Temporal and Spectral Characteristics of a Marine Piling Operation in ShallowWater

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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. A significant source of impulsive underwater noise is marine piling where a pile is driven into the sea-bed using a hydraulic hammer [1-3]. 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.

This paper describes work undertaken to monitor the underwater acoustic radiated noise during offshore marine piling. Analysis of the underwater radiated acoustic characteristics for marine piling operations for two pile diameters, 2 m and 4.74 m, in a relatively shallow-water site are presented. Measurements of the entire piling sequence for several piles were conducted at ranges from 10 m to 22 km for piles in 10-20 m water depth. Variations in the temporal and spectral characteristics of radiated energy are analysed in context of pile size, range from source, hammer energy used and pile penetration depth. The recent use of SEL as a metric has enabled the calculation of cumulative exposure over entire piling sequences. Examples are given of calculations of cumulative dose for an animal, both static and fleeing from the area.

Measurements

As part of the preparations for a UK offshore windfarm installation, measurements of the spatial, spectral and temporal characteristics of radiated underwater acoustic noise for marine piling were made. The sediment in the area mostly consisted of hard chalk. The pile diameter varied from 2 m to 4.74 m. Measurements took place from April 2006 to November 2007 on the same site. Complete piling sequences were recorded with combinations of fixed-position recording buoys and hydrophone arrays deployed from a workboat. Measurements were also made of the entire piling sequence using hydrophones deployed from the piling vessel itself at ranges from 10 m to 56 m for five of the piles. The depth of water in the area can vary from approximately 8 m to 15 m depending on local variation in bathymetry and the tide. The bathymetry data available for this area showed a relatively flat bottom, with sand banks located offshore to the south.

Methodology

The methodology used incorporated the use of custom designed, static deployed buoys that were capable of recording the entire piling sequence at one location and broadband hydrophone arrays operated from a movable work boat. This combination provided simultaneous recording of the entire piling sequence from fixed locations to assessing changes in the source over time (changes in hammer energy ‘soft start’, penetration depth, etc) and assessment of propagation losses within the water column by sampling at multiple ranges and depths along a specific transect. In some cases recordings were made using up to nine spatially diverse hydrophone systems simultaneously.
On several occasions a hydrophone system was deployed from the piling vessel itself. This was combined with buoy systems, each with up to two hydrophones distributed in the water column. Buoy systems were deployed at ranges between 1 km and 22 km from the pile. In addition to the buoy systems a work-boat was also used to deploy broadband (up to 200 kHz bandwidth) hydrophone arrays distributed within the water column at various ranges from the pile. The work-boat would start from within a few 100 m of the pile being driven and then perform a series of measurements on a radial transect away from the pile location. An identical transect from the pile to at least one of the static buoys was used. Measurements were made with the vessel *quiet* (engines, echo-sounder off) for a period up to 1-2 minutes. The vessel would then move to a new position along the transect. Using this methodology up to eight ranges were measured within a single piling sequence with a maximum range of around 16 km.

The full piling sequence data from the static buoy was then used to correlate variations in source level (soft-start, hammer energy, etc.) at the times the individual work-boat measurements were made. All recording stations were GPS position fixed and time stamped to better than 1 s accuracy. A sound velocity profile was taken using a TS meter at the location of the research vessel. The water was well mixed with no thermocline, and a water temperature of 7.1 ºC. The sound speed was estimated as 1497 ms^{-1}.

Equipment and Instrumentation

For the broadband systems on the research vessel, data acquisition was carried out using PC-based broadband analysis systems with sampling rates of 500 kHz or greater. This allowed signals with frequencies up to 200 kHz to be faithfully recorded. Three data acquisition systems were employed: data acquisition interfaces 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. Four hydrophones were used: two Reson TC4014 hydrophones (manufactured by Reson in Denmark), and two HS150 hydrophones (manufactured by SRD Ltd in UK). These hydrophones were deployed evenly distributed at three depths within the water

column: 4 m, 5.5 m and 7 m. Broadband, low-noise conditioning preamplifiers were used to amplify the signals form the HS150 hydrophones.
The additional hydrophone deployed from the piling vessel was also an HS150 hydrophone. Data were recorded digitally with a bandwidth from 20 Hz to 22 kHz with 16 bit resolution. No preamplifier gain was used. All data acquisition electronics and amplifiers were calibrated before and after the trial. All hydrophones used were calibrated traceable to UK national standards by NPL. The buoy systems use two HS70 hydrophone elements also from SRD Ltd. With data acquisition to solid state drives at up to 24-bits and a 48 kHz bandwidth.

