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# Diffracted sound field from an orchestra pit

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## 1. Introduction

This paper presents a measurement series which can serve as a benchmark test for calculation methods in room acoustics. Previously, three international round robins have compared calculations with measurements [1–3]. In those studies, only energy-based parameters in discrete receiver positions were evaluated. Here, the focus is on the edge diffraction effect and an orchestra pit is selected as a case where this effect is significant. Furthermore, measurements are made along a linear array, which makes it possible to identify wavefronts [4].

## 2. Measurement setup

A physical model of a simplified orchestra pit was constructed as illustrated in Fig. 1(a), where all dimensions are given in the 1:5 scale. The model has a very simple rectangular shape with three different states of covering:
- Completely open (no covers)
- Partly covered (cover A only)
- Half-covered (both covers A and B)

A reciprocity technique was used, placing a 1/4-inch condenser microphone with its membrane flush with the floor. A 1-inch loudspeaker element was moved in steps of 1 cm along a bar above the pit. A bandpass filtered inverse filter was developed for the loudspeaker. The frequency response was within ±0.5 dB from 590 Hz to 23.5 kHz using this inverse filter. The directivity of the loudspeaker was measured in octave bands that correspond to 125 Hz–4 kHz in full scale, see Table 1.

Impulse responses (IRs) were measured with the MLS technique, using a sampling frequency of 48 kHz. By measuring impulse responses to a length of 16383 samples (341 ms), using 32 averages, and truncating the IRs to a length of 1024 samples (21 ms), SNR of at least 20 dB was achieved over the frequency range 200 Hz–23.5 kHz, rising to approximately 40 dB over most of the spectrum.

## 3. Calculations

Computer calculations were made for comparisons with the measurements. A Matlab implementation of the edge diffraction (ED) algorithms in Ref. [5] was used, as well as an implementation of geometrical acoustics (GA), i.e. direct sound and specular reflections. Surfaces were modeled as perfectly flat and rigid and the source was modeled as omnidirectional. Only second order reflection and first order diffraction was included in the diffraction modeling.

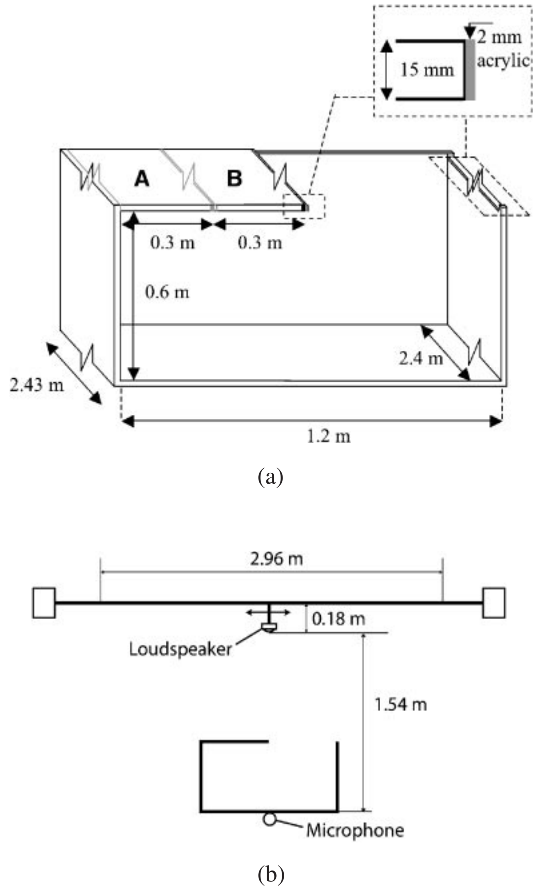


**Fig. 1** (a) Illustration of the orchestra pit scale model. Edges were covered with strips of acrylic to give smooth, flat surfaces. (b) The source and receiver positions.

