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Noise screening effects of balconies on a building facade

S. K. Tang[a)]
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

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The insertion loss and its spectrum due to a rectangular balcony on a building facade in the presence of sound reflection and scattering from adjacent balconies were examined using a scale model. The front panel of the balcony dictates the screening performance, while the side walls of the balcony are found to be insignificant. Balconies without a front panel do not provide acoustic protection in the presence of upper balcony reflection, especially for a distant noise source. Sound amplifications are also observed in many cases. In addition, the shapes of the insertion loss spectra are found to depend on the elevation angle of the balcony. Significant correlations between the A-weighted balcony insertion losses with this angle are found in the absence of upper balcony reflections. With such reflection, an angle defined using the balcony configuration and source position correlates within engineering tolerance to the insertion losses. © *2005 Acoustical Society of America.* [DOI: 10.1121/1.1931887]

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I. INTRODUCTION

Buildings in a densely populated city like Hong Kong are very often erected close to ground transportation lines. Many people have chosen to live in the countryside and the provision of transportation to these new residential areas is essential. This eventually leads to even more careful noise control planning as the background noise levels there are considerably lower than those in the urban areas.

Architectural features, like balconies and fins, are believed to be able to control the acoustical energy actually falling on the noise sensitive parts of a building, which in most cases are the windows. This topic has attracted the attention of many researchers in the past few decades. Both computational studies and scale model measurements have been carried out (for instance, Hothersall *et al.*,[1] Mohsen and Oldham,[2] and Hossam El-Dien and Woloszyn[3]). Several different forms of the balconies have been tested as well.[2–4] The Government of the Hong Kong Special Administration Region has considered the balcony as a form "Green features" and encourages building developers and architects to consider adopting such features in their designs by exempting the areas occupied by balconies from the calculations of "Gross Floor Area" and "Site Coverage Ratio."[5] However, the effectiveness of the balcony on a building facade as a screening device for ground transportation noise is still subject to debate. A clarification of its acoustical performance is therefore essential for future development of building design.

Many studies in the existing literature deal with the screening effect of a single balcony (for instance, Mohsen and Oldham,[2] Hammad and Gibbs,[4] and Cheng *et al.*[6]), but a standalone balcony can rarely be found in a high-rise city in reality. The reflection of noise from the upper balcony will probably deteriorate the original screening effect provided by the lower balcony. The reflection and scattering of noise by nearby balconies on the same building facade[7] have also added to the complexity of the subject. Wave interaction inside the balconies in the presence of a top reflection may lead to the amplification of noise. May[8] investigated the effects of acoustic linings on reducing noise levels inside a high-rise balcony well above a nearby freeway, but the actual insertion loss is difficult to estimate as the reference noise data in May's study were affected by the other balconies on the building facade. Besides, the form of the balcony will affect the noise reflection and scattering. However, the extent of these effects is unclear.

In the present study, a scale model was set up to study the acoustic protection offered by balconies inside of a balcony array, which simulated better the real scenario in a high-rise city. Four different balcony forms, which are commonly found in Hong Kong, were considered. It is hoped that the results can provide useful information on the application to balconies and help the future development of noise control plan.

II. THE SCALE MODEL AND THE MEASUREMENTS

Similar to the study of Mohsen and Oldham,[2] a 1:10 scale-down model was used in the present investigation. The scale model was made of half-inch-thick plywood with varnished surfaces, which were acoustically hard enough to simulate the concrete building facade of negligible sound absorption. Figure 1(a) illustrates the dimensions and construction of the present scale model. A balcony array of nine equispaced balconies was adopted. Each element of the model balconies, such as the side wall and front panel, could be detached from the balcony assembly if necessary. All the measurements were carried out inside an anechoic chamber of workable floor area and height of 4 m×5 m and 3 m, respectively. The air temperature and relative humidity inside the chamber were maintained at 22 °C and 50%, respectively. It is believed that the performance of the balconies will depend on several important angles, which are defined in Fig. 1(b). They will be discussed further later.

[a)]Electronic mail: besktang@polyu.edu.hk

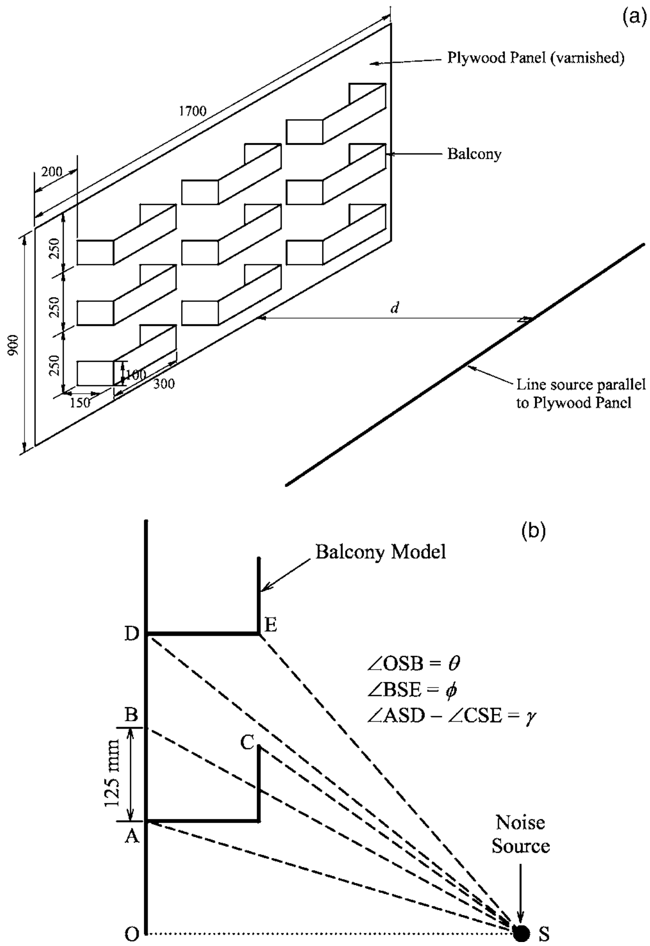


FIG. 1. (a) Dimensions of the scale model and the nomenclature adopted. (b) Definitions of important angles.

