SEAFLOOR DATA FOR OPERATIONAL PREDICTIONS OF TRANSMISSION LOSS IN SHALLOW OCEAN AREAS

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ABSTRACT; The Maritime Operations Division (MOD) of DSTO is assisting the Royal Australian Navy in its assessment of a sonar performance prediction tool for range dependent ocean environments: TESS 2, prepared by Thales Underwater Systems (TUS). This assessment has included comparisons between acoustic transmission loss data measured by MOD at shallow ocean sites with range-dependent transmission predictions obtained by TUS based on a geophysical-based seafloor database. This task has included an assessment of the potential for an MOD in-situ technique to infer seafloor reflectivity at shallow grazing angles and provide input to TESS 2 for regions for which existing holdings of seafloor properties are sparse. Examples of comparisons are detailed in this paper. This paper also reviews the need for more detailed description of the seafloor for steep angles of incidence, and shows progress of a MOD technique for inference of seafloor properties suitable for short range transmission predictions.

1. INTRODUCTION

For maritime operations in continental shelf zones, for which ocean depths are less than about 200 m, the detection performance of Undersea Warfare (USW) and Anti-Surface Warfare (ASuW) sonar systems may be highly dependent on the specular reflection of sound from the seafloor. At frequencies used for passive sonar (up to about 500 Hz), seafloor interaction is usually significant and the local reflectivity is a critical factor. For higher frequencies, as used by active sonar systems (2000 Hz to 8000 Hz approx.), seafloor reflectivity is significant if the ocean is downwardly refractive. In these circumstances for which sonar signals impinge upon the seafloor, it is essential that the properties of the seafloor are known, so that the acoustic transmission may be modelled with accuracy and the performance of sonar systems may be anticipated with precision.

The TESS 2 system is in the process of being delivered to the RAN as its standard tool for the prediction of the performance of sonar systems for USW and ASuW applications. TESS 2 includes databases describing generic sonar systems, and contains an underwater component (known as "SAGE" [1]) which includes range-dependent acoustic models, plus databases describing the global ocean environment, including geophysical/textural/descriptive seafloor data. These environmental databases, whilst inclusive of the best available data, of necessity contain historical information which may have limitations due to the practicality of extensive surveying. As with any estimate of sonar system performance, the accuracy of the prediction from TESS 2 is dependent, to a critical degree, upon the appropriateness of the input parameters. This present paper reviews an investigation of the degree to which the predictions of acoustic transmission within TESS 2 might benefit from supplementation of the historical seafloor datasets with on-site measurements. This work is a continuation of the joint MOD/TUS work reported earlier [2, 3, 4].

In support of the RAN's desire to have a state-of-the-art sonar performance prediction capability, MOD has on-going programmes of research on testing acoustic transmission models and on the acoustic properties of the seafloor in shallow ocean regions. In a focussed activity which draws on this research, MOD is engaged in the assessment of the TESS 2 system with particular reference to its use within the Australian region. The longer-term research has provided MOD with a considerable body of at-sea data to apply to the assessment of the TESS 2 system, with transmission loss (*TL*) for a number of sites. Further, its research of rapid sensing techniques has enabled MOD to assess the viability of applying a unique method for *in-situ* determination of seafloor specular reflectivity as an adjunct to the TESS 2 system. The technique for *in-situ* determination of seafloor reflectivity is a refined version of that reported by Jones *et al* [5, 6]. This paper describes recent progress in the assessment of transmission predictions obtained by TESS 2 for ocean sites corresponding to MOD's holdings of *TL* data, and presents three-way comparisons of measured *TL*, TESS 2-predicted *TL* and predictions of *TL* based on seafloor properties inferred by MOD's rapid assessment technique. TUS Pty Australia has been involved in these comparisons, so that it is in a position to advise the practicality of implementing recommendations resulting from this work.

2. SEAFLOOR MODELLING

For acoustic transmission modelling, the seafloor is regarded as either an extension of the transmission medium, with layers of material described by appropriate acoustic properties (e.g. Figure 1), or is treated as an impedance discontinuity and is modelled by bottom loss or sound pressure reflection coefficient and phase angle data for each angle of incidence (e.g. Figure 2). The particular form of data required is dependent upon the type of acoustic transmission model, and on the way the wave equation calculations are implemented therein. In

