A METHODOLOGY FOR THE MEASUREMENT OF RADIATED NOISE FROM MARINE PILING

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Abstract:

Marine piling is the most commonly-used method for offshore windfarm construction, and consists of steel monopiles being driven into the sea-bed using powerful hydraulic hammers. This is a source of high-level impulsive sound that can travel considerable distance in the water column.

This paper describes a methodology that has been developed for measuring marine piling noise, which is designed to record the temporal, spatial and spectral characteristics of the radiated sound field. In the method, a number of recording systems are simultaneously deployed at various ranges and depths. Fixed recording buoys allow the full piling sequence to be measured, and variations in the temporal and spectral characteristics to 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. To assess spatial variations in the radiated acoustic field, recording samples are also made using hydrophones deployed from a vessel which traverses the field along a radial transect from the pile location. This latter set of measurements allows an estimate of the effective source level to be made if a suitable transmission loss model is used. To illustrate the method, some results are presented of measurements made on marine piling in shallow coastal waters during the construction phase of offshore windfarms.

Keywords: *Underwater noise, marine piling.*

1. INTRODUCTION

Noise is often an unintended by-product of offshore activities, and the 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. Such a technique is typically used to position piles in relatively shallow water for construction of offshore windfarms, bridge supports, and offshore structures associated with the oil and gas industry.

A methodology that has been developed for measuring marine piling noise, which is designed to record the temporal, spatial and spectral characteristics of the radiated sound field. In the method, fixed recording buoys allow 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.[2] 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 from the pile location. [3-8] This latter set of measurements allows an estimate of the effective source level to be made if a suitable transmission loss model is used. To illustrate the method, some results are presented of measurements made on marine piling in shallow coastal waters during the construction phase of offshore windfarms. 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. [9,10]

2. METHODOLOGY

2.1. Measurement method

The methodology used for measurements has two main features:

- fixed recording buoys recording the full piling sequence so that variations in the temporal and spectral characteristics of the acoustic field may be determined;
- recorded samples of the field using hydrophones deployed from a mobile vessel to determine the spatial variation of the acoustic field.

The fixed buoys are custom-designed, static recording buoys that are capable of recording the entire piling sequence at one location. The vessel-deployed recording systems consist of broadband hydrophone arrays operated from a work boat which is free to move along a transect in a radial direction away from the pile location. This combination 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. In some cases, recordings have been made simultaneously using hydrophone systems at up to nine spatial positions within the acoustic field. On several occasions, a hydrophone system has been deployed from the piling vessel itself. Figure 1 shows a schematic diagram of the typical spatial arrangement of hydrophones employed for measurements.

