 – b) the higher points provide more protection level that the lower points. This reasonable because of the negative effect of the inclined ceiling form at lower points as explained in Fig. 2, where the ceiling surface rereflect the rays towards those lower points. So the windows may be the best architectural solution in that case where its surfaces will be protected by that inclined configuration.

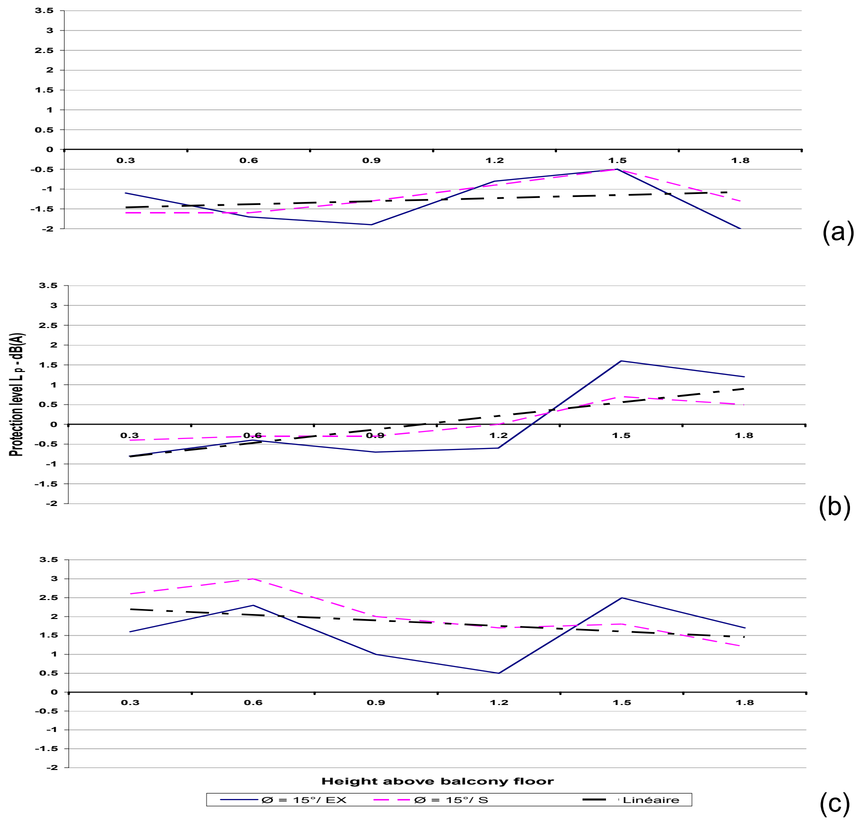

Fig. 7. Protection values provided at the centre of the balcony back wall with 2m depth, numerical simulation (dashed), and empirical equation (lines) at (a) 2nd floor, (b) 4th floor, and (c) 6th floor for an angle Ø equal to 15°.

5.2. Balcony with 3m depth

By using the same method, we found that the acoustic performance of inclined ceilings for a closed balcony with 3 m depth provides more reduction at lower levels than that obtained from the previous configurations and also for higher levels. The average reduction obtained at the lower floors is more effective than the previous depth, and also for the higher floors. Reduction values are negative at the 2nd floor and begin to increase from the 3rd floor to reach its maximum value at the 6th floor (Fig. 8). In general, the average protection gained from that configuration is from 0.5 to 4 dB (A).

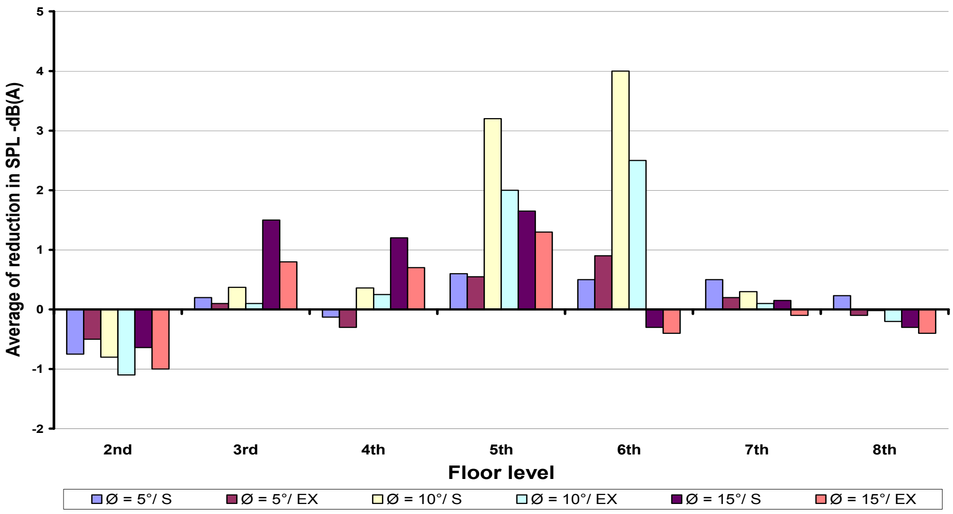

Fig. 8. Average of protection offered by inclined ceilings of a balcony with 3m depth, experimental results (EX) and simulation results (S).

