ME5106 CA3: Acoustic Measurement and Analysis based on a Noisy Singapore Condominium Building

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1 Introduction

The research object is The Parc Condominium (S127161), where I am living in. As it is located besides the AYE street and West Coast Road (**Fig 1**), the noise is always a concern by the residences. In this term report, the noises are measured varying with the floor level, and day or night. Based on acoustics theories like wave propagation, the acoustic characteristics are analysed. The reasons regarding the high-level noise are listed. Serving as sound barriers, the trees and acoustic panels show their significance on noise control. Moreover, the doppler effect of the road vehicles is obtained as well.

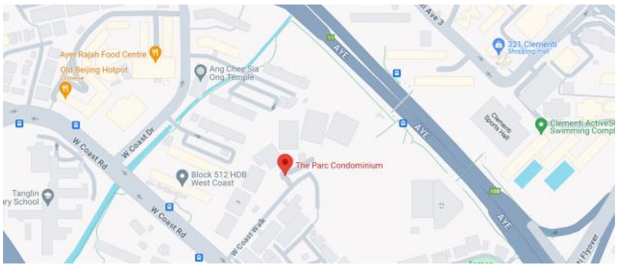

Fig 1. Measurement location, The Parc Condominium.

2 Methodology

Measurement. The measurement is conducted with the help of personally self-built system, which is consist of a condenser microphone (TakStar PC-K200), an audio interface (UMC22), an XLR analogue audio cable, a laptop with digital audio workstation software installed (Presonus Studio One Pro). The system was calibrated at sound pressure level (SPL) and frequency response by comparing with a professional sound meter in Dynamics Laboratory (NUS E1-02-03). During the calibration, the relationship between voltage level (dBu) and sound pressure level (dB) is obtained in the full frequency range, ensuring the error is within ± 0.9 dB (50Hz - 15kHz).

Calculations. The SPL are defined by **Eq 1**, and obtained and calibrated by **Eq 2**:

$$SPL = 20 \lg \frac{P}{P_0} \text{ (dB)} \tag{1}$$

$$SPL_{cal} = \sum A(f) \cdot f(U(t)) \tag{2}$$

, where P is the sound pressure, P_0 is the reference sound pressure, A and f are correction function obtained during calibration. U(t) is the voltage level signal. And the Roughness by Zwicker Model (ZR)[1] is given by **Eq 3**:

$$ZR = 0.3 \frac{f_{mod}}{1000} \int_0^{24} \Delta L dz \tag{3}$$

, where f_{mod} represents the modulation frequency, L is the masking depth, and z is the splitting frequency range defined in Zwicker Model. Then, the frequency and spectrogram are calculated by Discrete Fourier Transform (DFT) and Continue Wavelet Transform (CWT), respectively.

3 Results

Floor Level. SPL determines the loudness (physic), while roughness represents the impact of sound on human comfort (psychological). Together, they embody the noise interference from the perspective of sound psychology. The SPL and Roughness in both day and night are shown in **Fig 2**. The frequency distributions are shown in **Fig 3**. For variable controlling purpose, they are all measured in the day time, namely 14:00.

Measuring Time. To investigate how the noise changes along the time, two sets of noise are collected, shown in **Tab 1**. The measurement time is 14:00 and 02:00 for day and night time, respectively.

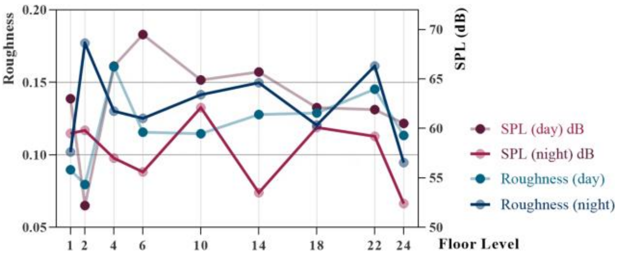

Fig 2. Sound pressure level (SPL) and Zwicker Roughness (ZR) varying with floor level in the day time.

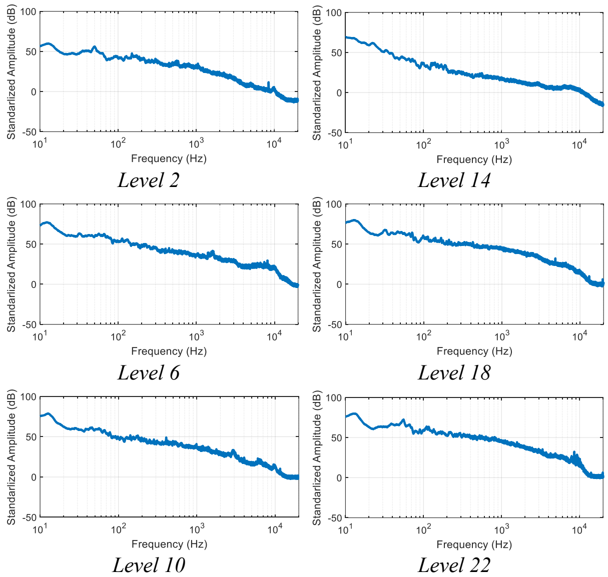

Fig 3. Normalized frequency characteristics of selected floor levels in the day time.

Tab. 1. Averaged sound pressure level (SPL), Peak (PK), and Zwicker Roughness (ZR) varying with day (14:00) and night (02:00). The measuring point is at level 4 and level 18.