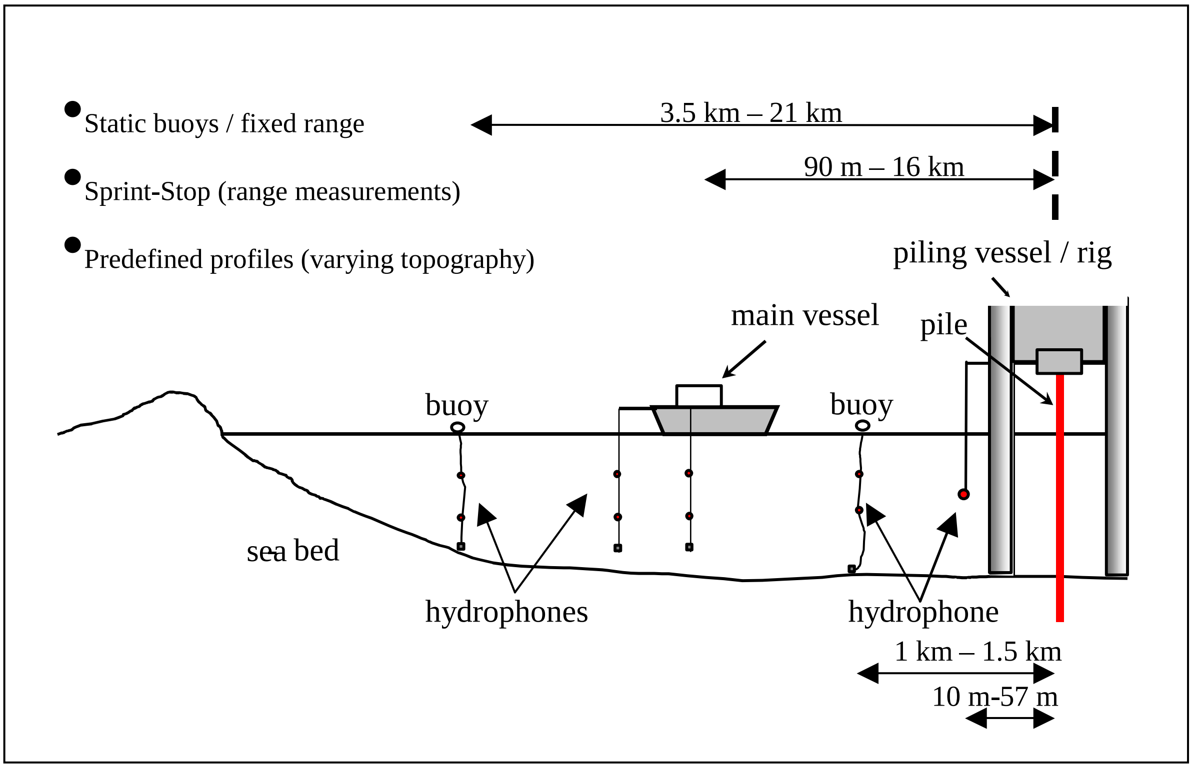

Fig. 1: A schematic diagram showing the methodology employed for measurements.

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. Buoy systems are generally deployed at ranges of between 1 km and 22 km from the driven pile. At least 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 are positioned at other locations of interest, for example close to areas where sensitive marine species are present. Where possible, a hydrophone and recording system is deployed form the piling vessel itself. This allows measurements to be made at close range, between 10 m and 50 m from the pile.

In addition to the buoy systems, a work-boat is also used to deploy broadband hydrophone arrays with up to 200 kHz bandwidth. The hydrophone sensors are distributed within the water column and measurement samples are taken at various ranges from the pile. Typically, the work-boat starts at around 100 – 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 using a "sprint/stop/measure" procedure. The transect used is chosen to pass through the location of the static calibration buoys. 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 minutes. 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.

The full piling sequence data from the calibration buoy is then 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.

2.2. Equipment and Instrumentation

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. Two models of hydrophone have been used for the vessel deployment: Reson TC4014 hydrophones (manufactured by Reson in Denmark), and HS150 hydrophones (manufactured by SRD Ltd in UK). These hydrophones are deployed at evenly distributed depths within the water column. Broadband, low-noise conditioning preamplifiers are used to amplify the signals from the HS150 hydrophones. The 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. Data from these hydrophones are in general only used for measurements made at ranges greater than 2 km from the pile.

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. When an additional hydrophone is deployed from the piling vessel itself, this is an HS150 hydrophone, with data recorded digitally with a bandwidth from 20 Hz to 22 kHz with 16 bit resolution. In this case, no preamplifier gain is required.

All data acquisition electronics and amplifiers are calibrated before and after the trials. All hydrophones are calibrated by NPL over their complete frequency range of use, with calibrations traceable to UK national standards at NPL.

3. RESULTS

Some results are shown below for measurements of noise radiated from marine piling operations made using the above methodology. The pile diameter was 4.74 m and the sediment in the area mostly consists of hard chalk. The depth of water in the area varies from approximately 8 m to 15 m depending on local variation in bathymetry and the tide.

Figure 2 shows the time and spectral content of typical waveform recorded at a range of only 10 m from a 4.74 m diameter pile at full hammer energy (1900 kJ). In general, the pulse periodicity observed was approximately 2.5 seconds during the main piling sequences studied. Acoustic pulse durations were about 0.15 s close to the source, but could be as long as 0.5 s at a range of 21 km. Primary frequency content is around 200-300 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.

