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ACOUSTIC GROUND IMPEDANCE ASSESSMENT

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1. INTRODUCTION

In an extensive field trial program investigating blast wave propagation in the open, carried out in Norway during 1994-96 by the Norwegian Defence Construction Service, the need for characterizing the ground acoustically was addressed. The aim of the trials was to establish a body of propagation data, usable for prediction model development. The propagation situations differed significantly, including summer- and winter conditions, propagation through forest and above hilly terrain, all at different distances. The problem was to supply some kind of acoustic ground characterization which could act as a relevant parameter when evaluating and processing the propagation data. In this paper some measurement methods are considered, giving results from which the acoustic impedance of the ground can be assessed.

2. ACOUSTICAL GROUND CHARACTERIZATION, POSSIBILITIES AND LIMITATIONS

The classical way of characterizing the ground acoustically, relevant to linear acoustics and spherical wave propagation in air between source and receiver above the ground, is by determining the frequency dependent specific acoustic impedance seen into the ground surface, Z. This is the important "description" entering into propagation models under such simplified circumstances. The relevance of this description for blast noise in the non-linear region near the source, is of course questionable. Despite this, it is assumed that outside this region and especially in the receiver area, the acoustic impedance may still be of some importance for assessing the ground interaction. So, the methods

deal with the measurement of the acoustic impedance, or related parameters, of the ground.
Most blast noises have low-frequency energy spectra, which often peak well below 100 Hz. This is a great challenge to the methods investigated, because they are more or less «standard» methods having low-frequency limitations.

The blast noise trials were numerous, and covered a wide range of propagation paths. No attempts were made to cover these great areas adequately. The ground characterization was restricted to a small number of sample measurements during summer- and winter conditions.

Three methods are considered in the following, with examples of results :

1. Impedance tube method
2. In-situ direct measurement of the reflection coefficient
3. Field gradient method by short range sound propagation

3. IMPEDANCE TUBE MEASUREMENT

This well-known principle implemented with the 2-microphone technique [1] was applied to samples of the forest floor in summer, and snow samples in winter. In the latter case the tube was brought in-situ for measuring the samples immediately after pick-up. Special attention was paid during pick-up to ensure undistorted samples. A "mobile" tube was built, with diameter and length approx. 0.2 m and 2.4 m respectively, giving a frequency range of about 30 - 1000 Hz. A smaller tube was also applied, having diameter and length approx. 0.1 m and 1.2 m respectively, and frequency range about 60 - 2000 Hz. The measurement setup included a two-channel FFT-analyzer, a portable pc with the appropriate software, amplifiers and conditioning for the microphone- and loudspeaker signals.

An example of impedance functions for a snow sample is shown in Fig. 1.

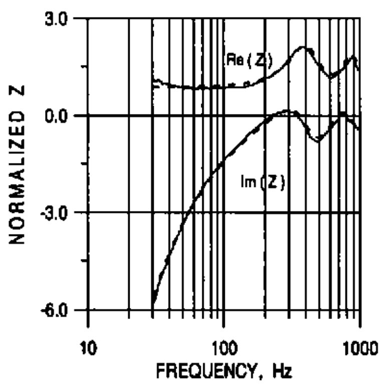


Fig. 1. Normalized acoustic impedance for a snow sample (0.27 m of slightly layered dry snow), — measured, - - - Z-model after parameter estimation.

The measured impedance data were further procesesed. A fitting procedure gave estimates of material parameters according to the four-parameter impedance model proposed by Attenborough and Howorth [2], yielding values for the porosity P(%), tortuosity^2 Q (-) and effective flow resistivity S_e (= $s^2_p \cdot S$, s_p is the pore shape ratio, S is the traditional air-flow resistivity) (Pa·s/m^2). The result of this procedure is also shown in Fig. 1.

An additional example on the use of the impedance tube method is shown in Fig. 2. Here the impedance functions of a soil sample taken from the forest floor are shown, and compared to results obtained using an in-situ measurement method, see below.

4. IN-SITU DIRECT MEASUREMENT OF THE COMPLEX REFLECTION COEFFICIENT

In-situ measurement without disturbing the ground surface was obtained by using a relatively new subtraction technique with Maximum Length Sequences (MLS) as the excitation signal. In using this type of signal one may obtain a very high signal to noise ratio. The basic ideas for the implementation followed the outline of Mommertz [3], where in principle the reflected sound field close to a ground surface is found by subtracting the direct field from the total sound field in the same position. This procedure operates on impulse responses in the time domain, which are recovered by crosscorrelating the measured response with the excitation signal. This is carried out using the fast Hadamard transform. The procedure also allows for time-window filtering of unwanted reflections. The practical implementation of the method is described in [4] and [5]. The frequency-dependent complex reflection coefficient R is the Fourier transform of the reflected impulse response. The acoustic impedance of the ground surface is then obtained by the relation :

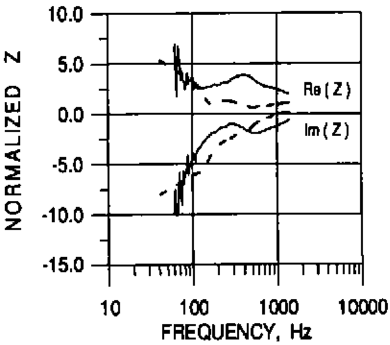
$$Z = \cos^{-1} \emptyset \cdot (1 + R)/(1 - R)$$

where Ø is the angle of incidence. Z and R are complex functions of the frequency.