Results

Over 13,300 hammer blows were assessed at various ranges and depths from the piles with combinations of simultaneous recordings being made at ranges from as close as 10 m up to distances of 22 km. In total, over 45,400 acoustic pulse waveforms have been recorded, and over 40,000 waveforms have been analyzed. Figure 1 shows the time and spectral content of typical waveform recorded at a range of 10 m from a 4.74 m diameter pile at full hammer energy.

Figure 2 shows the entire piling sequence for a 4.74 m diameter pile recorded on a static buoy at 1.5 km range. The upper panel shows the entire time domain sequence. Note that during initial hammer strikes short sequences and then gaps at lower hammer energy are often used. The middle and lower plots show the peak-to-peak and Sound Exposure Level (SEL) for each individual hammer strike respectively. In this case the effect of the soft-start during the main sequence can be seen [4]. Figure 3 shows the received SEL level in relation to step increases in hammer energy for the soft-start period shown in Figure 2. In general, the pulse periodicity 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 but with a majority of the energy at frequencies of less than 10 kHz.

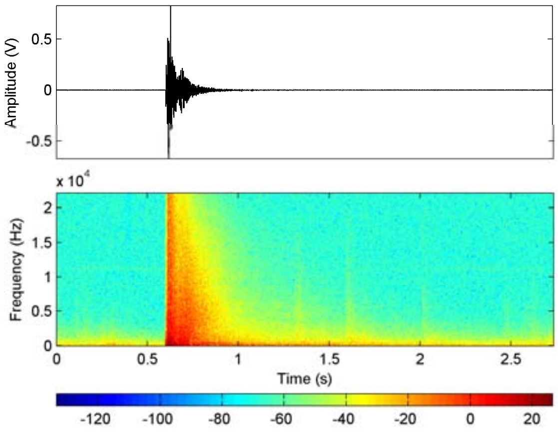

Figure 1: A typical pulse recorded using the hydrophone at a range of approximately 10 m. This recording system operated over audio band frequencies (maximum frequency of 22 kHz).

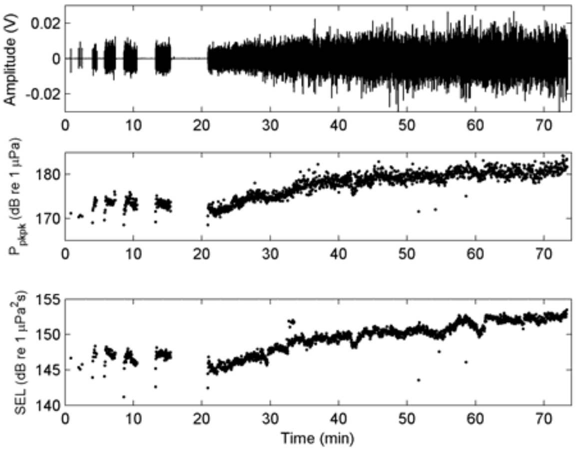

Figure 2: Full piling sequence recorded at a range of 1.5 km. Upper plot: time waveform. Middle plot: peak-to-peak pressure levels relative to 1 µPa (peak-peak) for each measured pulse. Lower plot: SEL values for each measured pulse.

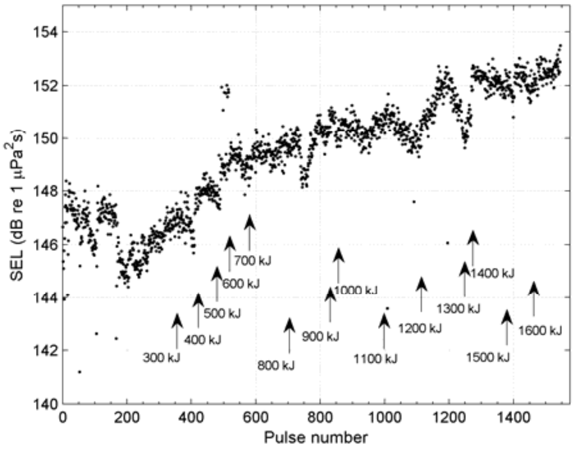

Figure 3: The received SEL level in relation to step increases in hammer energy for the soft-start period shown in Figure 2 recorded at a range of 1.5 km.

