Relationships of underwater sound pressure and particle velocity in a shipbuilding dock

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Introduction

Underwater sound is characterized

1. directional particle motion
2. scalar pressure waves

Theoretically these are related and it is possible to estimate the particle velocity through measurements of pressure (e.g. Filiciotto et al. 2016, Nedelec 2016). However, this relationship assumes that sound propagates as a plane wave; an assumption that is not met in shelf seas or shallow water regions, where a wide range of fish and invertebrate species have been shown to respond to both sound pressure and particle velocity (e.g. Radford et al. 2012).

Objectives

This work compares direct measurements of sound pressure level (SPL) and particle velocity generated by experimental pile driving.

Data collection and analysis

Measurements of SPL and particle velocity were recorded during experimental pile driving conducted in a former shipbuilding dock (dimensions: 92 m X 18 m, average water depth 2.5 m with 3.5 m of sea-bed sediment). A 200 kg hammer (~1.6 kJ hammer energy) was used to strike a 7.5 m long, 0.17 m diameter, steel pile that rested on the simulated seabed, at a rate of 10 strikes per minute.

Trials were performed with the pile located in both the deep and shallow ends of the dock (Figure 1). Simultaneous recordings of sound pressure level (SPL - dB re 1μPa) and particle velocity were collected at 27 locations and at two depths (1 m and 1.8 m) (Figure 1).

The recordings from each trial were analysed using PaPAM software (Nedelec et al, 2016) to obtain:

1. the average single strike values for both SPL (SPLss) and particle velocity
2. the average single strike third-octave band Power Spectral Density (PSD) for both SPL and particle velocity

Note: The analysed PSD third-octave bands were: 100 Hz to 2500 Hz.

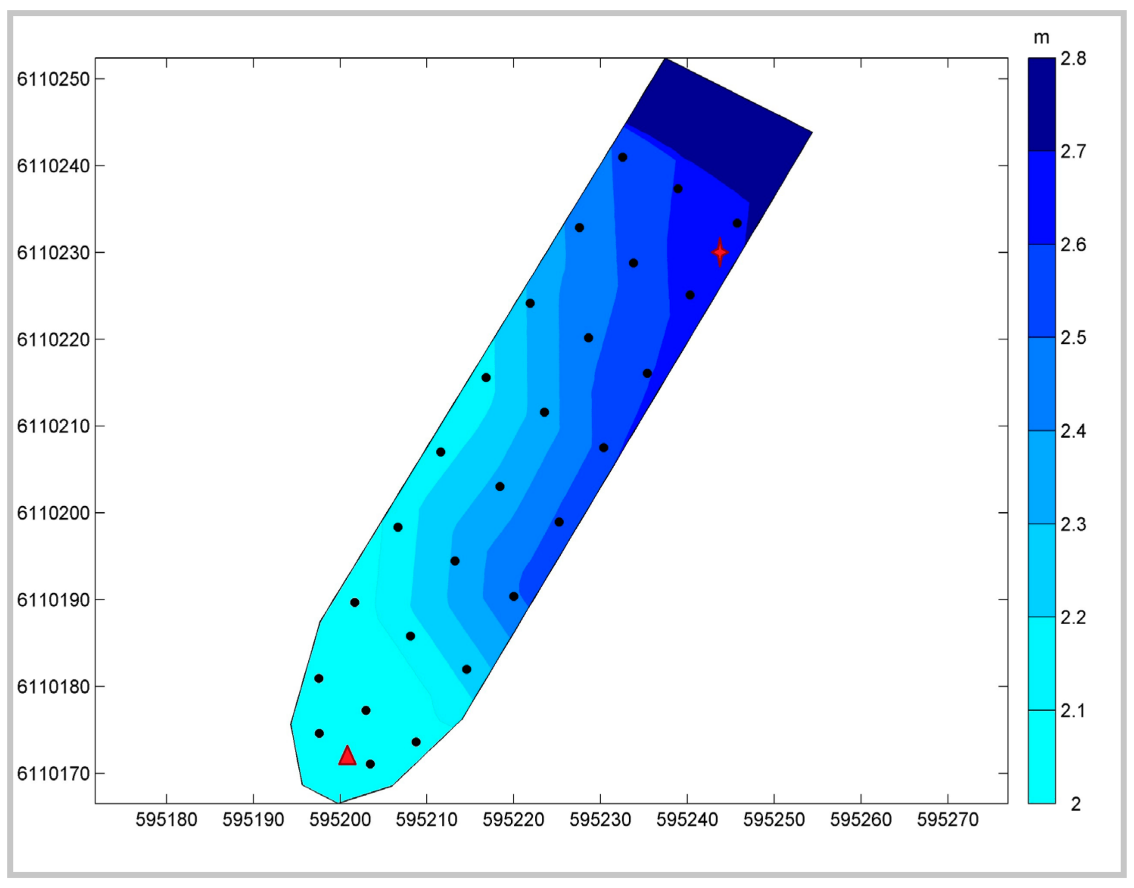

Figure 1: Map of the shipbuilding dock. Red triangle indicates the location of the pile in the shallow side of the dock and red star indicates the location of the pile in the deep side of the dock. Black points indicate the points of recording and the colours represent the depth of the water column. NB. the deep area without sediment (dark blue) was not used for sound recordings.

