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Whistling Building Objects, Origins and Solutions

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ABSTRACT

Widespread complaints often occur due to whistling sounds caused by building objects, such as (high rise) buildings and viaducts, under specific meteorological circumstances, especially wind speed and direction. In many cases this is related to the application of specific grating. Much is already known about the relevant parameters for this phenomenon from measurements in practice and in laboratories. To obtain more understanding into this subject and to be able to prognosticate the possible occurrence and intensity of it in the design phase of building objects, systematic research has been done under laboratory conditions. The sound power level and frequency characteristics of whistling sounds dependent of wind speed, angle of incidence and grid configurations were studied. Also the sound reducing effect of different and practically feasible modifications of gratings was part of the study. The paper presents the results of this study.

1 INTRODUCTION

Sincere complaints occur during periods with high wind velocities when high tonal sound levels are caused by specific parts of objects, mostly grating. Practical cases were analyzed, using the acoustical laboratory facilities of Peutz. From this a special measurement program was derived to obtain more systematic knowledge of this phenomenon. Moreover, practical provisions to reduce this kind of sound were studied.

2 THEORY

The aeolian tone is a monotonic aerodynamic sound generated by an air flow around an object due to shedding of vortices. The frequency of the aeolian tone is related to the dimensionless Strouhal number S:

$$f = S \cdot \frac{v}{D} \qquad (1)$$

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with:
f (oscillation) frequency [s^{-1}]
D characteristic dimension of the object perpendicular to the air flow [m]
v velocity of the air flow in front of the object [m/s]

This formula shows a direct dependency between frequency and air flow velocity, which provides a good description of aeolian tones. Often this concerns phenomena in the lower frequency range related to common dimensions of obstructions in air flows. The tones described in this paper are mostly in the higher frequency range and depend less on the air flow velocity.

3 COMPARABLE STUDY

A recent experimental Japanese study deals with aeolian tones generated by a an object with square cross-section. square cylinder under different angles of attack in an air flow [1]. The studied object has some resemblance with parts of the grating under consideration since it has sharp edges, and the flow attacks the frontal surface under different angles. Highest sound level appears with an angle between air flow and frontal surface of the square cylinder of 0°. The frequencies of observed aeolian tones are relatively low, roughly between 80 and 100 Hz.

In most of our practical cases (also) much higher frequencies have been determined. Differences are the dimensions of the grating: different dimensions of the surfaces and the repetition of bars behind each other. With a grating the same vortices can be expected, but the repeated presence of objects influences this phenomenon.

4 ANALYSIS OF PRACTICAL CASES

4.1 General

In different practical situations high sound levels with a tonal character have been observed during specific wind conditions. In many cases gratings appeared to be the cause of it. This was verified by performing measurements in the reverberation room of the Peutz laboratory, using the grating from the real object. The following examples show the investigated phenomena in laboratory conditions. In all cases these are galvanized steel gratings with sharp edges.

Gratings are positioned in such a way that the air flow is perpendicular to the length of the bearing bars, and at an angle at which the highest sound levels occur.

4.2 Path next to railway

The grating concerns an escape and inspection path next to a railway viaduct. The geometry of the grating is as follows:

Bearing bar thickness/height:		3,5 mm / 30 mm
Filler bar height:		11 mm
Center to center spacing:	- bearing bars:	30 mm
	- filler bars:	30 mm

Figure 2 shows sound power spectra at different air velocities. Higher sound levels are generated with the air flow coming from below the grating than from above the grating.

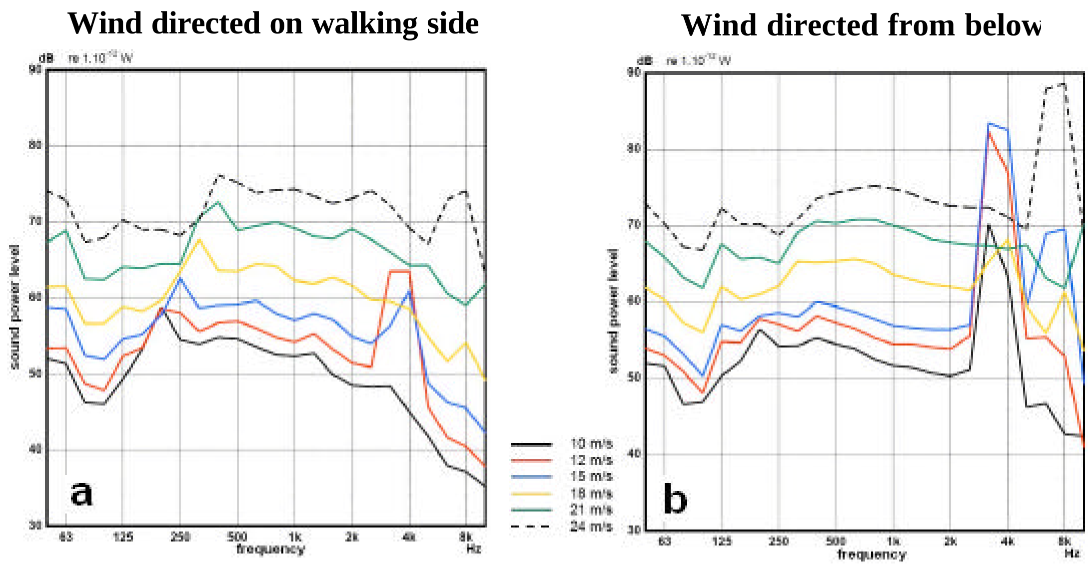


Figure 2: Spectral sound power levels of the grating at different air velocities

4.3 High rise building 1, grating 1

The geometrical information of the grating is as follows:

Bearing bar thickness/height:		2,1 mm / 40 mm
Filler bar height:		10 mm
Center to center spacing:	- bearing bar:	35 mm
	- filler bars:	70 mm

Figure 3 shows sound power spectra at different air velocities.

