Estimation of Soil Permeability Using an Acoustic Technique

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The propagation of elastic waves in saturated soils causes the coupled motion between solid particles and pore water.

Characteristic Frequency

The coupled behavior involves the permeability of soils.

By measuring the characteristic frequency of elastic waves in saturated soils, the permeability of soils is estimated.
Theory: Characteristic Frequency and permeability
(Biot, 1956)

- Characteristic frequency is related to the viscosity of the fluid and pore size (and eventually to the permeability of soils).
- When the frictional loss is maximum, the attenuation is maximum.

\[
k = \frac{\phi \cdot g}{2\pi \cdot f_c}
\]

\(f_c\) : Characteristic Frequency
= frequency at Maximum (specific) Attenuation

Specific Attenuation

\(f_c\)
Frequency (Hz)

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Specific Attenuation

\[ A_2 = A_1 e^{-\alpha (r_2 - r_1)} \]

\( \alpha = \text{attenuation coefficient} \)

- Specific attenuation

\[ Q^{-1} = \frac{\alpha c}{\pi f} \]
Experimental Set Up (To capture $f_c$)

- Wave generator
- Digital oscilloscope
- Amplifier
- Receiver 2
- Underground Actuator
- Receiver 1

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Measured Signal

Frequency: 400 Hz

Amplitude: $X_1 \approx X_2$

Very little attenuation: not the characteristic frequency

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Measured Signal

Frequency: 3000 Hz

Amplitude: $X_1 < X_2$

Very high attenuation: Characteristic frequency

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Comparison of Dry and Saturated Conditions

Saturated Condition: $w = 23.14$ (%)  
Dry Condition: $w = 0.098$ (%)  

![Graph showing comparison between dry and saturated soil properties](image-url)
Field Testing

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### General Properties of Soils for Field Tests

<table>
<thead>
<tr>
<th>Location</th>
<th>$G_s$</th>
<th>$W$ (%)</th>
<th>$\gamma_d$ ($t/m^3$)</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sardis Lake</td>
<td>2.65</td>
<td>24.15</td>
<td>1.616</td>
<td>0.390</td>
</tr>
<tr>
<td>Tillatoba River</td>
<td>2.67</td>
<td>25.90</td>
<td>1.364</td>
<td>0.489</td>
</tr>
<tr>
<td>Baton Rouge</td>
<td>2.68</td>
<td>45.56</td>
<td>1.210</td>
<td>0.550</td>
</tr>
</tbody>
</table>

![Grain Size Distribution](image)

- **Tillatoba River**
- **Baton Rouge**
- **Sardis Lake**
Field Test at the Sardis Lake (Sandy Soil)

Acoustic Tech.: $2.02 \times 10^{-4}$ m/sec
Field Perm. Test: $3.65 \times 10^{-4}$ m/sec
Tillatoba River (Sandy Silt)

Acoustic Tech.: $1.73 \times 10^{-4}$ m/sec
Field Perm. Test: $3.70 \times 10^{-5}$ m/sec

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LSU Lake, Baton Rouge, Louisiana (Silty Clay)

Acoustic Tech.: N/A
Field Perm. Test: \(8.82 \times 10^{-6}\) m/sec
Expected \(f_c = 900\) kHz

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Conclusions

• Laboratory tests showed the existence of Biot’s characteristic frequency.

• Field tests for sandy soils and silty soils showed clear characteristic frequencies which can be used to compute the permeability of soils according to Biot (1956) theory.

• Field tests for silty soils did not show the good agreement with the field permeability test data.

• Field tests for clayey soils did not provide the characteristic frequency because of the limitation of the equipment.
Thank you for your attention.

Any Questions?
• Checking system compliancy

Lab. test with water only

Errors from incorrect alignment

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System characteristic frequency is approximately **10000 Hz**
• Checking Near Field Effect

Near field (Fresnel zone): the amplitude with distance does not follow the geometric attenuation

\[ x \approx \pi \frac{R^2}{\lambda} \]

\( R \) : radius of the source
\( \lambda \) : wavelength

Hunter and Bolt (1955); Kinsler et al. (1982)

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\[ k = \left( \frac{\pi}{11} \frac{D + L}{t_2 - t_1} \right) \ln \frac{h_1}{h_2} \]

D : the diameter of a stand pipe
L : the length of a sample