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RAY-TRACING PREDICTION OF NOISE LEVELS IN A LADLE METALLURGY FACILITY BEFORE AND AFTER ACOUSTIC TREATMENT

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1. INTRODUCTION

This case study discusses the application of ray-tracing techniques to the prediction of noise levels in a ladle metallurgy facility before and after acoustic treatment. The objectives were to determine noise levels in the facility as designed, relative to the applicable noise exposure criterion, $L_{eq,8\ hour}$ = 85 dBA, and to evaluate the efficacy of proposed noise-control measures. The work was carried out for the acoustic consultant at the design stage. Ray-tracing techniques were applied because of the complexity of the building and because of their proven inherent accuracy [1].

2. THE RAY-TRACING MODEL

The ray-tracing model used in this work was that developed in France and modified by the author. Full details of this model are published elsewhere [2] - only a brief description is given here. Of particular interest to factories is its ability to model the effect of the enclosure contents - the fittings. The fittings are the various obstacles in the space which scatter and absorb propagating sound. The distribution of obstacles, which scatter omni-directionally, is assumed to follow a Poisson distribution. The factory volume is subdivided into a number of sub-volumes; each sub-volume is assigned a fitting scattering cross-section density and an absorption coefficient. As implemented, the model simulates an enclosure defined by plane, specularly-reflecting surfaces whose absorptions are quantified by the absorption coefficients. Sources are assumed to be omni-directional points. Receivers are defined by a plane of cubic cells of a certain side length and located at a certain height. Diffraction effects (such as those relevant to sound propagation over partial-height partitions) are not modelled.

The ray-tracing model was programmed in FORTRAN, with its compiled version run on an IBM 4381-2 computer.

3. THE LADLE METALLURGY FACILITY AND PROPOSED ACOUSTIC TREATMENTS

The ladle metallurgy facility treats steel to reduce the carbon content and/or add alloys. Molten steel is transported into and out of the facility using three huge ladles. The steel is treated by drawing off gases using a vacuum system, consisting of a series of steam ejectors and condensors.

The facility is housed in a large building of complex shape, as illustrated in Figure 1. The building is in the shape of a vertical 'L', with a horizontal extension and vertical tower. The tower contained over 20 partial mezzanine floors. On the main and some mezzanine floors were situated a number of enclosures (control cabins, equipment rooms, etc.). The three ladle assemblies, about 5 m high and cylindrical in shape, were located at the bottom of the tower. From the ladle assemblies, the steam ejector ducts rise up into the tower. Near the top of the tower are a series of vibrating feeders associated with the material handling system.

Besides the mezzanine floors, enclosures and ladles, the building was fitted with equipment, pipe and duct work, stockpiles, etc. The density of fittings was particularly great on the main floor in the horizontal extension.

The main floor of the facility was made of concrete. The mezzanine floors were constructed of solid steel. The external walls and roofs of the building and of the condensor room were of metal cladding. The surfaces of the other enclosures were of concrete or blockwork.

The main noise sources in the building were the steam ejector duct, the condensor room and associated pipework, and the vibrating feeders. In addition, there were a number of secondary sources, such as fans, pumps and motors, located throughout the building.

The main receiver locations were on the main floor and four of the mezzanine floors.

Two acoustic treatments were proposed by the acoustic consultant. Both were designed simply to reduce the sound power levels of the ejector duct and condensor room, the two main noise sources. The first (LAGGING case) consisted of lagging the external surfaces of the duct and room with 100 mm of fibreglass covered with 22 ga. sheet metal. The second (ENCLOSURE case) consisted of enclosing the entire duct and room with an acoustic enclosure, built out from one wall of the vertical tower.

4. MODELLING THE FACILITY

4.1 Building geometry

For ray-tracing prediction, the building surfaces are modelled as planes of rectangular shape. This generally involves considering non-rectangular surfaces as a collection of rectangular ones, and simplifying the room and surface shape. In the present case, the shape of some of the mezzanine floors was simplified. In addition, in order to reduce computer run times, it is of interest to keep the number of surfaces as low as possible. In the present case, several enclosures and mezzanine floors located far from important noise sources and receiver locations were ignored. Figure 2 shows plans and sections of the building as modelled for ray tracing.

4.2 Surface and air absorption

Predictions were made in octave bands from 63-8000 Hz. Surface absorption coefficients for the various surface constructions were assigned using standard tabulated diffuse-field values and, in the case of the metal cladding, on the basis of past research [3]. Air absorption coefficients corresponded to T = 20 °C, RH = 50%. The various coefficients are shown in Table 1.

