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Directivity of Sound from a Metal-Clad Factory Roof

Athol Day (1), Peter Eisenhuth (2)

(1) Day Design Pty Ltd, Peakhurst, NSW
(2) Benbow Environmental, Parramatta, NSW

Abstract

This paper discusses the directional properties of sound emitted from a large inclined metal-clad roof surface.

An opportunity was recently presented to measure the sound emission from a particularly large ribbed galvanised steel roof deck with a very loud broadband noise below from many noise sources. In 37 years of practice, the author has not been presented with a better opportunity to quantify the directivity of sound from a flat roof surface.

Measurements were taken at 0.5 metres above the roof and at distances of 10, 50 and 150 metres from the lower edge of the roof. The sound power level of the roof was established from the close proximity measurements and simple surface area calculations. The level of noise emission from the roof was calculated at three noise measurement locations to determine the horizontal "directivity" of the roof noise emission.

Its directivity was found to be related to the energy vector in the direction of sound propagation.

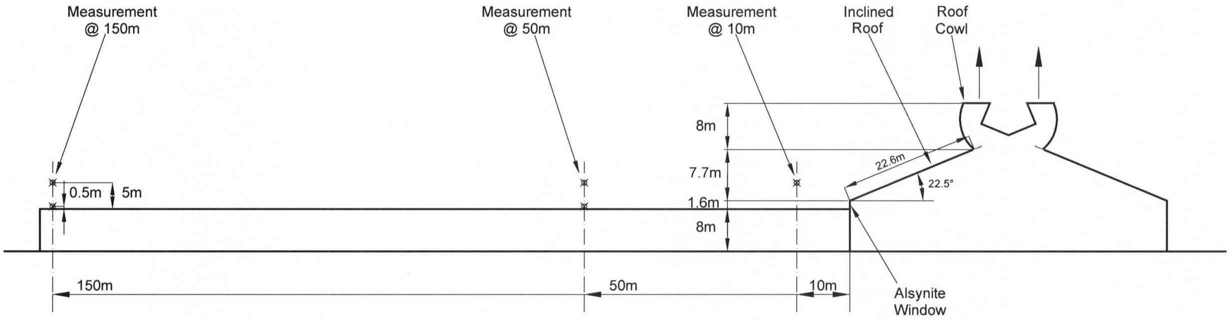

Figure 1 Location of Sound Measurement Positions

ROOF NOISE SOURCE MEASUREMENTS

This Kliplock galvanised sheet steel factory roof was very large, one side measuring 23 metres wide by 140 metres long and sloping up at an angle of 22.5 degrees, with just one vertical discharge opening along the ridge. Beneath the roof eave was a vertical highlight Alsynite translucent window 1.8 metres high by the full 140 metre length of the roof. A very large flat roofed factory extended a horizontal distance of 150 metres from the foot of the window as shown in the above Figure 1.

The sloped roof, which was the main source of noise, was high above ground level and safety harnesses were used by the authors while conducting roof noise measurements.

The Leq (1 min) space-averaged, steady, broadband noise level inside the factory was in excess of 90 dBA. The sound pressure level above the roof was in the order of 76 dBA (within one decibel from one end to the other), and there was an Alsynite window at the lower edge that emitted noise at 78 dBA. The sound pressure level of noise from a vertical discharge roof vent cowling at the top edge of the inclined roof was 71 dBA at 0.5 metre.

The ambient noise at 0.5 metres above the lower horizontal roof varied from 61 to 63 dBA. The contribution from the horizontal roof was estimated to be approximately 60 dBA.

SOUND POWER LEVELS OF ROOF NOISE SOURCES

Sound power levels were calculated from the close proximity sound measurements by log averaging multiple readings of each source element and adding 10 x log A, where A was the area of the sound radiating surface. The following results were obtained:

Inclined Roof	L_w = 111 dBA (Q = 2)
Vertical Disch. Ridge Vent	L_w = 106 dBA (directional)
Vertical Alsynite Windows	L_w = 101 dBA (Q=4)
Roof Vent Cowling	L_w = 101 dBA (Q=4)

Q = 2 indicates that the sound source radiates in a hemispherical manner and Q = 4 indicates that the sound source radiates in a quarter-spherical manner.

Predicted Noise Levels

The inclined roof, the vent cowling and the Alsynite window being much longer than wide, were each considered as line sources in calculating noise emission at the three receptor locations.

