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### 1aNS8. Sound fields inside street canyons with inclined flanking building façades

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Street canyons are common in modern cities. It is well known that the multiple sound reflections within the canyons tend to increase the noise levels inside the canyons. An scaled down model experiment was conducted in the present investigation to study the effect of the inclination of building façade on the sound field. A line source consisted of 100 2-inch aperture loudspeakers were used to simulate the road traffic source. The whole experiment was carried out inside an anechoic chamber. The canyon was 4m long, 2m high and 1m wide (1:4 scale down ratio). The case of a single façade was used acted as the reference. The reverberation inside the model canyon was strong when the two model façades are vertical (inclination 90 deg) and parallel to each other. However, it was found that such reverberation deteriorated very rapidly as the inclination of one of the model façade was reduced to 80 deg. The sound strength inside the model canyon was also reduced. The sound levels at the top region of the canyon decreased more rapidly. It was also found that the effect of the opposite façade was basically unchanged once its inclination was less than 60 deg.

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#### Introduction

Sound propagation inside long partial enclosure has attracted the attentions of many researchers (for instance, lu and Li [1] and Kang [2]). In a congested city like Hong Kong where flat lands are limited, residential buildings usually flank the two sides of a main truck road. The use of noise barriers is also relatively common for limiting the exposure of residents to traffic noise.



Figure 1 An example of dense urban canyon

The buildings form the well known street canyons. An example of the multiply connected urban canyon is given in Fig. 1. Though lots of the buildings have vertical façades, there are buildings built facing hill terraces with a busy road running between the buildings and the terraces (Fig. 2). Some terraces are planted with vegetation, but some are just blank reflective ones.



Figure 2 Road flanked by buildings and terraces

Dual sound barriers are used in Hong Kong when the expected traffic noises are significantly higher than the statutory limit. Non-vertical barriers can be used as described in the CRTN [3]. Sound propagation along long partial enclosures with non-parallel boundaries is therefore an important topic in traffic noise control.

A scale down model was setup in the present study to investigate the sound field inside the long partial enclosure and the effects of the boundary inclination on the sound energy distribution inside such enclosure.

#### **Experimental Setup**

A 1:4 scale down model with boundaries made up of ½ inch thick varnished wood panels was setup for the present experiments. These panels were strong in mechanical strength and sound reflective. All the present measurements were done inside an anechoic chamber. Figure 3 illustrates the scale model. The inclination of one of the vertical panel was varied while the other panel was kept vertical. The model measured 4 m in length, 1 m in width and 2 m in height. The sound source was made up of 100 small loudspeakers aligned in a linear array (5 m long) located mid-way of the model width as shown in Fig. 3. These 100 loudspeakers were arranged in clusters of similar impedances. The sound level variation along its length (less 10 loudspeaker lengths at both ends) was about 2 dB to 4 dB over the working frequency range.



Figure 3 The scale down model

The locations of microphone measurements adopted in the experiment are illustrated in Fig. 4. There are all together 152 measurement locations evenly distributed across half the model canyon, forming a 19 by 8 measurement matrix. One point at the top of the vertical panel in the middle of the canyon was used as a reference in case the output of the loudspeakers varied. The measurement along each column was carried out simultaneously using a Brüel & Kjær PULSE system with a sampling rate of 64k samples per second per channel. Brüel & Kjær 4951 ¼" microphones were used. White noise signals of constant magnitudes were fit into the loudspeaker array throughout the experiment. The case of a single vertical façade (i.e. when the opposite panel was horizontal) was included in the present study as a reference case.



Figure 5 Sound fields on the vertical plane

#### **Results and Discussions**

In Fig. 5 are presented some one-third octave band sound magnitude distributions over the vertical panels with the opposite panel inclined at 60°, 70°, 80° and 90°. The result of a preliminary test showed that the variation of sound level became slow when this inclination was smaller than 60°, and thus the inclination angle in the present study was restricted at 60° to 90° (vertical). The frequencies shown in Fig. 5 and in the foregoing discussions are scaled back to the intended size of the canyon (8 m high and 4 m wide).

