Australian Acoustical Society Conference,
Joondalup, Australia. 15-17 November 2000.

Seafloor Reflectivity – A Test of an Inversion Technique

Adrian D. Jones[1]*, Justin Hoffman*[2] *and Paul A. Clarke*[1]

[1]*Defence Science and Technology Organisation, Australia,* [2]*Student at Centre for Marine Science and Technology, Curtin University*

Abstract

A technique has been developed at the Maritime Operations Division of DSTO to determine the reflective properties of the seafloor in a shallow ocean, by using a broadband signal received at ranges of several km. The theory behind this technique indicates that the determination of bottom loss versus grazing angle is robust to moderate changes in separation range between the sound source and receiver, and so affords a practical means of seafloor determination. This paper reviews the basis of the measurement technique and shows how it has been used to invert the bottom loss versus grazing angle function from at-sea data gathered by Curtin University using an air gun as a signal source. In this study, the sensitivity of the inversion technique to source and receiver separation is investigated and the robustness of the technique to the nature of the air gun spectrum signature is considered. Also, the derived reflectivity values are compared with those determined from existing geoacoustic datasets for the particular seafloor location.

Introduction

The optimised deployment of anti-submarine warfare (ASW) and anti-surface warfare (ASuW) sonar systems during naval operations in littoral waters, and continental shelf zones, requires knowledge of the local underwater environment. At low acoustic frequencies (less than 300 Hz approx.), or with a downwardly refracting sound speed versus depth function, the transmission of sound to long range (50 km or more) in such shallow ocean regions is affected significantly by the seafloor reflective properties (1). An accurate prediction of sonar system performance is thus dependent upon knowledge of the seafloor suitable for an accurate prediction of transmission loss (*TL*).

At low acoustic frequencies, *TL* models require that the seafloor boundary is described by physical parameters. Usually, the seafloor is described by geoacoustic parameters for the sediment and basement, with the model inputs for each distinct layer region as listed in Table 1.

Table 1: Seafloor Geoacoustic Parameters

Compressional sound speed	c_p m/s
Compressional attenuation	α_p dB/λ
Shear speed	c_s m/s
Shear attenuation	α_s dB/λ
Density	$\mathrm{kg/m^3}$

As described by, for example, Jones et al (1), considerable efforts have been made to determine the parameters listed in Table 1 from geophysical data obtained by cores and grab samples. There is some risk applied to the process, and for many ocean regions the data coverage is sparse. In order to supplement these estimates, and to provide data for unsurveyed locations, MOD has developed a technique (2, 3) for the determination of the seafloor reflective properties based on *in-situ* acoustic measurements. An enticing aspect of the MOD technique is that the number of descriptive parameters is reduced (to one), whilst the ability to carry out phase coherent transmission predictions is retained. This paper describes recent work carried out as further validation of the MOD technique for seafloor property inversion.

Spectral Variability Inversion Technique

Many techniques exist by which acoustic signals may be used to determine the acoustic properties of the seafloor. Most of these techniques are, however, computationally intensive (e.g. matched field techniques - see, for example, Chapman and Lindsay (4)) or are otherwise not sufficiently practical for real-time seafloor properties determination within routine maritime defence operations.

At MOD, a new method has been devised. This technique is based on the statistics of multi-path transmission of broadband signals at medium source to receiver ranges ($r = 2 - 5$ km approx. in shallow water). As has been determined by Jones et al (3), the rate of variability of the received signal amplitude with frequency Δf_h is related to the geometry of the transmission situation, the speed of sound in the ocean medium, and the seafloor bottom loss as a function of grazing angle. By inverting the relationship, the frequency scale of transmission amplitude variability may be linked, directly, to a slope of bottom loss versus grazing angle, F dB/radian. This data, in turn, together with an assumed function of reflection phase angle versus grazing angle, provides a description of the seafloor which may be prepared for input to *TL* models. In the work carried out by MOD, the reflection coefficient and phase angle data have been input, directly, to the KRAKEN modal model (5) for phase coherent *TL* calculations.

