15th International Meeting
on
Low Frequency Noise and Vibration and its Control
Stratford upon Avon UK 22nd – 24th May 2012

Power to the People

Norm Broner SKM, 452 Flinders Street, Melbourne, 3000, Australia
Email: nbroner@globalskm.com

Summary

Peaking power plants are being developed around Australia to supplement electrical power demand and often are located quite close to either commercial or residential areas both in cities and in rural areas. Low Frequency Noise (LFN) from these plants need to be controlled in order to ensure that neighbours are not acoustically impacted. This paper will report on the experience of one plant where the LFN from the exhaust stacks of two OCGT's caused nausea and headaches in office workers in a building some 50 metres away from the exhaust stacks. It will also report on another site where a residence was over 1 km away and the residents were experiencing significant LFN annoyance. The solutions required and the implications will be described.

Introduction

Complaints about the effect of Low Frequency Noise (LFN) in the form of rumble, a "feeling of pressure" and resultant headaches and nausea have been known for decades (eg Broner 1976, Leventhall 2003). It can be said that the effects of LFN are broadly similar to those of high frequency noise in the sense that any unwanted sound is potentially annoying. However, LFN exhibits itself in the form of "rumble" and "pressure" and the sound level fluctuations can exacerbate the annoyance reaction when compared to higher frequency noise.

It is well known that gas turbines and boilers can produce LFN which can result in feelings of annoyance due to vibration induced rattle, nausea, headache and uneasiness. In Australia, there has been increasing reliance on the use of peaking power plants which utilise Open Cycle Gas Turbines (OCGT's) to supplement the daily power demand. Figure 1 shows a typical peaking plant. Without noise control, these plants are often a source of high level LFN which can result in complaints at neighbouring farms or residences if they are not carefully designed to achieve LFN attenuation. Generally, these plants are located away from residential areas, but even in rural areas where the background noise levels are generally low, there can be problems at the nearest houses or farms due to LFN. Indeed, some of these peaking plants are located near to industrial estates in rural towns and have the potential to cause LFN annoyance either at the nearest residential locations or at the nearest factories and office buildings. Figure 2 shows A-weighted noise levels predicted around a peaking plant and potentially impacting on a residential area as well as some commercial premises at the edge of a rural town. The question that then arises is how close to existing residential (or commercial) areas can these plants be placed without causing any adverse acoustical impact?

Figure 1 Typical peaking power plant

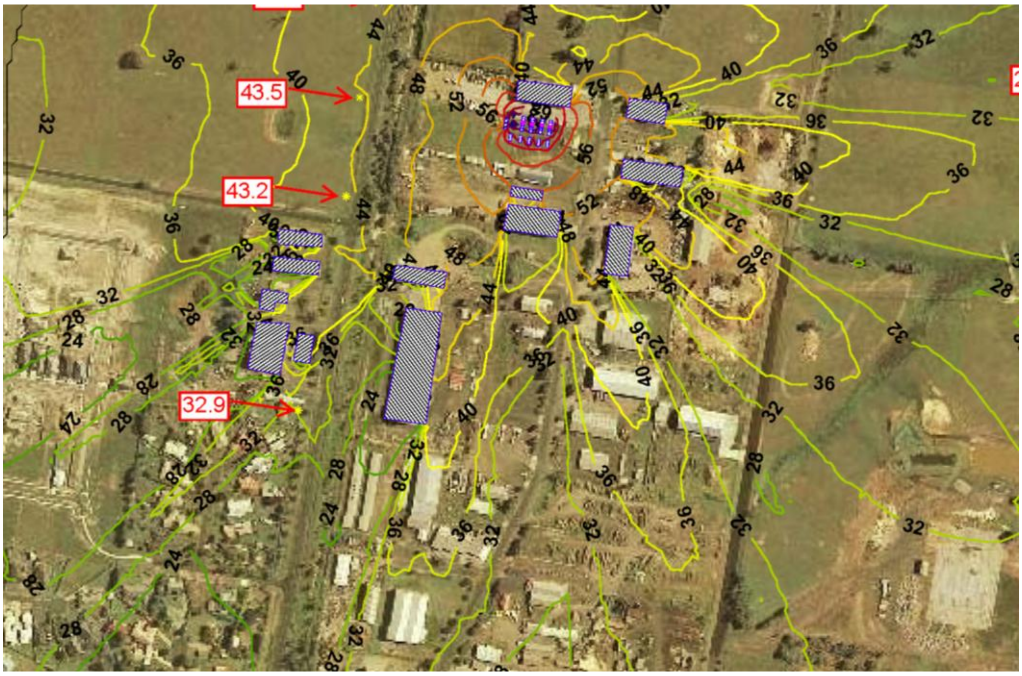

Figure 2 Power Plant Located Near an Industrial and Residential Area in a Rural Town