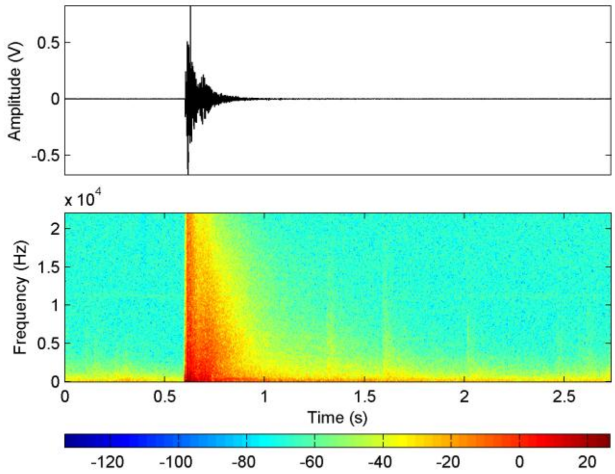

Fig. 2: A typical pulse recorded using the hydrophone at a range of approximately 10 m. This recording system operated over audio band frequencies (maximum frequency: 22 kHz). The amplitude of the spectrogram is normalised and plotted in dB.

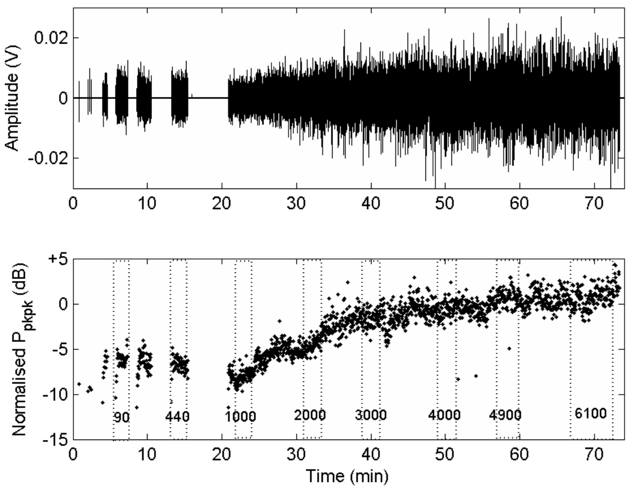

Fig. 3: Upper plot: time history of piling sequence measured at the calibration buoy. Lower plot: normalised peak-to-peak sound pressure levels for each measured pulse. This data may be used to correct the workboat data for source time-variation. Also shown with dotted lines are the time windows during which the workboat measurements were made, with the annotations indicating the range of the workboat from the pile in metres.

Figure 3 shows how the variation in source level determined from the complete piling sequence recorded by the static calibration buoy may be correlated with the data obtained from the workboat. The upper plot shows the time history of the received signals at the calibration buoy, with a gradually increasing amplitude as the hammer energy is slowly increased. Shown on the lower plot are the peak levels for the calibration buoy recording and the times during which the workboat measurements were made, with the annotations corresponding to the ranges from the pile in metres. In order to assess the transmission loss, the workboat data must be corrected to account for the time-variation. Since the maximum source level is typically of greatest interest when considering impact on marine life, the workboat measurements made at times before the pile had reached maximum level must be increased to a value representative of the value corresponding to the maximum source level. Figure 4 shows the data measured at each of the ranges covered by the workboat after correction using the data from the static calibration buoy. This data may then be used to estimate received level at intermediate ranges, and an effective source level using an appropriate transmission loss model.[4-8]

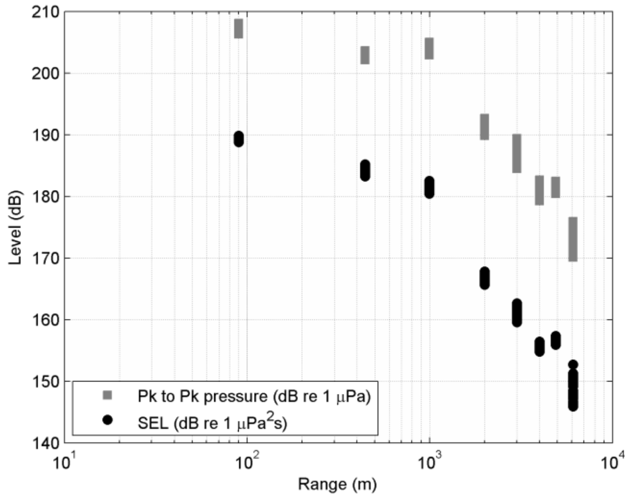

Fig. 4: Values of received peak levels and SEL plotted against range after correction for time variation using the calibration buoy data.