Table 1 - Octave-band surface and air absorption coefficients

	Octave band (Hz)							
Description	63	125	250	500	1000	2000	4000	5000
Blockwork	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
Solid Steel	0	0.005	0.01	0.015	0.02	0.025	0.03	0.035
Concrete	0	0.005	0.01	0.015	0.02	0.03	0.04	0.05
Cladding	0.2	0.17	0.14	0.10	0.08	0.06	0.06	0.06
Air (Np/m)	0.00005	0.0001	0.0003	0.0005	0.001	0.003	0.008	0.012

4.3 Fittings

In order to model the fittings in the building, the building was subdivided into three zones. Average fitting densities, which do not vary with frequency, were assigned to each zone based on a knowledge of the equipment to be installed in the zone and on past experience, as follows:

Zone 1 - horizontal extension, below 5 m = 0.2 m^{-1} (high density)
Zone 2 - horizontal extension, above 5 m = 0.05 m^{-1} (low density)
Zone 3 - vertical tower = 0.1 m^{-1} (moderate density)

The absorption coefficients of the fittings were 0.05 in all octave bands.

4.4 Sources

To model the sound sources, these must be approximated by point sources. In the case of the various small sources such as pumps, fans, etc., this was straightforward. In the case of the distributed sources - the ejector duct, pipework, condensor room surfaces - this involved dividing the source into subsources which, on the basis of their dimensions and distances to the nearest receivers, could be considered as points. The ejector duct was divided into 12 2-m lengths. Each surface of the condensor enclosure was divided into up to 4 sources.

In the end, a total of 29 noise sources were considered. Their positions are shown in Figure 2. The octave-band sound power levels of the sources were provided by the acoustic consultant. These were determined in various ways. Those for the ejector duct were estimated from measurements made on a similar facility and from manufacturer's data. Those for the other equipment were estimated from data provided by the equipment manufacturers, building owners and the main engineering contractor. There was considerable uncertainty associated with the sound powers of the steam ejector and condensor room.

The two acoustic treatments were modelled simply by reducing the sound power levels of the treated sources according to the insertion losses of the two treatments. These were provided by the acoustic consultant. Those for the enclosure were estimated in the usual way from the transmission losses of the enclosure surfaces. Those for the lagging were assigned on the basis of existing data, standard predictions and following considerable discussion between the consultant and his client. The insertion losses, used to modify the source powers, are presented in Table 2.

Table 2 - Octave-band insertion losses of proposed acoustic treatments (in dB)

	Octave band (Hz)							
Treatment	63	125	250	500	1000	2000	4000	8000
Lagging	0	1	3	5	13	20	26	34
Enclosure	8	15	22	30	33	42	44	44

4.5 Receivers

Regarding receiver positions, five receiver planes, on the main and four mezzanine floors, were considered. Predictions were made in 3 m steps in both horizontal directions over each plane. The noise level at a given position corresponds to the average level in a 3 m cube sitting on the floor. The extents of the various receiver positions are shown in Figure 2.

5. PREDICTIONS MADE AND RESULTS

5.1 Predictions and procedures

Predictions were made for the three cases (UNTREATED, LAGGING, ENCLOSURE) and for each of the five receiver planes; all octave bands are predicted in the same run. From the octave-band levels, A-weighted results were calculated and noise contour maps drawn.

In order to ensure a high prediction accuracy (that is, convergence of the prediction results - the accuracy of the input data is another problem), some care must be exercized in the course of the prediction work. In particular, the number of rays emitted by each source, and the number of reflections for which each ray is traced, must be sufficiently high. On the other hand, these should also be as low as acceptable to limit run times. By trial and error, it was found necessary in this case to emit a total of about 45000 rays and to trace each ray for about 60 reflections.

The resulting prediction accuracy (convergence) was about ±0.2 dB. Each run (one case, one receiver plane, eight octave bands) involved run times of about 4 hours.

There are two further limitations to the prediction accuracy which are associated with the ray-tracing model. First, since the model does not include diffraction effects, predicted levels at positions near the edges of planes will be relatively less accurate, especially at high frequencies. Secondly, averaging noise levels over a 3 m cube results in relatively low accuracy at receiver positions close to noise sources.

5.2 Results

Detailed results are presented for the main and two mezzanine floors. Figure 3 shows the predicted A-weighted noise maps for the three cases. Without going into detail, the prediction results show that noise levels in the untreated building vary relatively little over a receiver plane and are excessive. The proposed acoustic treatments reduce noise levels considerably, especially at positions distant from noise sources. While the lagging results in acceptable levels on the main floor, only the enclosure ensures acceptable levels at most positions on all floors.