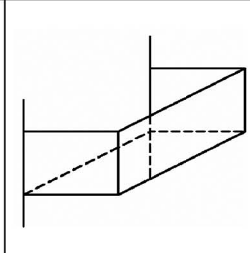
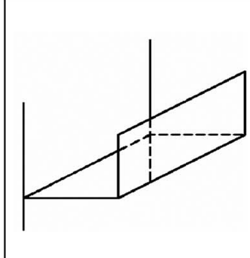
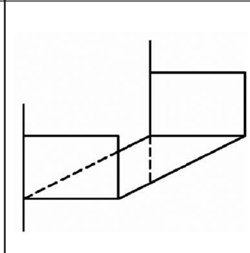
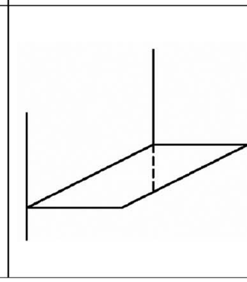
Balcony Form	Model Schematics	Real-life Example
'Closed'		
'Front-Bottom'		
'Side-Bottom'		
'Bottom'		

FIG. 2. Balcony forms and real life examples.

Four different balcony forms commonly found in Hong Kong were considered in the present study, as shown in Fig. 2, together with photographs of real life examples. The first one is the "Closed" form, which is similar to that of Mohsen and Oldham.[2] The second one is the "Front-Bottom," which represents the case where the balcony is made up of a solid hard front wall with fences installed between it and the building facade. The fences are acoustically transparent to sound propagation. This is also the type of balcony studied by Hossam El-Dien and Woloszyn.[3] The third one is the "Side-Bottom" configuration, wherein the balcony is made up of hard side walls with a fence in the front. The last one is the canopy-like "Bottom," which represents the case wherein fences form the three sides of the balcony.

The noise source adopted was a linear loudspeaker array consisting of a 4 m long wooden rod of triangular cross section with 54 identical small loudspeakers mounted on each of its two exposed surfaces (Fig. 3). Although these small loudspeakers could not produce much low-frequency noise, their operation frequency ranges fitted the 1:10 scale model requirement. Noise frequency range considered in the present measurements was from 1 to 20 kHz, which corresponds with the range of 100 Hz to 2 kHz for the full scale balconies. The loudspeaker array was set parallel with the model throughout the experiments. Its normal distance from the scale model (d) was varied from 0.5 to 2 m in the present study. The angles defined in Fig. 1(b) varied accordingly.

Noise spectra were recorded at 25 equally spaced locations behind the middle column balconies with and without the balconies by a Brüel & Kjær Type 4935 0.25 in. microphone mounted flush with the plywood panel surface (dark points on the middle balcony column in Fig. 3) and the NORSONIC RTA840 real time frequency analyzer. The frequency resolution in the spectrum sampling was 62.5 Hz. The power supplied to the noise source was chosen so that the noise spectra over the frequency range considered were all higher than the background by at least 10 dB. In the foregoing discussions, the frequencies are scaled down already, such that the frequency resolution of the spectra presented later is ~6 Hz.

III. NOISE SOURCE CHARACTERISTICS

Figure 4 illustrates the noise spectrum measured at $d = 1$ m with a height of 0.6 m. It is normalized by the 1/3 octave band level at 1 kHz. Its shape falls within the spectral boundaries of vehicle noises shown in Berglund *et al.*[9] The

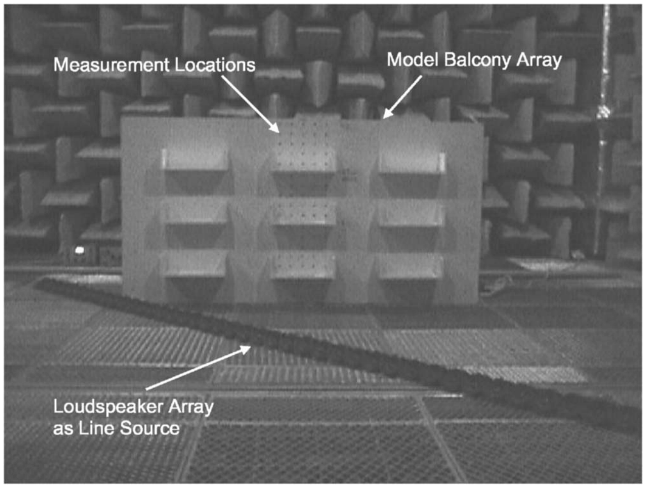


FIG. 3. The scale model and noise source (Side-Bottom model balconies are shown).

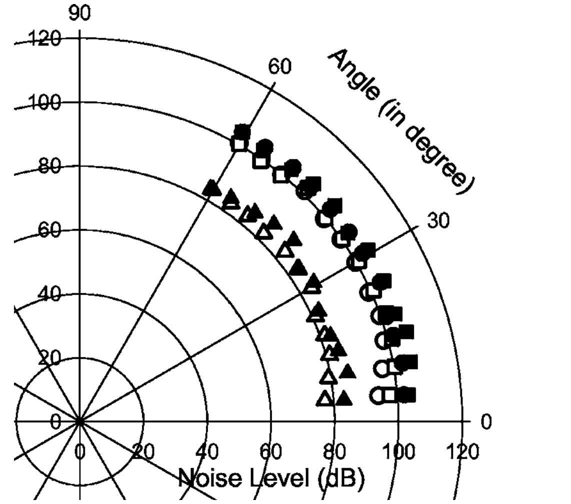


FIG. 5. Directivity patterns of the noise source in different 1/3 octave bands. ○: 250 Hz; □: 500 Hz; △: 1 kHz. Closed symbol: at radius 1 m; open symbol: at radius 2 m.