The MOD inversion technique has been developed to utilise broadband transient signals, as generated by impulsive signal sources. A processing tool, GRASP (6), has been developed to simplify the processing of received transient data. This determines the spectral variability parameter Δf_h and outputs the bottom loss function F dB/radian, via the MOD algorithm. The theory behind the MOD inversion algorithm shows that values of Δf_h are independent of source to receiver range, for ranges for which refraction is not significant. As explained in an earlier paper (2), Δf_h is defined as the frequency displacement at which the normalised autocorrelation of the amplitude of the sound channel frequency response, $\rho_{|p|}(\Delta f)$, falls to 0.5. This normalised autocorrelation is carried out as

$$\rho_{|p|}(\Delta f) = \frac{\langle |p(f)||p(f+\Delta f)|\rangle - \langle |p(f)|\rangle^2}{\langle |p(f)|^2\rangle - \langle |p(f)|\rangle^2}. \qquad (1)$$

where equation (1) implies that the autocorrelation is carried out on the zero-mean sound pressure modulus, that is, on $|p(f)| - \langle |p(f)|\rangle$.

Air Gun Data

The Centre for Marine Science and Technology (CMST) at Curtin University has considerable experience with the operation and use of air guns (7). Further, MOD and the CMST have carried out joint activities using air gun sound sources and a considerable data set has been generated for seafloor and underwater acoustic transmission research.

For the present study, transients received at source to receiver ranges out to 5 km were input to the GRASP processing tool. The transients were generated by an air gun of 20 cubic inch capacity. The transient data were obtained in the Rottnest Shelf area along a track for which the ocean depth was 100 m. Source depth was 10 m, receiver depth 40 m.

Based on available geophysical data, the geoacoustic properties for the relevant region of seafloor are assumed to be as shown in Figure 1.

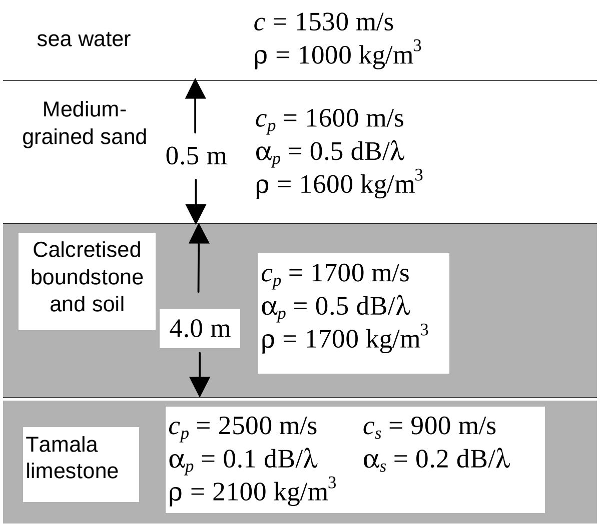

Figure 1 Geoacoustic Parameters – Rottnest Shelf

Inversion of Seafloor Reflectivity

Using the GRASP processing tool, the bottom loss function, F dB/radian, was determined for source to receiver ranges from 100 m to 4500 m at octave bands centred on 63 Hz, 125 Hz, and 250 Hz. These inverted data values are shown in Figure 2.

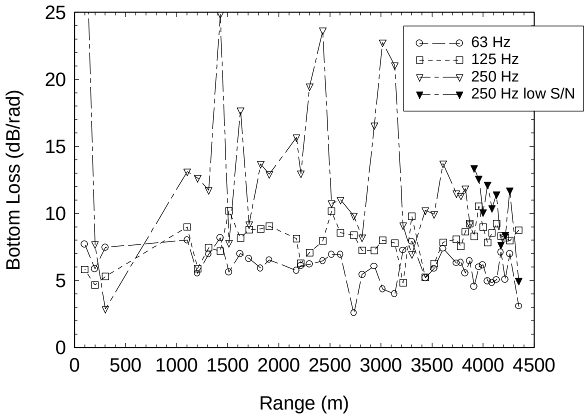

Figure 2 Bottom Loss Function F dB/radian derived from Rottnest Shelf air gun data

The data shown in Figure 2 for 63 Hz and 125 Hz show a remarkable consistency with range, as anticipated from the theoretical derivation of the MOD algorithm. The data for 250 Hz shows more scatter, but is also consistent with range. It must also be noted that the data shown in Figure 2 was obtained using raw spectra from the air gun signals – no spectral shaping was carried out.

