



Exercises in Validating Shallow Water Pile Driving

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Abstract - Structures supported by piles are commonplace among marine infrastructure. Piles are driven into the seafloor via a variety of methods, including impact and/or vibratory piling. Sound produced during pile driving can exceed thresholds associated with a range of effects in marine fauna, including behavioural response, temporary and permanent acoustic injury, physiological effects, and mortality. Underwater noise modelling and monitoring can be used to assist in quantifying the range to effect thresholds, with monitoring essential in locations where input information is limited to improve predictions and increase confidence in modelling results.

1 INTRODUCTION

Validating underwater noise models with in-field measurements from pile driving activities enhances confidence in modelled results. This validation study compared measured and modelled results and was structured as follows:

1. Simple cylindrical spreading model to estimate noise levels to inform hydrophone placement.
2. Noise measurements with near and far hydrophones.
3. Underwater noise modelling of source levels and propagation loss.
4. Comparison of measured and modelled results to refine input parameters for model.
5. Repeat steps 3 and 4.

To begin, a Damped Cylindrical Spreading (DCS) model (Lippert et al. 2018) was used to estimate the potential noise emissions from pile driving. DCS adds an additional loss factor to standard spreading loss equations and our implementation uses the plane wave reflection coefficient of the seabed which was initially assumed to be silt. The estimated propagation loss, shown in Figure 3, was used to inform the measurement study, specifically in relation to hydrophone placement. It was planned to place the near-field hydrophone at 10 m from the pile to comply with ISO 18406 (2017), however, the final deployment locations were at a distance of 7, 10, and 11 m from the pile across three deployments. Far-field measurements were acquired via drift measurements. The distances for the far hydrophone varied between ~30 – 50 m.

In-field measurements of the received levels of the pile driving sound used one stationary AMAR (Autonomous Multi-channel Acoustic Recorder; JASCO Applied Sciences) approximately 10 m from the pile and a drifting OSM2 (Ocean Sound Meter 2; JASCO Applied Sciences) at multiple distances. Specifications for the recording devices are shown in Table 1 and example measurements from the AMAR and OSM2 are shown in Figure 1. The acoustic pressure waves were measured using a hydrophone as a change in voltage through a piezoelectric element which was converted to the sound level using the system gain. The impulses from the pile driving were detected using JASCO's PAMlab™ software suite to extract the sound exposure level (SEL), sound pressure level (SPL), and peak (PK) sound levels. As seen in Figure 1, most of the energy is in the 100's of Hz and the sound produced is impulsive with a signal length <100 ms.

Table 1. Specifications of acoustic monitoring equipment.

Recorder	Channel	Hydrophone	Hydrophone system gain (dB re FS/ μ Pa)	Sample rate (ksps)	Recording bandwidth (Hz)	Nominal hydrophone depth
AMAR	-	M36-V00-101	-221.92	64	10–32,000	2 m off bottom
OSM2	1	M36-C35-900	-200.40	128	10–64,000	~mid water depth

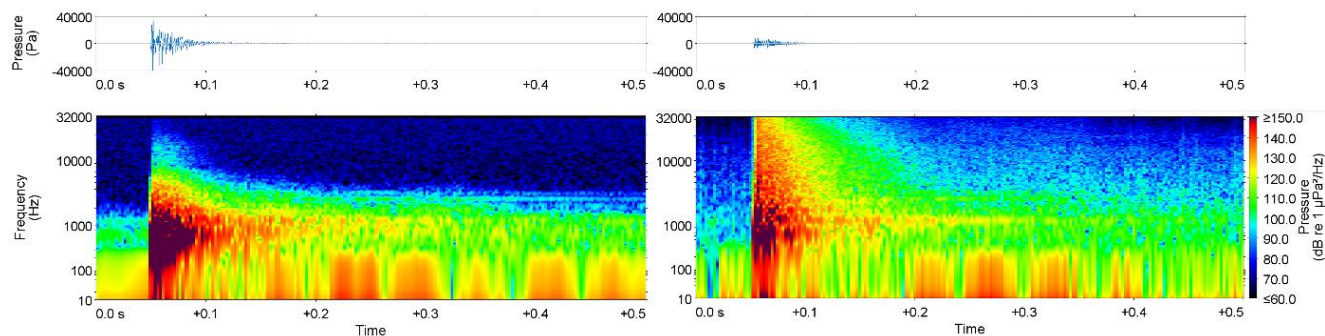


Figure 1. Spectrograms for the AMAR (left) at 7 m from the pile and OSM2 Channel 1 (right) at 35 m from the pile.