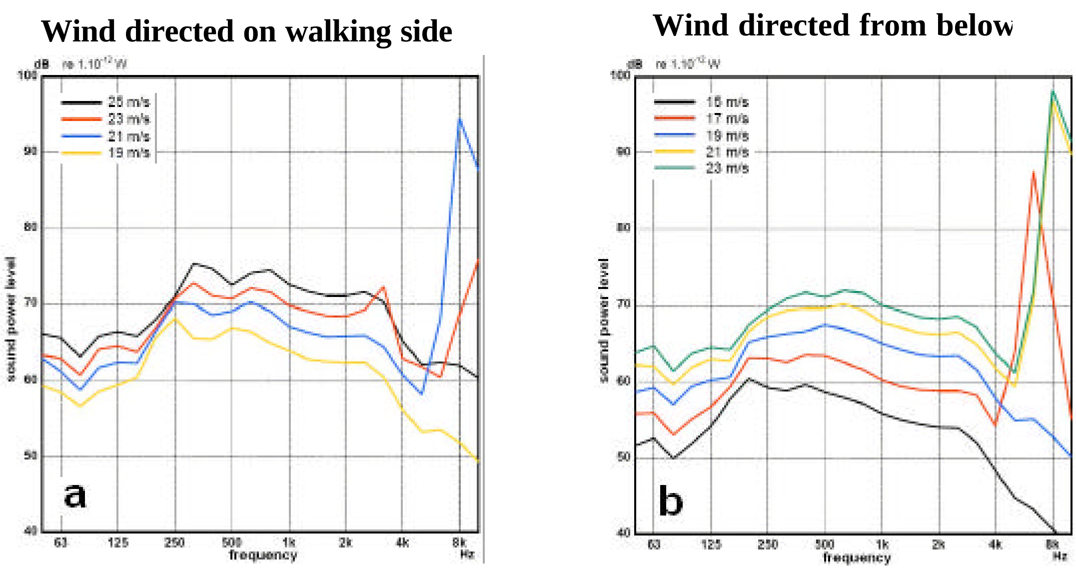


Figure 3: Spectral sound power levels of the grating at different air velocities

Also in this case higher sound levels are generated when the air flow is coming from below.

4.4 High rise building 1, grating 2

The second grating from this building has the following geometry:

Bearing bar thickness/height:		2,1 mm / 40 mm
Filler bar height:		10 mm
Center to center spacing:	- bearing bar:	55 mm
	- filler bars:	100 mm

Figure 4 shows sound power spectra at different air velocities.

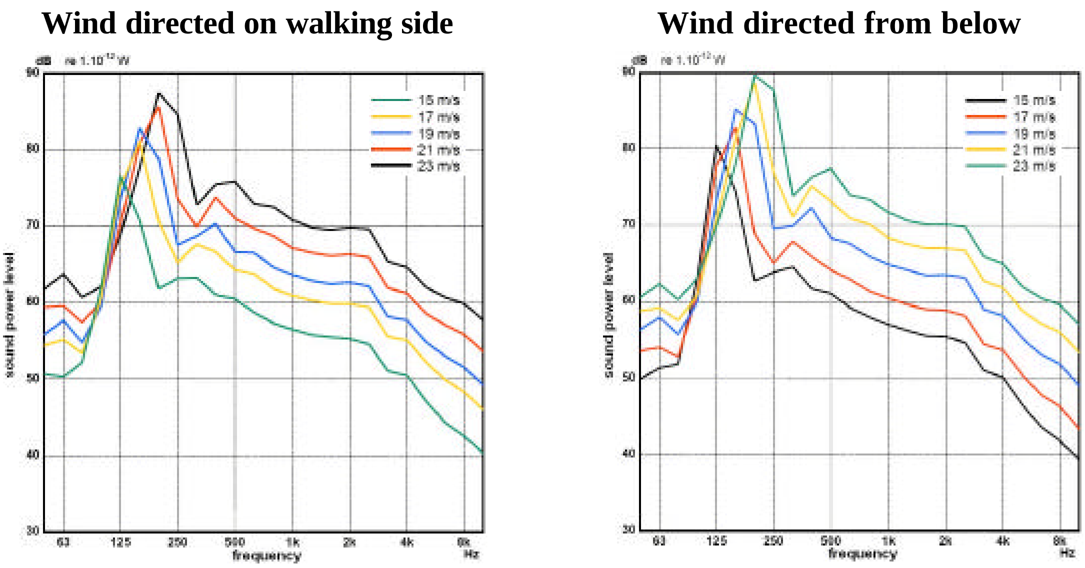


Figure 4: Spectral sound power levels of the grating at different air velocities

This grating does not generate aeolian tones at higher frequencies as the former grating showed, but only in the lower frequency region (125 up to 200 Hz). Furthermore the frequency of the peaks clearly increases with increasing air velocities.

4.5 High rise building 2

The gratings in this building are not meant to be walked on, but primarily for architectural reasons. Figure 5 shows this grating, constructed from slightly tilted and non-tilted bars. The geometry is as follows:

Bearing bar thickness:	3,0 mm
Center to center spacing slightly tilted bars:	53,5 mm

The angle of attack is slightly tilted in conformity with the real situation in the building. Although this configuration differs from the other practical cases, it also generates aeolian tones in the higher frequencies; see figure 6.

N.B. These measurements were carried out in the Peutz wind tunnel. Disadvantage of that measurement set up was that no “silent air” was available. Nevertheless the tonal effects are clearly observed.

