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VERY HIGH FREQUENCY BACKSCATTER FROM A ROUGH SEDIMENT

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Modelling of sediment backscatter at high frequencies is currently limited to frequencies below 150 kHz. Whilst many systems such as sidescan sonar use frequencies above this limit, the backscatter is generally treated as an image, and little attempt has been made to understand the physical processes involved. Therefore a study has been conducted to examine differences in measured and modelled backscatter between 100 kHz and 950 kHz. The lower frequency was chosen so that it fell into the range where current backscatter models are valid and could hence be used as a benchmark. Monostatic measurements were made over a range of grazing angles from fine sand that had been placed in a laboratory tank. The backscatter strength from a range of different frequencies, angles and roughness spectra (including an acoustically flat surface) are presented. Measurements were also taken from a flat water surface to provide a calibration. The experimental results are compared with a number of different models (fluid, effective density, visco-elastic and a grain scattering model).

1. INTRODUCTION

Reverberation due to the backscatter of acoustic energy from the seabed is an important factor in limiting the performance of active detection and classification sonars. The upper acoustic frequency limit for such sonars has tended to be fixed by the resolution requirements of mine hunting activities, which typically require classification frequencies greater than 300 kHz. Recently, however, the use of unmanned underwater vehicles (UUVs) in mine countermeasures (MCM) has meant that stand-off distances between sonar and mine may be reduced. This means that acoustic attenuation is no longer such a limiting factor to sonar performance, permitting the use of higher frequencies. The use of UUV sonars at frequencies above 1 MHz is not uncommon.

Unfortunately, the understanding of the physics involved with acoustic backscatter from the seabed, vital in being able to predict the performance of these sonars, has not kept pace with the rise in frequencies employed. Currently, state-of-the-art modelling of seabed backscatter has concentrated within the frequency range 10-100 kHz, and has received only limited validation up to 200 kHz [1]. This research has been conducted to assess the suitability of existing scattering models at very high frequency (VHF), here taken to be frequencies in the band 300 kHz to 1 MHz. In the absence of a suitable existing model, a new model will be developed. This paper presents data collected in a laboratory tank at the Institute of Sound and Vibration Research (ISVR), University of Southampton. These data are used in assessing the validity of selected backscatter models.

2. MODELS

Two models have been used in this investigation. The first, described here as a 'fluid model', treats the sediment as a fluid with a rough interface, and includes backscatter from the sediment volume. The second, is a poroelastic model, which deals only with interface scattering.

The fluid model used in this research was developed by the Applied Physics Laboratory, University of Washington (APL-UW) [2]. It treats the seabed as a fluid with a rough interface. Backscatter contribution from the rough interface is modelled using an interpolation between the Kirchhoff approximation at high grazing angles, and the Born approximation (first-order small roughness perturbation theory) at low grazing angles, together with empirical sediment volume scattering. This model is used to predict seabed reverberation in many sonar performance models at MCM detection frequencies.

A poroelastic model treats the seabed as a porous, elastic solid. Using Biot theory, differential elastic motion of the pore fluid and solid sediment frame can be calculated, which leads to frictional energy losses. The result, due to conservation of energy results in reduced reflection coefficients and scattering strength when compared with fluid models. A disadvantage of this model is that it requires many input parameters, including elastic moduli that are difficult to measure. The formulation adopted in this research is that of a saturated poroelastic seabed [3], and was chosen because it uses the Born approximation and was also developed by APL-UW, so providing maximum consistency with the selected fluid model. This model deals only with interface scattering and does not include in-sediment volume effects.