Values of bottom loss versus grazing angle were determined by averaging the data in Figure 2 for each frequency band. The resultant bottom loss versus grazing angle variation is shown in Figures 3 and 4, together with bottom loss data obtained directly from the geoacoustic parameters of Figure 1. Here, the geoacoustic parameters were input to a plane wave reflection model.

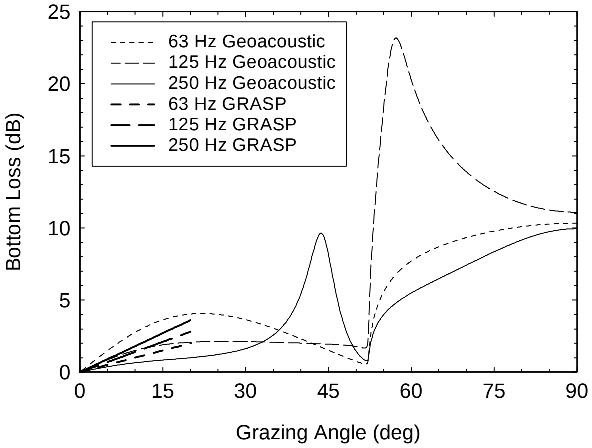

Figure 3 Bottom Loss for Rottnest Shelf 0º - 90º

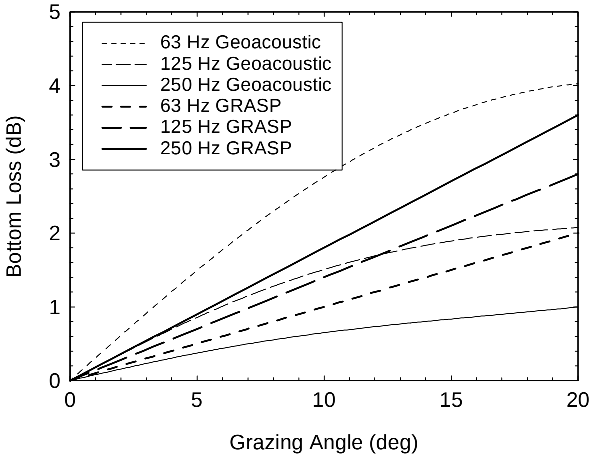

Figure 4 Bottom Loss for Rottnest Shelf 0º - 20º

In Figure 3, the inverted data is plotted to 20º grazing angle, only, as the MOD algorithm is valid for small grazing angles. The data in Figures 3 and 4 do show that the seafloor properties inverted by GRASP are similar to those implied by the geoacoustic parameters (labelled “geoacoustic”) – the seafloor is moderately reflective is low frequencies. It must be noted that there is no absolute reference for the seafloor reflectivity, so the values implied by the data in Figure 1 are not necessarily correct.

Prediction of Long Range Transmission Loss

The inferred seafloor reflection data shown in Figures 3 and 4 were used as input to calculations of *TL* to long range (50 km). Here, it was assumed that the bottom loss rose linearly with grazing angle. The seafloor reflection phase angle was assumed to vary linearly from 180º at 0º grazing angle, to 0º at the grazing angle for which the bottom loss was 6 dB. These assumed bottom loss and phase angle data were supplied as input to the KRAKEN transmission model (5) which was run in the mode to use these data, directly. KRAKEN was run in phase coherent mode. *TL* predictions so obtained are shown in Figures 5, 6 and 7, for frequencies of 63 Hz, 125 Hz, and 250 Hz. Also shown in these figures are *TL* values obtained using the geoacoustic data in Figure 1. For these calculations, the ocean is assumed to be isovelocity.