For an opposite panel inclination angle of 90°, the sound magnitudes on the vertical panel are relatively uniform, probably due to the strong reverberation inside the model canyon. At lower frequencies, there is a tendency that the sound level will decrease as the measurement location is closer to the edge of the model. The less serious reverberation and the less number of effective sound sources there result in lower sound pressure at this region. The larger the inclination angle, the earlier the sound decay will take place inside the canyon. The reduction in the reverberation strength inside the model canyon as the canyon is gradually opened up also results in the lower sound levels compared to those inside canyons with parallel opposite panels. Some standing wave patterns can be observed at moderate frequencies (at 1000 Hz and 3150 Hz for example) when the inclination angle is smaller than or equal to 70°. One can observe from the sound level maps with inclination angles 60° and 70° at the frequencies 1000 Hz and 3150 Hz that there are regular patterns of high and low sound level along the height of the vertical panel. These patterns may exist inside the canyons with larger inclination angle, but their effects could have been masked by the reverberation and thus cannot be clearly seen from the data. This is left to further studies.

The effect of the opposite panel inclination in the present study is defined as the difference in sound levels on the vertical panel before and after the introduction of the opposite panel. A positive difference represents that the introduction of the opposite panel has increased the sound level. In order to make the present results relevant to traffic noise study, the normalized traffic noise spectrum given in EN1793-3 [4] is adopted here to convert such difference into a single A-weighted sound level difference.

The sound level differences along the heights of the vertical panel under an opposite panel inclination angle of 90° are shown in Fig. 6. It can be observed that the introduction of a parallel panel increases the significantly the sound levels on the vertical panel, especially near the bottom of the canyon. Such increase in sound level in general decreases with increasing distance from the bottom of the model canyon. There is about 3 dB increase in the sound level at the end of the model canyon, but the increase can be as high as 8 dB within the canyon. There are up-and-down of sound level increase as the distance from the canyon end increases. There may be due to the end reflection and the local dips of sound level increase tend to suggest the presence of standing waves. Further investigation is required.

Figure 7 illustrates the sound level differences on the vertical panel when the opposite panel was inclined at 60° with the horizontal. It is found that the sound level differences inside the canyon are basically uniform, except at location near to the canyon end. Standing wave pattern is not obviously found at this inclination angle. Again, the sound level difference decreases as height from the canyon bottom increases in general. However, the addition of the 60° inclined opposite panel can only increase the sound level at or below a height equal to about 60% of the canyon full height. Sound levels at the canyon end are even lowered upon the introduction of the inclined panel. Some sort of end reflection in



the presence of an opposite panel can be the reason for the lowering of sound level. This is left to further investigation.



Figure 7 Sound level differences for inclination angle of 60°.

#### Conclusions

A 1:4 scaled down model experiment was setup to investigate sound field inside a long partial enclosure (a canyon) flanked by a vertical wall and an inclined wall. The effect of the inclination angle of the inclined wall on the sound field is the main focus.

It is found that the reverberation within the enclosure when the two flanking side walls are parallel is strong and the sound field inside the enclosure is relatively uniform, especially at low frequencies. The sound level near to the end of the enclosure is weaker. As the inclination of one of the wall decreases, the reverberation strength decreases quickly and the sound field becomes less uniform. The difference between sound levels at the enclosure end and at the middle of the enclosure increases with decreasing inclination angle. Some standing wave patterns can be observed when the inclination angle is reduced to 70° or below.

The sound fields on the vertical walls measured in this study are compared with that on a vertical wall without the opposite wall. The increase in sound level due to the presence of an opposite vertical wall can be as high as 8 dB probably because of the multiple images effect and the increased reverberation. Such increase in sound level decreases with increasing distance from the bottom of the enclosure. Such increase in sound level decreases to ~3 dB at the enclosure end. For the case of 60° inclination angle sound levels at larger distances from the enclosure bottom (above 60% of enclosure height) and at the enclosure end are weakened by the introduction of the opposite wall. Further investigation is required to explain the above observed acoustical phenomena.

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