higher band levels within the 500 and 630 Hz bands are also not worse than those of the loudspeaker array employed by Hammad and Gibbs.[4,10] However, it deviates from the typical tire noise spectrum[11] and the standard traffic noise spectrum.[12] The latter appears to agree well with that of freely flowing traffic noise in Hong Kong obtained from a separated study of the author (not presented here). Therefore, a special weighting relative to the standard traffic noise spectrum has to be applied to the present measurement so that a more relevant A-weighted insertion loss can be calculated as in Mohsen and Oldham.[2] The variation of the spectra along the length of the model is less than 2 dB, which is reasonable as compared with that of Hammad and Gibbs.[10]

Some directivity patterns of the sound source at radii of 1 and 2 m are given in Fig. 5. In general, the deviations of the noise levels from the mean values are less than 1.5 dB and those for the 1/3 octave bands below 500 Hz and the A-weighted levels are even around or below 1 dB. The radiations at an angle less than 6° are less uniform, but these have insignificant influence to the results presented later as only around 6% of the measurements at $d=2$ m were done at these angles. Real traffic noise is neither a two-dimensional nor a point source. The A-weighted and 1/3 octave band noise levels generated by the present loudspeaker array drop 3 to 4 dB when the radius is increased from 1 to 2 m. The noise level thus falls off with distance to the power ~1 to 1.33. This appears acceptable.

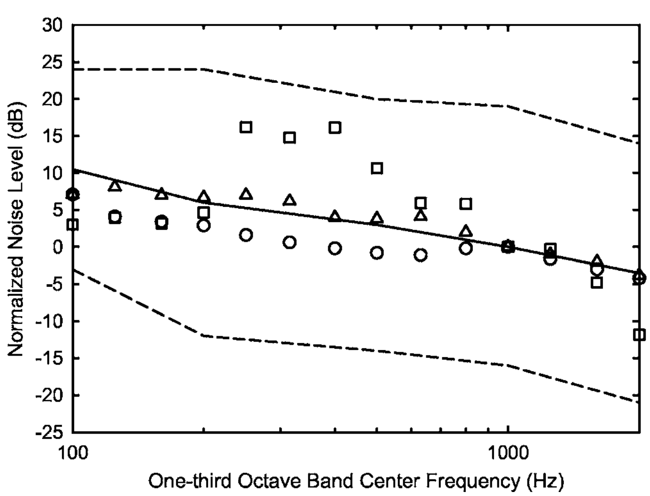


FIG. 4. Noise spectrum of the source. ○: ISO717;[12] △: Delany *et al.* (Ref. 4); □: present data; – – –: boundaries of Berglund *et al.* (Ref. 9); —: midpoint between boundaries of Berglund *et al.* (Ref. 9).

It is found in a preliminary experiment using the Closed form balcony that the introduction of an upper balcony to the middle balcony in the absence of the two side balcony columns results in an A-weighted noise level increase of ~6 dB at $d=0.5$ m. This increase drops to ~4 dB at $d=1$ m. The introduction of the side balcony column gives rise to a very slight decrease in the insertion loss of the middle and bottom balconies (~0.2 dB). However, such a decrease is around 1 to 2 dB behind the top balconies. This effect of the side balcony columns is expected to be more serious when the "Bottom" form balconies are installed because of the edge scattering.

IV. RESULTS AND DISCUSSIONS

There were five rows of equally spaced measurement points behind each middle column balcony, with two of them above, two below, and one leveled with the edge of the front panel of the Closed balcony form (Fig. 3). A-weighted sound pressure levels are adopted here to describe the general screening effects of the balconies as in many references; for instance, Mohsen and Oldham[2] and Hammad and Gibbs.[4] Insertion loss (IL) is defined as the drop in sound pressure level after the installation of the balconies. A negative IL thus means sound amplification. Since the maximum path difference due to the balcony in the present study is less than 10 cm, the air absorption will result in a noise attenuation of at the most 0.05 dB at 20 kHz (~0.5 dB/m and even less at lower frequencies[13]). This is comparable to noise measurement uncertainty and thus correction for air absorption to IL is not necessary here.

Various angles defined in Fig. 1(b) are expected to be important to the ILs of the balconies and their correlations

TABLE I. Various angles of the balconies.

d (m)	Position	θ (rad)	ϕ (rad)	γ^{a} (rad)
	Top	0.9978	⋯	⋯
0.5	Middle	0.8098	0.2670	0.1236 (C,FB)
				0.0155 (B,SB)
	Bottom	0.5028	0.3491	0.1515 (C,FB)
				−0.0637 (B,SB)
	Top	0.6594	⋯	⋯
1.0	Middle	0.4835	0.1695	0.0747 (C,FB)
				−0.0171 (B,SB)
	Bottom	0.2684	0.1714	0.0778 (C,FB)
				−0.0335 (B,SB)
	Top	0.4768	⋯	⋯
1.5	Middle	0.3367	0.1121	0.0543 (C,FB)
				−0.0124 (B,SB)
	Bottom	0.1813	0.1068	0.0560 (C,FB)
				−0.0164 (B,SB)
	Top	0.3697	⋯	⋯
2.0	Middle	0.2567	0.0812	0.0429 (C,FB)
				−0.0080 (B,SB)
	Bottom	0.1367	0.0763	0.0440 (C,FB)
				−0.0094 (B,SB)

[a]C: Closed; FB: Front-Bottom; B: Bottom; SB: Side-Bottom.

with the ILs will be discussed in detail in the following subsections. Table I illustrates the values of these angles for different balcony and noise source positions.

A. A-weighted attenuation

Figures 6(a)–6(l) illustrate the average IL at the five different height levels behind the balconies at various perpendicular distances of the loudspeaker array from the model. For the top balcony [Figs. 6(a)–6(d)], there is no reflection from its top.

For $d=0.5$ m, the Bottom balcony form provides the weakest protection, which is very much expected. The Closed form gives the best acoustic protection at heights at or above the edge level of the balcony front panel, but the extent of the attenuation is reduced at lower height levels within the balcony. A similar phenomenon is observed for the Front-Bottom balcony form. This will be discussed further. The Side-Bottom form offers the best attenuation at lower height levels inside the balconies. This is reasonable as the multiple noise reflections inside the balconies is significantly weakened in the absence of the front panel.