Low Frequency Noise Annoyance

Prediction and assessment of annoyance due to LFN is not simple. What is very clear and well known is that the A-weighted SPL alone is not successful in assessing the response to LFN. Indeed, it is known and recognised that the primary effect due to LFN appears to be annoyance which is much greater than would be expected based on the A-weighted level alone, eg. Berglund et al. 1996, Broner 1976, 1978, 1980, Broner and Leventhall 1983, Bryan 1976.

A review of case histories indicates that very annoying sounds often have rather low A-weighted SPLs but nevertheless cause significant annoyance. This is due to the presence of an unbalanced spectrum (as would normally be experienced indoors due to an external noise source and due to the high frequency acoustic filtering of the house façade), and additionally may have an amplitude and/or temporal fluctuating characteristic.

For sounds with "tonal" low frequency content below 50 Hz and for infrasound (< 20 Hz), particularly where the sound level is perceptibly fluctuating or throbbing, annoyance and loudness are treated differently in terms of perception and that this perception difference may increase with time (Hellman and Broner, 2004). As the loudness adapts more rapidly with time than the annoyance (i.e. the perceived loudness decreases more rapidly with time than the perceived annoyance), the effect is to effectively increase the annoyance with time. This effect would be worse for infrasound where the sound is not so much heard but is rather perceived as a feeling and sensation of pressure.

The perception of annoyance is particularly dependent on the degree of amplitude modulation and spectral balance eg Bradley (1994) and Bengtsson et al (2002). As a result, it is considered that there is a significant limitation in the long term averaging of LFN noise levels, as this approach results in the loss of information on fluctuations e.g. Broner and Leventhall, (1983) and Blazier and Ebbing, (1992).

Empirical evidence shows that where the imbalance is such that the difference between the Linear and A-weighted SPL is at least 25 dB, the sound is likely to cause annoyance. Broner and Leventhall (1983) and DIN 45680-1997 suggested that a difference of 20 dB can result in an unbalanced spectrum which could lead to LFN annoyance. Others suggested that a difference of only 15 dB was a good rule of thumb to identify a potential infrasound LFN problem situation e.g. Kjellberg et al (1997). In Australia, the New South Wales Industrial Noise Policy recommends that a +5 dB modifying factor be added to the outdoor measured/predicted noise when the (C - A) difference is 15 dB or greater. This latter approach is currently being reviewed as it has resulted in limiting power station developments where residential areas are some kilometres away and where due to distance alone, the (C-A) for difference exceeds 15 dB. The New South Wales Department of Planning therefore adopted the Broner (2010) overall C-weighted criteria to determine the acceptability of new power station developments. The (C – A) level difference is an appropriate metric for indicating a potential LFN problem but that its predictive ability is of limited value (See also Leventhall 2003).

Case History – An Upset Administration Office

A peaking plant consisting of two OCGTs had been built in an industrial area and started commissioning tests. Immediately, workers in the administration area of a plant across the road started complaining that the noise was causing them nausea and headaches and increased absenteeism was occurring. The owners of the adjacent plant, with the office area located only some 50 metres from the two open cycle 150 MW gas turbine plant exhaust stacks, complained to the plant owners.

Figure 3 shows a view from the Board Room of the administration office block towards the exhaust stacks while Figure 4 shows the noise spectra measured in two internal rooms (the Board Room and an office) in this block. The hearing threshold curves from the ISO and ANSI and DIN Standards are shown for comparison and it can be seen that most of the low frequency energy could be quite audible. During a noise survey, it was noted that the external windows (seen in Figure 3) were visibly shaking and some rattling of wall panels was also occurring.

Figure 3 View From Board Room to the Exhaust Stacks 50 metres Away.