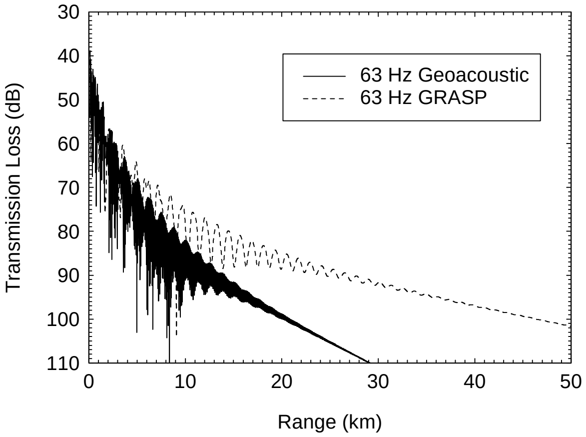

Figure 5 *TL* for Rottnest Shelf, 63 Hz

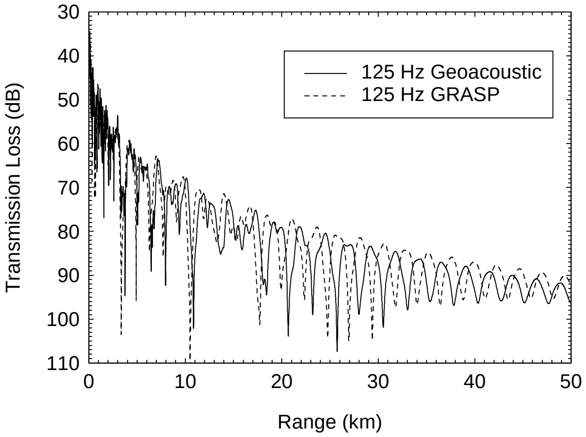

Figure 6 *TL* for Rottnest Shelf, 125 Hz

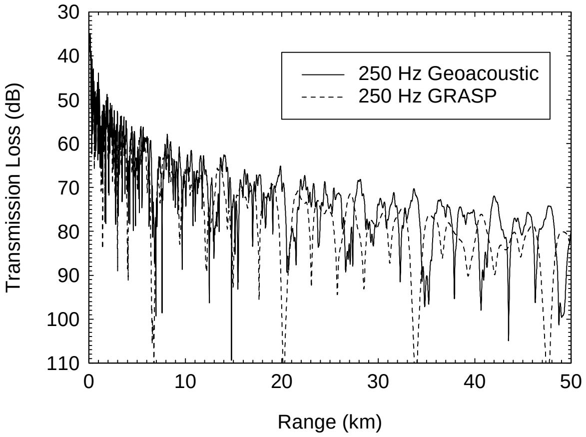

Figure 7 *TL* for Rottnest Shelf, 250 Hz

As expected from the good agreement between the inverted and geoacoustically-derived bottom loss data, the *TL* values shown in Figures 6 and 7 are in good agreement. The data for 63 Hz shown in Figure 5 show a poorer agreement as the bottom loss values shown in Figure 4 differ by more than a factor of 2.

Prediction of Short Range Transmission Loss

The inferred seafloor reflection data shown in Figures 3 and 4 were used as input to KRAKEN calculations of *TL* to short range (5 km). Again, it was assumed that the bottom loss rose linearly with grazing angle and that the seafloor reflection phase angle varied linearly from 180º at 0º grazing angle, to 0º at the grazing angle for which the bottom loss was 6 dB. These assumed bottom loss and phase angle data were supplied as input to the KRAKEN transmission model. *TL* predictions so obtained are shown in Figures 8, 9 and 10, for frequencies of 63 Hz, 125 Hz, and 250 Hz, together with *TL* values obtained using the geoacoustic data in Figure 1. Again, the ocean is assumed to be isovelocity.