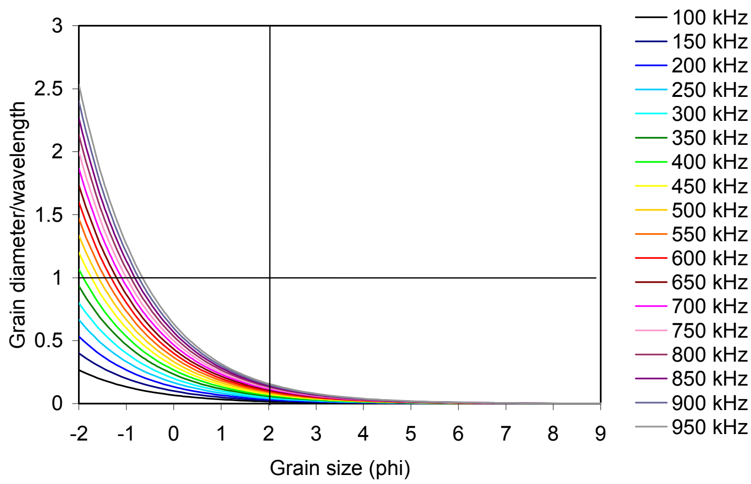

Fig.1: Ratio of grain diameter to acoustic wavelength for the frequencies examined in this paper, for full range in sediment types (phi=-1 is gravel, phi=9 is clay). The vertical line

identifies the sediment used in this experimentation. The horizontal line signifies where the grain diameter is equal to the acoustic wavelength.

3. DATA ACQUISITION

Backscatter experiments were conducted in a tank in the AB Wood Laboratory at ISVR. Table 1 shows the measured and estimated geoacoustic parameters used to characterise and model the sediment within the tank.

A rough surface to the sediment was created to mimic a shallowly rippled sea floor (see Fig. 2. This surface could then be profiled using a laser scanner. This profiling was conducted through the air-water interface, so as not to introduce any air bubbles to the sediment that could affect acoustic backscatter. Thus, to obtain the correct height field of the sediment surface, corrections for refraction at the air-water interface have been applied. Acoustic backscatter were gathered from 4 independent patches within the tank, as shown in Fig. 2. The corrected height fields at each of the 4 patches were used to calculate roughness spectra following the methodology of [4]. The mean roughness spectral strength and spectral exponent to be used in were calculated to be 0.0000160756 cm^4 and 2.34311 respectively.

Parameter	Value	Means of evaluation
Mean grain size	242.7 μm (2.043ϕ)	Measurement (sieving)
Sorting	Moderately well sorted 1.493 μm (0.578ϕ)	Measurement (sieving)
Skewness	Finely skewed -1.065	Measurement (sieving)
Mesokurtic	11.66	Measurement (sieving)
Porosity	0.468	Measurement
Grain density	2650 kgm^{-3}	Known density of quartz
Water density	1000 kgm^{-3}	Known density of distilled water
Bulk modulus of grains	3.65×10^{10} Pa	Estimated
Bulk modulus of water	2.25×10^9 Pa	Known
Fluid viscosity	0.001 $kgms^{-1}$	Known for given temperature
Permeability	10^{-8} m^2	Empirically derived from porosity
Tortuosity	1.25	Estimated

Table 1. Geoacoustic parameters characterising the tank sediment and used in backscatter modelling.

To gather the backscatter data, a monostatic transducer was mounted on a frame which could be oriented to interrogate the sediment at a full range of grazing angles down to 13 degrees. The mounting kept the transducer a constant range of 0.451 metres from the sediment surface, independent of grazing angle. Narrow band data were gathered in the frequency band 100 kHz to 950 kHz in 50 kHz increments, using transmit pulse lengths of 10 microseconds, 50 microseconds and 100 microseconds. The signals backscattered from the sediment were calibrated using normal incidence reflections from the flat water surface within the tank.

