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THE PREDICTION OF NOISE RADIATION FROM INDUSTRIAL BUILDINGS CONSTRUCTED FROM LIGHTWEIGHT CLADDING

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1.INTRODUCTION

Modern industrial buildings are commonly constructed by mounting lightweight metal cladding panels to a steel frame. This may be relatively cheap and simple but can result in poor sound insulation causing environmental noise problems in surrounding residential areas.

A large amount of work has been carried out in the area of outdoor sound propagation : this involves predicting the effects of wind and temperature gradients, turbulence, diffraction and a description the ground effect. However, most of this work has concerned itself with ideal noise sources such as a single point source. To accurately model the propagation of noise from a factory, for example, one must know the nature of each real source; such as a wall, which may be described in terms of its size, sound power and directivity. The directivity may be defined as the sound pressure level at a certain angle of incidence from the noise source, divided by the level expected at the same angle if the source is omnidirectional and of the same sound power.

This paper considers several theoretical models which have been applied to the above problem and compares them with simple directivity measurements on a proportionally shaped building constructed with one type of single-skinned cladding. Discrepancies between theory and measurements are discussed and form the basis of recommendations for further work.

2.EXISTING MODELS

A wall constructed from cladding panels can be thought of as a rectangular noise source. Maekawa (1) predicted the noise reduction due to distance and directivity of such a source by considering it to be composed of an infinite number of elemental point sources radiating in random phase. The overall directivity of the source could be obtained from attributing a particular directivity to each surface element. This method would be useful in computing the propagation of noise from a rectangular source as the ground effect and various other atmospheric phenomena could be applied to each point source in turn. The level at any receiver position could then be found by adding the contributions energetically. However, each element of a wall does not have phase characteristics independent of other elements; i.e. there are waves travelling in the panels and standing wave patterns/ vibrational modes may occur. One must therefore describe the vibration of the entire wall in some way.

One way of achieving this is to think of the wall as a homogeneous plate (2). It is then possible to write Newton's second law for the wall as :

$$D.\nabla^4 w(x,y,t) + \rho h.\delta^2 w(x,y,t)/\delta t^2 = f(x,y,t) \qquad [1]$$

where $w(x,y,t)$ is the displacement function of the plate described in the xy-plane, $f(x,y,t)$ is the pressure differential across the plate, ρ and h are the density and thickness of the plate and D is the bending stiffness which may be found from Young's modulus (E) and Poisson's ratio (σ) by $D=Eh^3/12(1-\sigma^2)$. It should be noted that D may be replaced by a complex quantity by introducing flexural rigidity D^* in order to account for the loss factor of internal damping (μ), where $D^*=D(1+j\mu)$. This equation can be solved to predict radiation from a homogeneous plate and to define the parameters needed for a scale model investigation. It can be shown that (2,3) the loss factor and boundary conditions applied to the plate have little effect on the radiation patterns observed, such that a cladding panel may be scale-modelled by a homogeneous plate clamped in any way at its edges. Apart from the frequency of the excitation sound field and size of a plate, one need only scale-up the plate's critical frequency.

A model plate may then be clamped over a small reverberant chamber and the directivity is measured in a plane perpendicular to its surface. Results from such measurements (3,4) show that large lobes (of magnitude 20dB. or more) occur close to and above the critical frequency of the plate (figure 1). These lobes are due to the well-known effect of wave coincidence and are observed fairly close to the matching angle for a particular frequency, given by :

$$\theta_m = \sin^{-1}\sqrt{(f_c/f)} \qquad [2]$$

where f_c is the critical frequency of the plate and f is the frequency at which the model wall is excited. In general, the lobes tend towards the normal of the plate (i.e. $\theta_m \to 0°$.) and increase slightly in magnitude as the excitation frequency increases above the critical frequency. However, equation [2] was found by this author (4) to consistently overestimate the matching angle θ_m. This is because equation [2] is derived from a consideration of an infinite plate; as opposed to the finite model wall. It was noted that the error decreased with increasing frequency as θ_m tended to 90°. such that the matching angle could be described empirically (to within ±5°.) by :

$$\theta_m=\sin^{-1}\sqrt{(f_c/1.5f)} \qquad [3]$$

It was further noted (4) that the lobes increased in angular width as the bandwidth of the excitation sound field increased, although there was no noticeable depreciation in lobe magnitude up to the 1/1 octave bandwidth. However, one would expect this magnitude to decrease as the bandwidth increased further because measurements on plates excited by broadband noise showed the radiation pattern to be roughly elliptical such that the level in the plane of the plate is up to 10dB. greater than that on the normal. This agrees well with the observations of Gösele and Lutz (5) (figure 2) who concluded that most building materials "radiate more sound parallel to a facade than perpendicular to it". Lobes were also observed below the critical frequency (4). An explanation for this may be that the critical frequency is dependant on the fixing of the plate. It may then be advisable to measure this quantity *in situ*.