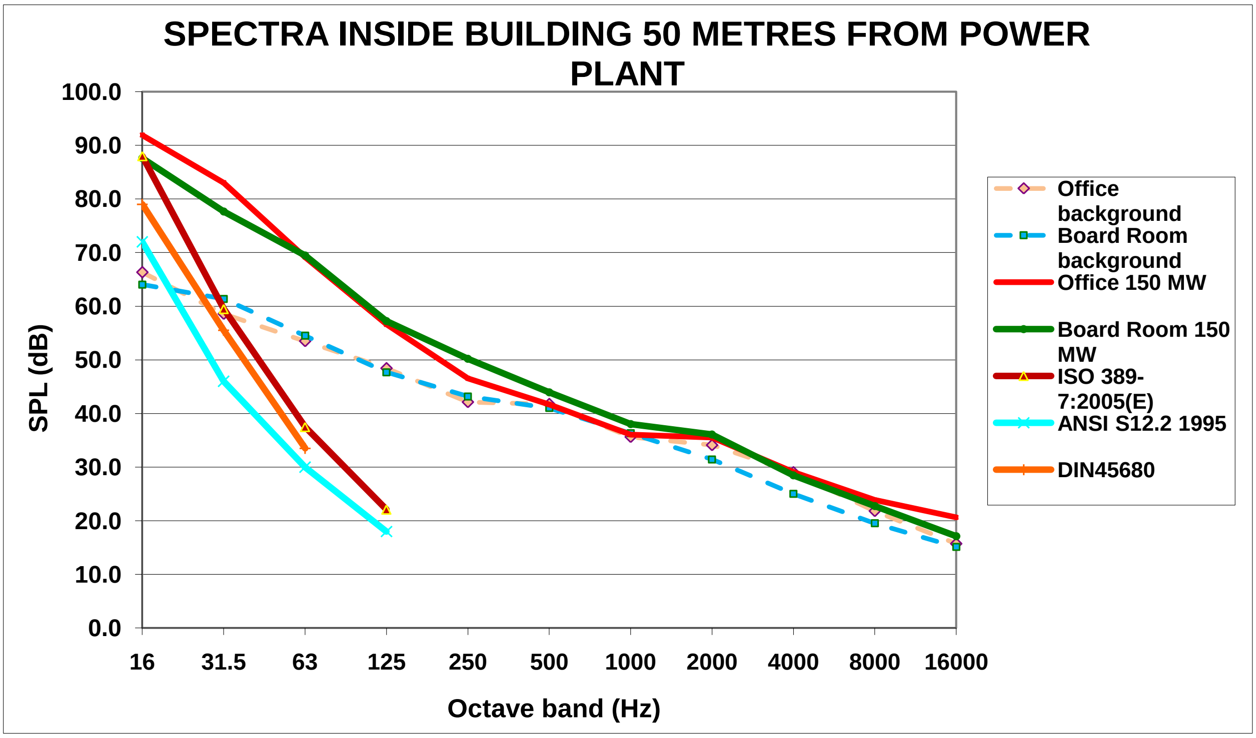

Figure 4 $L_{Aeq,1sec}$ Noise Spectra Measured in a Board Room and Office While the Gas Turbines Were Operating and When They Were Shut Down

The A-weighted SPL in the Board Room and Office area was 48 dBA and 46 dBA respectively while the C-weighted SPL was 84 dBC and 82 dBC respectively. It can be seen from the comparison of background noise level versus the operational noise level that there was a significant increase in low frequency energy when the plant was running. Various acoustic testing was conducted at the power plant and in the office area and it was determined that the stack exhaust noise was the main source of the LFN annoyance..

The peaking plant owners investigated various methods of reducing the stack exhaust noise level using computer modelling such as CFD modelling (Hetzel and Putnam, 2009). The end solution was based on the design of a perforated plate between the gas turbine diffuser and elbow to provide a more uniform flow distribution and to create a spin breaker behind the perforated plate to reduce the swirl in the flow. Further, guide vanes were to be added inside the elbow to enhance uniformity of the exhaust gas flow in the upper stack and to remove the sharp corner and abrupt area changes.