Figure 5: Grating with slightly tilted and non-tilted bars

Measurement in practice of grating high rise building 2

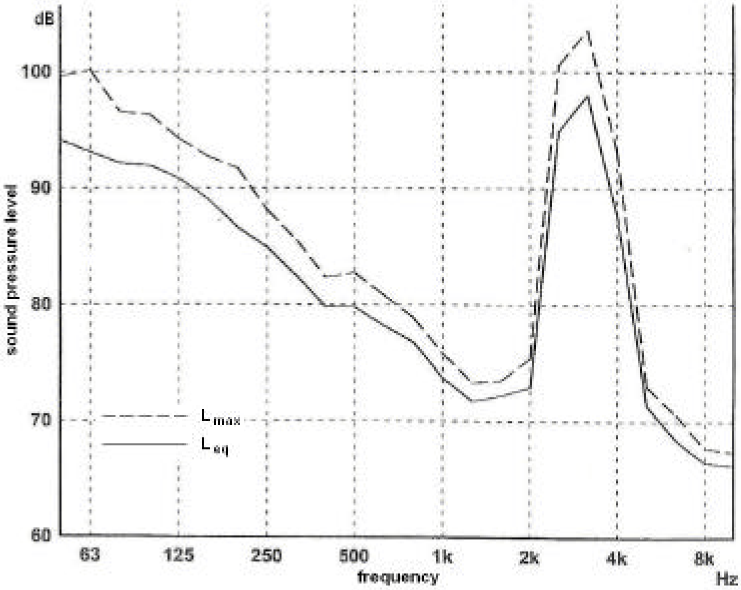


Figure 6: Spectral sound pressure levels of the grating measured in practice

5 SYSTEMATIC MEASUREMENTS IN LABORATORY CONDITIONS

5.1 Comparison with practical situation

Air flow conditions are different in real life compared with those in laboratory conditions. Nevertheless, it is shown that frequencies that appear in practice also appear in laboratory conditions; see for instance figure 7, to be compared with the spectra of figure 2b with similar air flow velocities.

Measurement in practice

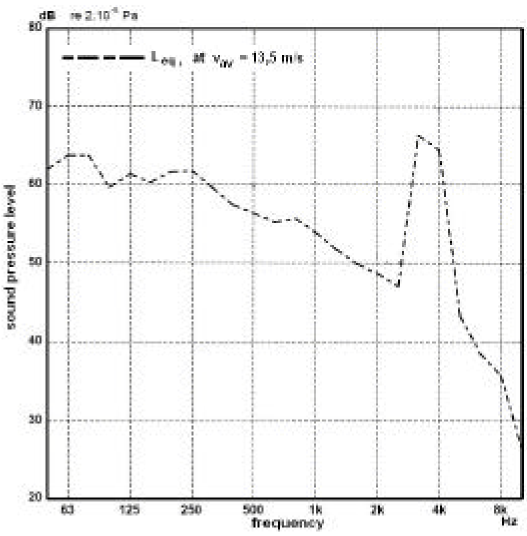


Figure 7: Spectrum of sound level of grating in practice at a distance of about 80 meters. The high sound levels up to a frequency of 500 Hz are due to high wind speeds.

5.2 Parameters of interest to be investigated

The aspects which were assumed to be most important for the generation of aeolian tones by wind through gratings are investigated.

Material:
All gratings were made of galvanized steel.

Resonance of the material:
It has been checked whether the sound levels are really aeolian tones or originate from radiation of vibrations of the gratings. Figure 8 shows the sound levels due to air flow through the grating as well as the vibration levels on the gratings. The spectra in figure 8 show that vibrations of the grating due to excitation by a hammer respectively by the air flow are dominant below 4000 Hz, with main peaks below 2500 Hz. Aeolian tones appear above 4000 Hz for this type of grating. Therefore it is clear that the high sound levels are air flow induced.

Sound and vibration measurements on grating 1 of high rise building 1

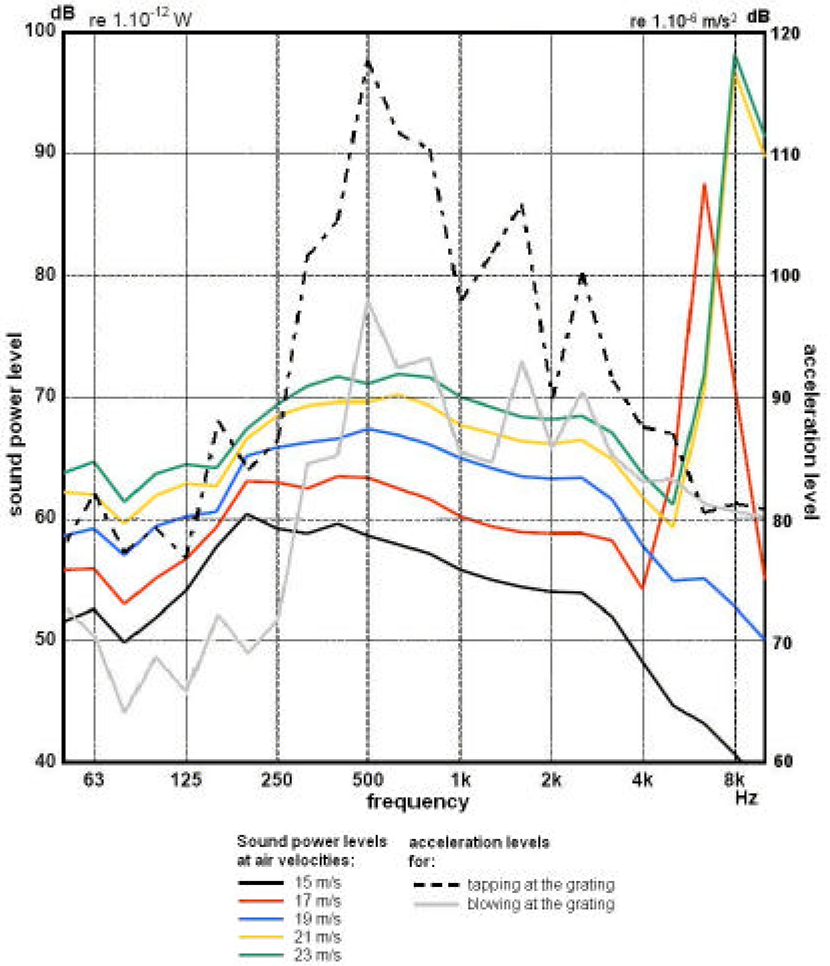


Figure 8: Spectral sound power levels and acceleration levels of grating 1 of building 1

Grating bars:
Grating bars perpendicular to the air flow are the main cause of aeolian tones. Therefore this study is mainly directed at the bearing bars, of which different heights are considered.