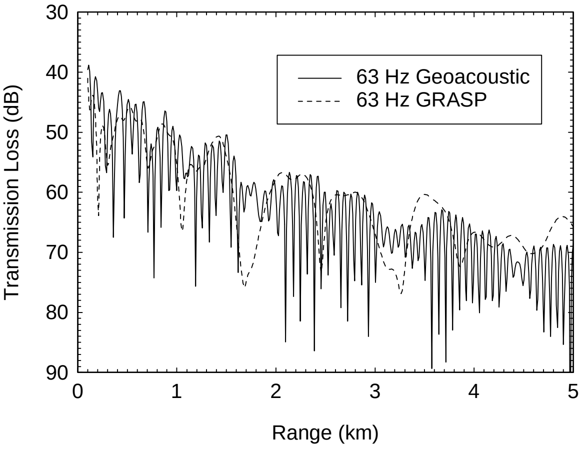

Figure 8 *TL* for Rottnest Shelf, 63 Hz

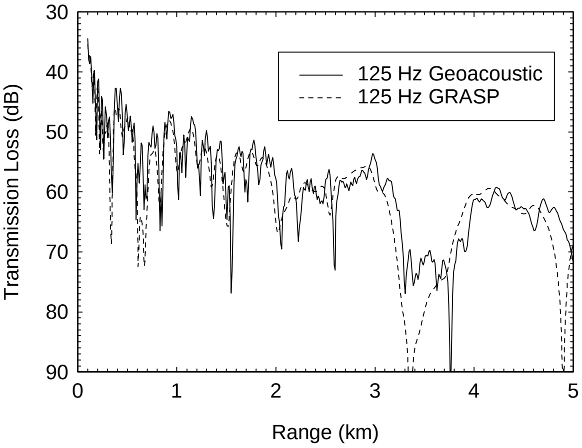

Figure 9 *TL* for Rottnest Shelf, 125 Hz

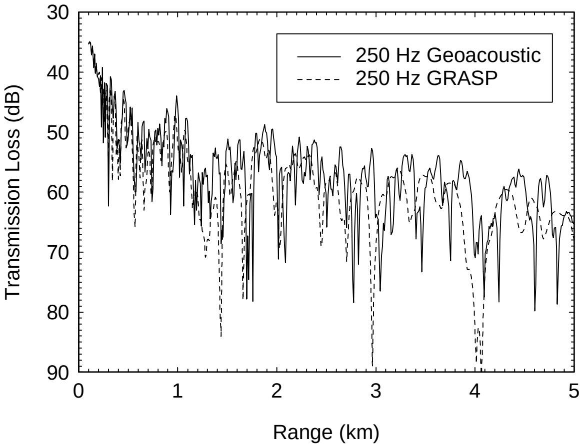

Figure 10 *TL* for Rottnest Shelf, 250 Hz

The data shown in Figures 8, 9 and 10 show an even better agreement in *TL* between the inverted seafloor and geoacoustic seafloor types. Here, both the amplitude of the *TL* and the gross features of the phase coherent *TL* are similar in each respective case. This is an interesting result, as the short range data requires knowledge of the bottom loss and phase angle at steep angles of incidence – the inverted seafloor description was expected to be overly simplistic for these cases.

Effect of Downward Refraction

The above transmission loss calculations were repeated for a downward refracting sound speed profile of gradient - 0.04 s^{-1}. This was expected to accentuate the effect of the seafloor on transmission loss, due to the increased bottom interaction.

Corresponding plots of *TL* for 250 Hz are shown in Figures 11 and 12.