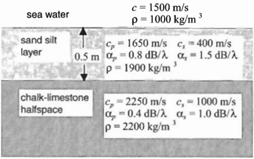

Figure 1: Simulated seafloor with absorptive basement

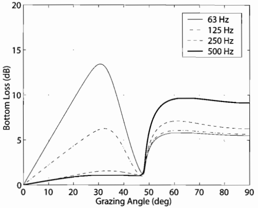

Figure 2: Bottom loss versus grazing angle for simulated seafloor of Figure 1

fact, both these forms of seafloor representation may be shown to be equivalent, and some models, e.g. KRAKENC [7], include algorithms which permit input to be provided in either form. Whatever the form of input data, a practical implementation in an operational model such as TESS 2 requires a dataset descriptive of seafloors in all zones in which operations are relevant. Historical data sampling is of necessity limited in extent and detail, and so some regions may be described with greater accuracy, whereas others are poorly known. A minimum level of description is a single set of parameters describing the seafloor as a uniform half-space for which the reflectivity is frequency-independent. By including detail, such as the nature of a sediment layer overlying a basement of alternate type (see Figure 1), frequency variations in reflectivity may be modelled. For the example of the data shown in Figure 1, the low frequency reflectivity approximates that of the absorptive basement (Figure 2), whereas the higher frequency behaviour approximates the high reflectivity of the thinner sediment.

For operational use, a seafloor model need be only as detailed as is required. For general USW applications, for shallow oceans, range values of interest are such that shallow grazing angles (< 10° approx.) describe effectively the complete seafloor behavior. As is apparent in Figure 2, but not derived here for sake of brevity, an appealing option is to limit the seafloor description to a linear function of bottom loss with grazing angle. However, as may also be shown by analysis, for short range predictions (< 500 m, very approximately), it is necessary to describe either the bottom loss and phase data at steeper angles of incidence, or it is essential to model the sub-bottom as a variation in properties with depth. The SAGE database achieves the latter to some degree, and the MOD *in-situ* inversion technique is based on, and uses, the former approximation, whereas for short-range predictions, a multi-layered description, as obtained by Hall [8] for example, is necessary.

3. ALTERNATE MODELLING OF SHALLOW SEAFLOOR BASED ON *IN-SITU* DATA

As input to TESS 2, TUS Pty Australia has developed a database of seafloor geophysical/textural/descriptive data and has applied algorithms for the inference of reflective acoustic properties. The SAGE global geoacoustic database has been derived from over eighty independent sources in the open literature and includes sediment province data gridded to a resolution of 2 minutes. As reported earlier [2] MOD and TUS have compared *TL* predictions, based on the SAGE database, with at-sea measurements of acoustic transmission carried out by MOD Salisbury. This work was limited in extent, but did show that for a shallow ocean region for which the seafloor was well surveyed, predictions of transmission loss obtained at low frequencies (125 Hz and 500 Hz) matched well the measured *TL* data for both range-independent (along-contour) and for range-dependent (down-slope) situations. This present paper shows how this work has been extended to show the result of using MOD's unique method for inversion of seafloor reflectivity [5, 6], as an alternative to the SAGE data, to illustrate the potential advantage of using the technique for rapid assessments in unsurveyed shallow ocean regions. In particular, this present study has focussed on the ability of the MOD inversion technique to provide a seafloor description which is appropriate for the prediction of underwater signals to long range in shallow ocean regions.

The site discussed in this paper (Site #2 ref [2]) was within the area covered by the Australian Continental Shelf Sediment Series (of the Australian Geological Survey Organisation and its predecessor, Bureau of Mineral Resources), for which the seafloor data available for TESS 2 existed as samples with 10 nautical mile spacing. Sand, silt, clay and gravel percentages, as well as the percentage carbonate, for surficial sediment, then classified the data. The geoacoustic properties installed within the SAGE database were determined using a modification of the Biot equations [9].

For data gathered during MOD acoustic transmission trials, the sound speed profiles for Site #2 are shown in Figure 3, and the bathymetry is shown in Figure 4. Here, Run 5 corresponds with a direction down the continental slope, whereas Run 6 was along the contour of the slope, at a depth approximated for modelling at 195 m. The sound speed data was inferred from temperature data versus depth obtained from

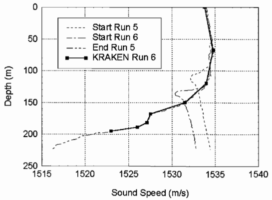

Figure 3: Sound speed profiles at Site #2

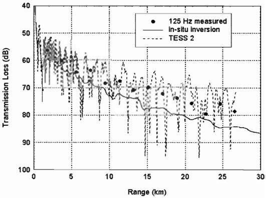

Figure 5: TL measured & predicted, Site #2 Run 6 – range-independent, 125 Hz

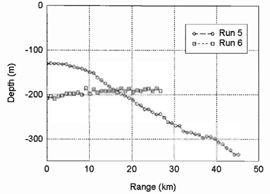

Figure 4: Bathymetry at Site #2

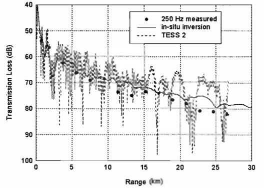

Figure 6: TL measured & predicted, Site #2 Run 6 – range-independent, 250 Hz

AN/SSQ-36 bathythermograph buoys. The ocean depth data was obtained from a 30 second resolution database [10].