Bearing bar spacing:

Because practical situations showed that the distance between the bearing bars is of influence on the occurring sound levels, a test grating was designed, of which the distances could be varied without changing other parameters.

Thickness of steel:

Although the thickness of the steel of the bearing bars could influence the origin of aeolian tones, this has not been varied in this study. Based on common practice a thickness of 2 mm has been used.

Dimensions of the grating:

All steel gratings are in full scale, in general about 1 m^2, with different heights of the bearing bars. It is important that the surface of the grating is large enough to obtain a situation in which the air flow from a pipe flows over the grating, even with tilted gratings. Of course, in practice the total surface of the grating is rather important because it determines the total generated sound power.

Sharpness of steel:

Sharp edges of the steel bearing bars have been used since practice showed that rounding the edges was of influence, decreasing the generated sound levels.

5.3 Measurement set up

Main parts of the measurement set up are a stable air flow, the dimensions of the test grating and the measurement equipment.

Air flow:

In the acoustical laboratory of Peutz in Mook "silent air" is available. Therefore the sound levels in the reverberation room are only due to air flowing through the grating. The velocity of the air flow is variable from 0 up to about 30 m/s, with an air pipe with an exhaust opening with a diameter of 315 mm.

Test grating:

A special test grating was designed to be able to determine the influence of height and distance between bearing bars, as well as the sharpness of the edges and the angle of attack of the air flow; see figure 9. The distance between bearing bars could be changed with intervals of 1 cm. The height of the studied bearing bars is 20, 30 en 40 mm.

The inner dimensions of the test grating were 700 × 500 mm, sufficient to position it in the full air flow, also with different angles of attack of the air flow.

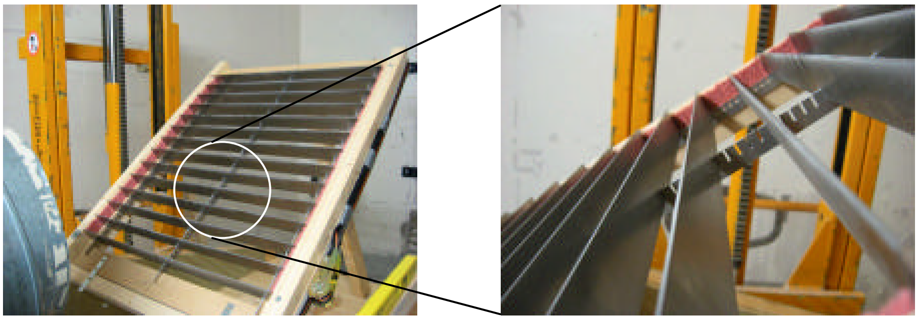


Figure 9: The test grating

When at a certain air velocity an aeolian tone is observed for the first time, the angle of attack is changed in small steps. The angle of attack a is 0° when the air flow is parallel to the surface of the test grating.

6 RESULTS

6.1 Height of bearing bar of 40 mm

In figures 10a to 10d measurement results regarding the test grating with bearing bars with a height of 40 mm and varying center to center (c.t.c.) spacing of bearing bars of respectively 30, 40, 50 en 60 mm are shown. The angle α of the air flow in this specific case is 26°, at which the aeolian tone is at its loudest.

