THE NOISE RADIATED BY MARINE PILING FOR THE CONSTRUCTION OF OFFSHORE WIND FARMS

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Abstract:

The most commonly used method for the installation of offshore wind turbines in the shallow coastal waters in the UK is marine piling. The construction technique consists of steel piles being driven into the seabed using powerful hydraulic hammers. It is a source of high-amplitude impulsive sound has the potential for impact on marine life.

Methodologies developed for measurement of marine piling are described in this paper, and data are presented for piles of 5.2 m in diameter driven by hammers with typical strike energies of up to 1,370 kJ. Data were recorded as a function of range from the source using vessel-deployed hydrophones, with the data then used in the estimation of energy source level.

In addition, fixed acoustic buoys were used to record the entire piling sequence, including soft-start. The dependencies of the radiated noise on the physical parameters of the piling operation are discussed, along with limitations and knowledge gaps.

Keywords: *Underwater noise, marine piling*

1. INTRODUCTION

Increasing levels of man-made sounds in the ocean (whether deliberately generated or not) have led to concern over marine noise pollution and its effect on marine life [1]. A significant source of impulsive underwater noise is marine piling where a pile is driven into the sea-bed using a hydraulic hammer. This technique is used to drive piles into the sea-bed in relatively shallow water for construction of offshore windfarms, bridge supports, and offshore structures associated with the oil and gas industry.

In this paper, results are shown of measurements of the noise radiated during construction of offshore windfarms in the UK. Data is shown in this paper for piles of 5.2 m diameter driven by hammers with strike energies of up to 1,370 kJ. The methodology developed for measuring marine piling noise has been designed to record the temporal, spatial and spectral characteristics of the radiated sound field [2]. In the method, the use of a fixed recording buoy allows the full piling sequence to be measured so that variations in the temporal and spectral characteristics of the acoustic field may be assessed. This enables the effect of any source level variation with time to be determined, for example that due to a soft start procedure [3]. To assess spatial variations in the radiated acoustic field, recorded samples are also made using hydrophones deployed from a vessel which traverses the field along a radial transect away from the pile location [4-9]. This latter set of measurements allows an estimate of the effective source level to be made if a suitable transmission loss model is used. Measurements made using the described methodology may be used to estimate the overall sound exposure of marine life using accepted exposure metrics and criteria for the threshold of bio-physical or behavioural effects [10,11].

2. METHODOLOGY

The methodology used for the measurements reported here has been described elsewhere in detail [2]. It has two main objectives: (i) determining the temporal variation of the source output using hydrophones deployed from fixed recording buoys which record the full piling sequence; (ii) obtaining an empirical estimate of transmission loss by making measurements as a function of range from the source, using hydrophones deployed from a mobile vessel (this determining the spatial variation of the acoustic field).

The custom-designed, static recording buoys are capable of recording the entire piling sequence at one or more location. The vessel-deployed recording systems consist of broadband hydrophone arrays operated from a survey vessel which travels along a transect radially away from the pile location. This combination of recording systems provides simultaneous recording of the entire piling sequence from fixed locations to assess changes in the source over time. Such changes may be due to changes in hammer energy (due to a ‘soft start’ procedure), or due to increasing pile penetration depth, changes in sediment composition, etc). The combination also provides an assessment of propagation losses within the water column by sampling the field at multiple ranges and depths along a specific radial transect. The exact configuration adopted depends on the particular requirements. Figure 1 shows a schematic diagram of the typical spatial arrangement of hydrophones employed for measurements.

