Modeling Scattering from Rough Poroelastic Surfaces Using COMSOL Multiphysics

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Outline

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• Scattering Strength Calculation
• Results
• Conclusions
Motivation

• Acoustic scattering from seafloor important source of interference with sonar systems.

• Necessary to accurately model physics of how sound interacts with the sea bottom.
  – Roughness effects
  – Physics of sediment (poroelasticity)
Problem

Implementation: Geometry

(not to scale)
Implementation: Physics

• Physics assignment
  – Fluid domain modeled with Pressure Acoustics, Frequency Domain Interface.
  – Poroelastic domain modeled with Poroelastic Waves Interface.

• Boundary conditions
  – Continuity of normal stress
  – Continuity of pressure
  – Continuity of normal displacement

Porous, Pressure Node
Normal Acceleration Node
Implementation: Physics

• Modified Gaussian tapered plane wave used to guard against edge effects.
  – Implemented as Background Pressure Field.

• Far-Field Calculation node used to find far-field scattered pressure.
Implementation: Mesh

- Rule of thumb: at least 6 elements per smallest wavelength supported by domain.
  - Poroelastic: minimum of slow/shear wavelength.
- Computationally demanding due to disparity between compressional and slow/shear speed.
- Slow and shear waves have high attenuation.
  - Sufficient to mesh finely on interface and based on compressional wave elsewhere.
Scattering Strength Calculation

• Many models with unique rough surface realizations run to obtain ensemble average of far-field scattered pressure.

• Average intensity used to calculate scattering cross section.

\[
\sigma(\theta, \theta_s) = \frac{\langle I_s \rangle r \sin \theta}{E_f}
\]

• Scattering strength: \(10 \log_{10} \sigma(\theta, \theta_s)\)

Numerical Results

• COMSOL calculations compared with more conventional scattering formulations.
  – Perturbation theory
  – Kirchhoff approximation
  – Small-slope approximation

• Monostatic and bistatic results shown for least and most rough cases studied.
# Numerical Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness Parameters</td>
<td></td>
</tr>
<tr>
<td>Frequency ((f))</td>
<td>100 Hz and 3 kHz</td>
</tr>
<tr>
<td>(rms) surface height ((h))</td>
<td>0.1 and 1 m</td>
</tr>
<tr>
<td>Surface cutoff length ((l))</td>
<td>10 m</td>
</tr>
<tr>
<td>Bistatic grazing angle ((\theta))</td>
<td>45 degrees</td>
</tr>
<tr>
<td>Material Properties</td>
<td></td>
</tr>
<tr>
<td>Fluid sound speed ((c_f))</td>
<td>1530 m/s</td>
</tr>
<tr>
<td>Fluid density ((\rho_f))</td>
<td>1023 kg/m³</td>
</tr>
<tr>
<td>Fluid compressibility ((\chi_f))</td>
<td>4.176×10⁻¹⁰ Pa⁻¹</td>
</tr>
<tr>
<td>Fluid viscosity ((\mu_f))</td>
<td>10⁻³ Pa·s</td>
</tr>
<tr>
<td>Drained density ((\rho_d))</td>
<td>1404.5 kg/m³</td>
</tr>
<tr>
<td>Drained bulk modulus ((K))</td>
<td>43.6 + i2.08 MPa</td>
</tr>
<tr>
<td>Drained shear modulus ((G))</td>
<td>29.2 + i3.86 MPa</td>
</tr>
<tr>
<td>Biot-Willis coefficient ((\alpha_B))</td>
<td>0.998 – i8.15×10⁻⁵</td>
</tr>
<tr>
<td>Permeability ((\kappa_p))</td>
<td>3×10⁻¹¹ m²</td>
</tr>
<tr>
<td>Tortuosity ((\tau))</td>
<td>1.2</td>
</tr>
<tr>
<td>Porosity ((\varepsilon_p))</td>
<td>0.38</td>
</tr>
<tr>
<td>Reference frequency ((f_c))</td>
<td>410.4 Hz</td>
</tr>
</tbody>
</table>

Taken from Yang et al., *IEEE Ocean Eng.*, **27**(3), 2002.
Results: Monostatic

- For $f = 100$ Hz, $h = 0.1$ m, $l = 10$ m:
  - Backscattering Strength [dB] vs Grazing Angle [deg]

- For $f = 3000$ Hz, $h = 1$ m, $l = 10$ m:
  - Backscattering Strength [dB] vs Grazing Angle [deg]
Results: Bistatic

- **f = 100 Hz, h = 0.1 m, l = 10 m**
- **f = 3000 Hz, h = 1 m, l = 10 m**
Conclusions

• Scattering from rough poroelastic surface successfully modeled using COMSOL Multiphysics.
• COMSOL Multiphysics robust tool for evaluating conventional scattering models.
• Good agreement between FEM and small-slope approximation.
• FEM monostatic results at shallow grazing angles warrant further study.