The effects of the side walls can be found by a comparison between the performance of the Bottom and Side-Bottom balconies and between that of the Closed and Front-Bottom ones. The side walls usually result in maximum 1 dB higher noise attenuation at or above the edge level of the front panel (which is also that of the side wall). Below this edge level, they have negligible effects in the presence of the front panel, but have substantial contributions once the front panel is taken off. The overall 4 to 8 dB noise attenuation appears consistent with the results of Hammad and Gibbs.[4]

The effects of top reflection become important when the middle balconies are concerned [Figs. 6(e)–6(h)]. The strong reflection at short distance from the noise source result in amplification of sound at nearly all height levels inside the balconies. While such amplification is not dependent on the balcony form at levels close to the top reflecting surface, less amplification is observed inside the Closed and Front-

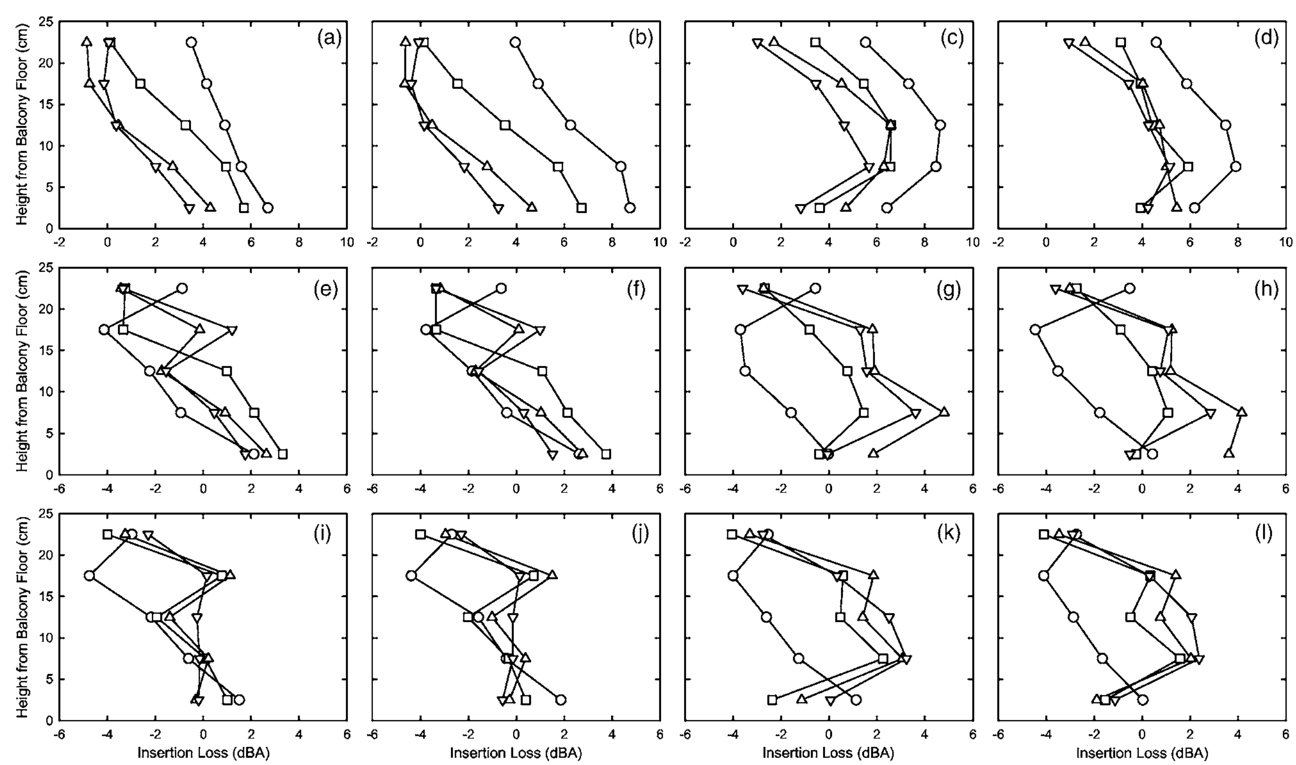


FIG. 6. Vertical variations of A-weighted noise level insertion loss within balconies. Top balcony: (a) Bottom; (b) Side-Bottom; (c) Closed; (d) Front-Bottom. Middle balcony: (e) Bottom; (f) Side-Bottom; (g) Closed; (h) Front-Bottom. Bottom balcony: (i) Bottom; (j) Side-Bottom; (k) Closed; (l) Front-Bottom. ○: $d=0.5$ m; □: $d=1$ m; △: $d=1.5$ m; ▽: $d=2$ m.

Bottom balconies at other height levels, especially those close to the balcony floor. Largely similar observations can be made inside the bottom balcony. It is noted that the magnitudes of the noise amplification in the presence of upper balcony reflection obtained in the present study with noise source close to the model are less than the equivalent sound pressure level differences measured by May[8] without acoustic linings. Using the noise level outside the balcony as a reference, as in May,[8] may not reflect the true insertion loss.

The increase in the distance of the noise source from the balconies from 0.5 to 1 m results in an overall reduction in sound attenuation inside the top balcony. Although the screening patterns of the four different balcony forms basically follow those for $d=0.5$ m, their differences have been reduced in general. Significant changes in these patterns are observed within the middle balconies. Stronger sound attenuation than in the previous case of $d=0.5$ m is observed for all balcony forms, but the reverberation due to the front panels in the Closed and Front-Bottom balconies does not allow higher sound attenuation near to the balcony floor. The situation within the bottom balcony appears to be a combination of those observed within the two upper balconies and the vertical IL distribution becomes irregular. The serious top reflection in the bottom balcony still results in strong sound amplification near to the ceilings of the balconies. The increase in the suspended angle of the balcony ceiling from the noise source [$\angle$DSE in Fig. 1(b)] does not improve the IL close to the balcony floors.