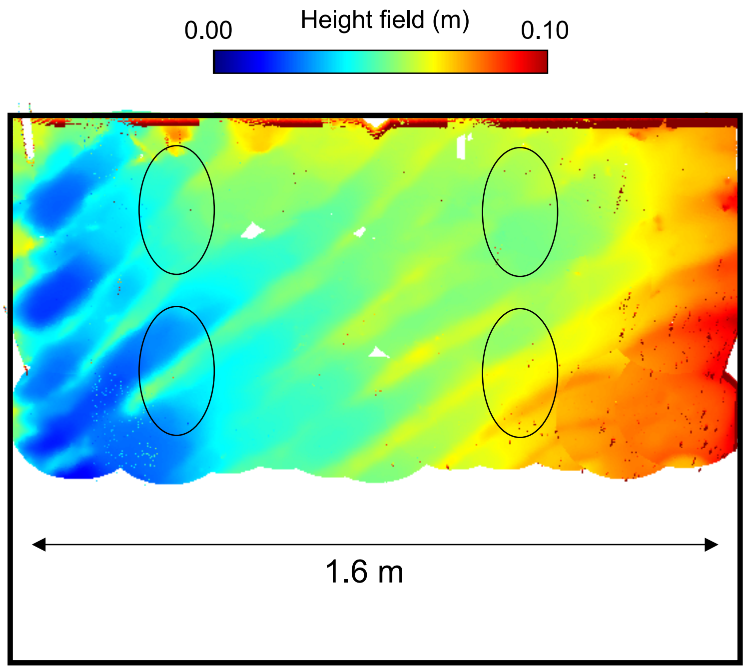

Fig.2: Height field of sediment surface in tank derived from laser scanning. Note the field shown is uncorrected for refraction, but highlights the rippled nature of the surface. The 4 independent scattering patches used are also shown.

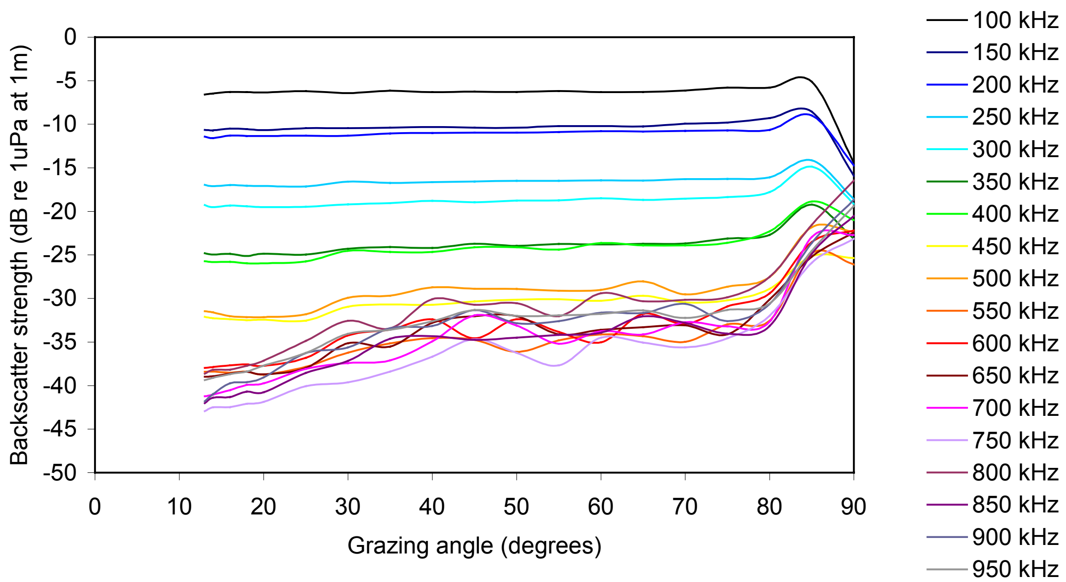

Fig. 3: Backscatter strength vs grazing angle at different frequencies calculated from data gathered in the tank. These data are averaged over pulse length and scattering patch.

4. BACKSCATTER RESULTS

Fig. 3 shows backscatter strength results calculated from data gathered in the tank. These values were derived using a backscatter area calculated from the –3dB azimuthal beam width of the transducer at each frequency, and the length of sediment interface intercepted by the pulse length at the centre of the main vertical beam. The data shown in Fig. 3 are mean values calculated over all pulse lengths and scattering patches. It is immediately apparent from Fig. 3 and Fig. 4, that the data shows an unusual reduction in backscatter strength as frequency increases from 100 kHz, until around 650-700 kHz, where levels become constant, or rise slightly with frequency.

