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# UW180. Modelling the vertical directivity of noise from underwater drilling

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To the novice, quantifying acoustic propagation from an underwater source is often limited to spherical spreading. This approach is justified when considering a high-frequency, omni-directional source located far from a boundary however there are other scenarios where this is insufficiently rigorous. Attention is drawn to the emerging marine renewables sector where acoustic propagation from sources of sound, in particular underwater drilling, cannot be modelled accurately using such a simple representation. For these, the variation in sound level radiating directionally from the source is a key parameter. It is noted that the sound directivity arising from the drilling site has, hitherto, received scant attention in the published literature with little data available. A pragmatic approach to modelling radiated noise from underwater drilling is therefore required. A simple frequency-dependent radiation pattern of sound from the source is proposed. The radiation pattern is used as an input parameter to calculate acoustic propagation losses determined using otherwise standard computer programs. The applicability of the directivity model is demonstrated by comparisons with real data acquired during the summer of 2011 when underwater noise was recorded during the drilling of a foundation socket for a wave energy device at the EMEC range, Billia Croo, Orkney.

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# 1 INTRODUCTION

The potential impact on marine life of man-made underwater sound has been the subject of intense scrutiny for a number of years. Certainly in the UK, a project that is involved in generating sound underwater requires the submission of relevant documentation to the regulatory authorities before consent is granted. The associated studies often involve the prediction of underwater sound levels as an aid to determining the acoustic footprint of a particular activity. Often though, the acoustic propagation is based on rudimentary techniques involving simple geometrical spreading [1, 2]. In the context of underwater drilling noise, this technique has the advantage of being very easy to compute – often involving nothing more than some mental arithmetic. There are however a number of drawbacks – (i) the impact of the environment on the underwater sound is completely ignored and (ii) the technique fails to take into account the vertical directivity of the sound being emitted by the drill. By ignoring the distribution of acoustic energy at the point of emission, it is possible that modelled sound pressure levels (SPL) may be under- or over-estimated at some location downstream.

This paper commences by discussing a series of noise measurements made in the vicinity of underwater drilling activity. A simple model for the vertical directivity of sound from an underwater drill is proposed. An acoustic propagation computer programme is used to estimate levels of sound which are subsequently compared with the measured data.

# 2 MEASUREMENTS

The European Marine Energy Centre (EMEC) is an organisation based in Orkney which is involved in the testing and development of marine renewables namely underwater wave devices and tidal turbines. Developers may site their prototype devices on one or other of the EMEC ranges for the purpose of gaining long-term performance data.

During the summer of 2011, a location at the EMEC wave energy site, Billia Croo (see Figure 1), was prepared for the subsequent emplacement of an Oyster 801 wave device currently under development by Aquamarine Power Ltd [3]. The Oyster is a hinged device that opens and closes under the action of passing waves. This results in the pumping of hydraulic fluid under pressure across a turbine which itself is connected to an electrical generator. The Oyster 801 is secured to the seabed by means of a foundation pile which is grouted into a foundation socket drilled into the seabed. The drilling equipment used was the Seacore Teredo 40 reverse circulation, large diameter drill rig [4]. This was equipped with a 4.25 m diameter drill bit dressed with tungsten carbide roller cutters that ground away at the rock interface. As the depth of the resulting socket increased, sections of drill stem were added and this allowed steady continual downward pressure to be maintained at the drill head. The rock cuttings were flushed away using a jet of water which travelled up the drill stem and eventually over the side of the drilling vessel from a height of several metres above water level.

Baseline noise recordings were made over a series of transects centered on the installation site and these are shown in Figure 1. The hydrophone used was a Reson TC4032 calibrated over the frequency range 50 Hz to 100 kHz and having a nominal receive sensitivity of -168 dB re. 1V/µPa. All recordings were made with the hydrophone set to 8.5 metres depth.

Background noise levels around the site were recorded whenever drilling was not taking place. A typical example of the pressure spectrum averaged, in this case, over a 40 second window is shown in Figure 2. A series of recordings of underwater noise (including drilling noise) were also made during drilling activity and the time-averaged power spectral density is included in Figure 2.