Underwater noise modelling began with determining the stress wave characteristics that generate impulsive sound. We used the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010) to compute the force at the top of the pile, which was then propagated along the pile using JASCO’s Pile Driving Source Model (PDSM), a physical model of pile vibration and near-field sound radiation (MacGillivray 2014).

The propagation of sound from pile driving is dependent on the environment surrounding the pile which, in this study, consisted of unconsolidated sediments in shallow water. Shallow water leads to increased interactions with the seabed where the sound can be reflected or transmitted through the sediment layers. The model used to predict propagation characteristics was JASCO’s Full Waveform Range-dependent Acoustic Model (FWRAM), which computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments, including bathymetry, water sound speed profile, and seabed geoacoustic model. Coupling the source levels from PDSM with the range propagation gives a prediction of the entire sound field.

2 RESULTS AND DISCUSSION

Modelling was performed with the same specifications as the measurements to allow for an analogous comparison. FWRAM was modelled from 10–1250 Hz and an empirical extrapolation rate of 20 dB/decade was used to extend results to 25 kHz based on (Illingworth & Rodkin 2007). A comparison of the spectra between measured and first modelled results (Figure 2) revealed some significant differences: broadband source level, low frequency shape, peak frequency, and high frequency roll-off. To refine the model, a helmet was added and placed between the pile and the hammer to protect hammer and the pile, resulting in a higher broadband source level and louder higher frequency components. The higher frequency roll-off rate shown in the data collected on the AMAR is an interesting feature. We estimate that this roll-off is on the order of 50 dB/decade. It is not clear the exact mechanism for this difference between the AMAR and OSM. It may be attributed to a zone of destructive interference different propagation paths or potentially a near-field propagation characteristic that is not captured by the numerical simulation.

Modelling results at the hydrophone depth were compared to measured data in Figure 3, where the dotted line is the DCS model, which used a value of 178 dB re 1 μ Pa²s at 10 m, the dashed line is a fit to the data, the solid lines are the modelling results with PDSM and FWRAM, and the crosses are the measurements for the AMAR (7–11 m) and OSM (30–50 m). The PDSM-FWRAM modelling results are in good agreement compared with measurements and are more representative of the data when compared to the DCS approach, this then validates

the models in this shallow water environment. Moreover, the PDSM-FWRAM modelling approach allows for calculation for frequency weighted metrics, which can be used for impact assessments. The DCS, in its current implementation, does not as it is a broadband calculation.

In conclusion, this study showed that the use of measurements to improve and validate modelled results allowed greater confidence in the modelled outputs, enabling robust predictions for instantaneous and cumulative metrics over the whole modelling area. Validation of the modelling with in-situ monitoring provided the opportunity to create an almost circular process where the measured levels were used to improve the model, allowing the model to more effectively predict over time and space dimensions that could not feasibly be monitored (i.e. for every distance and depth within the modelling area, and for full 24 hour periods). Using modelling and monitoring results in combination enables robust outcomes that can act as a basis upon which to make informed decisions relating to marine construction operations, further contributing to the mitigation of potentially harmful effects to marine fauna.

