Project Title	Underwater noise and offshore wind farms.
Project Number	COWRIE – ACO-04-2002
Investigators	S J Parvin and J R Nedwell
Company	Subacoustech Ltd.
Report Number	726R0103
Date	25th October 2006

Underwater noise survey during impact piling to construct the Burbo Bank Offshore Wind Farm.

Introduction

The underwater noise generated during offshore wind farm construction has been highlighted as having the potential to impact on marine receptors. However, the information that is required to predict impact, that is, the levels of noise created, the extent to which the noise is able to propagate through very shallow inshore waters, and the likely response to this sound by marine species is not well established. The Collaborative for Offshore Wind Research Into the Environment (COWRIE) has taken an initiative to provide information in this area, and has contracted Subacoustech Ltd to undertake a series of measurements on their behalf. The programme involves baseline measurements prior to wind farm construction, and construction and operational noise measurements at UK wind farm sites.

The wind turbine monopile support can be secured into the seabed using a number of techniques depending upon the seabed substrate. The most common, and straightforward approach is to impact pile the support into to the seabed to a depth of approximately 20 m. This brief report provides a summary of the measurement of underwater noise during impact piling operations to construct the Burbo Bank offshore wind farm site. It is the intention that full analysis and reporting of the noise data is included in the final contract report for the programme, due in the Spring of 2007.

Measurements

The Burbo Bank offshore wind farm site is located in Liverpool Bay, at the entrance to the River Mersey. When complete the wind farm is intended to comprise twenty-five turbines. Each turbine is fixed to a steel monopile support, approximately 32 m in length and of 4.7 m diameter.

During the period from Monday 10th July to Monday 24th July 2006, Subacoustech Ltd deployed a team of engineers from Mostyn dock to undertake measurements of the impact piling noise during construction of the Burbo Bank offshore wind farm. During this period the construction was severely hampered by high winds and repeated failures of the construction barge crane. Measurements were, however, obtained on the evening of Monday 11th July during impact piling operations to secure pile B7 (BB27), and in the early hours of Sunday 16th July between 00:30 and 02:20 during operations to secure pile B4 (BB24). The team also deployed to sea on Friday 14th July and in the early hours of Monday 24th July, but due to faults and delays no piling took place and the team were only able to obtain background sea noise measurements.

All underwater sound recordings were undertaken using low noise Bruel & Kjaer hydrophones deployed from the side of the survey vessel. The hydrophone was attached to an anti-heave buoy, which trailed behind the boat. During sound recordings the survey vessel's engines and other equipment which might have interfered with the measurements, were turned off and the boat was allowed to drift

The sensitivity of the measuring hydrophones is traceable to Danish Primary Laboratory of Acoustics (DPLA) and National Institute of Standards and Technology, USA (NIST) international calibration standards. Signals from the hydrophones were pre-emphasised and amplified using purpose designed Subacoustech equipment. The underwater sound measurement system was calibrated using a Bruel and Kjaer, Type 4223 pistonphone calibrator (S/N 1051331). The calibrator is regularly compared with, and is traceable to, International Standards.

Underwater sound recordings were made at a sample rate of 350,000 samples.sec^{-1}. When de-emphasised these wideband frequency recordings allow post processed acoustic analysis over the frequency range from 1 Hz to 175 kHz (covering the full audiometric frequency range of fish, human divers and marine mammal species).

Unweighted sound levels.

Broadband sound recordings were undertaken at incremental ranges from the construction operation. The first set of measurements was taken on the 11th July at ranges from 100 m to 15 km along a transect line on a bearing of 310^{0}. The water depth along this transect varied from 7 m in the immediate vicinity of the pile to a depth of 24 m at 15 km. From the piling operation to a range of approximately 4 km, the water depth was shallower than 10 m. On this night there were high winds, and the construction operation was halted for a period. The sea was choppy with breaking waves, and a swell of several metres.

The unweighted peak to peak noise level data with range obtained during this construction operation is shown as 'Transect 1' in Figure 1. At measurement ranges from 100 m to 5 km, there was a high level of signal to noise, and the individual pile strikes can clearly be identified in the noise time history records. The data indicates that the unweighted peak to peak noise varied from 207 dB re. 1 μPa. at a range of 100 m to approximately 143 dB re. 1 μPa, at a range of 5 km. Data was also recorded at ranges of 10 km and 15 km, but with the high background sea noise level on this night, the pile strikes are difficult to distinguish, and the data may therefore be influenced by the background noise.