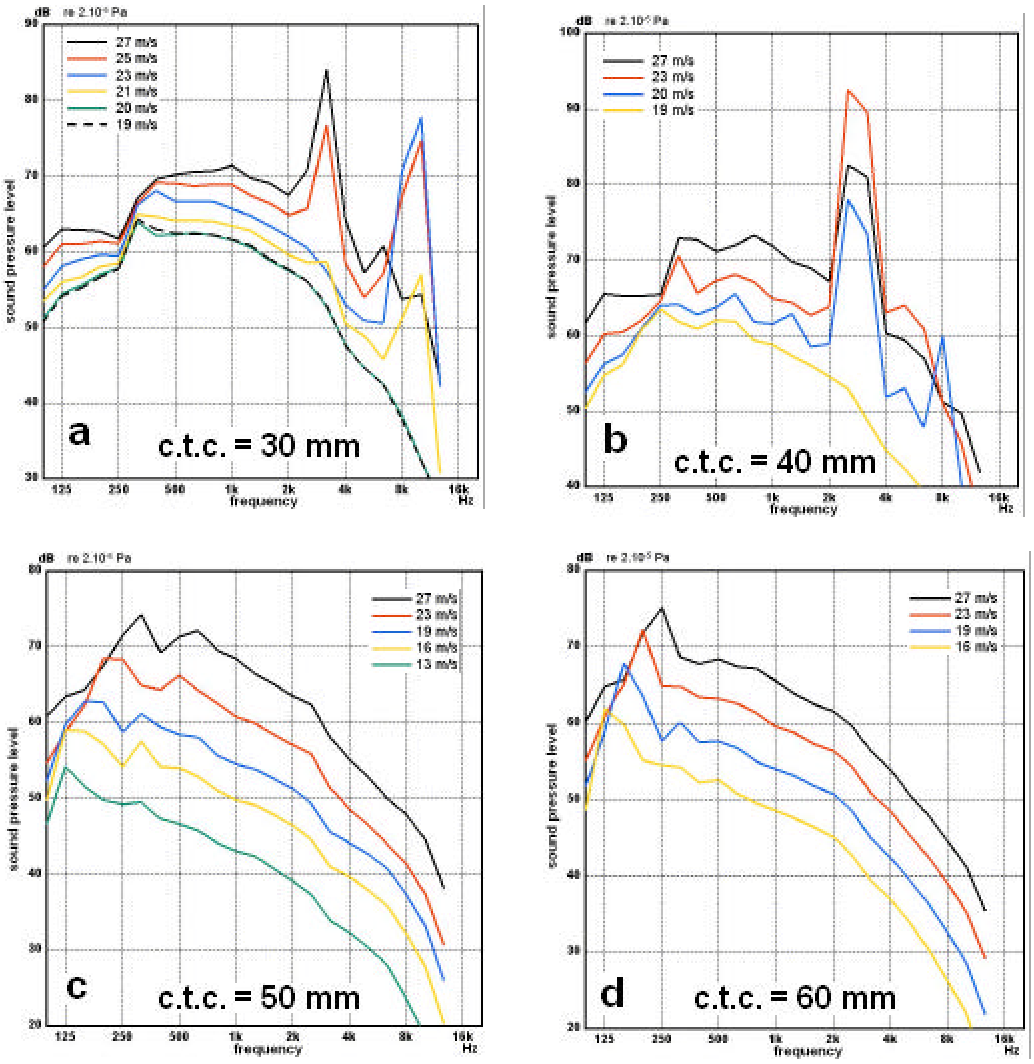


Figure 10a-d: Measurements on the test grating with a bar height of 40 mm.

Figure 10a shows a clear peak at an air flow of 27 m/s in the 3150 Hz third-octave band. At an air flow velocity of 25 m/s two peaks are observed, in the 3150 and 10000 Hz third-octave bands. These tones alternate in time, as can be seen from figure 11, showing the sound spectra as function of time.

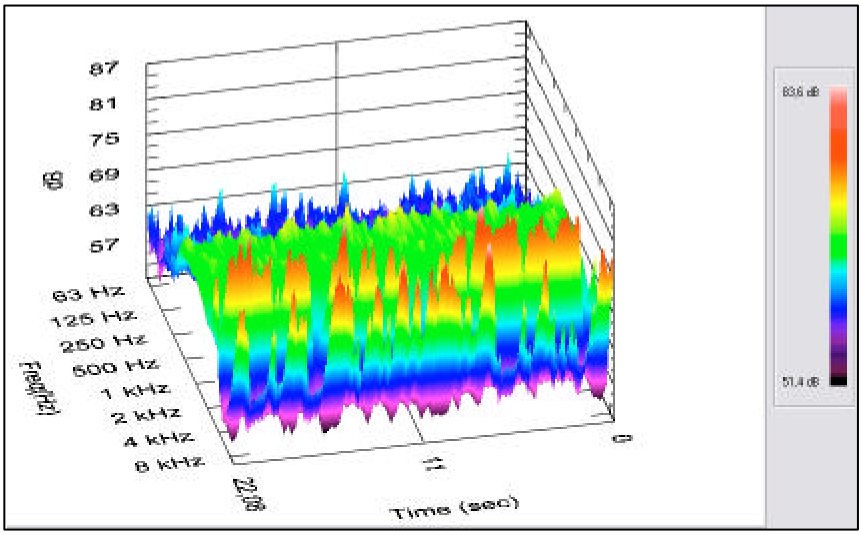


Figure 11: Spectral sound power levels as function of time for grating with bearing bars height / distance of 40 mm / 30 mm at an air velocity of 25 m/s

With air flow velocities below 20 m/s no tone is observed anymore.

Figure 10b (c.t.c. spacing of 40 mm) shows that the tone in the third-octave band of 2500 Hz at 23 m/s is about 10 dB louder than the tone of equal frequency at 27 m/s. At 20 m/s an extra but less loud tone is observed at the higher frequency in the 8000 Hz third-octave band. Below 19 m/s no tone is observed anymore.

As can be seen from figures 10c and 10d at c.t.c. spacing of respectively 50 and 60 mm no tone at higher frequencies is observed. This also applies to other angles of attack.

6.2 Height of bearing bar of 30 mm

Figures 12a and 12b show results with a height of the bearing bars of 30 mm at a c.t.c. spacing of 30 mm.

Air flow velocity: 17-27 m/s **Air flow velocity: 9-13 m/s**

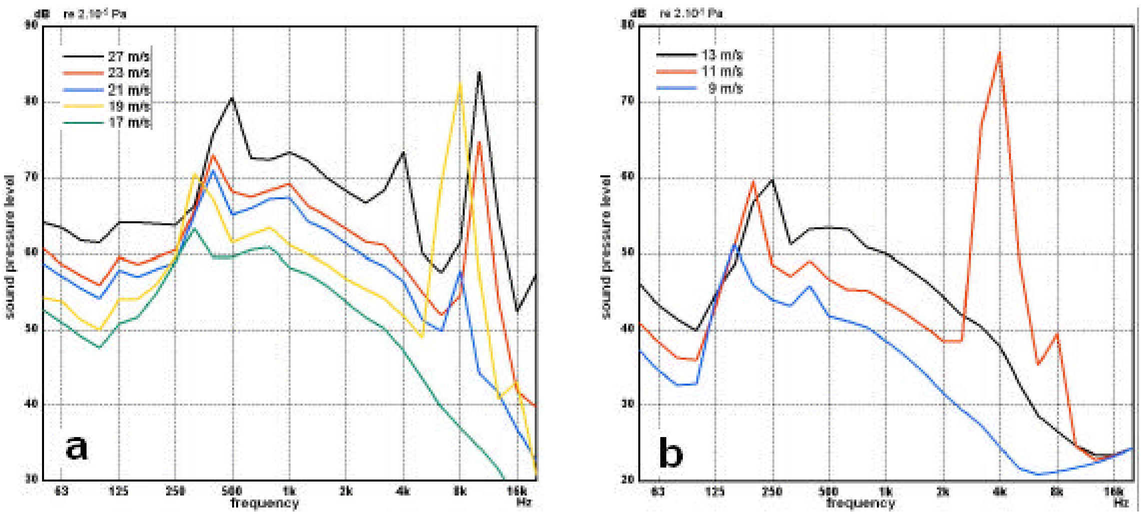
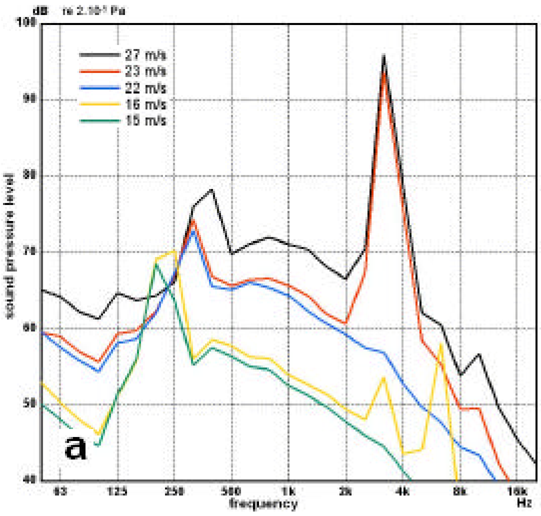


