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A measurement system for shear speed using interface wave dispersion

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THINK BIG WE DO℠

1st Seabed Characterization Workshop, Austin, Texas, 05-06, 2011

Amphibious Seismo-Acoustic Recording System

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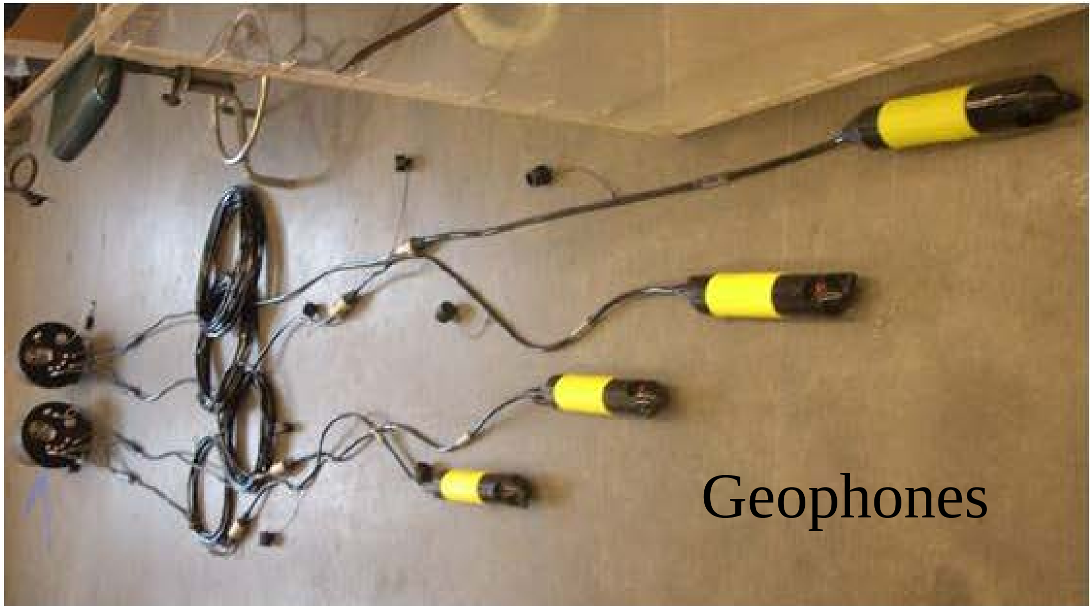
- Use the dispersion of the interface waves to estimate the shear wave speed
- Three Several Hydrophone Receive Unit (SHRU), geophones, hydrophones and a sled to house the data acquisition system
- Available (12) channels will be used to acquire data using geophone/ hydrophone combinations.
- SHRU sampling rate can be adjusted from ~ 1 to 10 khz.
- Data stored in hard disk and memory card.
- The SHRUs will be housed in a sled which will rest at the bottom.

SHRU



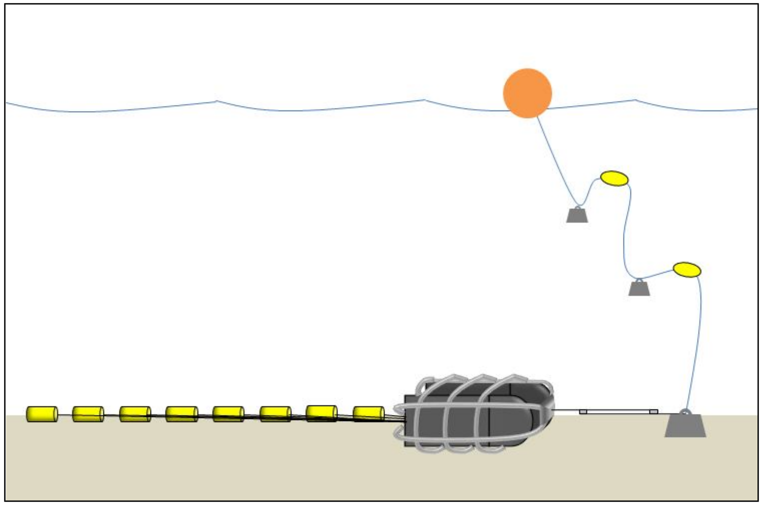
Geophones

Sensors Used in ASARS

- Geospace PV-1 Dual Vertical Axis Gimbaled Geophone and Hydrophone (8 nos)
- Geospace Sea Array 4 3-axis Gimbaled Geophone (three mutually perpendicular geophones) and Hydrophone (One unit)
- HTI-94-SSQ Hydrophone (8 nos)