MOD transmission loss data was obtained by deployment of small explosive signal sources (SUS charges) at intervals of one nautical mile, with receipt of signals on AN/SSQ-57 sonobuoys for which the output was appropriately attenuated. The received data were processed at MOD using the STAS software [11]. This was achieved by coherent determination of received signal intensity as a narrowband FFT spectrum, and an incoherent summation of intensity in the FFT bins within each one-third octave band, to arrive at one-third octave *TL* values.

4. TRANSMISSION MODELLING AND DATA

Acoustic transmission was modelled at Site #2 using the KRAKENC model [7] (run at MOD) and the TESS 2 version of the RAM model [12] (run at TUS). KRAKENC is a modal model capable of handling a seafloor supporting shear waves in range-independent and range-dependent ocean environments, whereas RAM uses the parabolic equation (PE) method for describing transmission in range-dependent ocean environments with zero shear speed in the sediment. RAM was run with the seafloor simulated as a half-space overlaid by a deep sediment in which the compressional speed increased linearly with depth according to an assumed gradient. KRAKENC was run with the seafloor described by a table of values of acoustic pressure reflection coefficient, and phase, as determined by application of the MOD seafloor inversion technique, which has been outlined in earlier studies [5, 6]. The sound speed profile data used for modelling is as shown in Figure 3. RAM was run using range-dependent data, where this was available; KRAKENC was run assuming range-independence for the along-contour Run 6 and range-dependent for down-slope Run 5.

The measured and modelled transmission data is shown in Figures 5 through 7. In each figure, the measured data is averaged over a one-third octave band for the relevant centre frequency, and is processed by the STAS software. The *TL* predictions obtained by the KRAKENC model have, likewise, been determined phase coherently at single frequencies, and are averaged incoherently over a one-third octave band - the same averaging process as imposed by the STAS software. For the range-dependent down-slope Run 5, KRAKENC was run using the coupled mode approximation. The RAM *TL* predictions are phase coherent determinations at a single frequency, and hence retain the amplitude variability typical of

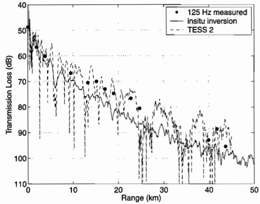

Figure 7: TL measured & predicted, Site #2 Run 5 – range-dependent, 125 Hz

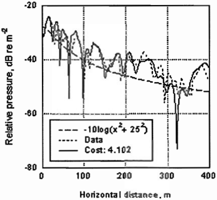

Figure 8: TL measured & predicted, seafloor model inverted using simulated annealing, 251 Hz

shallow water multi-path scenarios.

The data for Site #2 Run 6 show some variation over the frequency range 125 Hz to 250 Hz, but generally, the TESS 2 results, and the predictions obtained by KRAKENC with seafloor reflectivity determined by the MOD inversion, are all close to the measured data, even to 26 km range. In detail, at 125 Hz (Figure 5) the *TL* resulting from the TESS 2 prediction is slightly lower than from the KRAKENC prediction – presumably a result of the effective difference in seafloor reflectivity. At 250 Hz, in Figure 6, the TESS 2 data appears to under predict the measurement slightly, whereas at 125 Hz (Figure 5), the KRAKENC data based on the MOD seafloor inversion over predicts. Overall, both the TESS 2 result and the prediction of *TL* based on the MOD inversion are quite close to measurements for both frequencies and all range values shown. The good result from TESS 2 might be expected, as the seafloor knowledge for the site is extensive. The good agreement with the inverted seafloor reflectivity does suggest that the MOD technique is viable for unsurveyed sites.

For the range-dependent Site #2 Run 5, the RAM model predictions from TESS 2 are close to the measured data, as are the KRAKENC data which are based on the MOD seafloor inversion. As for the Site #2 Run 6 predictions at 125 Hz, the TESS 2 *TL* data are slightly less than the KRAKENC data, possibly a result of differences in the effective seafloor reflectivity implicit in the model input data. This issue is under present investigation.

5. SIMULATED ANNEALING INVERSION

To characterise transmission in shallow water environments at short range, descriptions suitable for small grazing angles, only, are not sufficient as significant components of the received signal arrive via steep angles of incidence. It is then necessary to have a geoacoustic model which is representative of the layered nature of the local seafloor. The method developed at MOD by Hall [8] uses received signal versus range data across several octaves to invert geoacoustic parameters (compressional and shear wave speeds, compressional and shear wave attenuations, density) for several layers of material, plus layer thickness, and an underlying basement.