There is a continuous reduction of the IL across the highest measurement row in the top balconies as d increases for the Bottom and Side-Bottom balconies, while those related to the other two forms become negligible as d increases further from 1.5 to 2 m. The screening patterns within the middle balconies are similar to those within the bottom balconies at small d. It can also be observed that there is an overall small increase in the IL within the bottom balcony as d increases from 1.5 to 2 m. The screening patterns are smoother at increased d and these are expected to observe within the middle balcony when d is further increased. At these distances, the side walls of the balconies do not have significant effects on the IL. However, the top reflections within the middle and bottom balconies still result in sound amplification. The approximately 3 dB amplification at $d=2$ m appears to be reasonable as the upper balcony reflects the diffracted and scattered sound at the edges of the front panel or the bottom panel onto the wooden panel behind the balcony. The wave front of the noise is more or less planar when it arrives at the model balcony, which is not the case at small d.

One can notice that the screening effects provided by the Bottom and Side-Bottom balconies at the bottom of the scale model are not good. The patterns at $d=2$ m, which eventually will be those within the middle balconies at larger d, suggest slight noise amplification. The bottom panels/floors of these balconies cannot offer acoustic protection for distant noise sources.

Figure 7 illustrates the variation of the overall A-weighted sound pressure level reduction behind the middle column top balconies with the elevation angle θ.

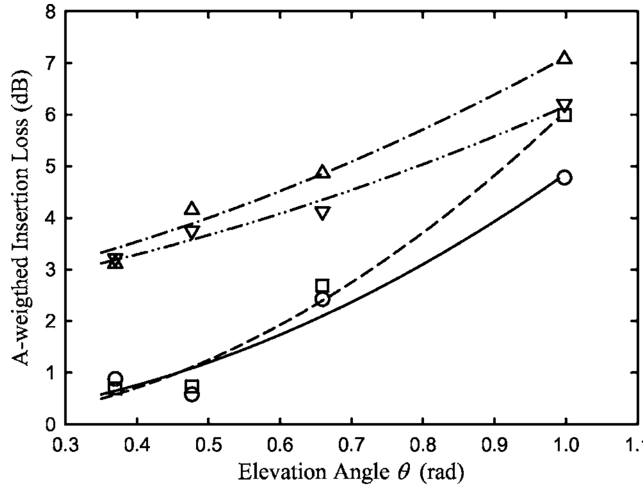


FIG. 7. Effects of elevation angle on overall A-weighted noise level insertion loss of top balconies. ○: Bottom; □: Side-Bottom; △: Closed; ▽: Front-Bottom. Regression lines:—: Bottom; – –: Side-Bottom; –·–: Closed; –··–: Front-Bottom.

These overall ILs are calculated from the average of the 25 measured noise spectra behind each balcony. The high sound attenuation behind the top balconies at larger θ is not surprising. The Bottom and Closed form balconies offer the weakest and strongest acoustic protection, respectively. As d increases, the sound path differences due to the configurations of the balconies become less, reducing the ILs as in the case of noise barrier.[14] At large d and thus small θ, these path differences will become small, and the trends shown in Fig. 7 indicate some degrees of convergence of the IL. The IL drops to about 0.5 dB for the Bottom and Side-Bottom balconies and ~3 dB for the other two balcony forms. This tends to suggest that the front panel of the balcony accounts for a 2.5 dB sound reduction at large d. Theoretically when $\theta \to 0$, the Bottom and Side-Bottom balconies will not offer any acoustic protection, while the front panels of the other two balcony forms will approximately stop 40% of the noise propagation (excludes the diffraction at the panel edge) as the height of the panel is 40% of the distance between two balconies in a column. The latter will result in an IL of 2.2 dB. This is independent of d. One can observe that the ILs shown in Fig. 7 follow quadratic variations with θ. The associated empirical formulae, the correlation coefficients, and the standard errors are given in Table II. Significant correlations are observed.

Overall A-weighted noise amplifications are observed in the middle and bottom balconies of all forms, but they do not scale on θ because of the reflections from the upper balconies. Figure 8 illustrates the variations of these ILs with the

TABLE II. Variations of top balcony insertion loss with elevation angle θ given in radians.

Balcony	Empirical formula	R^2	Standard error (dBA)
Closed	$IL=2.63\theta^2+2.29\theta+2.2$	0.99	0.2
Front-Bottom	$IL=2.07\theta^2+1.90\theta+2.2$	0.99	0.1
Side-Bottom	$IL=7.18\theta^2-1.10\theta$	0.99	0.2
Bottom	$IL=4.93\theta^2-0.07\theta$	0.97	0.3