Time	SPL	PK	ZR	SPL	PK	ZR
Level	Level 4			Level 18		
Day time	66 dB	75 dB	0.161	62 dB	71 dB	0.129
Night	57 dB	78 dB	0.130	60 dB	79 dB	0.120

Observations. Firstly, and the most important is, SPL presents a "∩" curve, means that the annoying noisy floor prize could be "awarded" to mid-low-height floors. On the other hand, higher floors exhibit a stronger proportion of low and middle frequency noise compared to lower floors. At very low floors (1^{st} to 2^{nd} floors), the SPL is actually lower, and the peak shifts towards mid to high frequencies (low frequencies fades much greater than that of other floors). In comparison between day and night, the average noise level is lower at night, and roughness are also lower compared to that in the day.

4 Discussions

In this section, the reasons of the above-mentioned phenomenon are analysed based on wave propagation and other acoustic theories.

Floor Level

Distance. Due to the high floors being farther away from the main noise sources (roads), a lower SPL aligns with the expectation compared to middle floors. However, when comparing theoretical and measured results, there are some noteworthy differences. Assuming free field conditions, this implies that the SPL decreases by 6 dB when the distance is doubled. Taking 10^{th} and 22^{th} floors as an example, the SPL is 64.9 dB and 61.9 dB, respectively. Due to a simply calculation, the propagation distance is 40 m and 75 m respectively, about two times aligned. From the theoretical calculation due to the two distances and SPL at 8^{th} floor as boundary conditions, the SPL at 16^{th} floor is supposed to be 59 dB. Potential reasons include temperature-related refraction, and sound absorption and diffusion.

On the other hand, low-frequency components of the noise could go through the obstacles (especially the acoustic panels around the condominium) easier. Compared to the baseline signal near the road, noise exerted to the building shows higher low-frequency distribution.

Sound Barriers. A series of government-built acoustic panels fade the noise for about 4 dB @50Hz, and 10 dB @2000Hz (day time). Interestingly, the trees also serve as sound barrier, shown in **Fig 4**, provide up to more than 15 dB (full band) reduction to the noise.

Fig. 4. Photography of trees serving as sound barriers beside the building, taken from level 2.

Measuring Time

Temperature. The measurement point for this analyse is on the opposite side to that before, where is favoured by "street racers", hence, supercars are often observed. After averaging from three cars (six in sum), the SPL during the day is 86.5 dB, which increased to higher than 90 dB at night. Due to wave propagation, the ground temperature is higher during the day, causing the speed of sound to increase with altitude. Consequently, the direction of sound propagation shifts towards the sky. At night, the opposite occurs. Sound reflects and diffuses more through the ground and buildings, directing more components into the measurement point. Despite this, it may have potential inaccuracies: as racers tend to be more reckless at night, possibly accelerating more aggressively.

Human Activities. Observations indicate that the traffic noise at night is significantly lower than during the day, meaning that on average, the SPL is much lower than that in the day. The noise from other human activities is also louder in the day, but not with great significance comparing to traffic. However, there are two motorcycle clubs located beneath the condominium. Every night, a large number of motorcycles roar by, causing severe spikes in noise levels. When the motorcycles pass, the noise can increase by almost up to 90 dB.

Transportation Doppler Effect

Interestingly, when motorcycles speed by, the Doppler effect is quite noticeable. The pitch of the engine noise significantly decreases. Spectrogram of this phenomenon is shown in **Fig 5**. From this figure, it is obtained that the upshifted frequency is 377.2 Hz, and the downshifted frequency is 346.5 Hz. According to **Eq 4**, the moving speed of motorcycle is estimated as 51.8 km/h (illegal).

$$\begin{cases} f'_{up} = f\frac{v}{v-v_s} \\ f'_{down} = f\frac{v}{v-v_s} \end{cases} \tag{4}$$

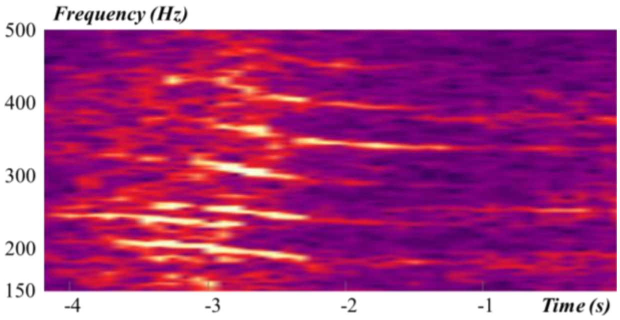

Fig. 5. Windowed spectrogram (based on Continue Wavelet Transform, CWT[2]) regarding the doppler effect of a motorcycle passing the measuring point at night.

5 Conclusion

In this case, three main conclusions are obtained.

– The loudest floor is mid-low floors, potential reasons include reflection and diffusion. Comparing the day and night, the noise is lower and with more comfortable roughness in the night.
– Acoustic panel and trees at lower floors serve as sound barriers, providing a significant insertion loss to the traffic noise.
– Human activities are the dominant factor to the noise on the building, include both normal traffic noise and extreme ones like motorcycle and supercars.

References

[1] E. Zwicker and H. Fasti, *Psychoacoustics Facts and Models* (2006).
[2] L. P. A. Arts and E. L. Broek, *Nat. Comput. Sci.*, **2**, 47–58 (2022).

Data Availability

Data measured and analysed, and Matlab code written and used in this report are uploaded to Github, and available from 29/03 until at least 30/04/2024: https://github.com/hweifluids/TempRepo.