An Investigation into Wind Generated Aero-Acoustic Tones

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1. INTRODUCTION

In early 2008, a newly constructed six level car parking building at a private hospital in Christchurch, New Zealand was the cause of complaint due to a tonal noise audible during windy conditions. Subjectively the noise was "like someone rubbing their finger around a crystal wine glass". A review of literature suggested that the noise could be generated by an aero-acoustic tone generated by wind flowing either over a thin obstruction or into a slot [1]. The building had two different types of balustrades and a number of thin slots, however the external balustrades were considered to be the most likely cause of the tone, due to their location where they were subjected to high wind velocities. The external balustrades were constructed from 36 steel balusters of dimensions 50mm x 6mm x 1050mm. The balusters were arranged vertically and spaced at 93mm centres. 70 balustrades were located in the building.

2. RESULTS OF TESTING

Testing was performed during windy conditions using FFT analysis to allow a narrow band assessment of the tone to be performed. The following graph shows the results of one measurement:

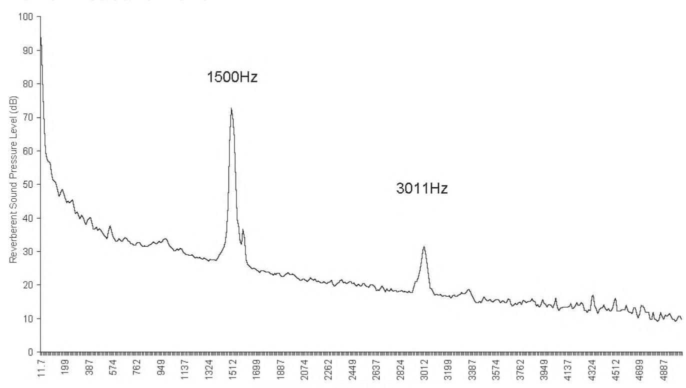

Figure 2.1: Reverberant sound pressure level in car park during tone generation. A distinct tone at 1500 Hz with a secondary tone at 3011Hz can clearly be seen. A smaller peak at 1550Hz is also shown.

A forced vibration response of the balusters was measured by exciting the fundamental mode natural frequency with a hammer and measuring the response with an accelerometer. The results show that the external baluster does have a natural frequency response at 1550 and 2753Hz in bending. Although a natural frequency response was not observed at 1500Hz it is possible that the baluster has a 1500Hz natural frequency of vibration in another axis that was not measured by the single axial accelerometer used for the measurement. Figure 2.2 shows the results of these measurements:

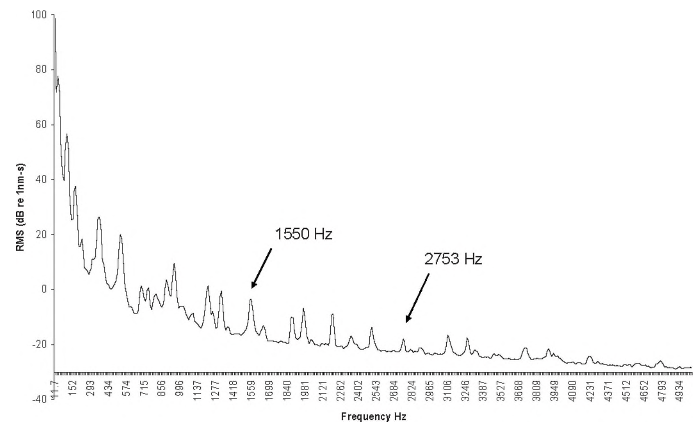

Figure 2.2: Forced frequency response of the external balustrade. The graph shows a natural frequency response at 1550Hz and 2753Hz.

Vibration monitoring of balustrades was also performed during windy conditions when the tone was being generated. Figure 2.3 shows the results of the monitoring of the external balustrade:

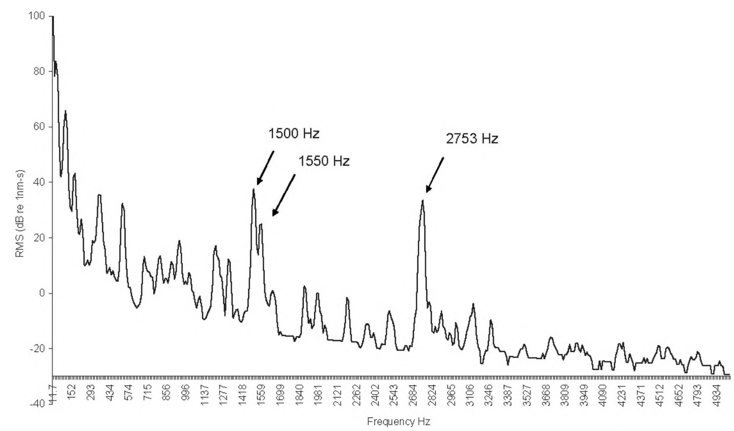

Figure 2.3: Vibration measurement of external balustrade during tone generation. A response at 1500Hz, 1550Hz and 2753Hz was observed.