Cumulative exposure estimate

Various methodologies / criteria have been suggested for impact assessment. Recently Southall *etal* [5] proposed a dual instantaneous criterion of peak pressure threshold and a cumulative SEL for the assessment of exposure impact from a sound source for various functional hearing groups of marine mammals.

Using this methodology it was possible to explore potential impacts from an entire piling sequence. Models were developed to estimate the exposure of an animal to cumulative exposure from a typical piling sequence. This made it possible to test various cases; for example an animal passing through an area, fleeing an area at the commencement of piling or remain static during the sequence.

Figure 4 shows an example of a fleeing animal exposed to a piling sequence of 1700 strikes with a linear increases in source level from around 200 to 210 dB re 1µPa^{2}s-m over the first 1100 hammer strikes. In this case the animal starts at a range of 10 m from the pile and flees the area at a swim speed of 1.5 ms^{-1}. The upper plot shows the received level at the animal versus hammer strike. The black trace (during the soft-start) initially shows a reduction in received level at closer ranges due to increased transmission loss with range. Eventually the relative change in level due to increased range, and therefore transmission loss, is less than the increase due to the increasing source level and an increase in received level is observed. This trend then reverses as the source level remains static at the end of the soft-start period (red trace). The lower panel shows the cumulative exposure. In this case a 198 dB re 1µPa^{2}s exposure would be exceeded for an animal starting 10 m from the source at a range of 2.5 km.

It is then possible to run this model for various start ranges to determine minimum start range to avoid exposure to a specific level. Figure 5 shows total cumulative exposure for various start ranges for the above piling sequence example. In this case the black trace shows that if the animal starts at a range greater than 25 m the 198 dB re 1µPa^{2}s threshold would not be exceeded. However if the animal is static (blue trace) this range would be extended to 1.8 km.

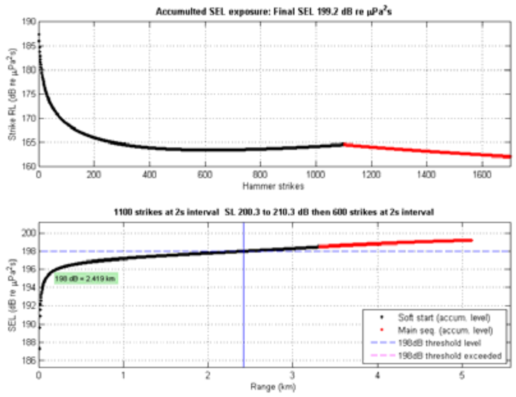

Figure 4: Upper panel received level versus hammer strike for a typical piling sequence with soft-start. Lower panel cumulative exposure for a fleeing animal. Start range 10 m swim speed 1.5 ms^{-1}.

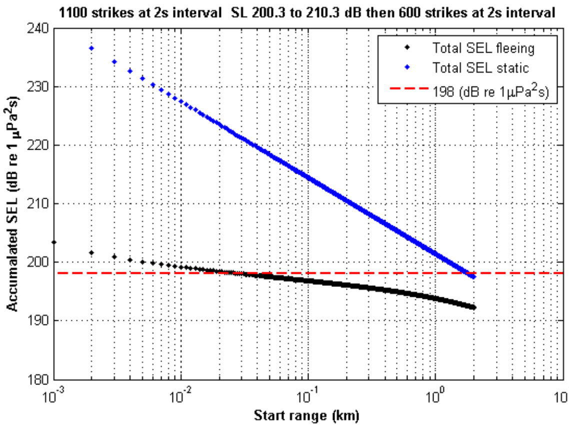

Figure 5: SEL exposure to a complete piling sequence for different start ranges.

Conclusions

Peak-peak received levels of 180 dB re 1µPa and equivalent SEL level of 153 dB re 1µPa^{2}s were observed at ranges of 1.5 km from a 4.74 m diameter pile using a maximum hammer energy of 1600 kJ. A full hammer SEL level of 192 dB re 1µPa^{2}s at a range of 10 m was observed. Although it is anticipated that the acoustic field close to the pile is likely to be complex and high variations may occur at relatively short ranges, estimates of source level based on both short and long range measurements, combined with range dependant transmission loss models, do however appear relatively consistent with measurements made on other similar North Sea windfarm sites [1].

Acknowledgments

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