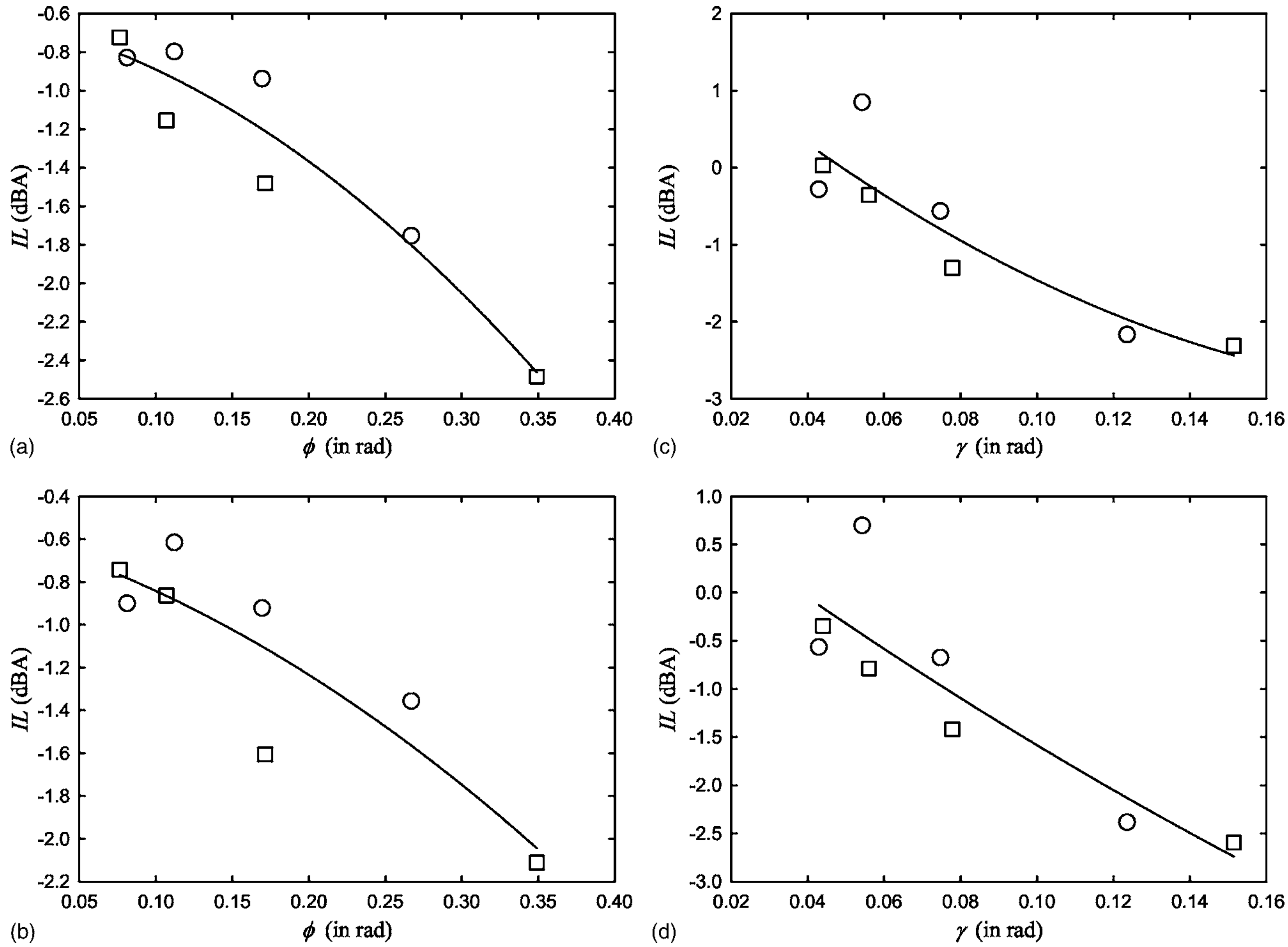


FIG. 8. Dependence of A-weighted noise level insertion loss on angle differences. (a) Bottom, ϕ; (b) Side-Bottom, ϕ; (c) Closed, γ; (d) Front-Bottom, γ. —: regression lines.

angles defined in Fig. 1(b). The corresponding empirical formulae, the correlation coefficients and the standard errors are given in Table III. It is found that the ILs of the Bottom and Side-Bottom form balconies do not correlate with γ, and the corresponding results are not presented. Those of the Closed and Front-Bottom balconies scale slightly better with γ. Their corresponding IL variations are curved downwards [Figs. 8(c) and 8(d)], suggesting slower IL variation at larger angle differences. Those for the Bottom and Side-Bottom ones varying with ϕ are opposite. Since all the ILs correlate with ϕ reasonably well, this angle appears to be more useful for design purposes.

One can also notice from Fig. 8 that the amplifications are slightly more serious for the Bottom and Side-Bottom balconies. The consistently higher amplification inside the Front-Bottom balcony than in the Closed balcony manifests that the side walls offer more diffraction loss than enhancing the reverberation.

TABLE III. Variations of balcony insertion loss with ϕ and γ given in radians.

Balcony	Empirical formula	R^2	Standard error (dBA)
Closed	$\mathrm{IL}=9.57\phi^2-13.92\phi-1.21$	0.78	0.5
	$\mathrm{IL}=94.41\gamma^2-42.73\gamma+1.87$	0.81	0.4
Front-Bottom	$\mathrm{IL}=-1.13\phi^2-9.20\phi+0.56$	0.74	0.5
	$\mathrm{IL}=28.06\gamma^2-25.51\gamma-1.09$	0.77	0.5
Side-Bottom	$\mathrm{IL}=-6.10\phi^2-2.09\phi-0.57$	0.77	0.2
Bottom	$\mathrm{IL}=-10.39\phi^2-1.65\phi-0.62$	0.91	0.2

B. Spectral analysis

This section will be focused on the frequency characteristics of the insertion loss. The frequencies presented in the foregoing discussions are scaled back to the real size of the balcony. One should note that the IL spectra are not affected by the spectral shapes of the noises.

Figures 9(a)–9(c) show the variations of ILs with frequency behind the top, middle, and bottom balconies, respectively, at $d=0.5$ m. Broadband attenuation of sound is observed behind the top balconies, resulting in high ILs [Fig. 9(a)]. The spectral performance of the middle and bottom balconies does not depend much on the forms of the balconies, implying further that the floors of the balconies play a determining role in the IL where the source is close to the balconies. The spectral amplification patterns within the middle and bottom balconies are also alike, with relatively more significant attenuations or less sound amplifications at around 680, 1000, 1250, and 2200 Hz. The amplifications at frequency below 400 Hz are believed to be due to the standing waves in the vertical direction inside the balconies.