Using the underwater sound transmission loss model of the form;

$$L_r = SL - N \log r - \alpha r \qquad \text{eqn. (1),}$$

where L_r is the underwater sound level at range r, SL is the source level, N is the geometric transmission loss coefficient and α is the underwater sound absorption loss in dB per metre. A least sum of squares fit to the measured data acquired at ranges from 100 m to 5 km indicates broadband (1 Hz to 175 kHz) sound propagation that can be described by the expression;

$$L_r = 249 - 21 \log r - 0.0047\, r \qquad \text{eqn. (2).}$$

The measured data from transect 1 therefore indicates a peak to peak Source Level of 249 dB re. 1 μPa @ 1 m, with a geometric spreading loss factor of 21 and an absorption co-efficient of 0.0047 dB.m^{-1}.

The second set of data was obtained during the impact piling operation to secure pile B4 (BB24) in the early hours of 16th July 2006. During this piling operation the sea state was slight with a low swell. Initial measurements were conducted at a range of 20 km, along a bearing of 270^{0} (Transect 2) in a water depth of 29 m. Distinct pile strikes (good signal to background noise) were recorded at a level of approximately 135 dB re. 1 μPa. The survey vessel therefore moved out to a range 25 km from the piling operation. At this range the individual pile strikes were audible on the instrumentation headphones, but were difficult to identify against the sea noise level in the noise time history data. Further measurements were taken along the 270^0 radial transect at ranges of 15 km, 10 km, 7 km and 5 km, at which point the piling ceased.

Figure 1 presents the peak to peak levels of unweighted noise measured along transect 2. In order to fit the data to an acoustic model, the data from transect 1 (100 m to 2 km) has been used to approximate the data at closer range. In this case the sound level with range is described by,

$$L_r = 250 - 23 \log r - 0.007\, r \qquad \text{eqn. (3).}$$

The measured data from transect 2 at long range, therefore indicates a peak to peak Source Level of 250 dB re. 1 µPa @ 1 m, with a geometric spreading loss factor of 23 and an absorption coefficient of 0.0007 $dB.m^{-1}$.

Although the depth profile of the two radial transects was similar, the broadband sound propagation data indicates a higher level of absorption with range for transect 1 than for transect 2. This becomes apparent for the measured data at ranges greater than 5 km. A possible cause of this variability is the high sea state conditions of the 11 July (transect 1) which may have caused higher levels of sound loss.

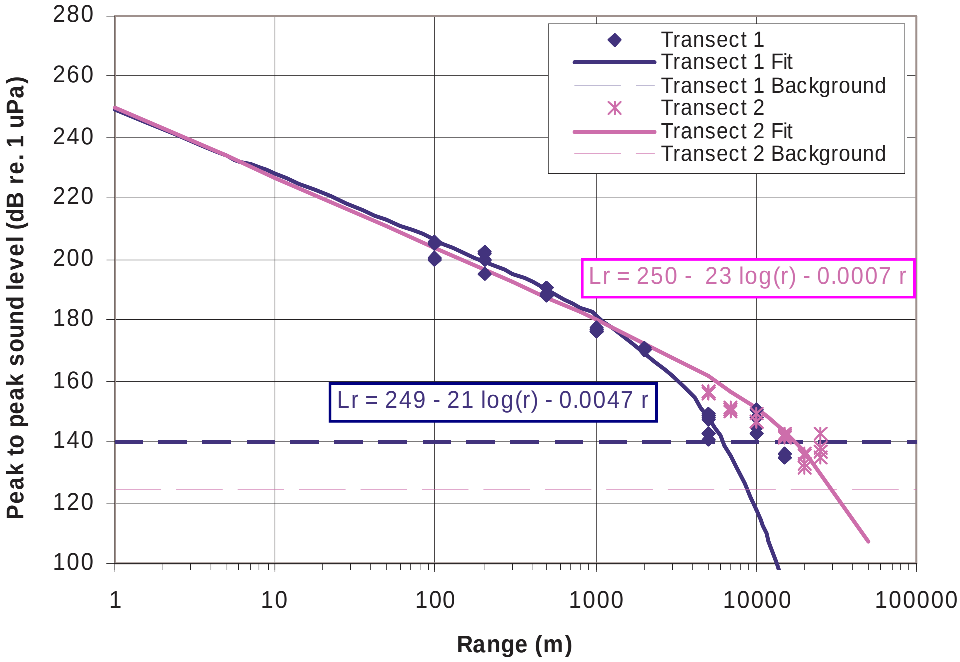

Figure 1. Peak to peak un-weighted impact piling noise with range measured during construction of the Burbo Bank offshore wind farm.