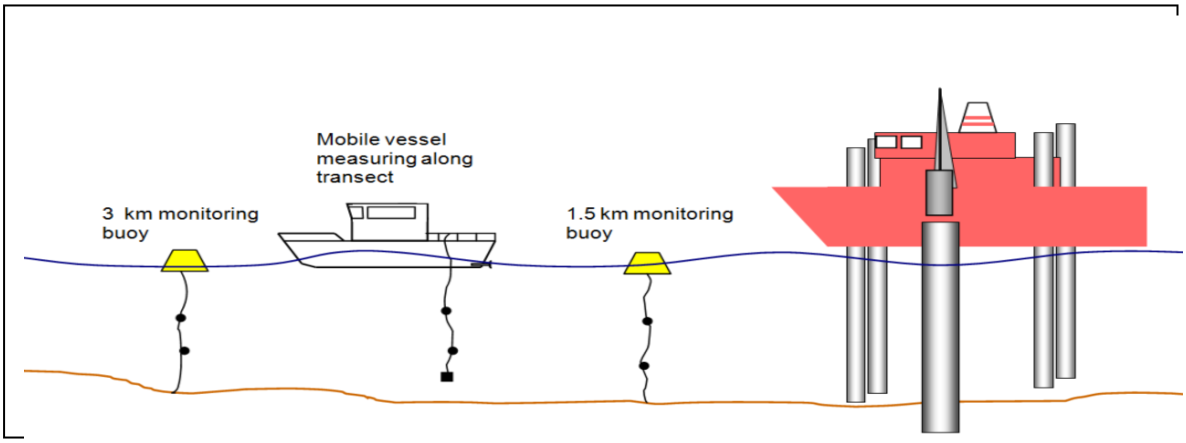

Fig. 1: A schematic diagram showing the methodology employed for measurements.

With the buoy systems, either one or two hydrophones are deployed in a bottom-mounted configuration on a sub-surface buoy, with the hydrophones distributed vertically in the water column. One buoy, termed the calibration buoy, is deployed within 2 km of the pile being driven to provide a clean recording of the whole piling sequence with a good signal-to-noise ratio. In addition, recording buoys may be positioned at other locations of interest, for example close to areas where sensitive marine species are present. The buoy recording systems use two HS70 hydrophone elements (also from SRD Ltd). Data acquisition is made to solid-state drives at up to 24-bits and a 48 kHz bandwidth.

For the broadband hydrophone arrays deployed from the survey vessel, hydrophone sensors are distributed within the water column and measurement samples are taken at various ranges from the pile. Typically, the survey vessel starts at around 200 m away from the pile being driven and then a series of measurements are made on a radial transect away from the pile location. The transect is chosen to pass through the location of the static calibration buoy. Measurements are made with the vessel quiet (engines off, echo-sounder off, and ideally with the generator off). Typical measured sequences last for a period of around 2-3 minutes, and then the vessel then moves to a new position along the transect. Using this methodology to measure a piling sequence lasting 80 minutes, typically eight ranges can be used with a maximum range of 15 - 20 km.

For the recording systems deployed from the work boat, data acquisition is carried out using PC-based broadband analysis systems with sampling rates of 500 kHz or greater. This allows signals with frequencies greater than 200 kHz to be faithfully recorded. Three data acquisition systems have been employed for this work: an NI-DAQ 6062 E at 500 kS/s and 12 bit resolution; NI-DAQ-USB NI9162 at 500 kS/s and 12 bit resolution; and a dual channel Brüel and Kjær Pulse broadband analysis system capable of sampling at 524 kS/s with 24 bit resolution. Several models of hydrophone are generally used for the vessel deployment: Reson TC4040 or TC4033 hydrophones are used for most of the deployments, though TC4014 hydrophones are sometimes used for larger ranges where greater sensitivity is desirable (TC4014 hydrophones contain integral preamplifiers of fixed gain which can distort or even saturate if used to measure the high-amplitude acoustic pulses present in the vicinity of the pile). Broadband, low-noise conditioning preamplifiers are used to amplify the signals from the TC4040/4033 hydrophones. All hydrophones are calibrated by NPL over their complete frequency range of use, with calibrations traceable to UK national standards at NPL. All data acquisition electronics and amplifiers are calibrated before trials, and B&K 4229 hydrophone calibrator is available for in-situ sensitivity checks.

If measurements from the survey vessel are made during the soft-start procedure where the hammer energy and acoustic output is generally increasing, the full piling sequence data from the calibration buoy may then be used to correct for the variations in source level that occur between the times that the individual work-boat measurements were made. By this means, the measurements made as a function of range may be normalised to the same source level (typically the maximum value is used). For the measurements to be correlated, all recordings must be accurately time stamped. The measurement ranges and buoy locations are GPS position fixed, and a sound velocity profile is taken using a CTD sonde at the location of the calibration buoy. In the shallow coastal waters where offshore windfarms are constructed, the water is typically well mixed with no thermocline present.

3. RESULTS

In this section, some results are shown below for measurements of noise radiated from marine piling operations made using the above methodology. The pile diameter for the measurements shown here was 5.2 m and the sediment in the area mostly consists of sand and gravel over a chalk substrate. The maximum hammer energy was 1,370 kJ. The depth of water in the area varies from approximately 15 m to 20 m depending on local variation in bathymetry and the tide.

Figure 2 shows the time and spectral content of a typical waveform recorded ranges of 240 m and 1 km. Primary frequency content is around 100-300 Hz, with a majority of the energy at frequencies of less than 10 kHz. However, close to the pile there are frequency components present at high tens of kilohertz.