As shown in Fig. 8, the inclined ceiling with 5° angle is less effective at lower levels, while its maximum effect appears at the higher levels. Furthermore, the effects of 10° and 15° angles are greater at higher levels. Generally, the maximum protection level can be obtained by an inclined ceiling with 5°. As the balcony with 2m depth, balconies with that configuration can give better protection on higher floors (Fig. 9 - a) at all the assessment points than those of lower floors (Fig. 9 - c). This reasonable because the effect of direct and reflected rays. While we notice at the 4th floor (Fig.7– b) the higher points provide more protection level that the lower points for the same reason we explained before. So the windows may be the best architectural solution in that case where its surfaces will be protected by that inclined configuration.

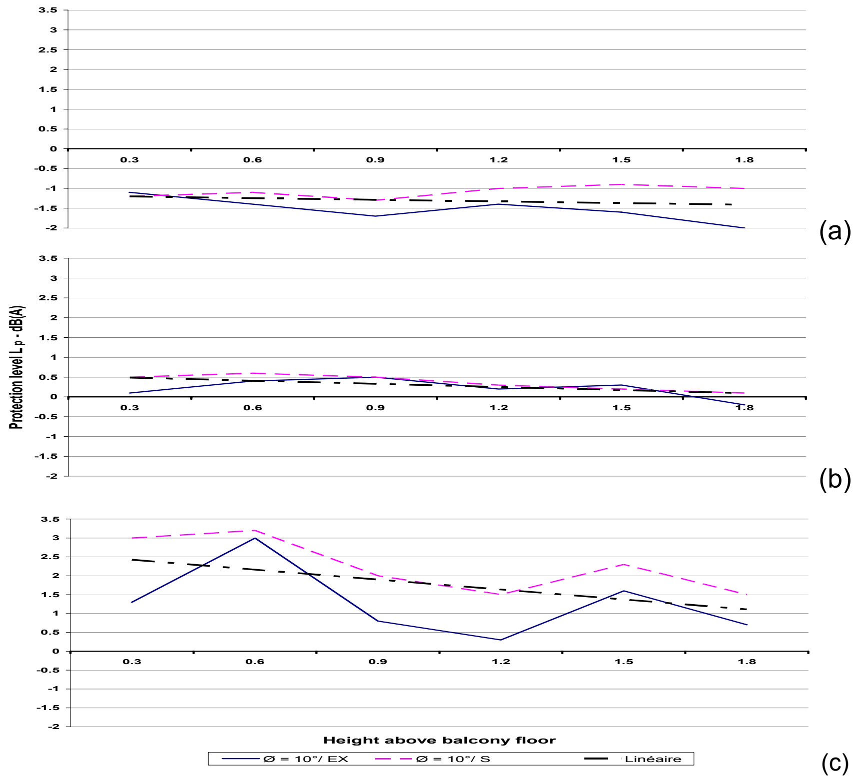

Fig.9. Protection values provided at the centre of the balcony back wall with 3m depth, numerical simulation (dashed), and empirical equation (lines) at (a) 2nd floor, (b) 4th floor, and (c) 6th floor for an angle Ø equal to 10°.

6. Conclusion

In this paper the Pyramid Tracing model and experimental measurements were used to predict the performance of a balcony ceiling with inclined form. The average noise reduction provided by that configuration with reflective surface was about 0.5 – 4 dB (A). This investigation showed that the inclined ceiling form can dominate the sound reflected from its bottom surface. Moreover, it can change the reflected ray direction away from a balcony back wall.
Reduction obtained increases with the increase of floor level and balcony depth. On the other hand, it decreases with the increase of the ceiling inclined angle at higher floors while it increases with the increase of the ceiling inclined angles at lower floors.
Generally, the predicted results showed that a balcony ceiling form can be employed to protect weak points on the facades, for high rise buildings, against traffic noise propagation.
In addition, the results of this investigation will hopefully provide practical information to the architect who wishes to design facades which can be described as self protected with respect to the external acoustic environment. It will be seen that a slight modification of existing building envelope design can provide additional sound protection without compromising other environmental requirements.
Furthermore, the numerical and experimental results provide a validation of the geometrical empirical equations which we obtained (Hossam El-dien and Woloszyn 2004).

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