The above results clearly show a vibration at around the same frequencies as the measured airborne tone. Given that the measurements of forced vibration showed a natural response at these frequencies it was considered the airborne tones were generated by the vibrating balusters. The mechanism by which the balusters are forced to vibrate was considered likely to be vortex shedding or a standing wave effect caused by the spacing of the balusters.

The standing wave frequency between the balusters was predicted using the formula f = V/D where f is the frequency of the standing wave, V is the speed of sound in air and D is the wavelength of which half corresponds to the distance between the balusters. Given the balusters are spaced at

93mm the standing wave frequency was predicted to be 1814Hz. This does not correspond with any of the frequencies measured.

An attempt to predict the vortex shedding frequency was performed using the equation for the Strouhal number $S(c) = f_{v.}c/U$ where f_v is the dominant shedding frequency, U is the velocity of the free stream air and c is the length of the baluster parallel to the wind direction. The balusters were effectively flat plates with a blunt edge and a chord/thickness ratio of 8.3. Research has shown that Strouhal numbers for these types of plate vary stepwise with chord/thickness ratio and are related by integer multiples of 0.6 [2]. However complicating this prediction was the fact that the wind direction was observed to be at an angle to the balustrade during tone generation, and that the balusters did not have a true blunt edge but a slight rounding. This made the correct Strouhal number difficult to determine. In any event, even assuming a Strouhal number of 1.8 [2] the observed tones did not line up well with the predicted natural Strouhal frequency. In spite of this it was considered that vortex shedding was the most likely cause of the vibration of the balusters.

3. WIND TUNNEL TESTING

In order confirm that the external balustrade was responsible for the tone generation, wind tunnel testing was performed. Testing at a range of frequencies and balustrade angles showed that the tone under investigation was generated only between 10.7 – 13.6 m/s at an angle of 24° ± approximately 3° from the wind flow direction. Figure 4.1 shows the generated sound pressure level and frequency as a function of wind speed.

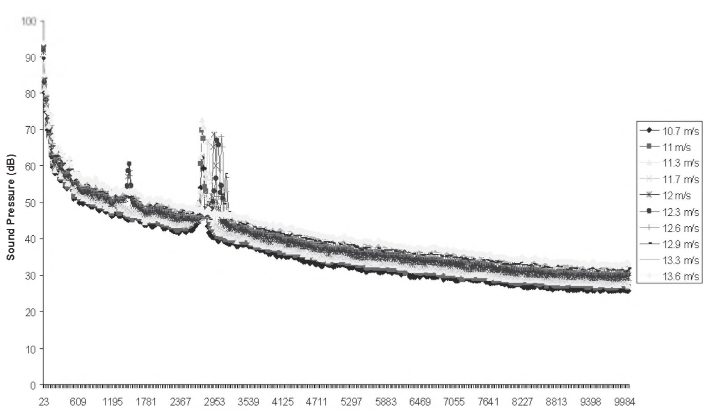

Figure 3.1 Sound pressure level and frequency as a function of wind speed.

It can be seen that both tones were successfully generated, however the tone at around 3000Hz was louder in the wind tunnel whereas the 1500Hz tone was louder in-situ. It can be seen that the tone varies with wind speed from 2742Hz to 3140Hz for wind speeds between 10.7 to 13.6 m/s.

The vibration response of the baluster was also measured during tone generation. Vibration responses between 1500 and 1550Hz and between 2742 to 3140 Hz were observed. The largest vibration response by a significant margin was observed at 11 m/s at a frequency around 2750Hz which is likely due to the natural mode of vibration of the baluster at this frequency.

3.1 Treatment Testing

The following treatments were tested in an attempt to eliminate the tone;

1. 14mm x 35mm expanded metal;
2. 50 x 50mm coarse square wire mesh;
3. 19mm x 19mm fine square wire mesh, and
4. Plastic stripping approximately 12mm in diameter.

All treatments were affixed to the leading edge of the balustrade. It was predicted that by affixing the above treatments the airflow over the balusters would be disrupted and the Strouhal vortex shedding frequency would be altered. All treatments were successful in suppressing the tone.

Vibration measurements were performed during testing of each treatment which showed that although the tone was suppressed by the treatments, some vibration remained for all treatments other than the plastic stripping. It is noted that in similar experiments by others, certain trailing edge treatments, such as perforated sheeting, have caused the amount of noise generated to increase [3]. On this basis the plastic stripping was considered the most suitable treatment.

Additional experiments showed that where plastic stripping was applied to each alternate baluster this reduced the level of noise considerably, however the tone still remained. Turning the balustrade around so that it was affixed at the leading edge rather than the trailing edge also reduced, but did not eliminate, the tone.

3.2 Hotwire anemometry testing

Hotwire anemometer testing was performed during conditions where the tone was being generated. This testing showed that the amount of turbulence from the balustrade reduced significantly when the leading edge treatment was affixed

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