6. CONCLUSIONS

Ray-tracing methods have been successfully applied to the prediction of noise levels on various floors of a ladle metallurgy facility before and after acoustic treatment. Clearly, no other existing prediction technique could do these predictions. However, care must be taken to ensure accurate prediction. Further, the results are limited by the accuracy of the input data, which is often estimated by very approximate methods. Despite this, ray tracing remains the only technique capable of predicting noise levels in fitted buildings of complex shape.

7. REFERENCES

[1] M.R. HODGSON, 'Accuracy of Analytic Models for Predicting Factory Sound Propagation', *Inter-Noise '88*, Avignon (1988).

[2] A.M. ONDET, J.L. BARBRY, 'Modelling of Sound Propagation in Fitted Workshops Using Ray Tracing', *JASA*, 85(2) pp. 787-796 (1989).

[3] M.R. HODGSON, 'Towards a Proven Method for Predicting Factory Sound Propagation', *Proc. Inter-noise '86*, pp. 1319-1323 (1986).

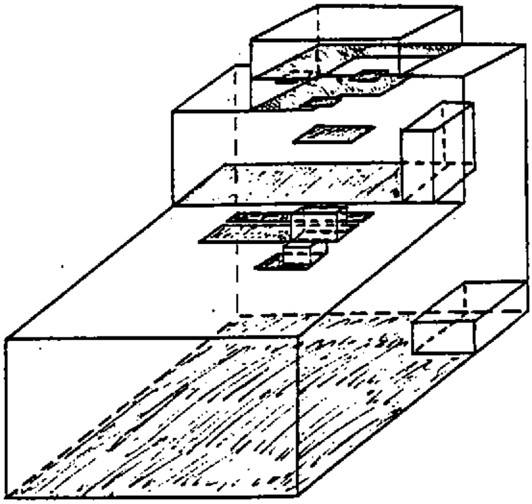

Figure 1 - Illustration of the ladle metallurgy facility.