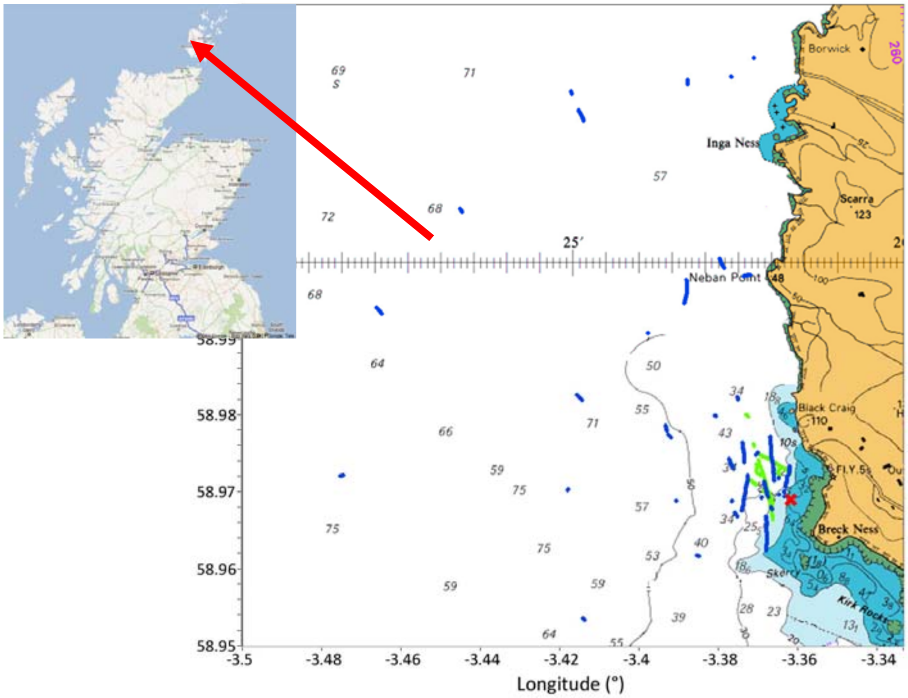

Figure 1: Location of background underwater noise (green), total noise (blue) and drill site (red cross) at the EMEC range, Orkney

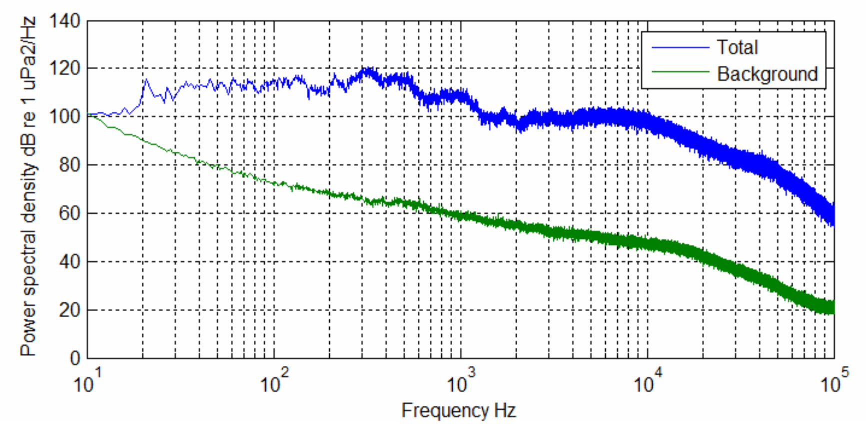

Figure 2: Averaged power spectrum of total recorded noise and naturally occurring background noise

# 3 COMPUTER MODEL

## 3.1 Sound source directivity

The application of a valid vertical directivity pattern to the outgoing sound is the key to this analysis. A review of the international published literature failed to reveal any work at all on this particular subject. In the absence of going back to first principles with regards to establishing an appropriate radiation pattern and in the interests of commercial expediency where a pragmatic solution was required, it was necessary to make a couple of assumptions in order that a suitable beam pattern model may be applied:

(i) Drilling noise arises principally from the action of the drill bit on the rock face and that any noise arising from or being transmitted by the drill stem is minimal;
(ii) The outgoing source pattern can be described as a circular plane array.