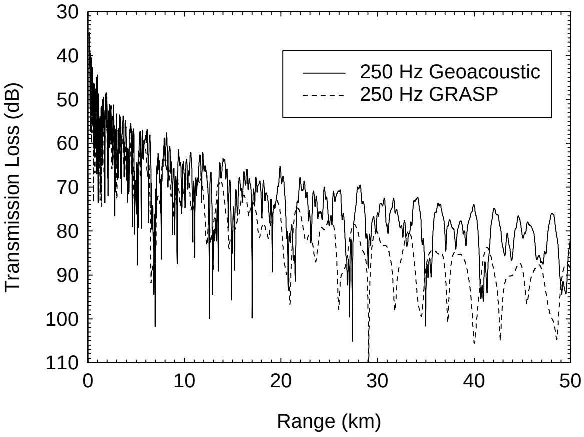

Figure 11 *TL* for Rottnest Shelf, 250 Hz, sound speed gradient – 0.04 s^{-1}

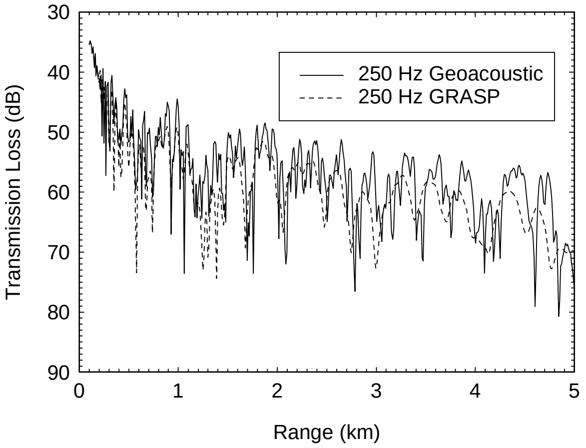

Figure 12 *TL* for Rottnest Shelf, 250 Hz, sound speed gradient –0.04

Figure 11 shows that the mean level of *TL* is sensitive to changes in bottom loss, but that the short range *TL* is less sensitive, as there is insufficient range over which the bottom can exert an influence. It is noteworthy that Figure 12 shows that the features of the phase coherent *TL* are still accurately predicted by the MOD inversion technique.

Conclusions

From the work presented above, it does appear that the MOD algorithm for the inversion of seafloor properties gives values of seafloor reflectivity for the Rottnest Shelf region which are in reasonable agreement with available geophysical data. Further, the MOD algorithm is shown to be robust to changes in source to receiver range, for small range values. Also, an air gun sound source, such as used by CMST, does appear suitable for use with the MOD technique.

If the reflectivity data inverted by the MOD technique are close to the actual values, it does appear that both long range and short range transmission data may be determined using that input data. With strong downward refraction, however, small errors in seafloor reflectivity do result in significant differences in long range transmission prediction.

References

1. Jones, A. D.; Clarke, P. A.; Bartel, D. W. and Sendt, J. S. “Transmission Loss inferred from a seafloor database – comparison with measured data”, 2000, Proceedings of UDT Pacific 2000, Darling Harbour, Australia, 7-9 February

2. Jones, A. D. and Bartel, D. W. “Spectral Variability in a Shallow Water Environment”, 1998, Proceedings of UDT Pacific 98, Darling Harbour, Australia, 24-26 February

3. Jones, A. D.; Bartel, D. W.; Clarke, P. A. and Day, G. J. “Acoustic Inversion for Seafloor Reflectivity in Shallow Water Environment”, 2000, Proceedings of UDT Pacific 2000, Darling Harbour, Australia, 7-9 February

4. Chapman, N. R. and Lindsay, C. E. “Matched-Field Inversion for Geoacoustic Model Parameters in Shallow Water”, October 1996, IEEE Journal of Oceanic Engineering, Vol. 21, No. 4, pp 347-354

5. Porter, M. B. “The KRAKEN Normal Mode Program”; 1995; SACLANT Undersea Research Centre

6. Mitchell, B. “GRaphical Acoustic Sediment Predictor (GRASP) using Spectral Variability”, AMRL Vacation Scholar Thesis, February 2000

7. Duncan, A. and McCauley, R. “Characterisation of an Air-Gun as a Sound Source for Acoustic Propagation Studies”, 2000, Proceedings of UDT Pacific 2000, Darling Harbour, Australia, 7-9 February