Unfortunately, the scale modelling method is compromised by several factors. For example, the excitation sound field is rarely diffuse. Model measurements (4) showed that changing the nature of the excitation sound field only decreased the lobe magnitude very slightly and lobes could be observed as long as there were a relatively small amount of reflecting surfaces present within the building/model chamber to ensure that a proportion of the noise was incident at the matching angle. Another problem is that typical cladding panels are profiled and thereby orthotropic. This results in two effective critical frequencies in different dimensions of the panel due to different bending stiffnesses (i.e. perpendicular and parallel to the corrugations). It is known (6) that the critical frequency may be typically reduced by a factor of 100 such that f_c may only be of the order 10^2 Hz. perpendicular to the profiling (in the xy-plane). One may conclude that this makes the possibility of the lobes being observed *in situ* much greater. However, a wall is constructed by fixing many strips of cladding material together. The connection between panels may not be such that the wall can be thought of as a single plate. One may then observe some energy-proportion of a travelling bending wave being reflected at a boundary between strips, whilst the rest is transmitted into the next strip or dissipated. In this case, it may be necessary to consider longitudinal, stretch and shear waves in the material as well as bending waves whereas for single, homogeneous plates Joung (6) showed that the radiation pattern was mainly determined by bending waves.

It can be seen that there is a large amount of uncertainty in the prediction of the directivity of single-skin cladding constructions. It was therefore thought necessary to make on-site measurements of this before any further progress in theory was attempted.

3.MEASUREMENTS OF IN-SITU PANELS

Measurements were undertaken on a simple, proportionately shaped building which was situated in a large, flat field (figure 3). The building was wholly constructed from 5mm. thick, single-skinned steel cladding panels (Ayrshire metals, Topsheet 35/1000) in 1m. wide strips. These were bolted together at 47cm. vertical intervals such that the long (designated "front") wall was fabricated with 24 strips. A 24" high-power loudspeaker was used as the noise source in the building and provided at least 100dB.S.P.L. at 1m. in each 1/1 octave band from 31.5Hz. to 2KHz. Sound pressure level measurements in two planes parallel to the front wall indicated that the sound field within the building was relatively diffuse. There were no other noise sources in the vicinity. The directivity was found by measuring S.P.L. in 1/3 octave and 1/1 octave bands on quarter circles of radii 20m. and 30m. about the centre of the front wall and deducting the S.P.L. measured simultaneously inside the building. It would have been preferable to measure on a larger radius as, at greater angles away from the wall's normal, the measurement position is effectively closer to the building. However, measurements were limited by wind noise. Further measurements were therefore taken on a line parallel to the wall in order to confirm the circular results.

It can be seen from the results (figures 4, 5 and 6) that the radiation from the building is close to omnidirectional in each 1/1 octave band. Lobes due to wave coincidence are not in any way apparent. In general, the S.P.L. varies by no more than ±3dB. and, in most cases, tends to increase towards larger angles which agrees with the findings of Gösele and Lutz (5) (figure 2). This could be expected because, at a certain angle, the receiver is in direct line of sight with both the front and end walls (neglecting the roof) such that sound travels to it in two unobstructed paths. This will not be the case at smaller angles (i.e. close to the normal of the front wall) as the noise contribution from the end wall is that diffracted around the corner of the building. The measurements on a line parallel to the front wall confirm this. The difference in level between frequency bands is due to the transmission loss of the steel cladding. Results inspected in 1/3 octave bands are much the same although the S.P.L. tends to vary about the average more; by ±5dB. at most.

4. DISCUSSION

It is shown that a wall constructed from cladding panels does not radiate in the manner of a single plate. As mentioned above, this may be caused by the fact that the wall measured was fabricated by bolting together many strips of cladding. The effects of the fixing may be to isolate, or semi-isolate, the panels from one another. In this case, one must model the radiation from each strip in some way. It may be the case that each panel does radiate as described by the scale model method above, such that the resulting radiation from many consecutively placed sources produces a broadly omnidirectional directivity for the entire wall. Therefore, further work will be concerned with the vibrational characteristics of such walls especially in relation to the way in which its constituent parts are linked. The measurements described will also be repeated around the whole of the above-mentioned building, and on other industrial constructions, using signal processing techniques (e.g. pseudo-random noise / M.L.S.) in order to increase the signal-to-noise ratio to enable measurement at large distances.