Species perceived sound level (dB_{ht}).

Audiological injury and behavioural effects of sound are related to the sound energy in the auditory bandwidth of the receptor species. To obtain a measure of this the raw underwater sound time history data files have been passed through a time domain Finite Impulse Response (FIR) filter that replicates the hearing sensitivity of the animal. The measure that is obtained, the dB_{ht}, is a measure of the level of the sound above the animals hearing threshold, or its "perception level".

Figure 2 presents the measured dB_{ht} peak to peak levels with range for the herring (*Clupea harengus*) during impact piling operations to construct the Burbo Bank offshore wind farm. As the hearing response of the herring does not cover the entire measurement range, or to the same level of sensitivity as the measuring hydrophone, the levels of sound after filtering for herring hearing sensitivity are considerably lower than those presented in Figure 1. The modelling of dB_{ht} level with range has been undertaken using the data from transect 1 for ranges from 100 m to 2 km, and from transect 2 for measurement ranges from 5 km to 25 km. In this case, the data indicates a source loudness level for impact piling operation of 178 dB_{ht}(*Clupea harengus*) @ 1 m, with losses with range described by the expression;

$$L_r = 178 - 25 \log r - 0.0011\, r \qquad \text{eqn. (4).}$$

Based on this 90 dB_{ht} loudness criteria, the data presented in Figure 2 indicate that the impact piling operation may cause a strong behavioural avoidance response in herring to a range of approximately 2.6 km. Comparison with the perceived background levels of noise measured during non-piling periods suggests that the piling operation would have been audible to the herring to a range of approximately 15 km.

Figure 3 presents the peak to peak dB_{ht} level with range for several species of fish and marine mammal, determined by the same analysis process as that for the herring. The marine mammal species initially hear the piling noise at higher loudness levels than the species of fish, but due to the higher propagation losses at the sound frequencies perceived by marine mammals, the dB_{ht} level decreases more rapidly with range.

Based on a 90 dB_{ht} loudness criteria, Table 1 presents the predicted behavioural response range for species of fish and marine mammal.

Species	90 dB_{ht} range
Bass	500 m
Dab	500 m
Cod	2 km
Herring	2.6 km
Harbour porpoise	5 km
Bottlenose dolphin	4 km
Striped dolphin	4 km
Common seal	3 km

Table 1. Summary of predicted behavioural avoidance range (based on a 90 dB_{ht} loudness criteria) from measured piling noise during construction of the Burbo Bank offshore wind farm

Discussion and summary

Based on measured noise data at ranges from 10 m to 25 km, a peak to peak Source Level noise of approximately 249 dB re. 1 μPa @ 1 m, has been determined for impact piling operations with a 4.7 m diameter steel pile during construction of the Burbo Bank offshore wind farm. This agrees well with the levels determined from measurements during construction of the Barrow (252 dB re. 1 μPa @ 1 m for a 4.7 m diameter pile), North Hoyle (249 dB re. 1 μPa @ 1 m for a 4.0 m diameter pile) and Kentish Flats (243 dB re. 1 μPa @ 1 m for a 4.3 m diameter pile). There is, however, considerable variability in the propagation of this sound with range. The sound propagation data for Burbo Bank resembles that for other very shallow water sites with silt and sand banks, where the sound propagation is probably dominated by interaction with the seabed, resulting in both high geometric and absorption losses.

.