The distances from the three noise receptor locations to the Alsynite window and the Vent Cowling were measured on site. However, the distance to the acoustic centre of the inclined roof had to be calculated. The leading edge of the roof was 10, 50 and 150 metres from the three receptor locations. The far side was 22.6 metres further away. The distance to the acoustic centre of the roof was calculated by considering 12 slices of roof, each 140 metres long, calculating the noise contribution from each at the receptor locations using formula 7.10 from Beranek (1988).

Predicted sound levels based on measured sound power levels and calculated distance losses were 4.2 dBA less than those measured at 10 metres from the roof.

The vector quantity of sound power from the sloping roof

$$= 10 \log (\cos \theta)$$

where θ is the change of direction towards the receptor locations of noise emitted normal to the roof. For a 22.5 degree pitch roof, θ = 67.5 and the directivity loss = 4.2 dB.

Bies & Hansen 1996 suggests that the directivity of noise from an incoherent plane radiator such as the roof or wall of a factory may be determined using a Cosine weighting factor. Our measurements support this recommendation.

Noise levels at the three measurement locations were calculated, as listed in Table 1 below, using a 4.2 dB roof directivity factor at all frequencies.

Receptor Noise Measurements

The adjacent large flat factory roof with low levels of noise emission offered a suitable location for receptor noise level measurements. It was close enough to the roof noise source that ambient noise was more than 10 dBA below roof noise emission at the 10 metre location. However, there was a significant level of noise from the flat roof, so sound measurements were made at heights of both 0.5 and 5 metres above the flat roof.

Receptor sound measurements, Leq (1 minute), were made at horizontal distances of 10, 50 and 150 metres from the edge of the main inclined factory roof. These measurements were made along the centre line of the building at 90 degrees to the edge of the roof. Measured and predicted noise levels at the three distances and at a height of 5 metres above the horizontal roof were as follows in Table 1 assuming a roof directivity loss of 4.2 dB applied across the sound spectrum.

Table 1. Comparison between Predicted and Measured Leq Sound Pressure Levels

Distance from Edge of Roof to Meas't Location	Predicted L_{eq} dBA	Measured L_{eq} dBA	Difference dB
10 m	71.1	71.1	0
50 m	65.2	66.3	1.1
150 m	58.7	61.1	2.4

Analysis of Measurement Results

The measured noise level at 5 metres above the flat roof and 10 metres from the sloping roof was predicted exactly. Both equalled 71.1 dBA.

The measured levels at the receptor locations 50 and 150 metres were 1.2 and 2.4 dBA (respectively) higher than those predicted. These variations were caused by noise contributions from the flat roof below. Noise measurements at 0.5 metres above the flat roof were two to three decibels higher than measurements at a height of 5 metres above the roof, and they were within 5 dBA of the measured noise emission levels. As the distance from the sloping roof increased, the effect of ambient noise levels increased, thus the difference between measured and computed sound pressure levels increased, as would be expected.

Instinctively we may expect the high frequencies to be more directive than the low frequencies (as with noise from the open end of a duct), but the octave band measurements and predictions listed in Table 2 indicate that the 4.2 dB Directivity Index may be applied equally across the sound spectrum, as we did in this case.

Table 2. Comparison between Measured and Predicted Octave Band Sound Pressure Levels - dB.

Frequency Hz	63	125	250	500	1k	2k	4k	8k
Predicted	71.7	70.2	70.8	68.3	66.4	62.4	58.5	53.4
Measured	74.3	71.7	71.7	68.6	65.3	62.1	59.6	55.3
Difference	2.6	1.5	0.9	0.3	-1.1	-0.3	1.1	1.9

The above measured octave band levels are listed to the first decimal point because they were the log mean of nine sets of readings in a horizontal line at ten metres from the edge of the roof, equally spaced along the 140 metre long roof. The totals of the nine sets of readings ranged from 69.0 dBA to 72.1 dBA.

CONCLUSION

These measurements demonstrate (within experimental accuracy) that the roof of a factory is directive, but not directive in the way that is found with sound from the open end of a duct.

These tests indicate that for a non-coherent noise source, such as a factory roof, at a directivity angle of 67.5 degrees, the directivity loss follows the Cosine weighting formula as suggested by Bies and Hansen and is the same at all frequencies.

REFERENCES

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