Application of high resolution acoustics for determination of the physical properties of fluid sediments

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Summary

• Introduction
• Survey area and methods
• Results: calibration survey (density)
• Results: regular survey (density)
• Results: yield strength
• Results: area dynamics
• Conclusions
• Questions
Introduction

Disadvantages of traditional low frequency echosounders:

• Low reliability
• No raw data, results difficult to validate
• Physical properties of seabed not known

Digital high resolution seismics with low echosounder frequencies offer more possibilities:

• Higher reliability of results
• Extensive opportunities for validation of data
• After calibration with geophysical point measurements provides physical properties of sediments (e.g. density, yield strength)
Introduction

Geophysical point measurements:

Examples:

• RheoTune. Based on tuning fork principle. Result: density and yield strength
• Transmission/Backscatter. Nuclear. Result: density

This presentation:
Case study
High resolution seismics with geophysical point measurements (RheoTune)
Survey area, equipment and methods

Area:

• Channel in tidal flat area in Waddenzee
• Tidal movements (+2 m, -2 m max)
• Related strong tidal currents

Equipment:

• Silas EBP-10: 24 kHz low frequency transceiver combined with a high resolution digital seismic system
• RheoTune
Silas EBP-10
All parameters constant

Silas
Digital seismic acquisition

Used configuration

Boomer
Sparker

Profiler Transducer(s)
3 – 12 kHz

Survey Transducer
24 kHz

AD card
Ethernet

Silas EBP-10
RheoTune

Measures:

• In-situ density (resonance frequency)
• Yield stress (amplitude)
• Depth (pressure)
• Temperature
• Inclination
Method: calibration

1) Surveylines with digital seismic
2) Geophysical point measurements on location of surveylines

High resolution seismic recording and location of a point measurement in fluid sediment in area of case study.
Method: calibration

Procedure of density calibration of high resolution seismics as applied by Silas.

A= Seismic registration, B= Received signal at calibration point, C= Synthetical density profile derived from seismics at calibration point, D= Results geophysical point measurement (RhoeTune)
Method: calibration

- At each point construction of synthetic density profile using HR seismics
- Synthetic density profile using standard acoustical laws which relate reflected/incoming signal power to impedance
- At each point iterative calculation of synthetical density profile with varying incoming signal power
- Result of calibration: Estimate of incoming signal power with best fit between synthetical density profile and point density profile
- After calibration, calibrated synthetic density profiles available for each seismic shot
- Calibration available for later measurements without point measurements
I) Impedance = ρ * v

in which:

ρ = density of sediment layer (kg./l.)

v = propagation velocity of p-waves in sediment (m/sec)

II) \( \frac{Ar}{Ai} = \frac{(\rho_2 v_2) - (\rho_1 v_1)}{(\rho_2 v_2) + (\rho_1 v_1)} \)

Ar = Reflected amplitude

Ai = Incoming amplitude just above seabed

ρ_1 = density in layer above transition (kg./l.)

ρ_2 = density in layer below transition (kg./l.)

v_1 = velocity in layer above transition (m/sec)

v_2 = velocity in layer below transition (m/sec)

Method: used formulas
Results calibration: absolute level of lutocline

<table>
<thead>
<tr>
<th>A</th>
<th>Location number</th>
<th>D</th>
<th>Depth seismic (m to N.A.P.)</th>
<th>E</th>
<th>Depth (Tune) (m to N.A.P.)</th>
<th>F</th>
<th>Depth Difference D-E (m)</th>
<th>H</th>
<th>Density Gradient (g./l/ per cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0001_759</td>
<td>3.58</td>
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</table>

First reflector seismic corresponds with first density change in point measurements. First density change is detected. Detection at low gradients of app. 0.4 g./l. per cm.
Results calibration: absolute level of lutocline

Depth difference
1st reflector seismic – 1st density change point measurements

<table>
<thead>
<tr>
<th>Depth Difference (m)</th>
<th>Time difference (minutes)</th>
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</thead>
<tbody>
<tr>
<td>-0.2</td>
<td>0</td>
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<td>0.2</td>
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Depth difference
1st reflector seismic – 1st density change point measurements

<table>
<thead>
<tr>
<th>Depth Difference (m)</th>
<th>Distance point measurement to seismic (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.2</td>
<td>0</td>
</tr>
<tr>
<td>-0.1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
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<tr>
<td>0.1</td>
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<tr>
<td>0.2</td>
<td>4</td>
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<tr>
<td>0.3</td>
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Depth difference
1st reflector seismic – 1st density change point measurements

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<thead>
<tr>
<th>Depth Difference (m)</th>
<th>Distance point measurement to seismic (m)</th>
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</thead>
<tbody>
<tr>
<td>-0.2</td>
<td>0</td>
</tr>
<tr>
<td>-0.1</td>
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<td>0.2</td>
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<td>0.3</td>
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</table>
Results calibration: density gradient at lutocline

Depth difference top lutocline
seismic - point measurements

Depth difference (m) vs. Density gradient (g./l. per cm)
Results calibration

• Small depth difference: First reflector seismics corresponds to first density change in point measurement
• Therefore density calibration of seismics is valid
• High resolution seismics can detect top of lutocline at a density gradient of at least 0.4 g./l. per cm
• Calibration: Pay attention to time and space! Differences between location of top of lutocline according to seismic and point measurement increase with time and distance.
• Differences shown are absolute: can also be due to other factors such as RTK accuracy, and natural variation in lutocline.
• After calibration the difference between predicted synthetical density level 1200 g./l. and point measurement < +0.2 m., standard deviation: 0.12 m.
Results regular survey

• Regular survey executed 3 weeks later in same area.
• Settings seismic identical to 3 weeks before.
• Geophysical point measurements executed to check validity of calibration of 3 weeks before
Results regular survey

- Difference between predicted synthetical density level of this calibration and geophysical p. measurement < +0.22 m., stdev 0.16 m. Calibration is valid

<table>
<thead>
<tr>
<th>A Location number</th>
<th>D Depth 1200 g./l. level seismic (m. to N.A.P.)</th>
<th>E Depth 1200 g./l. level (Tune) (m to N.A.P.)</th>
<th>F Depth Difference synthetic 1200 g./l. - 1200 g./l. (Tune) in m.</th>
<th>G Thickness Fluid sediment above 1200 g./l. level in m.</th>
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<tbody>
<tr>
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<td>4.70</td>
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<td>1.38</td>
</tr>
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</table>

StDev=0.16
Results: yield strength

• Yield strengths are generally low: < 20 Pa
• Low yield strength: sediment more susceptible to currents
• Low yield strength: less influence on manouvrability
• Consequently yield stress is an important factor for maintenance of navigable depth
• Use of rheological parameters such as yield stress/viscosity for maintenance of navigable depth is still to be investigated.
• This area: under 1200 g./l. level sharp transition to yield stress > 100 Pa
Results: area dynamics

• Dynamical situation: significant changes in location of top lutocline after app. 90 minutes.
• Changes in state of fluid sediment layer could be related to:
  - tidal currents
  - ship traffic
Conclusions

• Digital high resolution seismic gives more info and is more reliable than a traditional echosounder
• Digital high resolution seismic is a useful tool to measure physical properties of fluid sediments
• Digital high resolution seismic can detect small density gradients of 0.4 g./l. per cm in fluid sediment of low yield strength (< 5 Pa).
• In this area high resolution seismic density calibration is valid for at least 3 weeks, with a standard deviation of 0.16 m for the 1200 g./l. density level.
Questions and Discussion