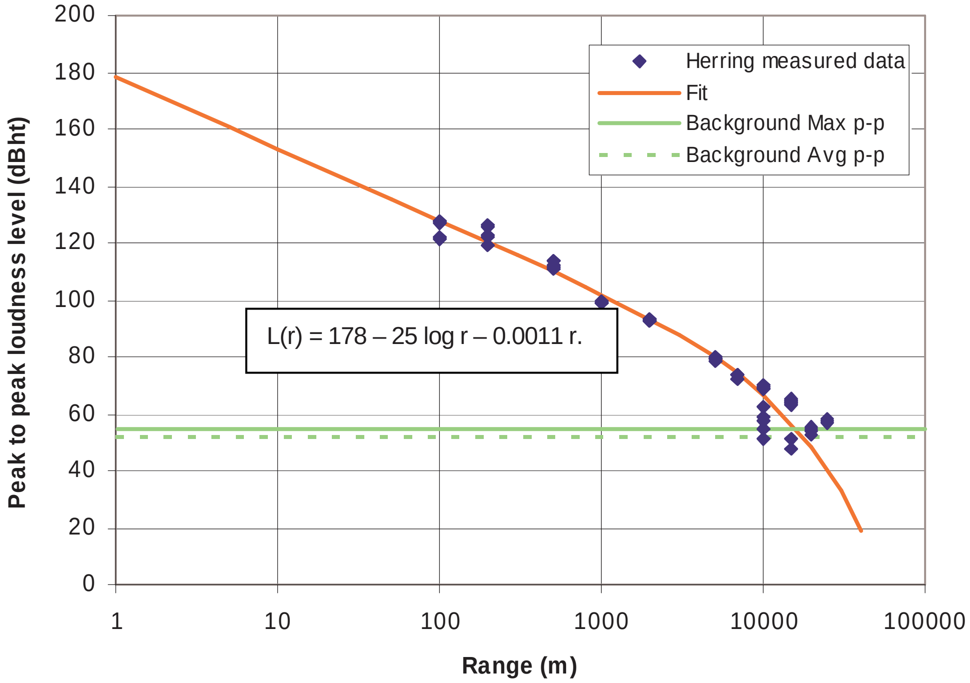

Figure 2. Peak to peak herring loudness level (dBht (Clupea herangus)) during impact piling operations to construct the Burbo Bank offshore wind farm.

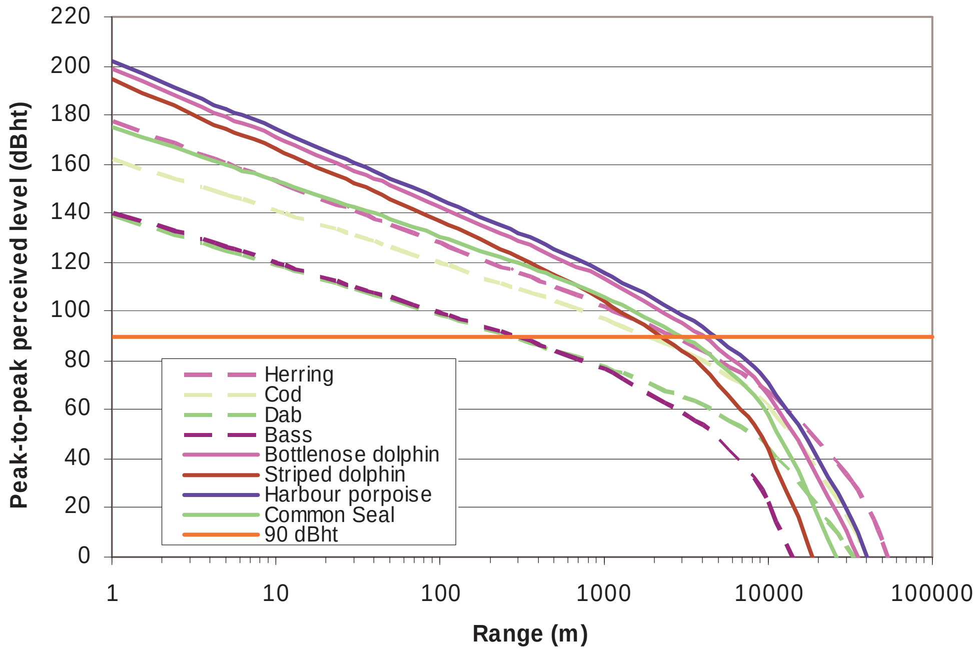

Figure 3. Peak to peak perceived sound level (dB_{ht}) for various marine species during impact piling operations to construct the Burbo Bank offshore wind farm.