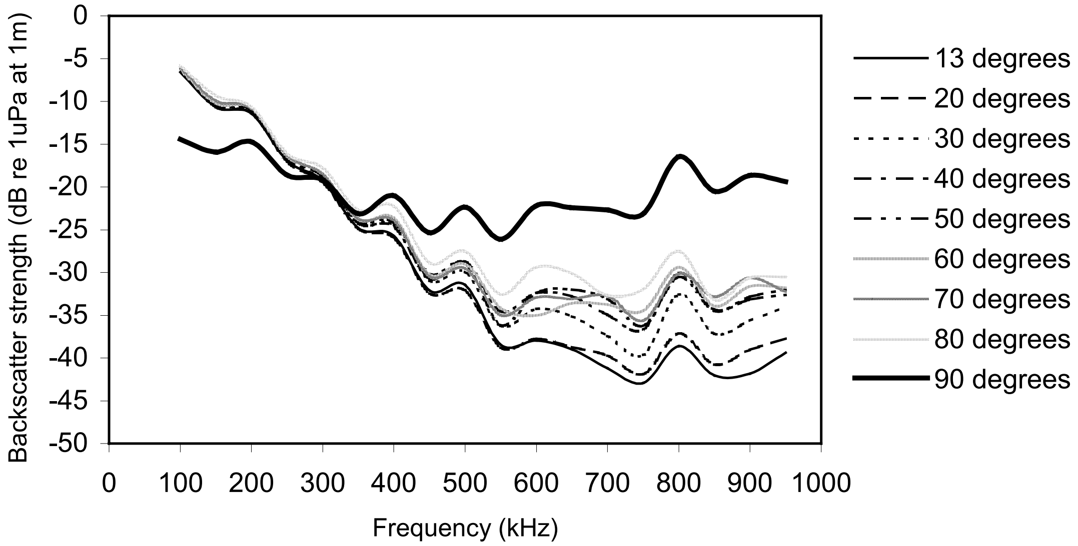

Fig. 4: Backscatter strength vs frequency for different grazing angles calculated from data gathered in the tank. These data are averaged over pulse length and scattering patch.

5. DATA-MODEL COMPARISON

Fig. 5 shows the backscatter strength predicted from only the interface in the fluid model, using input parameters in Table 1, and the roughness parameters presented in section 3.