HTI-94-SSQ SERIES -

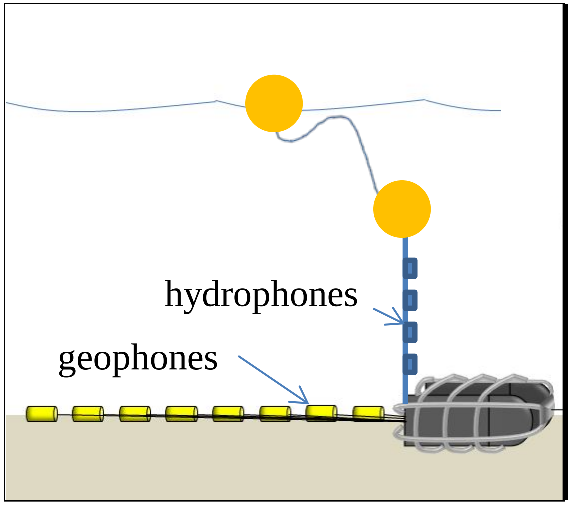
Possible Configurations



GS-PV1-S combination geophone/hydrophones manufactured by Geospace Technologies.

The geophone component (velocity sensor) has a natural frequency of 10 Hz and a sensitivity of 2.55 volts/in/sec.

The hydrophone (pressure sensor) has a natural frequency of 10 Hz and a sensitivity of 6.76 volts/bar.



8 Vertical Axis Gimbaled Geophones and One 3-axis Gimbaled Geophone available.

Adjustable spacing; cables run parallel and connected separately to SHRU (max. cable length=40 m).

Status: SHRU with geophone array has been tested on land and in shallow water (N. Bay)

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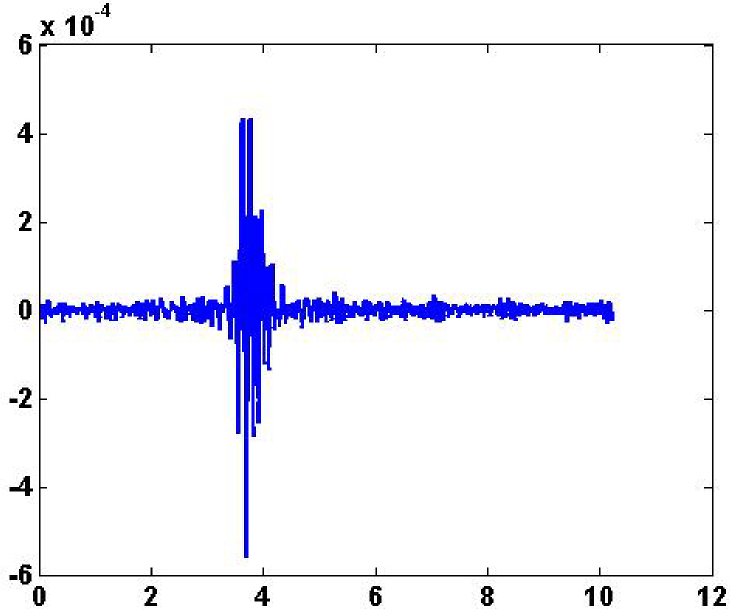
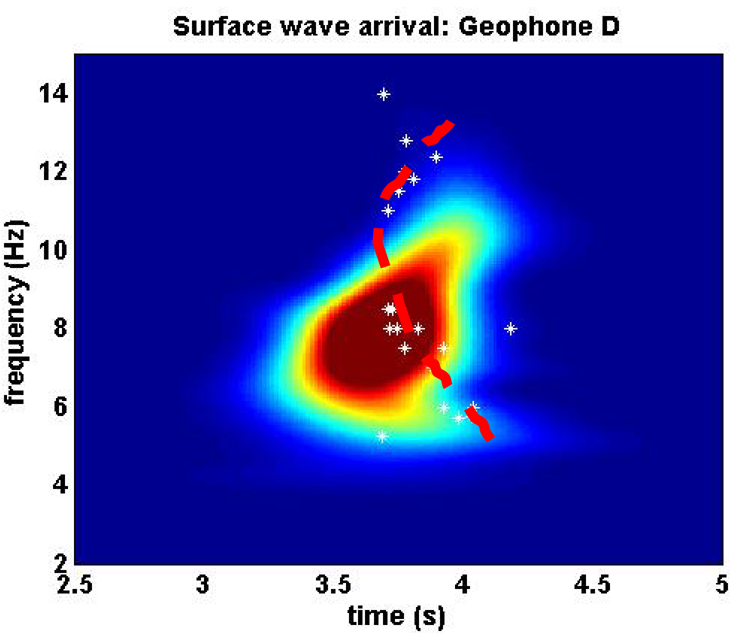
Sea-test – Narragansett Bay