## 4. Results

The measured and calculated impulse responses were filtered in octave-bands in order to compare them with measurements in different frequency ranges. A second-order Butterworth octave band filter was designed and Fig. 2 illustrates the impulse responses of an ideal pulse and the corrected loudspeaker element when filtered around 1,250 Hz, which corresponds to 250 Hz in full scale. It is clear that the corrected loudspeaker element is close to ideal when studying a filtered response.

**Table 1** Octave-band directivities of the loudspeaker element that was used in the measurements.

| | Octave band directivities rel. to the frontal direction (0°) [dB] | | | | | |
|---|---|---|---|---|---|---|
| Rad. angle | 625 Hz | 1.25 kHz | 2.5 kHz | 5 kHz | 10 kHz | 20 kHz |
| 10° | −0,1 | 0,0 | −0,2 | 0,0 | −0,5 | −1,4 |
| 20° | −0,4 | +0,2 | −0,6 | −0,6 | −1,7 | −6,0 |
| 30° | −0,6 | +0,3 | −1,1 | −1,6 | −3,4 | −15,9 |
| 40° | 0,0 | +0,3 | −1,7 | −3,1 | −5,5 | −25,9 |
| 50° | 0,0 | −0,5 | −1,4 | −3,8 | −8,7 | −20,6 |

The filtered IRs are plotted in a stacked fashion, as in Ref. [4]. Figure 3 shows the measured and calculated results for the fully open pit case. Wavefronts can clearly be identified as direct sound, specular reflections and diffractions. All measured wavefronts are continuous and smooth, which indicates good accuracy in the measurements. The GA calculations,

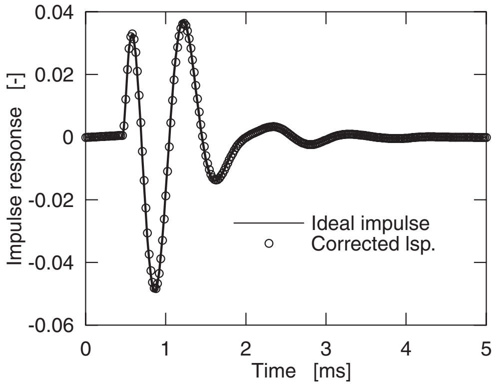


**Fig. 2** The impulse response of the octave band filter used in the analysis for an ideal impulse and for the corrected loudspeaker element.