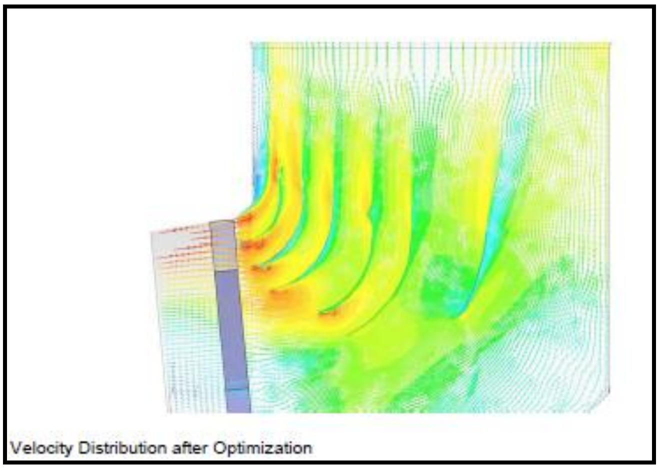

Figure 5 CFD Modelling of Measures to Enhance the Flow in the Exhaust Stack

While the end "fix" was being engineered a quick temporary fix was initiated. It was decided to stack a series of shipping containers three rows high in close proximity to the front of the building to act as a noise barrier to the offices behind. Figure 6 shows the barriers being placed along the front facade of the building which faced the exhaust stacks located on the other side of the road.

Figure 6 Shipping Containers Being Placed to Control LFN

Unfortunately, this approach was not very successful due to the containers being energised themselves and due to flanking of the LFN via the light weight roof of the building.

The exhaust fix was finally implemented at a cost of some $20 million and a reasonable LFN was achieved.

Case History – An Upset Residential Neighbour

A peaking power plant had been built in a rural area with the nearest farm residencelocated approximately 1.2 Km away. Two 150 MW open cycle gas turbines were to operate to provide power when demand required. On commissioning of the plant, the residents at the nearest house began to complain about the LFN from the plant. Figure 7 shows the $L_{Aeq,5min}$ noise spectra measured outside the residence at four separate times when the complainants stated that the LFN was "very bad". The A-weighted SPL was of the order of 40 dBA while the C-weighted SPL varied between 60 – 73 dBC. The hearing threshold curves from the ISO and ANSI and DIN Standards are also shown for comparison and it can be seen that most of the low frequency energy could be quite audible. Note that the characteristic fluctuations in SPL at low frequencies are not well represented in these spectra as the measurement was conducted in terms of the $L_{Aeq,5min}$ metric which would have averaged the fluctuations. To fully appreciate the potential LFN problem at this location, the noise level metric chosen by the consultant should have been the $L_{Aeq,1sec}$.