Results

A total of 1214 pile driving strikes were analyzed (Figure 1), with:

> 467 strikes in the deep location, and;

> 747 strikes in the shallow location

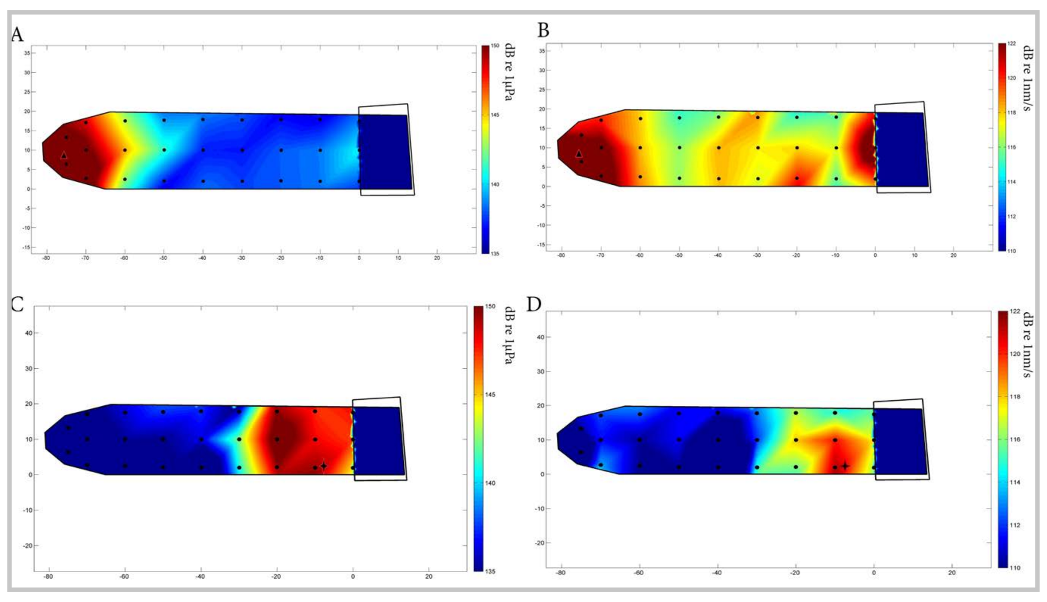

Figure 2: Spatial maps of SPL (A, C) and particle velocity (B, D) for both of the pile driving locations (black triangle indicates the location of the pile in the shallow side and black star indicates the location of the pile in the deep side of the dock)

Figure 3 shows the SPL_{ss} and particle velocity measurements for all recording locations and for both pile driving locations. Significant correlations between SPL_{ss} and particle velocity were found which were independent of the pile driving location (Pearson's correlation: Shallow: ρ=0.818, p<0.001; Deep: ρ=0.800, p<0.001).

During pile driving, the average values for SPL_{ss} and particle velocity show a similar trend with distance from pile (Figure 4).

However, sound pressure and particle velocity showed different frequency distributions.

> For sound pressure, a shallow water cut-off frequency below approximately 400 Hz was observed in the power spectrum which was independent of the distance from the source.

> A similar reduction in intensity at low frequencies was not observed for particle velocity (Figure 5).