Given these assumptions, guidance provided by Urick [5] was used to generate a suitable frequency dependent beam pattern based on a first order Bessel function and a plot of this for a number of signal frequencies is shown in Figure 3.

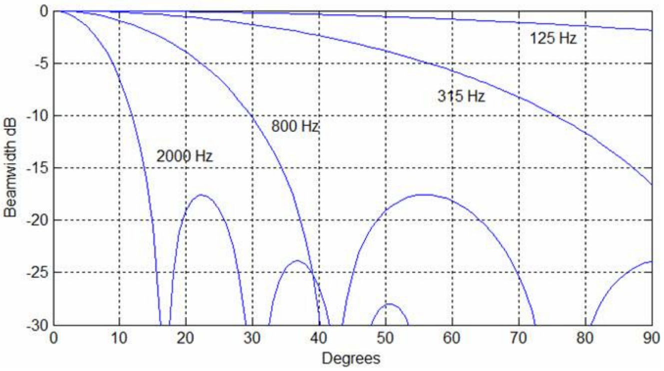

Figure 3: Beam pattern for 4 sample frequencies

## 3.2 Marine acoustic environment

In order to model the underwater noise recorded at Billia Croo, it was necessary to undertake broadband acoustic propagation modelling in the frequency range 50 Hz to 100 kHz. Modelling was carried out at a total of 36 x 1/3rd octave centre frequencies between these limits. Such that the broad range of frequencies was covered, computer programs based on two acoustic modelling techniques were used. For the low frequencies (from 50 Hz to 1000 Hz), RAM [6] was used while for the higher frequencies BELLHOP [7] was used. Both programs permit a description of the environment in terms of a range-dependent ocean overlying two lossy, fluid layers representing the seabed sediment of given thickness and a semi-infinite basement respectively.

From Figure 1 it was noted that a number of the recorded data locations were aligned along certain transects radiating from the drill site. Accordingly, bathymetry profiles along 3 transects at bearings 273°, 290° and 330° centered on the drilling site at 58°58.32' N, 003°22.8' W and of length 7 km were extracted from the global database ETOPO1 [8] and these are shown in Figure 4. It is noted that the transects are generally shallow, certainly at short ranges: at the drilling site, the water depth is only 17 m. The effect of this is that acoustic energy at very low frequencies (<≈80 Hz) does not propagate and is instead, rapidly attenuated by the seabed [5]. A sound speed profile for the area of interest was obtained from the oceanographic database WOA09 [9] and this is shown in Figure 5. Charts of seabed sediment coverage [10] indicate that sand overlying a metamorphic basement is the predominant geological structure. From the guidance provided by Hamilton [11, 12, 13] on seabed sediments, suitable geo-acoustic parameters for the seabed were derived and these are summarised in Table 1 below.

Frequency dependent propagation losses were applied to the drilling noise spectrum. To this was added the background noise spectrum given in Figure 2 in order to determine total SPL at a given depth and range.

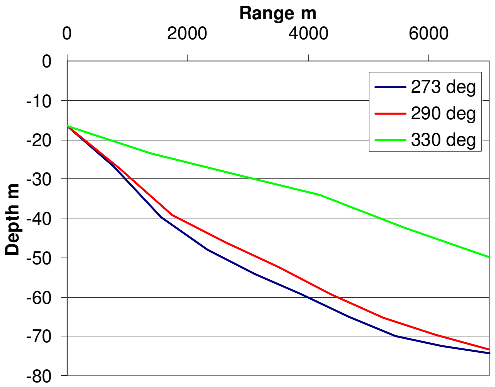

Figure 4: Bathymetry along each transect

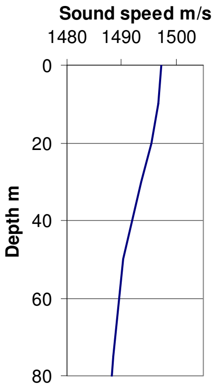

Figure 5: Sound speed profile

| Layer | Compressional wave velocity Vp m/s | Density kg/m$^3$ | Attenuation dB/m/kHz | Thickness m |
|---|---|---|---|---|
| Terrigenous sand | 1647 | 2000 | 0.454 | 10 |
| Metamorphic basement | 5548 | 2745 | 0.095 | -∝ |

