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New Method for Accurate Prediction of UnderwaterNoise from Pile Driving

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Abstract

Underwater noise from pile driving can only be mitigated efficiently, both from an environmental and cost perspective, if we understand the finer details of how noise is created and its propagation into the water. To achieve this understanding, accurate models are needed. A new approach combining geotechnical methods with vibro-acoustic modelling has shown promising results. DONG Energy Wind Power has together with Lloyd's Register Consulting conducted a variety of targeted industrial research and development activities to increase knowledge within this field.

Objectives

- The new **WEAP-FE** modelling technique presented here includes detailed representation of the hammer system and the seabed. It is applied to two full-scale measurement cases for **validation**:
  - **Vashon Island** [4], which investigates harbour piling of a 31.9 m long, Ø0.76 m steel pile using a Delmag D62-22 diesel hammer weighing 6200 kg.
  - Construction of **Anholt Offshore Wind Farm**, involving piling of 47.5 m long, Ø5.3 m steel piles at 17 m water depth using a multi-component IHC S-2000 hydraulic hammer system weighing ca. 100,000 kg. Underwater noise measurements were performed by Lloyd's Register Consulting on behalf of DONG Energy Wind Power.

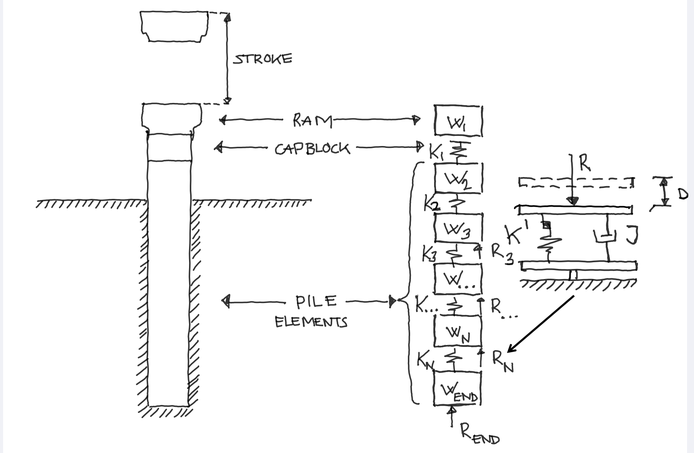
Photographer Poul Gerner

Methods

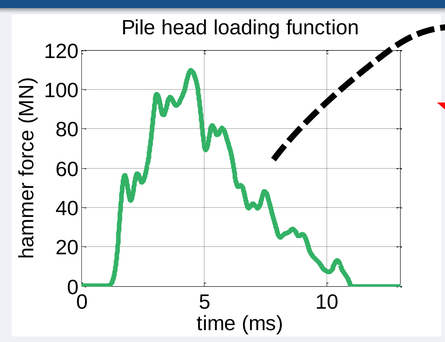
- **Wave Equation Analysis for Piles, WEAP:** 1D Finite-difference scheme for solving the stress wave equation of a driven pile [1]

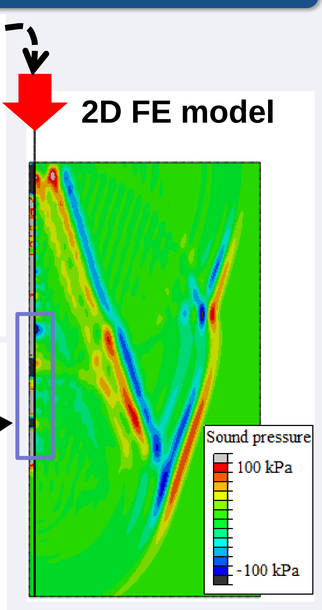
$$\frac{\partial^2 D}{\partial t^2} = \left(\frac{E}{\rho}\right)\left(\frac{\partial^2 D}{\partial x^2}\right) \pm R$$

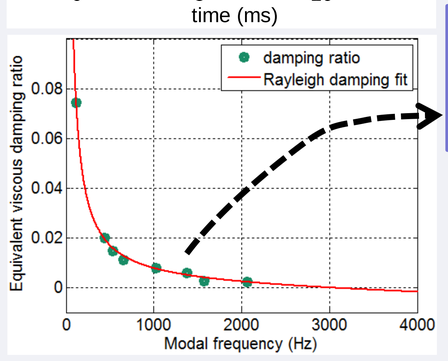
- **Soil-damping constant *J* and quake *Q*:** Input parameters to WEAP. Nonstandard soil mechanical parameters, but with decades of empirical experience within the geotechnical community [3]
- WEAP predicts **forcing function** on pile head, and **energy dissipation** in hammer-pile-soil system
- These are introduced to an axi-symmetric 2D **vibro-acoustic Finite Element (FE) model** of pile, water, and (fluid type) seabed
- **Energy dissipation** is introduced in FE as Rayleigh damping in the buried part of the pile
- WEAP-FE applied to the **Vashon Island** [4] case showed good agreement in time series and for 1/3-octave spectra. Overall level agreed within 1 dB
- WEAP FE applied to **Anholt Offshore Wind Farm** data was slightly more challenging due to sound interaction with the installation vessel's hull. Nevertheless, fair agreement in both time and frequency domain was achieved. Overall level agreed within 2 dB

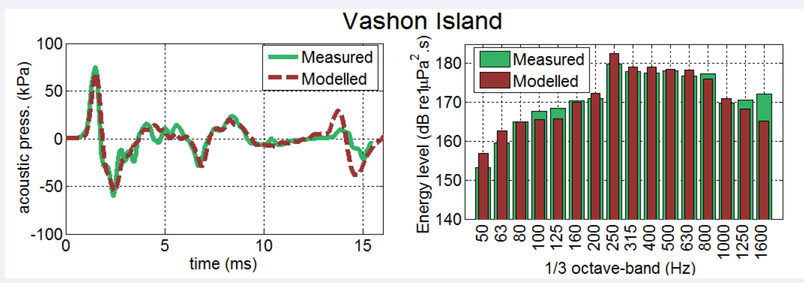


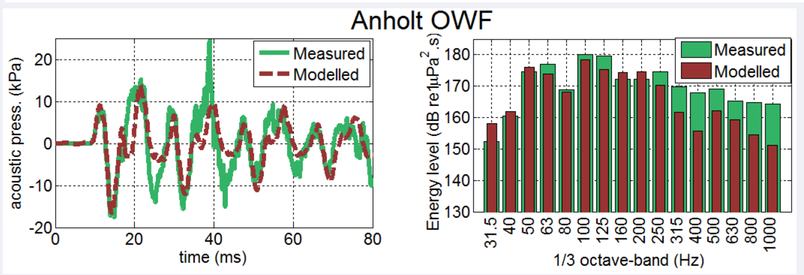
Illustrations courtesy of M. Bruun-Ringgaard [2]











Conclusions

- The geotechnical WEAP algorithm used in an acoustic context together with industry standard Finite Element looks very promising. Model results compared to measurement data show good agreement
- Particularly for the first positive peak corresponding to the time around the hammer impact onto the pile, the noise seems accurately modelled
- The time sequences of the noise related to the upward travelling wave is in fair agreement with measurements, but the vibro-acoustic model would benefit from a refined representation of the seabed

References

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4. Reinhall PG, Dahl PH. Underwater Mach wave radiation from impact pile driving: Theory and observation. J Acoust Soc Am. 2011;130(3):1209-1216.