The measurements and the signal processing was performed using a pc with a DSP-card and associated software. The system used a low/medium-frequency range loudspeaker. The positioning of the microphone relative to the loudspeaker had to be very accurate.

This method was applied to a typical forest floor surface in the trial area during summer contitions, and to snow surfaces in winter. The resulting forest floor impedance functions are shown in Fig. 2., and compared to the results obtained with the impedance tube method. The agreement in general seems to be reasonably good, with values of the same order of magnitude.

Fig. 2. Measured normalized acoustic impedance for forest floor, — Impedance tube method, - - - In-situ method.



The results obtained from the snow measurements using this in-situ method were unfortunately less convincing, especially in the low frequency range, i.e. below approximately 200 Hz. This matter is discussed later in the paper.

5. FIELD GRADIENT METHOD BY SHORT RANGE SOUND PROPAGATION

The sound field above a ground surface with finite acoustic impedance, will exhibit a vertical gradient. If the acoustic impedance and the source - receiver geometry are known, this gradient can be calculated. Inversely, if the field gradient is measured, the acoustic impedance can be assessed by using an impedance model, and adjusting the model parameters in a fitting procedure.

This method was prepared, intended for use in the winter when the snow cover was assumed to behave like a porous layer above the frozen ground. In practice, two vertically separated microphones were used, at heights of 0.15 m and 0.90 m above the snow surface. The source-receiver distance was 6-8 m, the source height was typically 1.2 m above the snow surface. The measurement site was a flat and open area in forest surroundings. The sound source was a 0.25 m diameter loudspeaker with output in the frequency range 30-1000 Hz. The impedance model proposed by Attenborough and Howorth [2] was used. The sound field was calculated according to Nobile and Hayek [6]. The sound pressure transfer function (level difference spectra) between the microphones was determined from two-channel impulse response measurements using MLS. This ensured an optimum signal to noise ratio in the measurements. The time-window setting allowed for a low-frequency limit of about 30 Hz.

An example of the measured transfer function is shown in Fig. 3. The model transfer function obtained by the fitting procedure and parameter estimation, is also shown. The mean snow cover depth was 0.35 m in the propagation area.

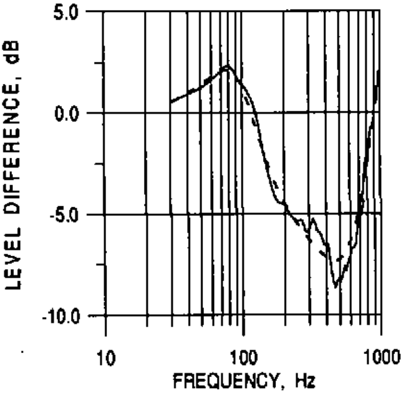


Fig. 3. Level difference spectra above snow cover. — measured, - - - model result after parameter estimation.

The comparison is generally quite good over a large frequency range, although some deviations are seen in the range 300-600 Hz. This may be due to the effect of a certain layering in the snow. The fitting procedure assessed the values of the model parameters P, Q and S_e, which in turn give values to the estimated acoustic impedance functions. The model impedance obtained in this way, came very close to the one measured in the impedance tube. This is shown in Fig. 4. The snow sample for the impedance tube measurement was taken close to the propagation area. The model impedance was adjusted to the proper thickness of the picked snow sample.

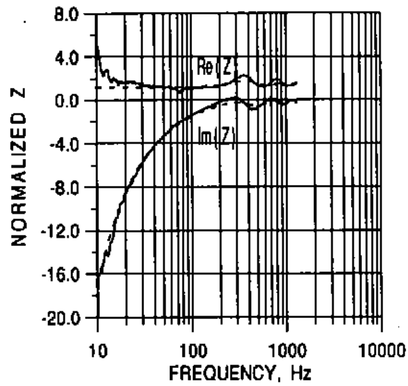


Fig. 4. Normalized acoustic impedance. — Measured by the impedance tube method, - - - - estimated by the field gradient method.

6. CONCLUSIONS

Three methods for determining the normal acoustic impedance of a ground surface, were implemented and applied in outdoor situations. All methods gave reasonable results, when applied under favourable conditions. Some comments and experiences should be mentioned :

The impedance tube method (1) needs good samples in order to work properly. For homogeneous samples the impedance modelling procedure will also give valuable parameter information. The tube dimensions must be considered if the low frequency range is to be covered. Especially for the snow samples a possible leakage problem at low frequencies was experienced.

The in-situ method (2) with the MLS application seems promising. For the forest floor ground the results compared reasonably well with the impedance tube results. The good signal to noise ratio inherent in the method is useful. The low frequency limit depends on the reflection environment. If the time window necessary to gate out the parasitic reflections becomes too short, poor low frequency resolution results.

The field gradient method (3) seems to work properly, at least when confined to one well-defined porous layer above hard backing. The results depend on the chosen impedance model, which may not suit all kinds of ground material. For general use, it is necessary to develop models for inhomogeneous ground materials.

The final results of this investigation in terms of acoustic impedance data, will be evaluated and discussed elsewhere.

7. REFERENCES

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