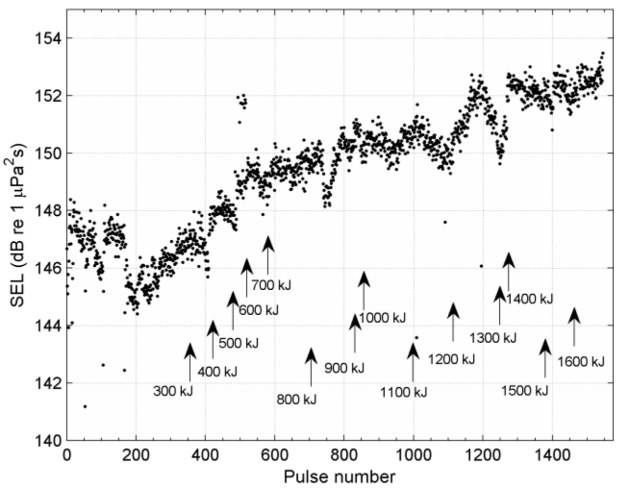

Fig. 5: The received SEL level in relation to step increases in hammer energy for a soft-start period recorded at a range of 1.5 km.

Figure 5 shows the received Sound Exposure Level (SEL) in relation to step increases in hammer energy for a soft-start. The SEL is a measure of the energy in the acoustic pulse and is obtained by integrating the square of the acoustic pressure waveform (the units are μPa^2s). This metric has found to be more robust than peak pressure (which is more sensitive to transmission loss fluctuations) and RMS pressure (sensitive to uncertainty in pulse duration).[2,3] SEL also has the advantage that it may be used to evaluate the cumulative exposure for an animal over a prolonged duration. [9,10]

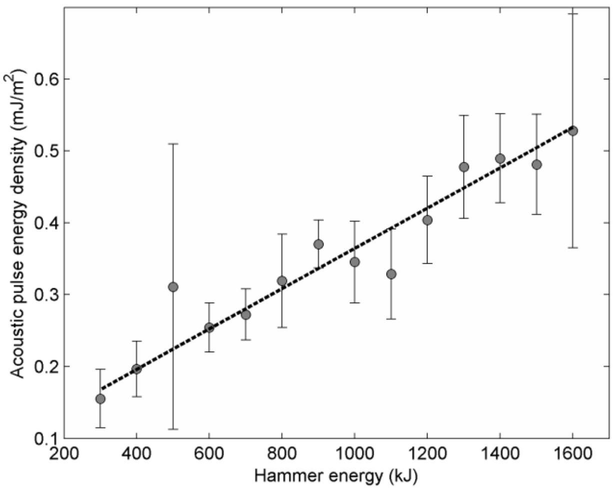

Fig. 6 Pulse energy (energy flux density in mJ/m^2) plotted against hammer energy (recorded at a range of 1.5 km). The error bars represent the random uncertainties and the straight line is a weighted least squares fit.

There are a number of reasons why the source level may appear to fluctuate with time, for example changes in sediment properties during seabed penetration, and changes in transmission loss due to local environmental changes (for example due to sea surface fluctuation in poor weather). However, a major reason is that the hammer energy is often increased during what is sometimes called a “soft start”. The energy in the acoustic pulse has been found to depend approximately linearly on the hammer energy. This is illustrated by Figure 6 which shows the results of plotting the mean acoustic pulse energy flux density (expressed in units of J/m^2) against hammer energy (in kJ). The error bars represent the random uncertainties expressed for a confidence level of 95% (essentially twice the value of the standard deviation) and the straight line is a weighted least squares fit (weighted according the inverse of the variance). It should be noted that although the dependence is linear over the energy range shown, the fitted line does not quite go through the origin (the intercept is 0.08 mJ/m^2). This illustrates that there are aspects of the radiation mechanism which are poorly understood. A comprehensive physical model is required in order to predict the dependencies accurately.

4. CONCLUSIONS

This paper describes a methodology that has been developed for measuring marine piling noise, which is designed to record the temporal, spatial and spectral characteristics of the radiated sound field. Results are presented for measurements in a shallow water coastal site where measurements of the entire piling sequence were conducted at ranges from 10 m to 22 km for piles in 10 m to 20 m of water depth. 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. This allowed assessment of source level variation at fixed locations, and the effect of propagation within the water column. An approximately linear dependence of acoustic pulse energy with hammer energy is demonstrated.

5. ACKNOWLEDGEMENTS

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