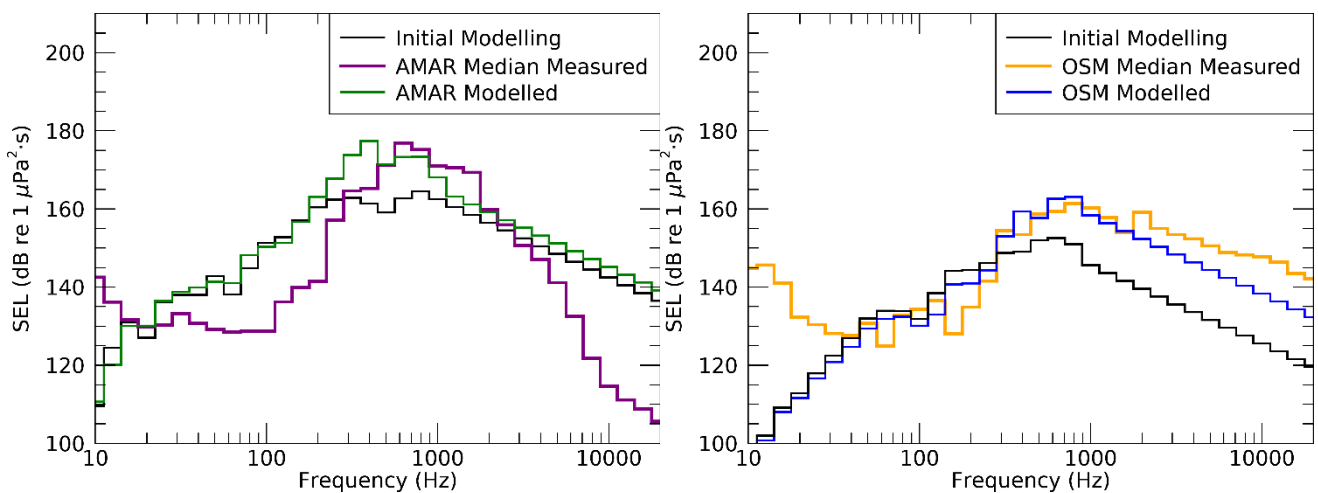


Figure 2. Refining the modelled spectrum based on the measured data: (left) AMAR at 7 m from pile and depth of 3 m and (right) OSM at 35 m from the pile and depth of 3–7 m.

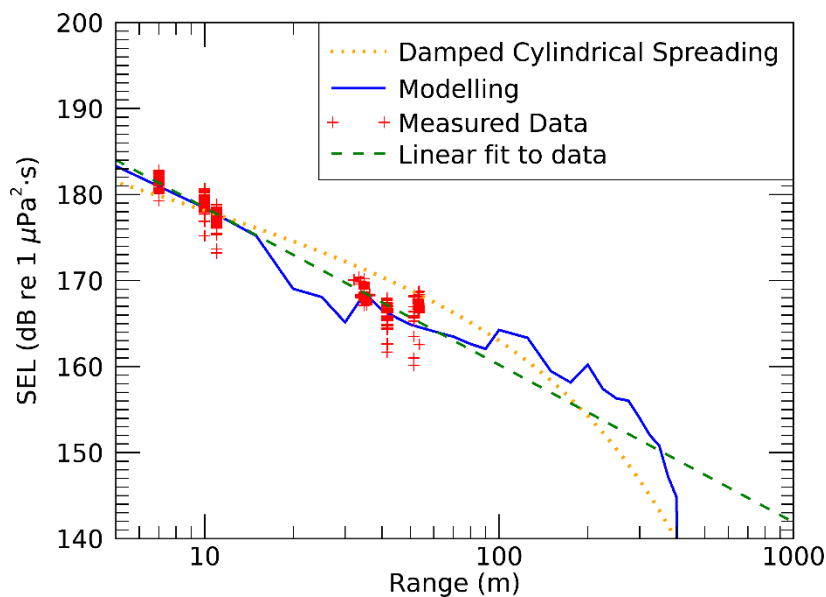


Figure 3. Propagation over range for DCS model (dotted line), and FWRAM using 20 dB/decade rate for high frequency roll-off (solid line). Measured results are shown as red crosses, and a dashed green line shows a linear fit through these points.

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