Figure 12a-b: Measurements on the test grating with a bar height of 30 mm and a c.t.c. spacing of 30 mm.

With these dimensions at relative high as well as at relative low air flow velocities aeolian tones are produced. At specific air flows of 17, 13, 9 m/s (and lower) no tones are observed. However at 11 m/s a strong tone exists at 4000 Hz.

Figures 13a en 13b show results with a height of the bearing bars of 30 mm at a c.t.c. spacing of 40 mm. Figure 13a deals with an angle a = 26°. Figure 13b gives the results with the grating tilted to 38°.

Angle of attack = 26°



Angle of attack = 38°

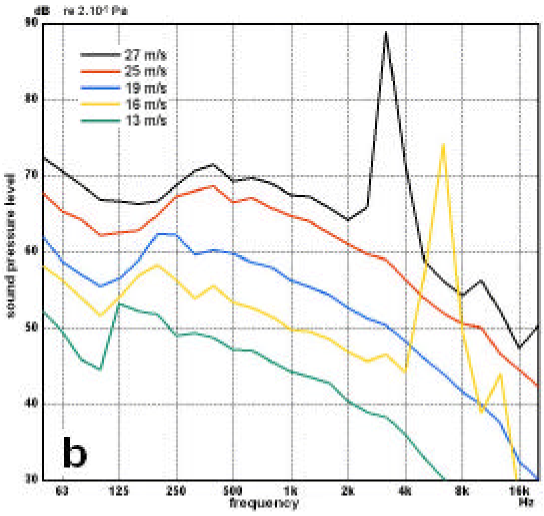


Figure 13a-b: Measurements on the test grating with a bar height of 30 mm and a c.t.c. spacing of 40 mm for two different angles of attack.

Figure 13a shows a clear peak in the 3150 Hz third-octave band, at air flows from 27 to 23 m/s with no significant change in sound level. At 22 m/s the tone disappears. At 16 m/s two tones are observed in the 3150 and 6300 Hz third-octave bands with a relative low sound level. At air flows lower than 16 m/s no tones occur.

Changing the angle of attack to 38° the tone in the 3150 Hz third-octave band only remains at higher velocities.

With bearing bars of 30 mm height and a c.t.c. spacing of 50 mm no aeolian tones are observed.

6.3 Height of bearing bar of 20 mm

Similar results are obtained with a height of the bearing bar of 20 mm and c.t.c. spacing of 20, 30, 40 en 50 mm; see figures 14a till 14d. Tones were observed with angles of attack a between 23° and 39°. Measurements are shown with an angle of attack a of 31°.

Figure 23d shows that at a c.t.c. spacing of 50 mm at all air flow velocities no tone is observed, which is the case with different angles of attack.