PREDICTION OF NOISE LEVELS IN A LADLE METALLURGY

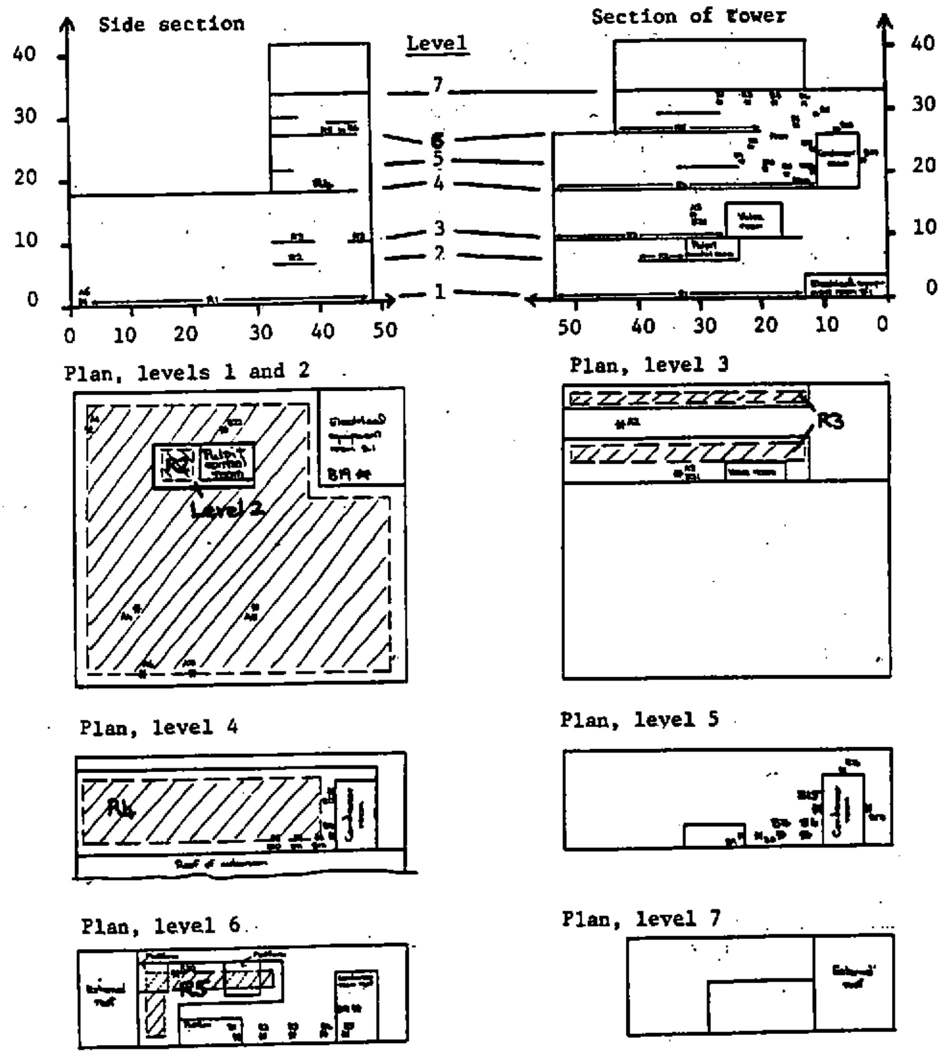

Figure 2 - Plans and sections of the ladle metallurgy facility, as modelled for ray tracing, showing its dimensions (in metres), source positions and receiver planes.

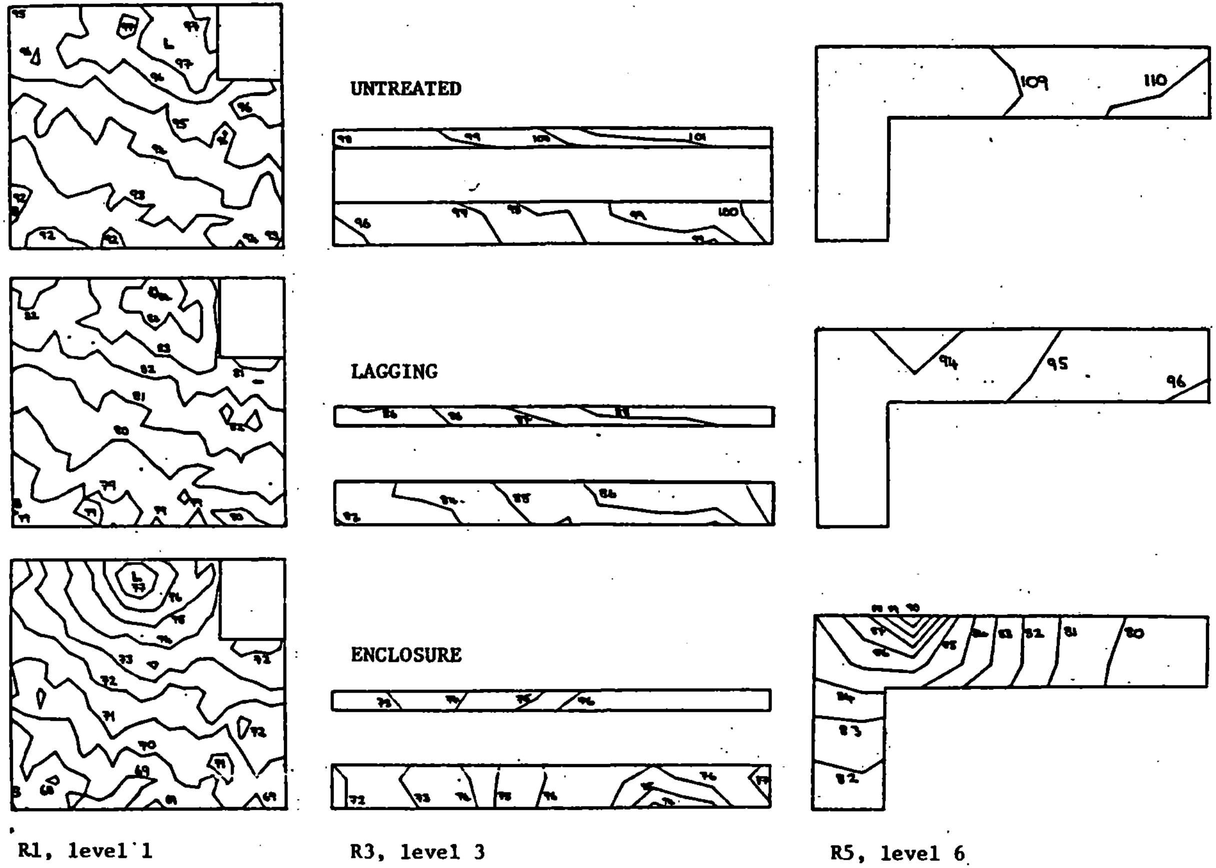

Figure 3 - Isocontour maps of the predicted A-weighted noise levels in the ladle metallurgy on three receiver planes before and after acoustic treatment.