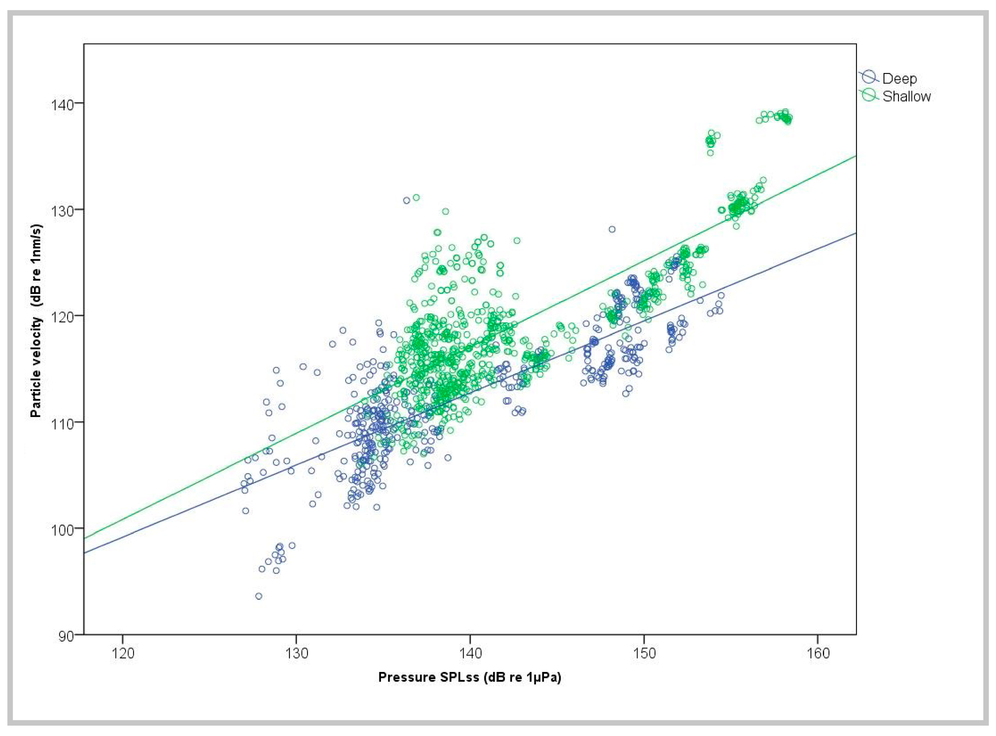

Figure 3: Scatterplot and regression lines of SPLss and particle velocity the two different pile driving locations

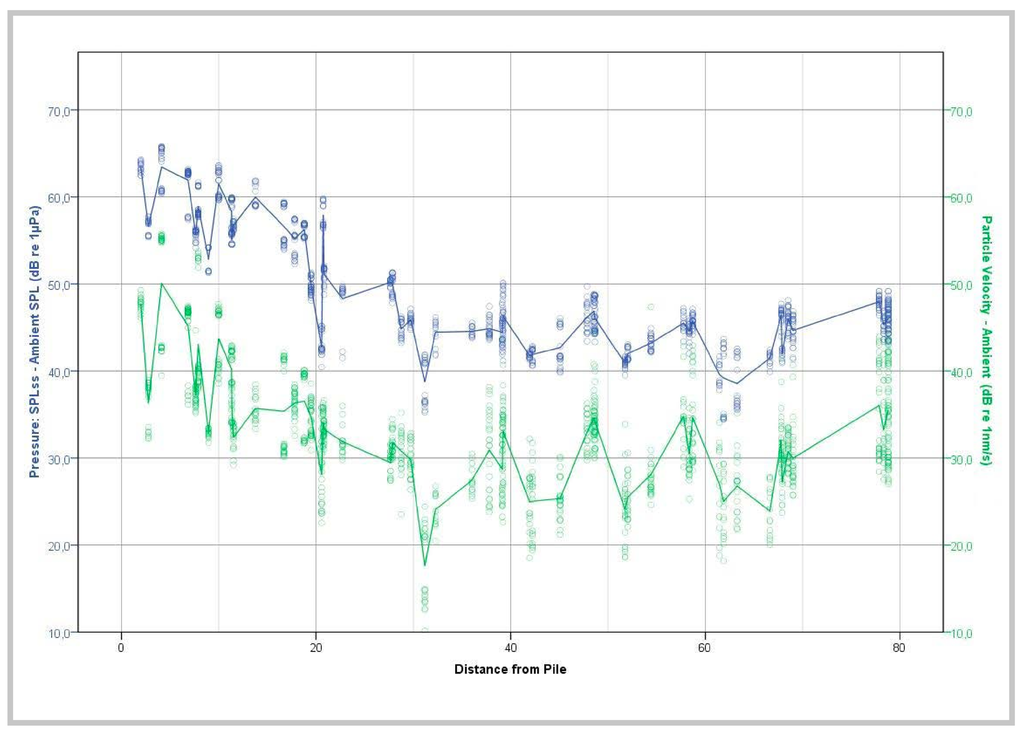

Figure 4: Relative differences between SPLss (blue points)and particle velocity (green points) during pile driving and ambient conditions for different various distances from the pile driving source.

This difference is possibly due to the non-linear relationship of particle velocity in the nearfield as described by Nedelec et al (2016; Equation 1), which counteracts the attenuation of the low frequencies due to shallow depth limitation. Further work is required to verify this.

$$u = \frac{p}{\rho \cdot c}\left[1 + \left(\frac{\lambda}{2\pi r}\right)^2\right]^{\frac{1}{2}} \qquad \text{(Equation 1)}$$

Where: u = particle velocity (m/s), p = sound pressure (Pa), ρ = water density (kg/m^3), c = sound speed (m/s), r = distance from sound source (m) and λ = wavelength of sound (m).