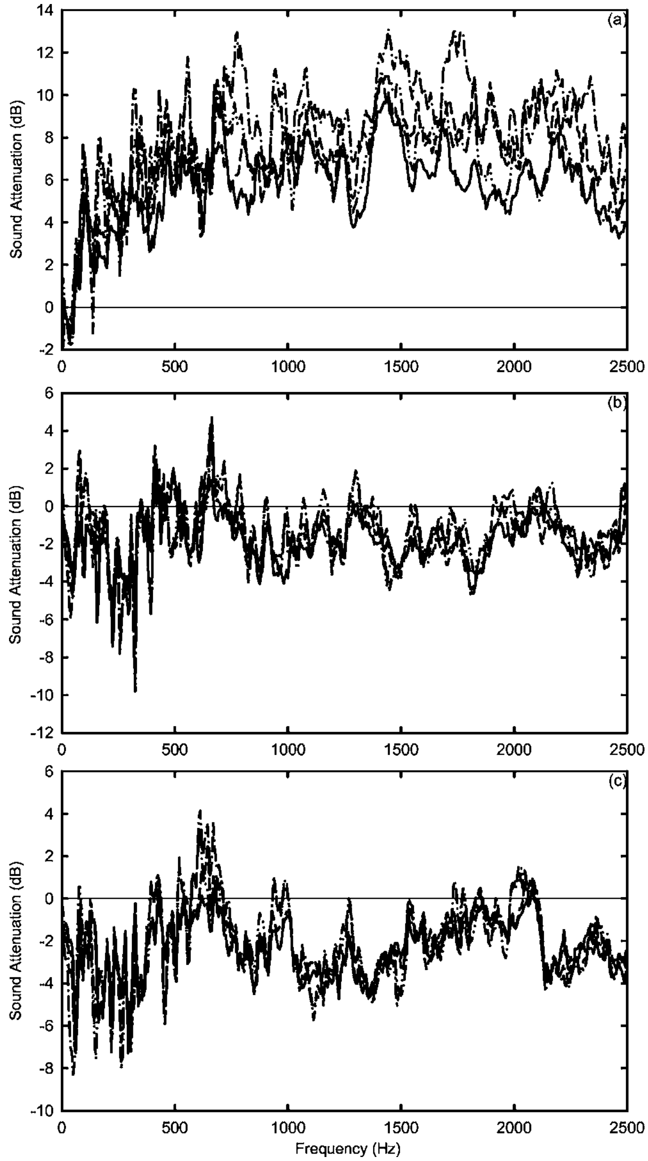


FIG. 9. Spectral characteristics of the noise screening at $d=0.5$ m. (a) Top balcony; (b) middle balcony; (c) bottom balcony. —: Bottom; – –: Side-Bottom; –·–: Closed; –··–: Front-Bottom.

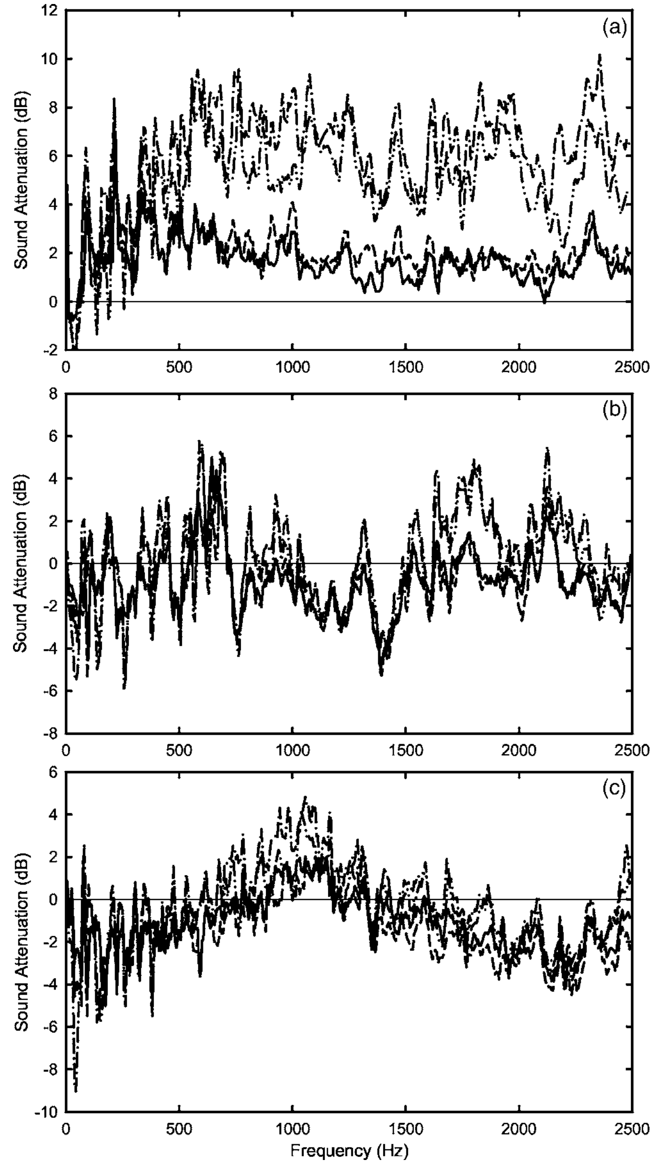


FIG. 10. Spectral characteristics of the noise screening at $d=1$ m. (a) Top balcony; (b) middle balcony; (c) bottom balcony. Legends: same as those in Fig. 9.

The increase in the distance of the noise source from the model to 1 m results in a nearly broadband drop of sound attenuation within the top balconies [Fig. 10(a)], but such drops at frequencies higher than 400 Hz within the balconies with a front panel are much more rapid. Within the middle balconies [Fig. 10(b)], the spectral performances of different balcony forms are similar, except that there are relatively higher attenuations at the frequencies round 1800 and 2200 Hz for balconies with a front panel (Closed and Front-Bottom). The overall A-weighted broadband attenuation inside these middle balconies is negative (Fig. 8), suggesting that the amplifications at frequencies below 1500 Hz dominate the overall screening property. One can observe that the spectral shapes of the ILs shown in Figs. 9(c) and 10(b) are similar, suggesting that θ plays a role in affecting the balcony screening, apart from the balcony form. The spectral performance of the bottom balconies does not depend much on the balcony form, except that a slightly higher noise attenuation at frequencies about 1000 Hz is achieved in the presence of a front wall panel [Fig. 10(c)].

As the source distance increases, a further drop of the IL within the top balconies at high frequency is expected [Fig. 11(a)]. The IL associated with a balcony without a front panel is around 1 dB across the whole frequency range of the present study. The two sharp amplification peaks at around 50 and 140 Hz associated with the Closed and Front-Bottom balconies, respectively, are believed to result from the acoustic modes within the balconies. The former is closed to the (1,0) mode and the other the (1,1) or (2,1) modes. One can observe these peaks in Figs. 9 and 10, but they are very prominent in Fig. 11. Such peaks are also found in the results with $d=1.5$ m (not shown here).