Present methods of predicting noise from industrial premises, e.g. (7), exclusively describe the real noise source by means of single, or arrays of, point sources. Hence, it was decided to construct a simple model of the above building by replacing each radiating surface with a point source at its centre. Diffraction around the building's edges was described by the well-known theory for a simple, thin barrier. The results (figure 7) are seen to provide a suitable description of the directivity around the whole building. From figure 7 it is easy to discern the point at which the receiver position comes into direct line of sight of the end wall by the rise in S.P.L at 24°. It should be noted that this will occur at smaller angles (<27°) as the radius of the measurement circle is increased, such that at a large distance the directivity will seem closer to omnidirectional.

If one was to use point sources for each surface and then apply models for outdoor sound propagation (the ground effect for example) to this, results would be misleading. This can be explained by imagining sound travelling in rays : by taking the wall's size into account it can be seen that sound will reach the receiver over different lengths of ground and at different angles of incidence to the ground. This may tend to "average out" the severity of large dips and peaks often observed in the frequency characteristics of propagation over finite-impedance ground. Hence, it is important to be able to describe accurately the radiation of noise over the entire surface of the building. It should then be possible to use ray-tracing techniques to accurately describe the attenuation in each ray path and to add these energy-contributions together to calculate the overall sound pressure level at any receiver position.

5. CONCLUSION

Present methods of describing the radiation of noise from buildings constructed with composite cladding-panel walls (i.e. using a point source in place of each radiating surface) are adequate as measurements have shown the directivity to be roughly omnidirectional. The whole wall does not therefore act as a finite, homogeneous plate which displays coincidence effects above the critical frequency. However, errors will occur if descriptions of outdoor sound propagation, such as the ground effect, are applied to a simple point source treatment as, in this case, the wall cannot be treated as infinitely small.

6. REFERENCES

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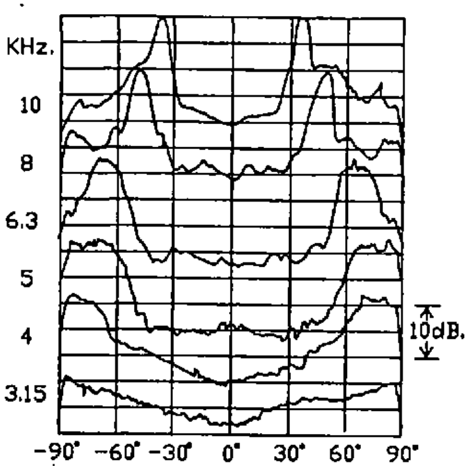

Figure 1 : Radiation from a homogeneous plate with lobes due to the coincidence effect (f_c = 4KHz. - after Jakobsen).

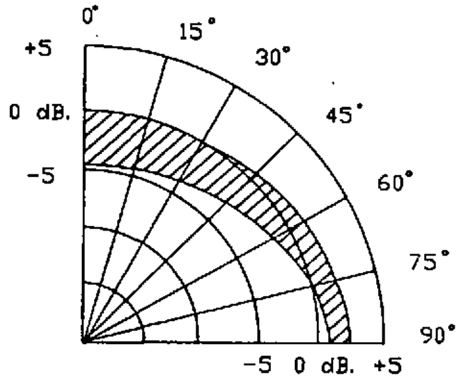

Figure 2 : Noise radiated from a facade (after Gösele and Lutz).

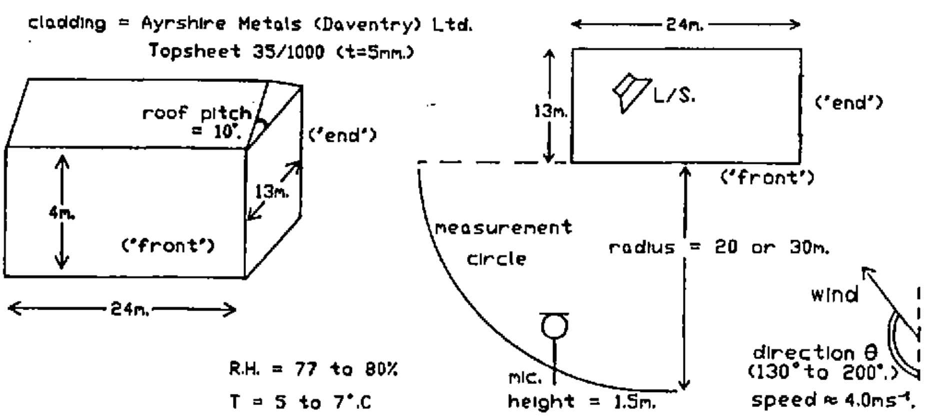

Figure 3 : Building dimensions and measurement positions.