Simple test: One SHRU with 4 geophones in water off the GSO dock

A 300 lb weight dropped to create an impulsive signal

Geophones performed well.

Used a land-based shear estimation technique (Spectral Analysis of Surface Wave): At 8 Hz the velocity of interface wave = 225 m/s

Shear speed ~ 0.9 x interface wave speed

Interface wave penetration ~ 1 to 2 wavelength

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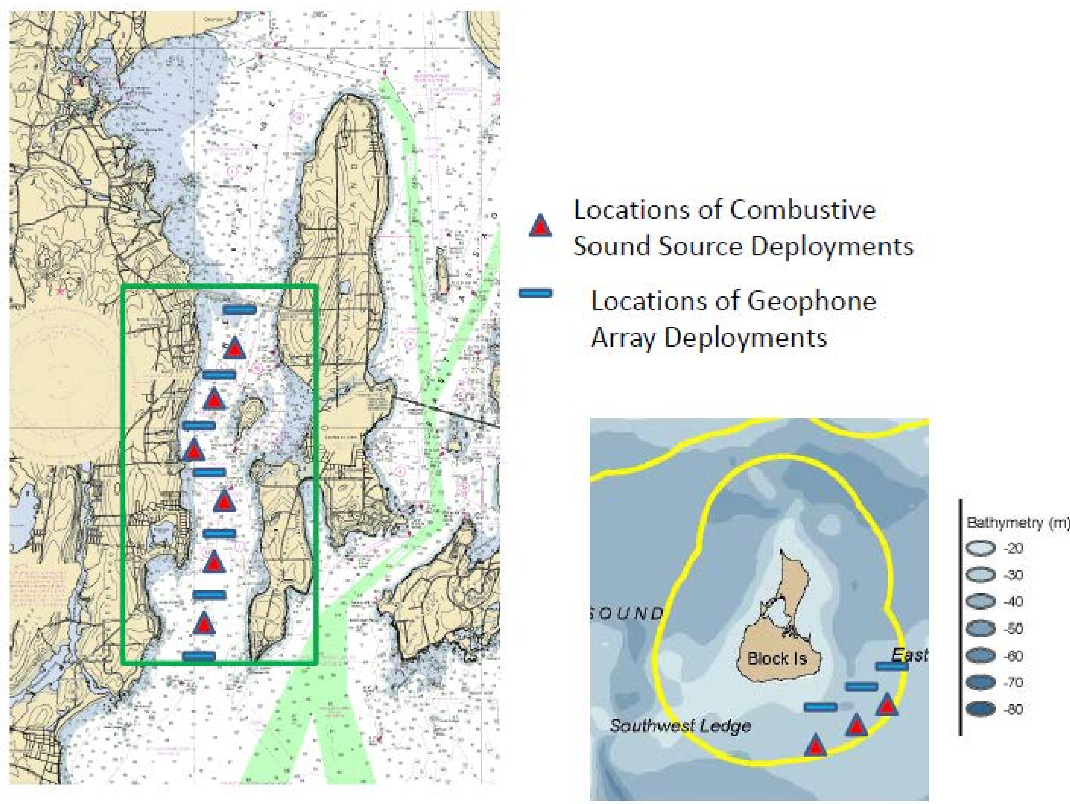
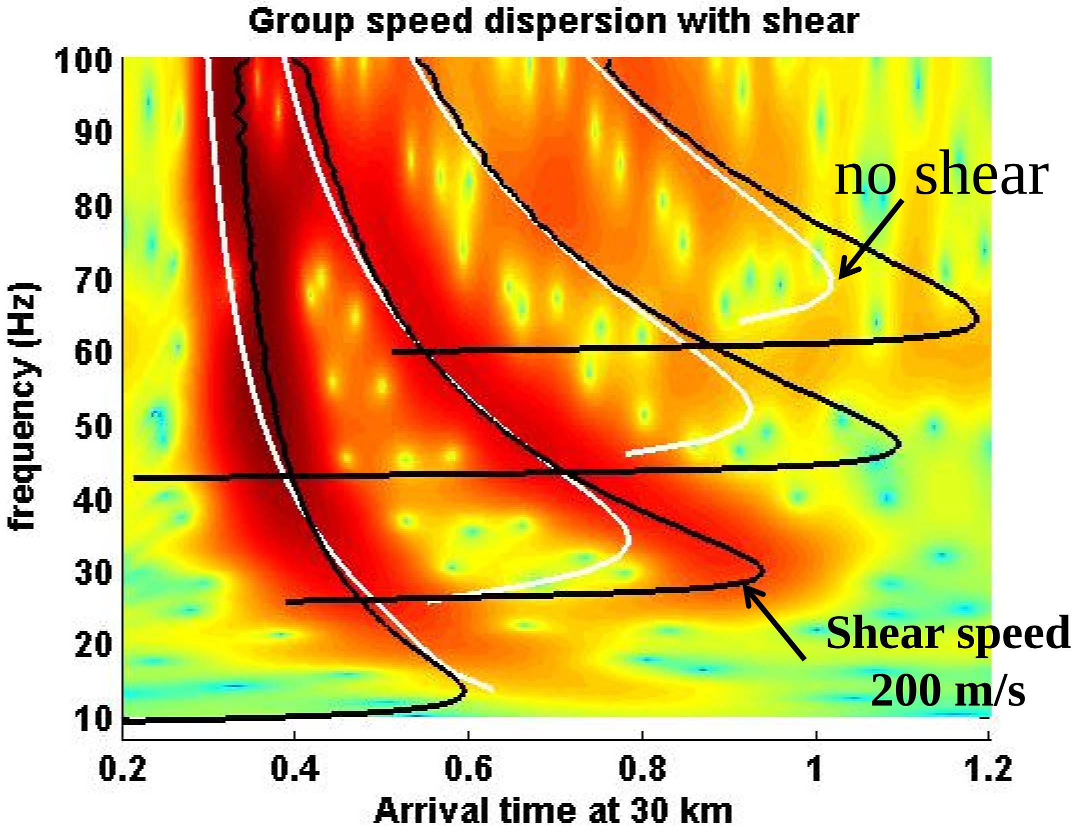
Full Scale Field Test

- Full scale field teats are planned in Narragansett Bay during this summer (August).
- Combustive Sound Sources (CSS) will be used as sources (Preston Wilson)
- Tests are planned in the Bay (~ 10 m water depth) and at a location off Block Island (~25 m water depth).
- Block Island location was investigated extensively for the Wind farm project (good bathymetry and sediment data)

Scope for collaboration

Possible issues to be addressed during the test include deployment procedure, geophone positioning, efficient coupling of energy into geophone, source depths (in water column Vs on the bottom) etc.