The spectral shapes of the IL within the middle balconies at the source distance of 2 m, shown in Fig. 11(b), are similar to those illustrated in Fig. 10(c). This further con-

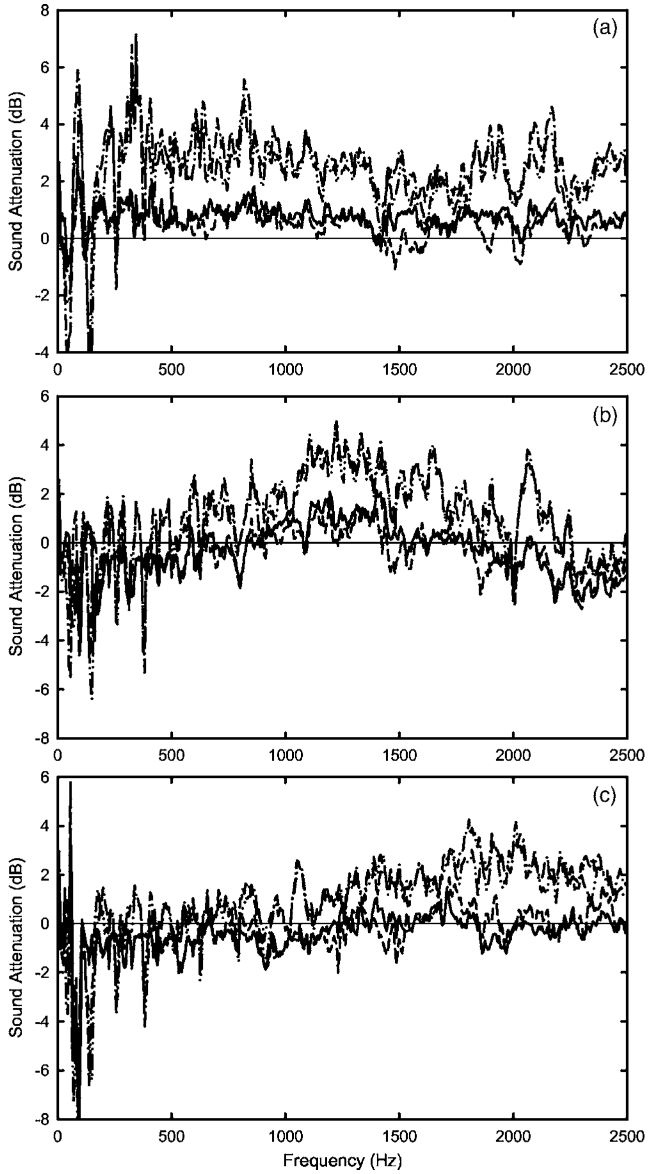


FIG. 11. Spectral characteristics of the noise screening at $d=2$ m. (a) Top balcony; (b) middle balcony; (c) bottom balcony. Legends: same as those in Fig. 9.

firms the importance of θ discussed previously. A broader frequency band of noise attenuation is observed in Fig. 11(b) compared to that in Fig. 10(c). Among the bottom balconies, relatively more significant attenuation can only be found at higher frequency within the Closed and the Front-Bottom balconies. Figure 11(c) indicates clearly that the balconies without a front panel will not offer any acoustic protection over the whole frequency range of concern when the noise source is far away from them. The reflection from the upper balcony makes thing worse, especially in the low-frequency range.

There have been consistent IL peaks at certain frequencies in Figs. 9–11 for the cases in which reflections from upper balconies are expected. For instance, the broadband IL peaks at around 650 Hz in Figs. 9(c) and 10(b), those at around 1000 Hz in Figs. 10(c) and 11(b), and the narrower band IL peak at around 2200 Hz in Figs. 10(b) and 11(b). The latter can also be observed in Fig. 9(c), although the corresponding magnitude is weak. The reasons for these observations are still not clear and these frequencies may change with the balcony dimensions. While the sharp IL peaks or troughs at frequencies below 200 Hz as discussed before can be ascribed to the effects of acoustic modes within the balconies, those above 400 Hz are difficult to explain in similar terms as the modal overlapping becomes very serious in this frequency range. Above 400 Hz, each data point may include contributions from one or more eigenfrequencies of the balcony, making the experimental isolation of modes difficult.[15] A numerical investigation with a large number of node points on the balcony surfaces and in the balcony voids is required for such mode isolations.

V. CONCLUSIONS

A scale model study on the acoustic protection offered by balconies on a building facade was carried out with reflections and scattering from adjacent balconies taken into account. Four different forms of rectangular balcony, which are commonly found in Hong Kong and many other cities around the world, were included. Effects of the distance between noise source and the balconies and some special angles defined using the balcony configurations and the noise source positions on the insertion loss were also discussed. The noise source was kept parallel to the balcony models throughout the experiment.

It is found that when the source is close to the balconies, the reflections from the upper balconies and the screening effects of the balcony floors have the major contributions to the insertion loss. However, the front panel gradually becomes the determinant member of the balcony in affecting the A-weighted insertion loss and the spectral characteristics of the screening as the distance between the source and the balconies increases. At large source distances, the balcony without a front panel does not offer any noise screening, while the one with a front panel still manages to provide limited noise attenuation at high frequency. There is significant noise amplification due to reflection from upper balcony at low frequency at such source distances. Sound amplification is observed near the upper balcony floor for all balcony forms.

The elevation angle of the balcony correlates very well with the A-weighted insertion loss produced by the balcony in the absence of top reflections. There is also evidence that the elevation angle influences the spectral shapes of the insertion loss (not the exact values). However, in the presence of top reflections, an angle defined using the midheight of the balcony and the bottom corner of the associated upper balcony appears to have good correlations with the A-weighted insertion loss, at least to engineering tolerance.

Spectral peaks of amplification and attenuation are found on the frequency variation of insertion loss. Those at low frequencies are related to the acoustic modes within the balconies, but those at high frequencies remain difficult to explain precisely through experiments because of modal overlapping. Numerical study with large number of node points is suggested as a follow-up of the present investigation.

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