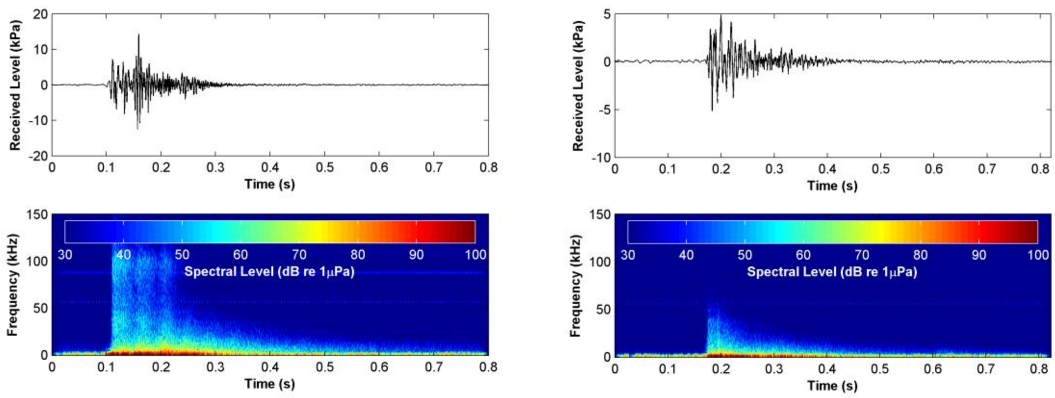

Fig. 2: A recorded hydrophone signal a range of 240 m (left) and 1 km (right) for a 5.2 diameter pile in water depths of 17 m. The spectrogram shows the increased high frequency content at lower ranges.

Figure 3 shows how the output level can vary throughout the piling sequence due to a soft start. The upper plot shows the time history of the received signals at the calibration buoy. After a number of short sequences of blows, the main sequence begins (after about 50 minutes), with gradually increasing amplitude as the hammer energy is slowly increased. Shown on the lower plot are the Sound Exposure Level values for each received pulse, expressed in dB re 1 μPa^2. A soft start variation of around 5 dB is evident from the data. The increase in acoustic pulse energy is generally correlated with the hammer energy [2].

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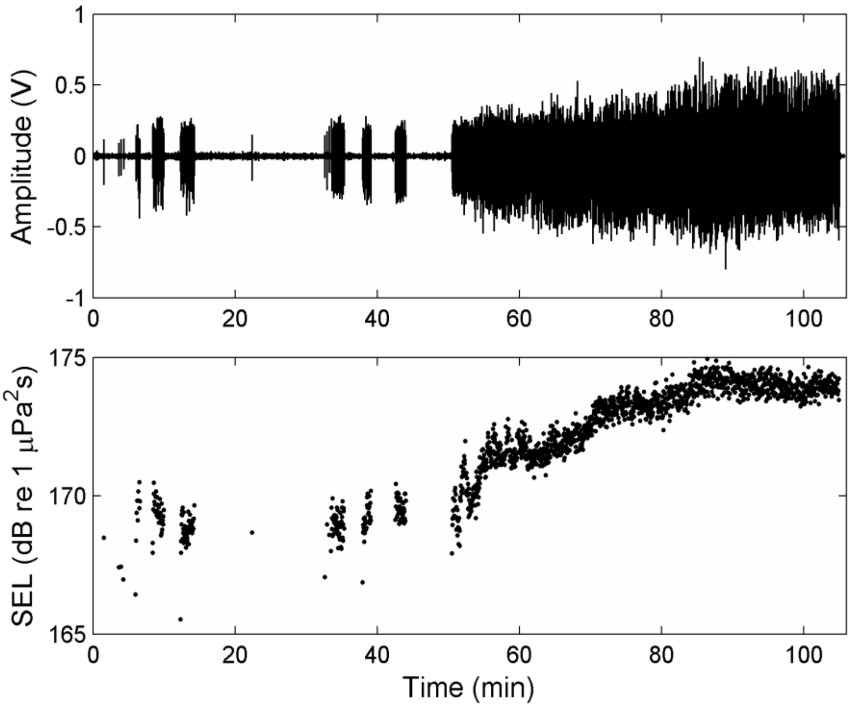

Fig. 3: Upper plot: example of time history of piling sequence measured on calibration buoy. Lower plot: normalised SEL for each measured pulse. This sequence has a soft start clearly evident in the SEL sequence.