Table 1: Geo-acoustic parameters for acoustic propagation modelling

# 4 DISCUSSION

Figure 6 shows modelled total SPL along each transect as a function of range for two examples: drilling noise with an omni-directional beam pattern; and drilling noise having the frequency dependent beam patterns as shown in Figure 3. It will be seen that over the entire range, the omni-directional SPL is consistently and significantly higher than that modelled using a directional source. The lower SPL is attributed to the directional source having a beam pattern where much of the acoustic energy above a frequency of around 100 Hz is directed predominantly downwards with much lower levels transmitted via the sidelobes being available for horizontal propagation.

Figures 7 to 9 allow comparison of predicted SPL with measured SPL for each transect. Figure 7 shows modelled and measured data for the transect 273°. When the omnidirectional beam pattern is included in the modelled SPL, it is seen that out to a range of approximately 2000 m the function is 40-50 dB higher than the SPL modelled with the beam directivity included. Also included in the figure are noise level data recorded at ranges 436 m, 685 m, 3240 m and 6540 m. At each range, the recordings are seen to vary by up to 18 dB. This is viewed as being due to a combination of the varying, localised effect of the environment on the sound as it propagates as well as to the multimodal structure of the sound field leading to peaks and nulls in the field at any given measuring location. In general however, it is evident that the modelled directional SPL is a consistently better fit to the measured data than the omni-directional SPL.

This contention is supported to a greater or lesser extent by the data shown in Figures 8 and 9 for transects 290° and 330° respectively. As before, the omni-directional modelled SPL is higher than the directional sound over the entire range modelled.

In order to determine the significance of the variance between the recorded noise levels with either of the modelled data sets, a single factor analysis of variance (ANOVA) was calculated using an appropriate null hypothesis. In this instance, the null hypothesis was that there was no significant difference between the omni-directional beam and the directional beam when compared with the measured data. For this, a rigorous significance level of 0.001 was selected.

The results, summarised in Table 2 for each of the data sets, show that F is greater than $F_{critical}$ and P is less than 0.001. The null hypothesis is therefore rejected as it is clear that it is 99.9% certain that the predicted data modelled with a beam pattern is a better fit to the measured data than is the omni-directional source.

| Transect | Beam | Average | Variance | F | $F_{critical}$ | P-value |
|---|---|---|---|---|---|---|
| 273 | $\theta(freq)$ | -7.130 | 74.473 | 392.3 | 11.124 | 8.40785E-51 |
|  | omni | -40.59 | 242.4 |  |  |  |
| 290 | $\theta(freq)$ | -7.433 | 39.081 | 3294.8 | 11.124 | 2.2957E-134 |
|  | omni | -55.45 | 38.602 |  |  |  |
| 330 | $\theta(freq)$ | -2.994 | 26.115 | 8238.4 | 11.124 | 2.5138E-176 |
|  | omni | -52.77 | 7.272 |  |  |  |

Table 2: Summary of ANOVA analysis on recorded and modelled data

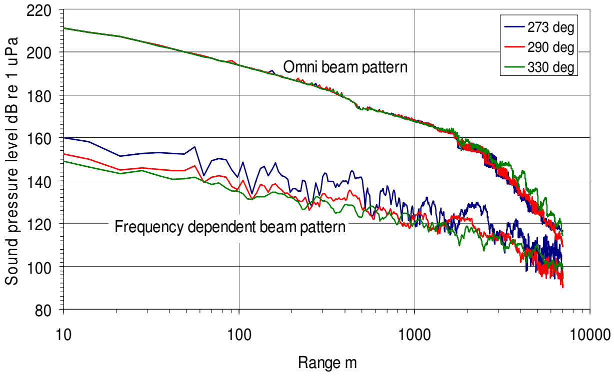

Figure 6: Modelled total underwater noise incorporating drilling noise with and without beam directivity pattern