Another interest:

Look at modal dispersion at different water depths and sediment types and use it for inversion

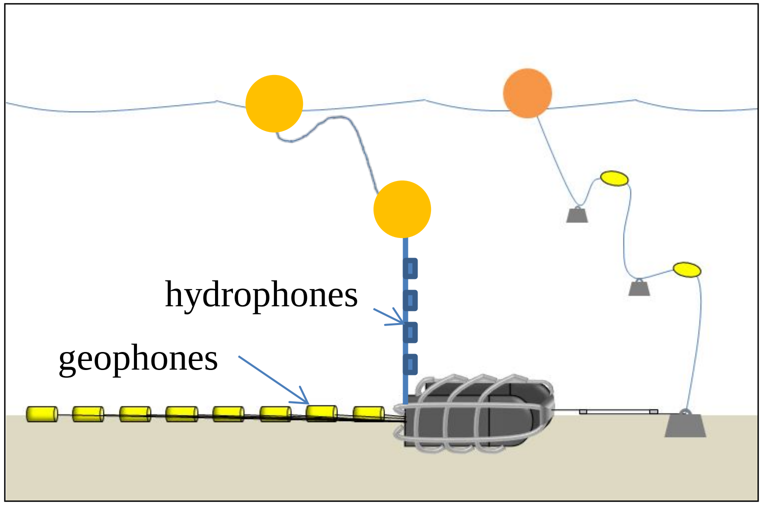
Understand the influence of shear on modal travel times and amplitudes near the Airy Phase region.

Compressional wave speed (Cp)– 1620 m/s

East China Sea (ASIAEX)

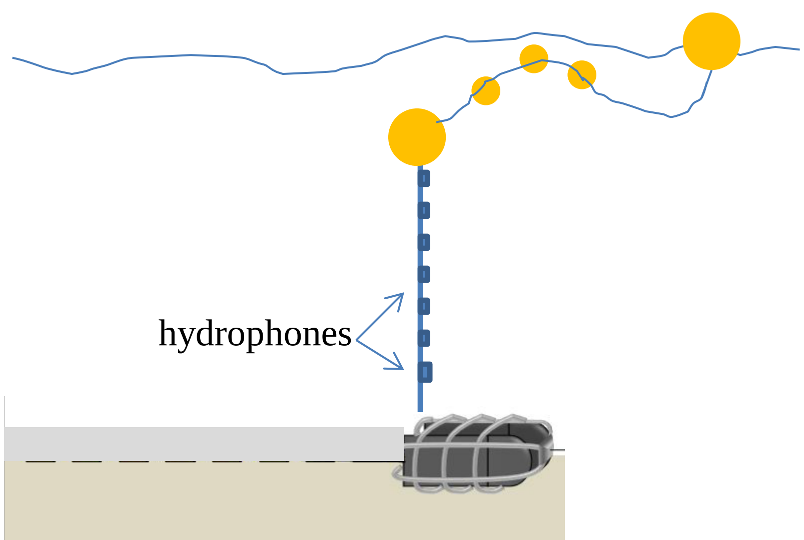
Additional Slides

Possible Configurations: Hydrophone Array



L shaped array with 4 hydrophones and 4 geophones .

Third SHRU can be used to connect the 3-axis geophone



Hydrophone Array with 8 phones

Third SHRU can be used to connect the 3-axis geophone or 4 vertical axis geophones

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The focus: shear speed in marine sediments

- Reliable models of in-situ shear-wave velocities of shallow-water marine sediments important for various geotechnical applications, lithological sediment characterization, and seismic exploration studies.
- Acoustic energy converts to shear waves at the seafloor
- Estimating shear - measurement of interface waves
- Map sediment variations, predict system performances