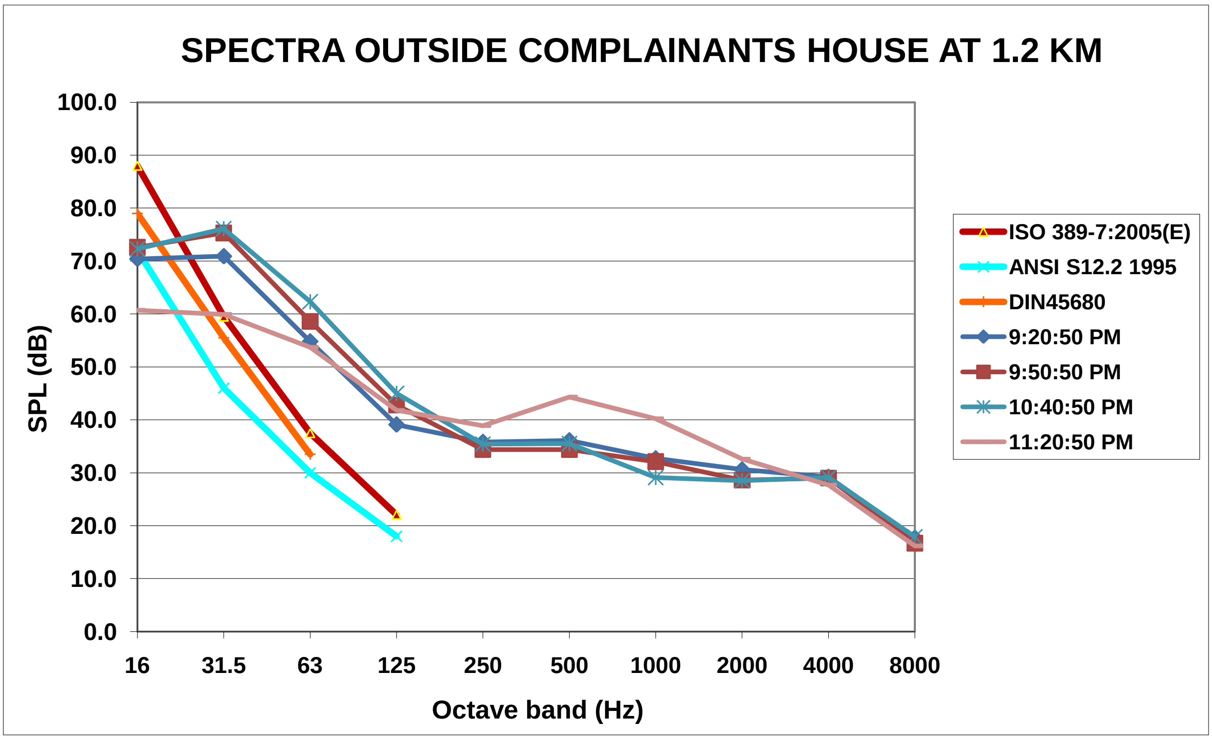

Figure 7 $L_{Aeq,5min}$ Noise Spectra Measured Outside the Nearest Residence 1.2 km Away

This plant is in the process of rectifying this problem.

Discussion

It seems clear based on the above case histories and others that most cases of LFN annoyance occur when an unbalanced spectrum occurs with a decreasing Sound Pressure Level as the frequency increases. LFN generally needs to be above the threshold for annoyance to occur but there is a very small percentage of the population that may be more sensitive to LFN than most i.e. they have relatively low LFN thresholds and thus reduced tolerance to LFN.

Ideally, LFN criteria should be set for indoors where the LFN complaints normally occur. However, in planning terms, it is much easier to set criteria for the outside of residences where artefacts of the measurement do not play such a big role and where there is no need to enter a person's premises after start-up to confirm compliance with an outdoors noise level specification. Similarly, an overall noise level criterion may be preferred to one relying on an octave band or third-octave band analysis and calculation. As a result of these considerations and based on empirical case history data (site noise level and annoyance/complaint data), Broner (2010) set the following criteria for assessment of LFN.

TABLE 1 CRITERIA FOR ASSESSMENT OF LFN

<table>
<tr><th colspan="2">Sensitive Receiver</th><th>Range</th><th>Criteria L_{eq} (dBC)</th></tr>
<tr><td rowspan="4">Residential</td><td rowspan="2">Night time or plant operation 24/7</td><td>Desirable</td><td>60</td></tr>
<tr><td>Maximum</td><td>65</td></tr>
<tr><td rowspan="2">Daytime or Intermittent (1 – 2 hours)</td><td>Desirable</td><td>65</td></tr>
<tr><td>Maximum</td><td>70</td></tr>
<tr><td rowspan="4">Commercial/ Office/ Industrial</td><td rowspan="2">Night time or plant operation 24/7</td><td>Desirable</td><td>70</td></tr>
<tr><td>Maximum</td><td>75</td></tr>
<tr><td rowspan="2">Daytime or Intermittent (1 – 2 hours)</td><td>Desirable</td><td>75</td></tr>
<tr><td>Maximum</td><td>80</td></tr>
</table>

On the other hand, it is possible to have two spectra with the same overall SPL but with a different spectral makeup resulting in a different perception for the two cases. So the 'jury' is still out as to the best way to characterise and assess LFN problems. One thing is clear. It is very important to ensure that any noise character involving level/spectral fluctuations and any amplitude modulation is captured and assessed.

Where Should Power Plants Be Located?

It seems that in order to prevent low frequency noise complaints due to OCGT's, it is necessary to consider all acoustic energy down to at least the 16 Hz octave band noise level and to also limit the noise levels outside the nearest residences to the order of 60 – 65 dBC maximum and outside commercial/industrial premises to the order of 70 - 75 dBC maximum.

What does this mean in terms of the siting of power plants "near" to residential areas or other noise sensitive receivers?

Unfortunately, there are many variables that need to be considered when wanting to recommend a minimum distance away for the nearest residence. These include:-

- The power generation equipment itself
- Its size and the number of units
- The package configuration

- Most importantly, the level of “standard” noise attenuation provided by the manufacturers. Most “standard” packages may reduce some low frequency noise but would not be aimed at achieving a significant noise reduction at 31.5 Hz and certainly not at 16 Hz, due to cost and size requirements.
- The local meteorological effects – e.g., temperature inversions may be a common occurrence in an area and can significantly increase the sound pressure level from the plant at the residence(s).
- Which way the wind blows and for how long and at what speed?
- The background noise level in the area of the residence(s) – the background noise might help to mask noise from the plant.

As a rule of thumb based on case histories and Sound Power Level considerations, in practice, we would recommend that for OCGT plants with a total Sound Power Level in the range 115 – 120 dBA, the minimum distance to the nearest residential premises should be no closer than the order of 1,500 – 2,000 metres away.
For commercial/office buildings, the power plant should not be located any closer than 350 – 500 metres.