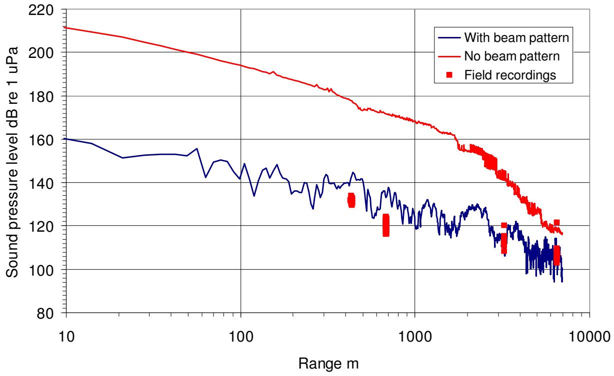

Figure 7: Comparison of modelled total underwater noise with noise recorded along transect 273°

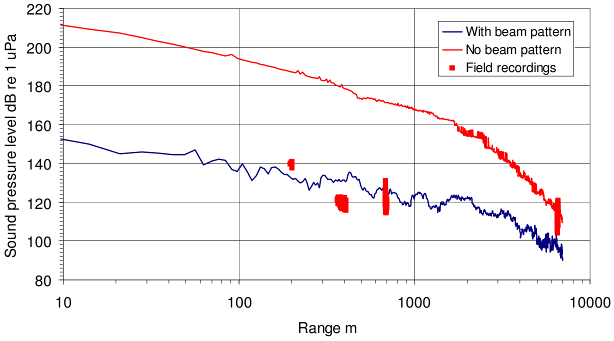

Figure 8: Comparison of modelled total underwater noise with noise recorded along transect 290°

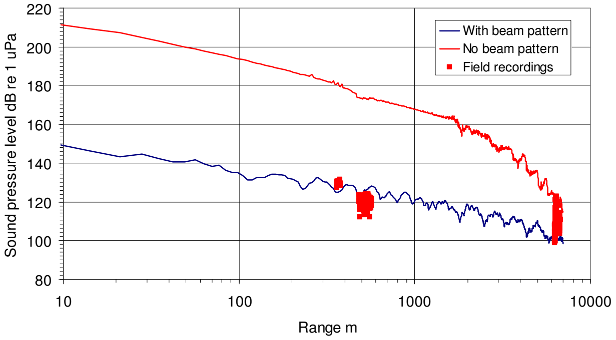

Figure 9: Comparison of modelled total underwater noise with noise recorded along transect 330°

## 5 SUMMARY AND CONCLUSIONS

On the basis of the evidence presented in this paper, it is clear that a beam pattern should be applied when attempting to model accurately the propagation of underwater drilling noise. Failure to do so could have significant consequences. For instance, in the context of environmental impact assessment, it is necessary to determine ranges over which various acoustic impact criteria such as permanent or temporary deafness; or behavioural reactions might arise. By neglecting to include a beam pattern to the outgoing noise, the SPL at a given range could be over-estimated. This in turn could lead to expensive and time-consuming mitigation procedures having to be applied when in actual fact, it might not have been necessary to do so.

The beam pattern used in the analysis discussed in this paper was based on a notional point source having a directivity pattern described by a first-order Bessel function. It is not clear whether this is the definitive radiation pattern for underwater drilling noise. However, the modelling discussed in this paper indicates that, in any event, it went some way to quantifying the acoustic directivity of the noise generated during drilling activity. It is hoped that this work may provide the spur to subsequent analysis of this arcane problem.

## ACKNOWLEDGEMENTS

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