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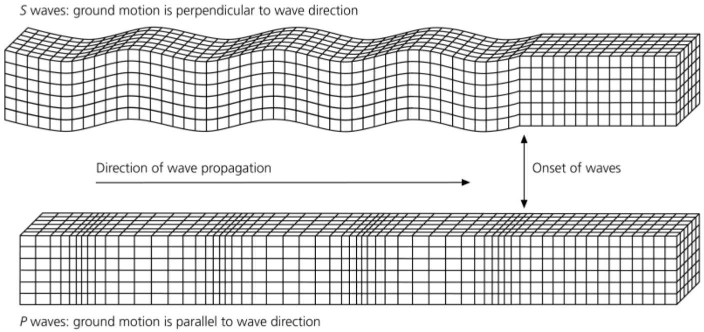
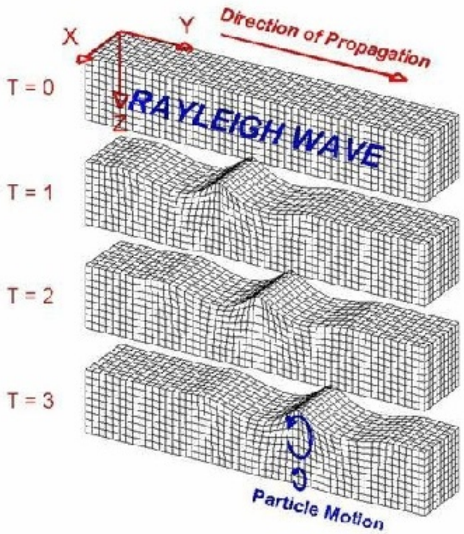
Elastic Waves

- Occur when a solid medium is deformed
- Unbounded
  - Dilatational (longitudinal)
  - Distortional (transverse)



- Free surface or surface boundary between two solids
  - Rayleigh surface waves



http://geophysics.eas.gatech.edu/classes/Geophysics/misc/Seismology.html

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Scholte Waves

- **The Scholte wave is an elliptically polarized wave which propagates along the water-sediment interface, decaying exponentially in amplitude away from the boundary in either medium(i.e., the wave is evanescent in both media).**

From Osler and Chapman, Canadian Acoustics, 24(3), 1

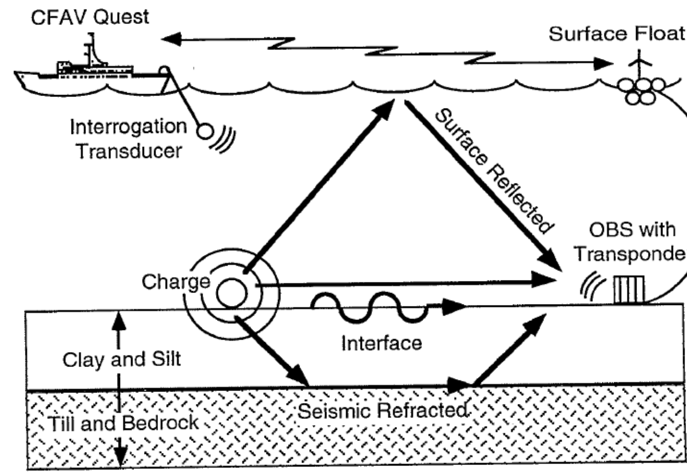
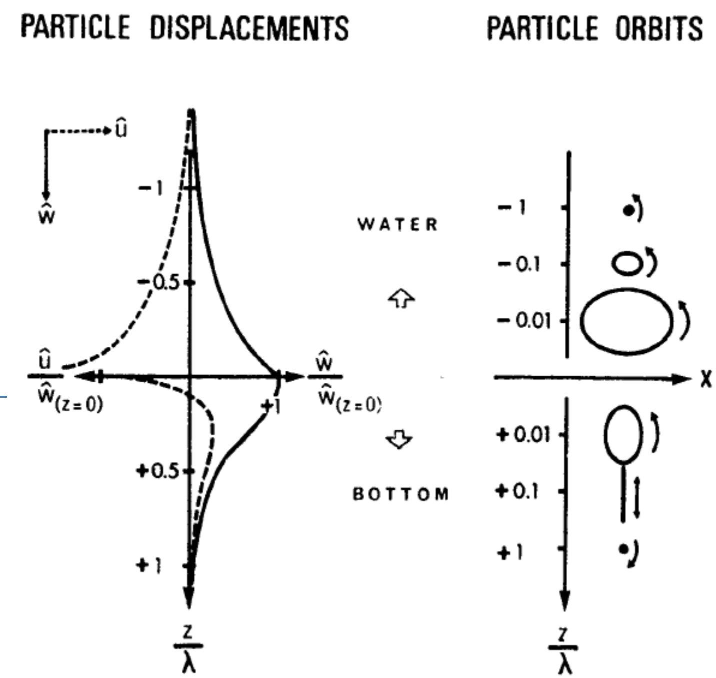