For application to a sound range site, for which ocean depth is 47 metres, the signal from a projector at 20 m depth was received at the seafloor, for tonal frequencies of 53, 63, 125 and 251 Hz, for horizontal ranges out to 400 m. Headwave data from earlier airgun tests were first used to estimate basement compressional wave speed (6100 m/s) and basement depth. The received CW signal data were then inverted to obtain remaining parameters of a geoacoustic model. The inversion algorithm was an implementation of an adaptive simulated annealing method [13]. Here, the cost function used by Hall is the rms of the residuals between measured and computed values for received signal (in dB) as computed with the OASES model [14] over the four frequencies. The performance of the inversion was examined as the number of uniform layers overlying the basement was set to 1, 2 and 3. A best result with 2 seafloor layers was found to be similar to a best result with 3 layers, and was selected for subsequent modelling work. An example of the agreement between measured received signal data and computed data (at 251 Hz) is shown in Figure 8, where comparison is also made with spherical spreading. The very high degree of agreement highlights the necessity of a description of seafloor layering for very short range predictions of signal data. The level of fidelity in such seafloor descriptions is not normally justified for inclusion in performance models such as TESS 2, unless very short range phenomena is of interest in a particular location.

6. CONCLUSIONS

Based on the limited comparisons presented above, it does appear that the TESS 2 system provides predictions of acoustic transmission of good accuracy for shallow ocean regions for which high resolution bathymetry data is available and for which there is a high confidence in the accuracy of data contained within its seafloor database. This brief study has considered low sonar frequencies. Further, it does appear from this work, that if determinations of seafloor reflectivity within operations are feasible using the MOD *in-situ* technique, it will be distinctly advantageous for these data to be selected as input to a sonar performance prediction tool, for shallow water applications in poorly surveyed areas. Lastly, a technique has been demonstrated which may aid effective surveying in some regions for which short range predictions are particularly critical. In any event, if an accurate prediction of acoustic transmission is to be achieved, detailed sound speed data is required.

ACKNOWLEDGEMENT

The authors acknowledge the beneficial suggestions made by Dr. M. V. Hall of MOD, and his provision of Figure 8.

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Letters to the Editor

Business Opportunity

Acousteel Ltd is a British company manufacturing an innovative sound deadened steel product – Acousteel. Utilising automotive laminated steel technology, Acousteel offers reductions in noise of up to 30 dB(A). Whilst the technology is proven the product is for the first time being manufactured in sheet format with gauges ranging from 1mm-6mm, thus making this extraordinary product available for the first time to all areas of industry ranging from Air conditioning to Roofing applications.

After a successful launch of the product within Europe, Acousteel Ltd is now looking for Agents/Distributors of the product within Australia, with the aim of duplicating proven and profitable markets whilst identifying new applications. For more information visit our website www.acousteel.com and/or contact Managing Director Mark Ingram at info@acousteel.com.

Expert Witness

I refer to Ken Scannell's letter (vol 29(3), 132), and endorse his suggestion that AAS might prepare a code of practice for members who may be approached to act as expert witnesses and are perhaps unfamiliar with the (very extensive) literature which now exists on their roles and responsibilities.

I am glad to report that in my own case, relating not to noise exposure but to issues in asbestos exposures and heat stress, none of the lawyers who have approached me have ever suggested a "no win – no pay" payment basis for my professional opinion. This experience relates to opinions requested over a period of some 15 years, and even includes those where my opinion has not been in support of the party on whose behalf it was requested.

The question of payment in advance is, however, a difficult one, or at least has been so in my experience, in view of the sometimes almost impossibility of indicating the time needed for preparation or still less the time which may be spend in court. When first dealing with lawyers for whom I have never previously provided opinion. I have indicated the time based consultancy fee rate it is usual for me to charge and submit accounts accordingly. Usually however the fees for appearances are governed by the practice of the court concerned and I think it unlikely that any arrangement for advance payment is possible.

Nevertheless I agree with Ken that it would be excellent if the AAS can indeed provide a Code to which members can refer as binding on them, as members of a professional society, in assisting the proper decision in any legal proceedings.

Gerald Coles (MAAS, FAIOH)

Expert Witness Reply

I would like to thank Gerald Coles for this reply to my letter (vol 29(3), 132) and his support for an AAS Code of practice for the Expert Witness. While I accept that the final fee for work carried out is nearly always impossible to predict, a retainer based on a minimum estimated fee would very useful. The final payment could be made after the case is completed. This would remove, or at least minimize, any inhibitions the expert may feel that she or he is under from expressing totally frank opinions.

Ken Scannell MAAS