Underwater Acoustic Propagation: Effects of Sediments

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Outline

• Background on Rhode Island Wind Farm
• Waves in sediments
• Finite element (FE) and parabolic equation (PE) modeling
• Small scale measurements to date and planned measurements at the site
• Sensitivity of benthic animals to pile driving
  – Application of Response Weighted Index (RWI) from Halvorsen et al.
• Plans for measurement program
• Conclusions
OCEAN Special Area Management Plan (SAMP)

$6.7 M, 2yr URI study to support siting of offshore wind farms in RI coastal waters in support of CRMC

60 URI researchers from Engineering, Oceanography and Environmental & Life Sciences

*RI has a leadership position in the nation in offshore wind energy development*
Block Island Site Phase I

• Area planned for development is near Block Island, Rhode Island.

• Significant commercial fisheries exist for American lobster and flounder.
Figure 4

Substructure types for offshore wind turbine foundations (after Musial et al., 2006).

- Shallow water gravity base: up to 30m water depth
- Shallow water monopile: up to 30m water depth
- Transitional water depth jacket quadropod / tripod: 30 to 60m water depth
- Mooring stabilized TLP / Semi-submersible with vertical anchors 60 to 300m+ water depth
- Ballast stabilized Spar with catenary moorings 120 to 300m+ water depth

• Four hollow steel 1.5 m dia. piles driven 60 m into the sediment for each turbine.
• It is estimated that 10000 strikes or blows needed for each pile. (Van Beek, 2013)
• 5 turbines near Block Island in Phase I.
• 100 turbines planned between Block Island and Martha’s Vineyard in Phase II.
Waves in the Sediment

\[ \theta_{\text{crit}} = \sin^{-1}\left( \frac{c_s}{c_p} \right) \]

Dynamic soil resistance generated along pile shaft and at the pile toe

This generates cylindrical and spherical waves – compressional (P) and shear (S) waves.

Surface (interface) waves are generated by refracted P and S waves

Seismic Waves – Body Waves

Compression Waves

The P-wave velocity \( c_p \) can be written (for an elastic medium) in terms of the rigidity \( G \), bulk modulus \( K \), and density \( \rho \).

\[
c_p = \sqrt{\frac{K + 4G/3}{\rho}}
\]

Shear Waves

The S-wave velocity \( c_s \) can be written (for an elastic medium) in terms of the rigidity \( G \) and density \( \rho \).

\[
c_s = \sqrt{\frac{G}{\rho}}
\]
The particles in a Rayleigh wave oscillate in an elliptical path within the vertical plane containing the direction of wave propagation. Within the elliptical path, particles travel opposite to the direction of wave propagation at the top of the path and in the direction of propagation at the bottom of the path.

\[ c_R = 0.9194c_S \]
Scholte Waves

- Decay exponentially in amplitude away from the boundary in either medium (i.e., the wave is evanescent in both media).

- The propagation speed and attenuation closely related to shear-wave speed and attenuation over a depth of 1-2 wavelengths into the seabed, but are relatively insensitive to the compressional-wave properties.

- Dispersion characteristics of the Scholte wave provide information about the sediment shear-speed gradient, and a shear-speed model can be constructed by matching the observed dispersion properties.


Rauch, Seismic interface waves in coastal waters: A review, SACLANT Report, 1980
• We use Abaqus finite element (FE) analysis software to simulate the pile and its response to the hammer.

• To achieve computational efficiency, an axisymmetric geometry and loading condition are considered assuming no variation along the azimuthal angle in the cylindrical coordinate system for shallow water environment.
• We use the Monterey Miami Parabolic Equation (MMPE) code by K. B. Smith to simulate the propagation of the pile driving signal in the ocean and seafloor.

• “The theoretical development is based on the parabolic equation approximation [V.A. Fock, *Electromagnetic Diffraction Problems* (Pergamon, 1965)] which automatically includes diffraction and all other full-wave effects, as well as depth- and range-dependent sound speeds and volume losses, and variable bathymetry.”
A compressional wave in the pile caused by the impact pressure loading produces an associated radial displacement motion due to the Poisson effect.

The radial displacement propagates downwards. The rapidly downward propagating wave produces an acoustic field in the shape of an axisymmetric cone.

The cone’s apex travels concurrently with the pile deformation wave front. When the wave front reaches the pile’s terminal end, it is reflected upwards.
URI Shear Measurement System

Several Hydrophone Receive Units (SHRUs)

3D Geophones

Shear measurement system consisting of a geophone/hydrophone array and data collection system (SHRU)

URI Geophysical Sled with tetrahedral hydrophone array for estimation of particle motion
Received Signal and Coherence

URI Shear Measurement System - Field Test

Location: Davisville Basin in Rhode Island.
Source: 114 kg weight impacting the bottom.
Measurement system: A sled holding two SHRUs and eight geophones
Range: Varied from 10 to 100 m
Geophone spacing: 2.5 m
Sediment ‘ground truth’: Historic bore hole data (N values converted using different models shown in black, green and cyan in

Giard et al., “Validation of an Inversion Scheme for Shear Wave Speed Using Scholte Wave Dispersion,” to be presented at the OCEANS-2013 meeting, San Diego, 23-26 September, 2013
Towed Array (with MAI)
Conclusions

• Wind farms are being planned for the US off Rhode Island and Massachusetts.

• Finite element (pile and immediate environs) and parabolic equation (distant) modeling have been conducted and predictions for effects have been made.

• Calculated Response Weighted Index (RWI) as a function for range for the Block Island environment. An estimate for moderate trauma is estimated to be out to 500 m for 1920 strikes. But RWI was developed using salmon, a fish with a swimbladder. Therefore we expect this to be a very conservative estimate for flounder.

• Measurement program being prepared for the construction.