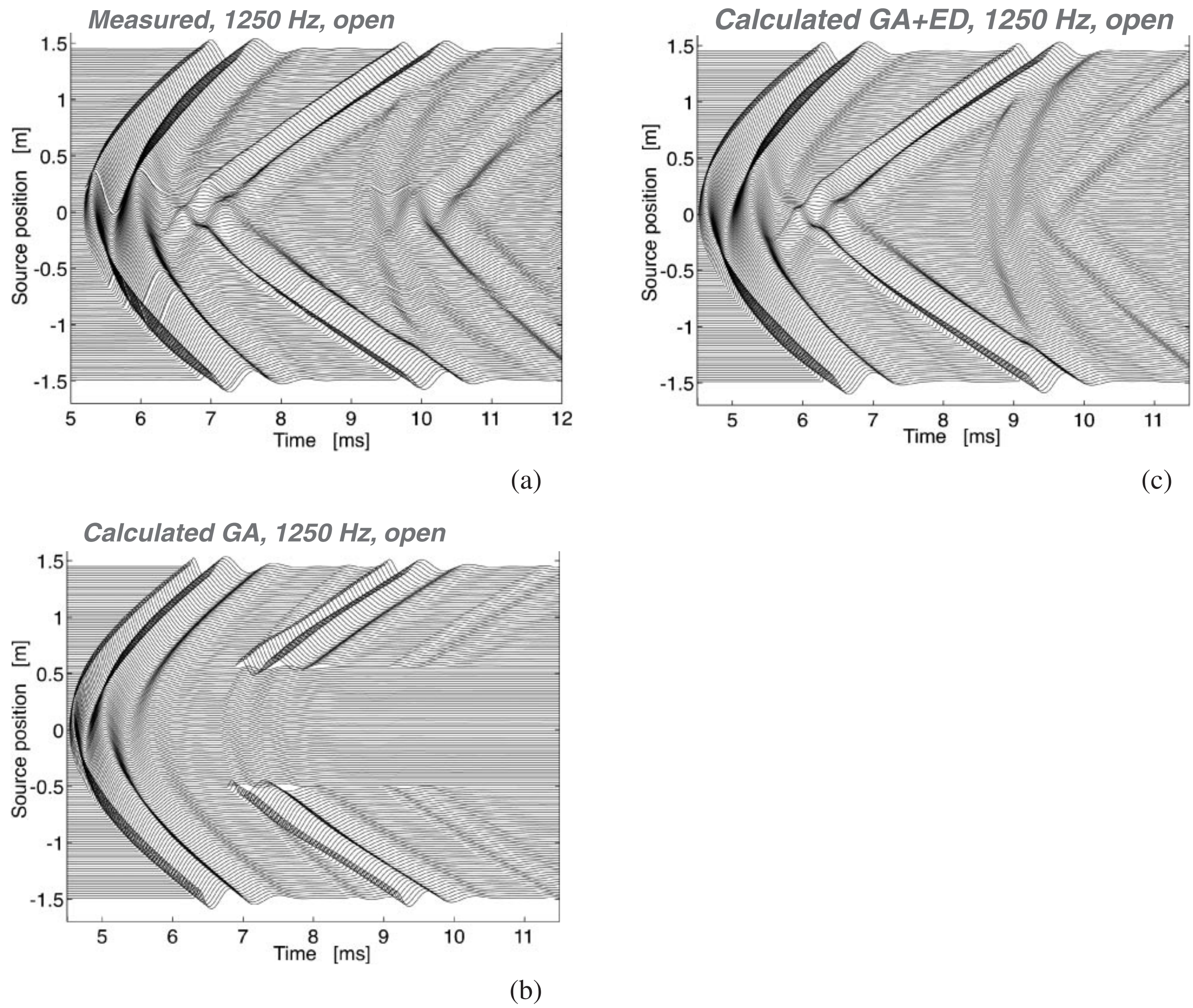


**Fig. 3** Impulse responses for all source positions, filtered with a 1,250 Hz octave band filter for the fully open pit case. (a) Measurements (b) Calculations with GA (c) Calculations with GA and ED.

with specular reflections only, in Fig. 3(b), give truncated wavefronts, which is clearly erroneous, whereas the inclusion of edge diffraction (ED) corrects the wavefronts. The GA results are accurate for receiver positions far away from the wavefront discontinuities. The same tendencies can be seen for the other cases, as the GA wavefronts become more erroneous when the pit is partly covered.

## 5. Conclusions

This paper presented measurements for a case where the importance is clear for including edge diffraction in computational methods. The measurement results can serve as benchmark results to test computations against. All measurements are available from the authors upon request.

## References

[1] M. Vorländer, "International round robin on room acoustical computer simulations," *Proc. Int. Congr. Acoust.*, Trondheim, Norway, 26–30 June 1995, pp. 689–692 (1995).

[2] I. Bork, "A comparison of room simulation software — The 2nd round robin on room acoustical computer simulation," *Acustica/Acta Acustica*, **86**, 943–956 (2000).

[3] I. Bork, "Simulation and measurement of auditorium acoustics — The round robins on room acoustical simulation," *Proc. Inst. Acoust.*, **24**, Pt. 4, CD-ROM ISBN 1-901656-47-0 (2002).

[4] A. J. Berkhout, D. de Vries and J. J. Sonke, "Array technology for acoustic wave field analysis in enclosures," *J. Acoust. Soc. Am.*, **102**, 2757–2770 (1997).

[5] U. P. Svensson, R. I. Fred and J. Vanderkooy, "An analytic secondary source model of edge diffraction impulse responses," *J. Acoust. Soc. Am.*, **106**, 2331–2344 (1999).