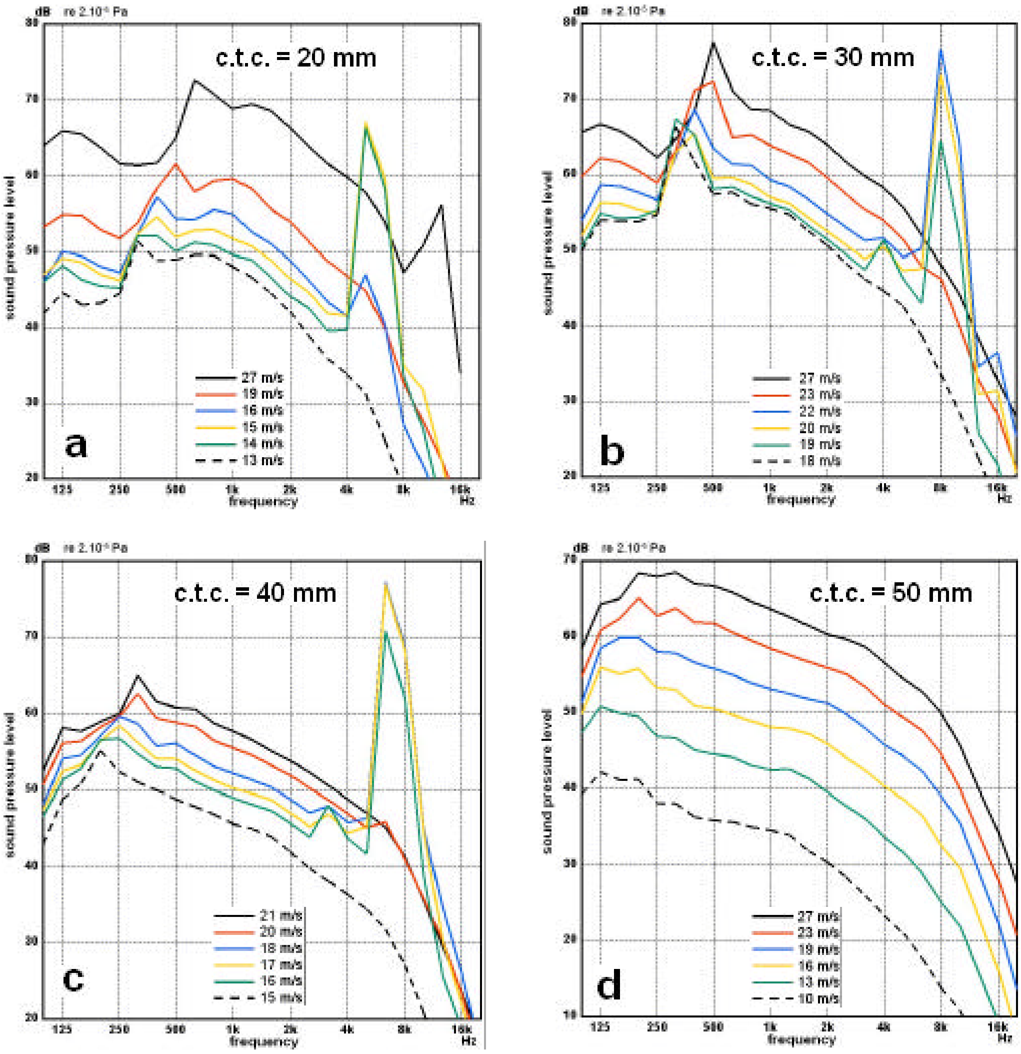


Figure 14a-d: Measurements on the test grating with a bar height of 20 mm.

6.4 Influence of the amount of bearing bars

To investigate the dependency of the number of bearing bars a test was executed starting with 1 bearing bar in the air flow and subsequently adding an extra bearing bar in the test grating. It appeared that only with 9 bearing bars an aeolian tone was generated at the same frequency as with the complete grating (see figure 15 and compare with figure 12a); the air flow velocity is 27 m/s, bearing bar height is 40 mm and the c.t.c. distance between bearing bars is 30 mm. This clearly shows that the repetitiveness of the bearing bars of the grating is very important in generating this specific type of aeolean tones.

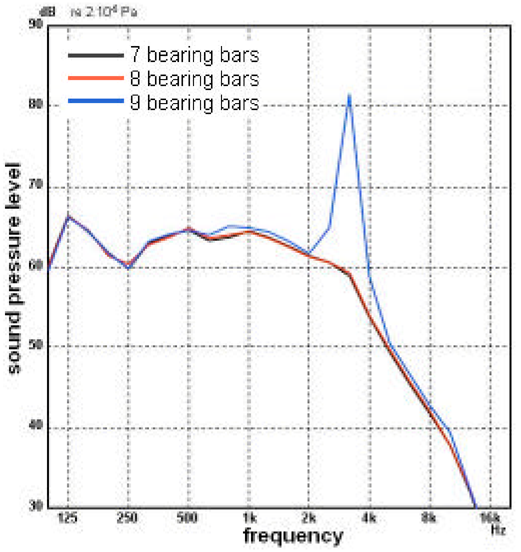


Figure 15: Dependency of number of bearing bars

6.5 Sound reducing provisions

Bearing bars with rounded edges

To determine the influence of rounding the edges of the bearing bars, tape was applied at the edges. Figure 16 shows a detail of the tape treated bearing bars. Only bearing bars with a height of 40 mm at a c.t.c. spacing of 30 mm are investigated. For comparison reasons the results with the untreated bearing bars are also shown.

Figure 16: Bearing bars with tape-rounded edges

It appeared that the treated bearing bars generate the loudest tone at a = 26° (see figure 17) at an air flow velocity of 27 m/s in the 3150 Hz third-octave band. Fourier transformation (FFT) analysis showed that the frequency in both configurations are exactly the same.

At other velocities and angles of attack no tones were observed.

Grating with sharp edges (untreated) **Grating with tape-rounded edges**

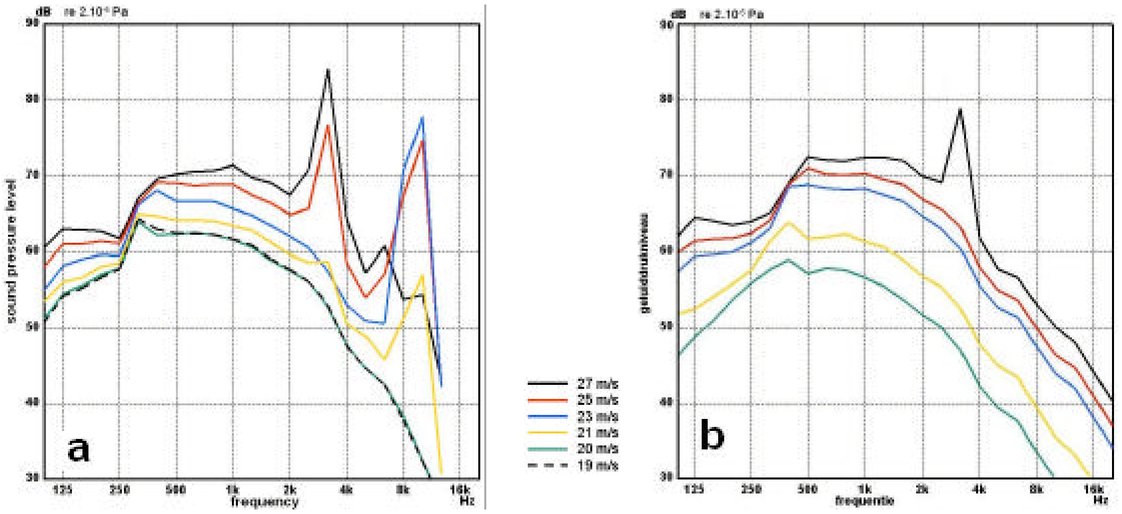


Figure 17a-b: Measurements on the test grating with a bar height of 40 mm with sharp edges (a) and with tape-rounded edges (b).