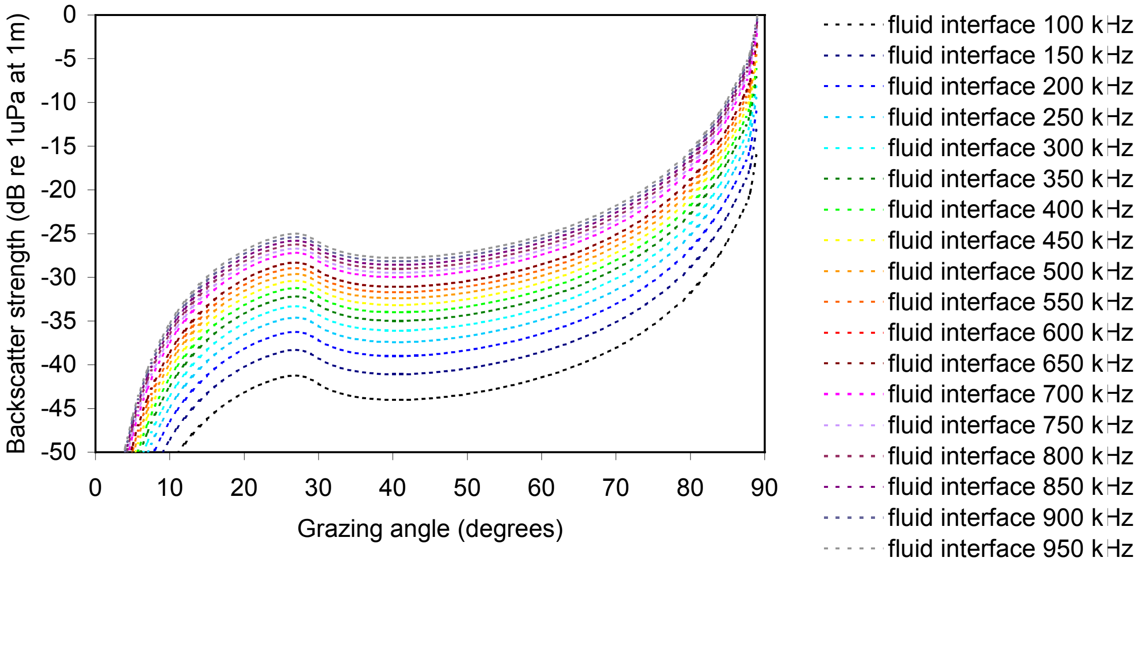

Fig. 5: Backscatter strength vs grazing angle at different frequencies calculated by the fluid model for interface scattering only. These data are averaged over pulse length and scattering patch.

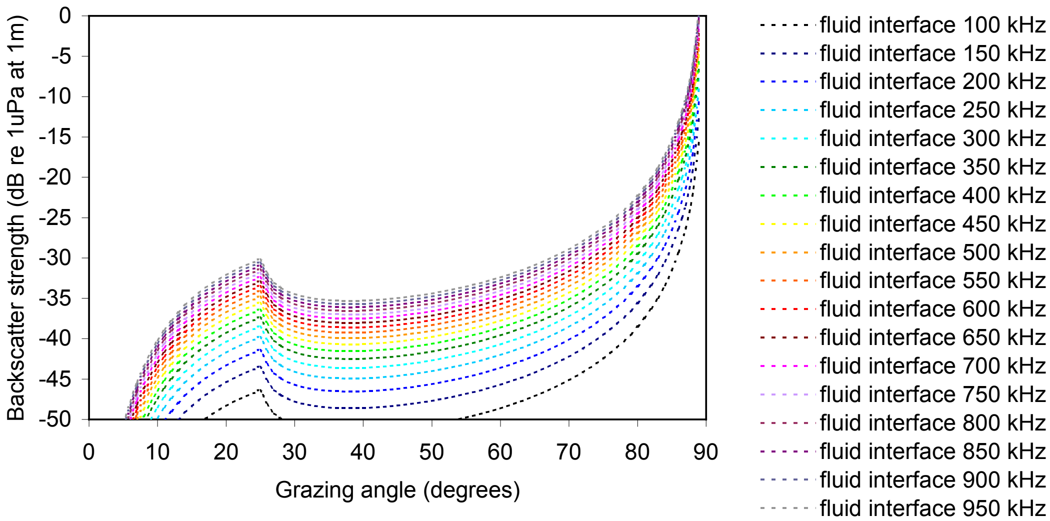

Fig. 6: Backscatter strength vs grazing angle at different frequencies calculated by the poroelastic model for interface scattering only. These data are averaged over pulse length and scattering patch.

Fig. 6 shows the same interface backscatter predicted by the poroelastic model.

The predictions of the models compare within reason for the higher frequencies (the poroelastic model fits the data more closely), but not for the lower frequencies. This observation, together with the trend exhibited by the experimental data with frequency, suggests that backscatter in the tank at grazing angles less than 60 degrees is being dominated by in-sediment volume processes at frequencies up to 600kHz or 700 kHz. Above this frequency, interface scattering dominates, hence the improved model predictions.

Incorporating the in-sediment volume scattering component of the fluid model, however, does not predict the recorded backscatter. This model component was partially derived by empirical methods at lower frequency. Thus, it is suggested here that this component is not suitable at VHF.

6. ACKNOWLEDGEMENTS

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