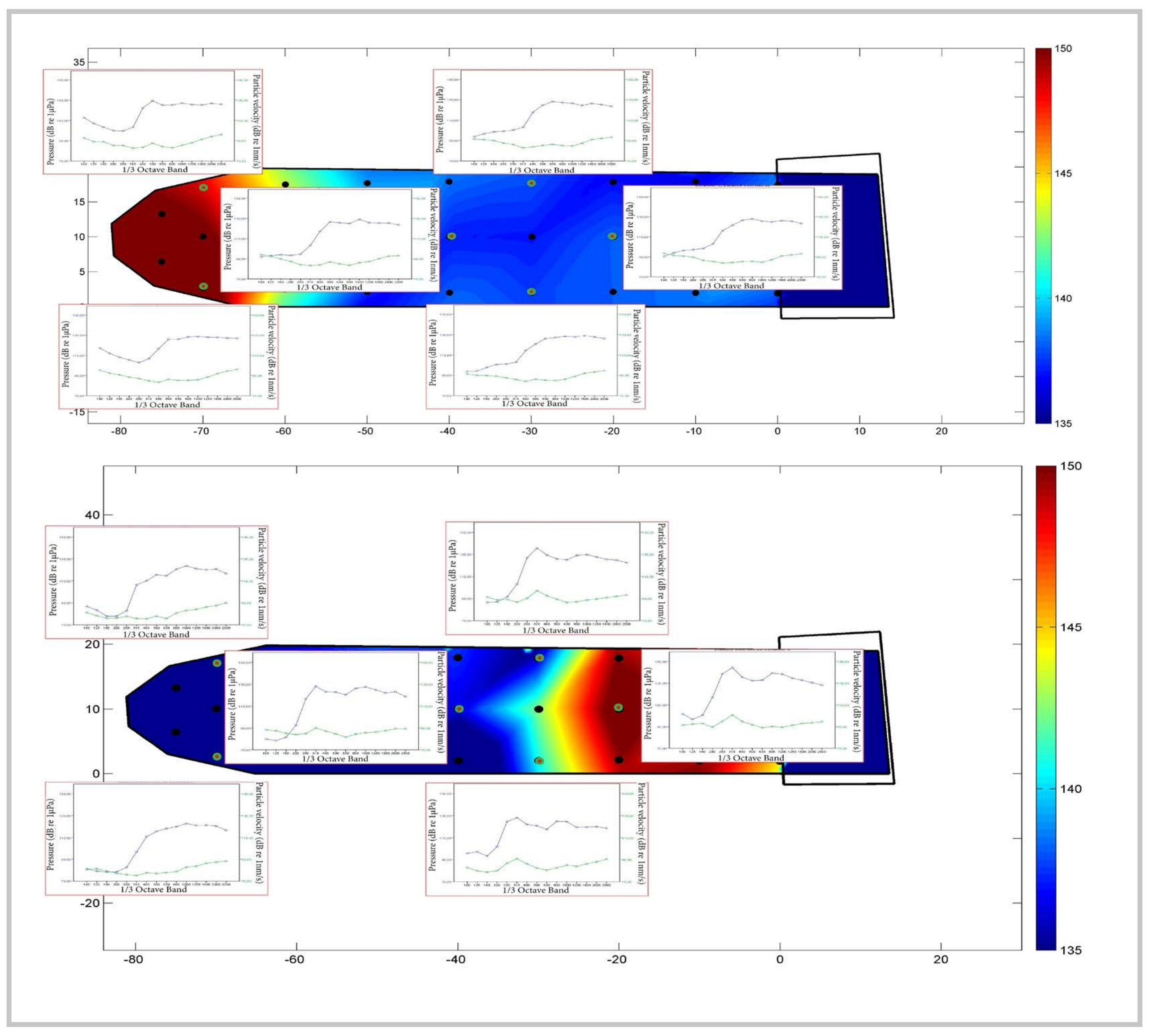

Figure 5: Average single strike third-octave band PSD for SPL (blue line) and particle velocity (green line) for several recording points during pile driving at the two pile driving locations.

Conclusions

> Few studies have analysed simultaneous direct measurements of sound pressure and particle motion (Lugli 2007).

> Initial analysis found a significant correlation between broadband SPL and particle velocity, but the correlation is poor for lower frequencies (<400Hz). This is probably caused by the non-linearity in the relationship between SPL and particle velocity in the near-field which counteracts the shallow water frequency cut-off.

> Estimates of particle velocity derived from SPL measurements should be considered as approximate estimates only, especially close to the source and in shallow water and/or confined environments.

> Further analysis of the results and additional studies are required at different locations to better understand this relationship between sound pressure and particle motion.

References

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