Figure 4 :

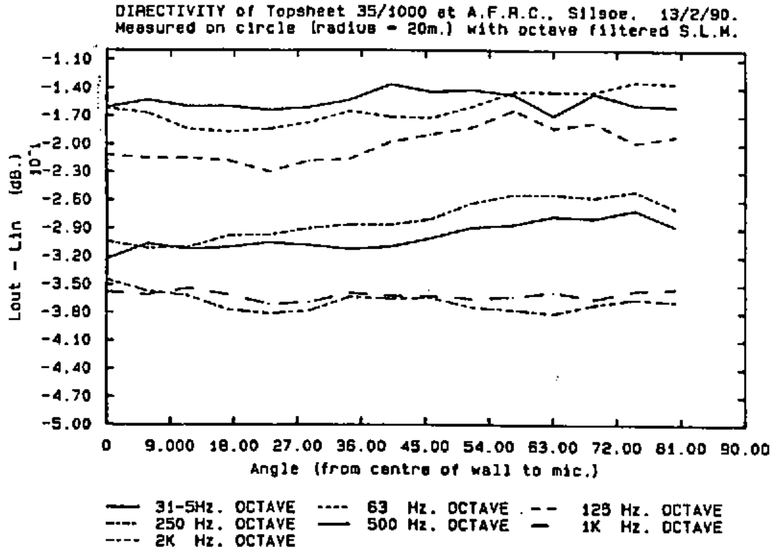

Figure 5 :

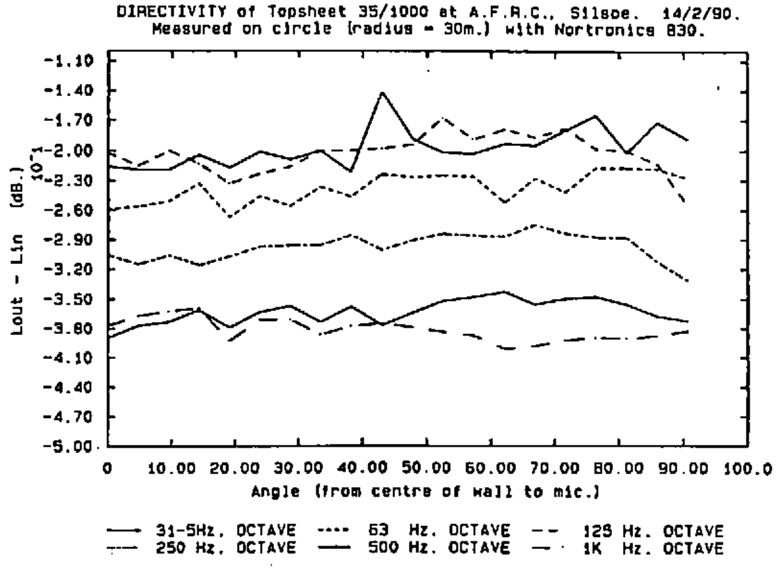

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Figure 6 :

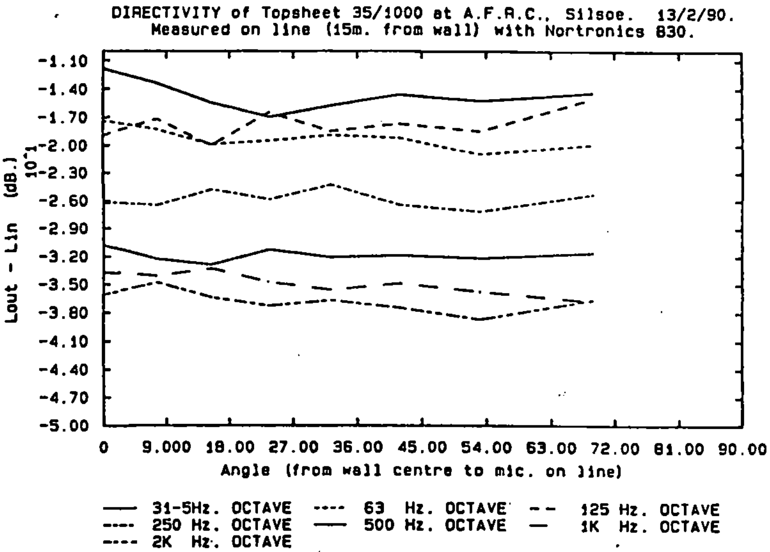

Figure 7 :