When assessing underwater noise in relation to its impact on marine life, analysis in one-third octave-bands is useful as in some cases it may approximate the critical masking band in mammals [1]. Figure 4 shows the third-octave band spectra for pulses recorded at a variety of ranges from the source. The spectra shown are not spectral density values expressed per hertz, but instead represent the sum of the energy in the third-octave band (this is sometimes termed a power spectrum representation). The sum of the third-octave band values represents the broadband SEL value for the pulses. Also plotted in the same units are the third-octave band levels for the background noise measurements made just before the start of piling. Note that these background noise measurements are "snapshots" over a few minutes and so do not represent the temporal variation in background noise with weather, etc. Note also that these background measurements were made in the presence of sources of noise due to other activities associated with the windfarm construction such as auxiliary vessels in transit, extraneous noise from the piling vessel mechanical equipment (eg lifting equipment), vessel echosounders, etc. It can be seen that the level at 100 Hz is more than 60 dB higher than background at 380 m, reducing to less than 40 dB above background at 5 km. The corresponding values above background at 10 kHz are 45 dB and 20 dB.

It is possible to represent the acoustic output of marine piling in terms of energy source level by propagating the measured values at range back to the source using an appropriate propagation model. Using the data shown in Figure 4, this may be done for each of the third-octave band frequencies, with the values summed at the source to produce a broadband source level. This result of this methodology has already been reported elsewhere [12]. An alternative way to represent the acoustic output of the source is by stating the received level at a specified range. This has been adopted as a preferred method by some researchers [8]. Using this approach, the SEL values obtained from the measurements described here *for a distance of 750 m* are in the range 172 – 177 dB re 1 μPa^2, whereas the peak-to-peak levels measured at this distance are in the range 200 – 205 dB re 1 μPa.

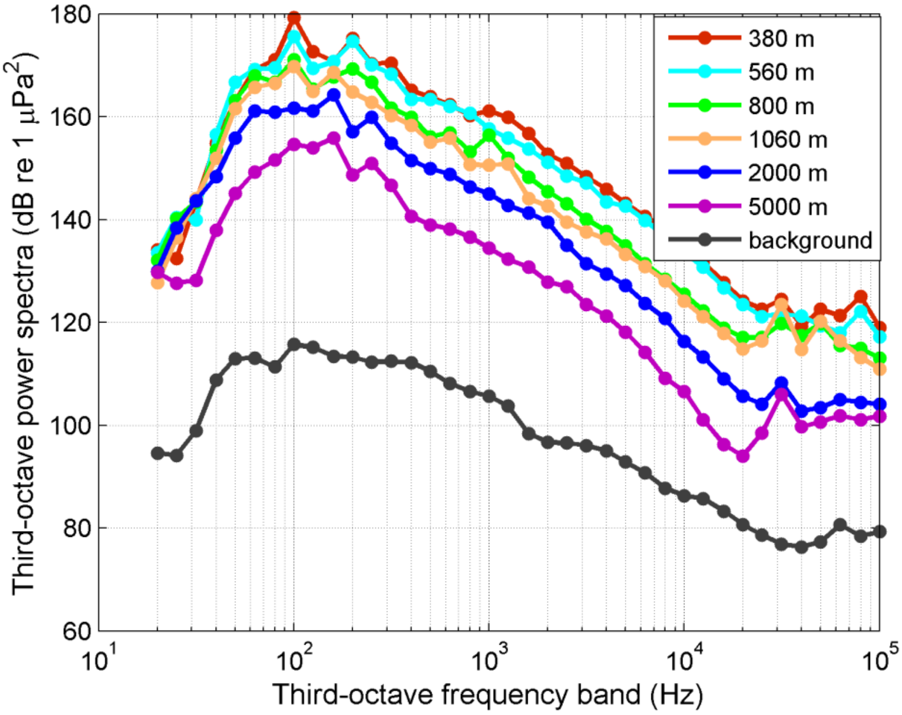

Fig. 4: The third-octave band spectra for pulses recorded at ranges from 380 m to 5 km from the driven pile. Also shown are the levels for the background noise.

4. CONCLUSIONS

This paper describes the results of measurements made of the noise radiated during construction marine piling for construction of an offshore windfarm in the UK. Data is shown in this paper for piles of 5.2 m diameter driven by hammers with strike energies of up to 1,370 kJ. To assess variations in the temporal, spatial and spectral characteristics, a number of recording systems were simultaneously deployed at various ranges and depths, allowing the full piling sequence to be measured. There remain a number of outstanding issues and knowledge gaps which hamper further progress in this area. An effective definition of source level is required, and agreement regarding which acoustic metrics are the most useful and appropriate. A physical model of the radiation mechanisms would allow better predictive utility, and better understanding of the dependencies in the process.

5. ACKNOWLEDGEMENTS

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