For the untreated configuration a tone in the 3150 Hz third-octave band was observed, approximately 5 dB louder (see figure 17a). To see whether the same frequencies were involved, for both configurations a FFT was made, see figure 18 (in both cases with an air flow velocity of 27 m/s).

Grating with sharp edges (untreated) **Grating with tape-rounded edges**

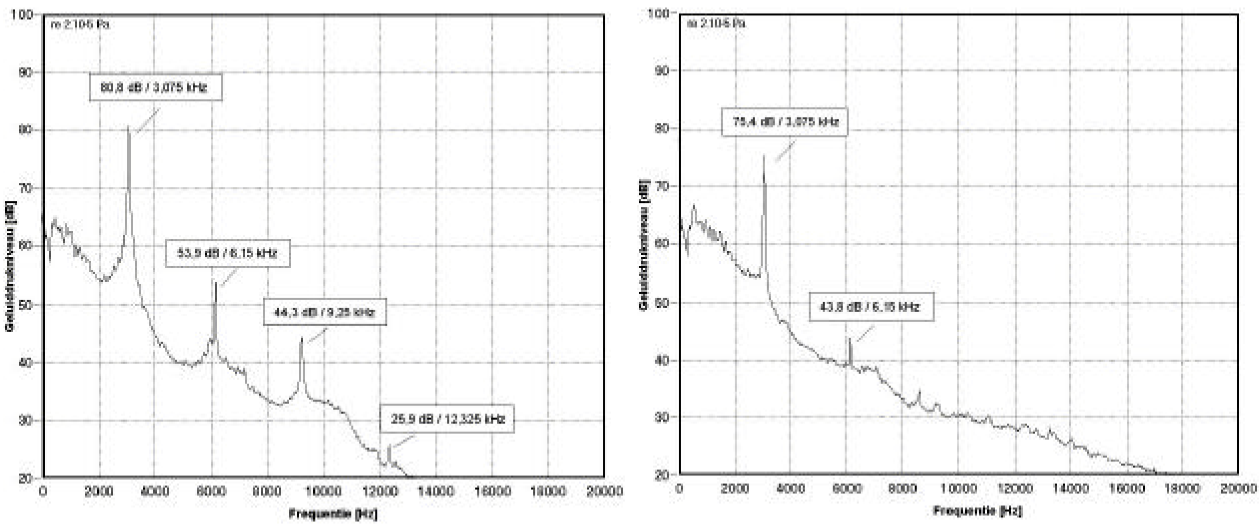


Figure 18a-b: FFT of measurements on the test grating with untreated sharp edges (a) and with tape-rounded edges (b); air flow velocity of 27 m/s.

Figure 18 shows that the frequencies remain the same in both configurations, but the sound level is decreased with approximately 5 dB in the treated situation. No observable tones below 25 m/s are generated in the treated situation.

Grating with net attachement

Measurements regarding a grating with a net attached (see figure 19) show that this provision sufficiently reduces aeolian tones (spectra to be compared with figure 3b).

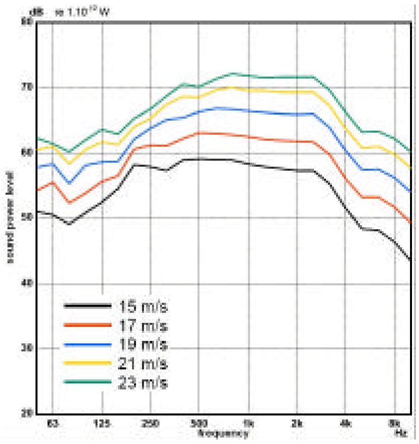


Figure 19: Grating 1 of high rise building 1 treated with a net attached to the under side (left) and the measurement results for different air flow velocities (right)

7 CONCLUSIONS

Aeolian tones at higher frequencies are generated at gratings with air flow velocities roughly between 10 to 27 m/s (comparable with 5 to 10 Beaufort). Within a certain range of air flow velocities no change of generated frequency occurs. Only the sound levels differ. At a certain air flow velocity this frequency jumps to another value, to remain constant again in a certain range of air flow velocities. In specific situations two frequencies are observed, however not simultaneously but alternating in time.

The repetitiveness of the bearing bars of the grating is very important in generating this specific type of aeolian tones. This seems responsible for the sound generation in the higher frequencies, since no aeolian tones are observed when only a small number of bearing bars are set in the air flow.

At which air flow velocity aeolian tones start to occur depends, amongst others, on the height of the bearing bars; no general valid relationship could be derived until now. With a height of the bearing bars of 30 mm the widest range of air flow velocities (11 to 27 m/s) has been observed at which aeolian tones were generated.

Also up till now no relationship has been derived between specific dimensions of the bearing bars (height, thickness) and spacing, and the generated frequencies. Further research is needed for that.

At all configurations no aeolian tones are observed form a c.t.c. distance between the bearing bars of 50 mm and higher. In those configurations only aeolian tones occur in the lower frequency range, of which the frequency is depending on the air flow velocity in conformity with formula 1.

Whether an aeolian tone occurs, depends on the angle of attack a of the air flow on the grating. Regarding the test grating it appeared that aeolian tones only occurred when a was roughly in the range of 20° to 40°.

Rounding the edges has led to a significant decrease of noise generation. This has been achieved either by adequate coating of the grating or by (provisionally) adding tape on the edges of the bearing bars. Another efficient provision to decrease the noise generation is wire netting fixed on the grating. These provisions appear to interfere sufficiently with the specific causes of the aeolian tones to prevent the origin of it. Further research is needed to determine the specific demands regarding the smoothness of edges of bearing bars, required to prevent aeolian tones of the kind described in this paper.

Also it is recommendable to investigate alternative types of gratings with less or different repetitiveness of bearing bars, of which some are already available on the market.

8 REFERENCES

[1] Hajime Fujita, Yasumasa Suzuki, Tatsunori Itou and Yuuki Hashimoto The Radiation Characteristics of the Aeolian Tone from A Square Cylinder, Internoise, Istanbul, Turkey, 2007