Conclusion

With increased use of Open Cycle Gas Turbine power plants to provide electrical power when demand peaks, there is a need to consider low frequency acoustic energy not only down to the 31.5 Hz octave band but also to include energy in the 16 Hz octave band. People are much more aware of noise in general and are much more ready to complain if their work or living environment is affected by noise, especially by LFN. To prevent low frequency noise complaints, the noise level outside the nearest residences should be limited to the order of 60 – 65 dBC maximum. In practice, this means that OCGT power plants with a Sound Power Level of the order of 115 – 120 dBA should be sited so that they are at least of the order of 1,500 – 2,000 metres away from the nearest residential premises. For commercial/office buildings, the power plant should not be located any closer than 350 – 500 metres.

References

J. Bengtsson, K. Persson-Waye and A. Kjellberg, (2002) “Sound characteristics in low frequency noise and their relevance for performance effects” Proc. Inter-Noise 2002, Dearborn, USA, 19-21 August 2002
B. Berglund, P. Hassmen and R.F.S. Job, “Sources and effects of low frequency noise”, J. Acoust. Soc. Am. 99, 2985-3002 (1996)
W.E. Blazier and C.E. Ebbing, (1992) “Criteria for low frequency HVAC system noise control in buildings”, Proc. Inter-Noise 92, Toronto, Canada, 20-22 July 1992, pp. 761-766
J.S. Bradley, “Annoyance caused by constant amplitude and amplitude modulated sounds containing rumble” Noise Con. Eng. J. 42, 203-208 (1994)
N. Broner, “The effects of low frequency noise on people – a review”, J. Sound Vib. 58, 483-500 (1978)

N. Broner, “A criterion for Predicting The Annoyance Due to Higher level low Frequency Noise” J. Sound Vib. 84(3), 443-448 (1982)
N. Broner: A Criterion for Low Frequency Noise Annoyance. 10th ICA Sydney 1980, Paper C1-4.4 Sydney, Australia, 9-16 July 1980
N. Broner, H.G. Leventhall: Low Frequency Noise Annoyance Assessment by Low Frequency Noise Rating (LFNR) Curves. Journal of Low Frequency Noise and Vibration 2(1) 20-28, 1983
N. Broner: A Simple Criterion for Low Frequency Noise Emission Assessment, J LFN& V, 29 (1), 1 – 14, 2010
M.E. Bryan: Low Frequency Noise Annoyance in Infrasound and Low Frequency Vibration edited by W. Tempest, Academic Press, London 65 – 96, 1976
DIN 45680:1997, Measurement and evaluation of low frequency environmental noise, Foreign Standard, 1997
M.E. Hale, “Controlling power plant noise with a stringent C-weighted noise limit”, Proc. Inter-Noise 2009, Ottawa, Canada, 23-26 August, 2009
R.P. Hellman, and N. Broner, “Relation between loudness and annoyance over time: implications for assessing the perceived magnitude of low-frequency noise”, Proc. 147th Meeting Acoust. Soc. Am. (75th Anniversary Meeting), New York, 24-28 May 2004.
D.M. Hessler and G.F. Hessler, “Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States”, Noise Con. Eng. J., 59(1), 94-104, 2011
R. Hetzel and R. A. Putnam “Sources and Rating Criteria of Low Frequency Gas Turbine Exhaust Noise – Via Case Study” InterNoise 2009, August
A. Kjellberg, M. Tesarz, K. Holmberg and U. Landstrom, “Evaluation of frequency-weighted sound level measurements for prediction of low frequency noise annoyance” Env. Intl. 23, 519-527, 1997
H.G. Leventhall and K. Kyriakides, “Environmental infrasound: its occurrence and measurement” in Infrasound and Low Frequency Vibration (W. Tempest, editor), Academic Press, London, pp. 1-18, 1976
H.G. Leventhall, A review of published research on low frequency noise and its effects, Dept. Environment, Food and Rural Affairs (DEFRA), UK, Research Project Report (2003)
ISO7029:2003 Acoustics – Statistical distribution of hearing thresholds as a function of age
C. Roberts, “A guideline for the assessment of low-frequency noise” *Acoust. Bulletin*, 33, 31-36, Sep. Oct. 2008
New South Wales Industrial Noise Policy. Environmental Policy Branch, NSW Environment Protection Authority January 2000