Figure 5: Source to receiver arrival paths and schematic of experimental setup.



Dosso and Brooke, J. Acoustic. Soc. A., 98(3), 1995
Rauch, Seismic interface waves in coastal waters: A review, SACLANT Report, 1980

Uses of the Scholte Wave

- Dispersion provides an insight into geoacoustic properties of the sea floor
- Phase speed of dispersive waves used to determine the shear speed profile through inverse modeling
- Waves exhibit physical properties that are directly related to the power-law depth-dependence of shear rigidity

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Shear Properties

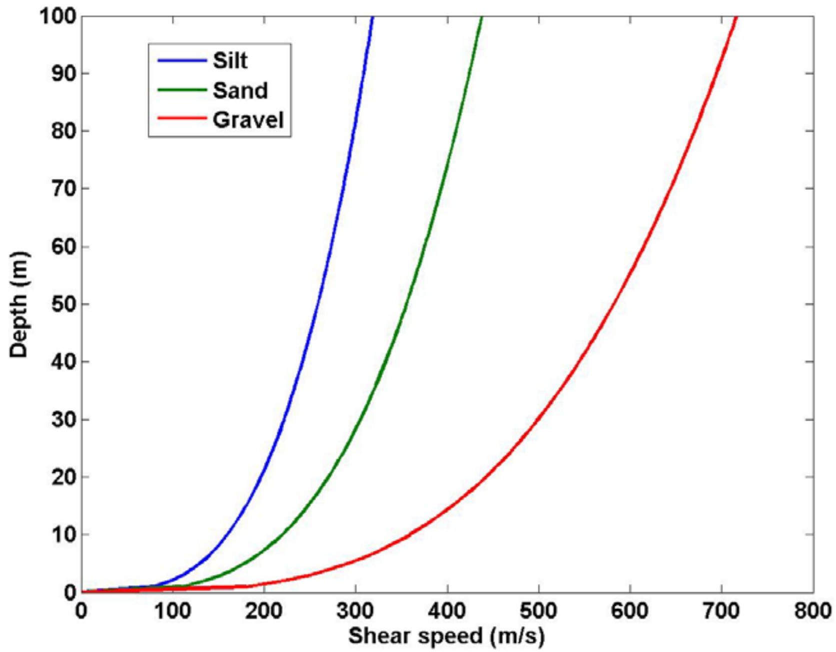
Table 1.3 Geoacoustic properties of continental shelf and slope environments.

Bottom type	p (%)	ρ_b/ρ_w -	c_p/c_w -	c_p (m/s)	c_s (m/s)	α_p (dB/λ_p)	α_s (dB/λ_s)
Clay	70	1.5	1.00	1500	< 100	0.2	1.0
Silt	55	1.7	1.05	1575	$c_s^{(1)}$	1.0	1.5
Sand	45	1.9	1.1	1650	$c_s^{(2)}$	0.8	2.5
Gravel	35	2.0	1.2	1800	$c_s^{(3)}$	0.6	1.5
Moraine	25	2.1	1.3	1950	600	0.4	1.0
Chalk	-	2.2	1.6	2400	1000	0.2	0.5
Limestone	-	2.4	2.0	3000	1500	0.1	0.2
Basalt	-	2.7	3.5	5250	2500	0.1	0.2

$c_s^{(1)} = 80\,z^{0.3}$
$c_s^{(2)} = 110\,z^{0.3}$
$c_s^{(3)} = 180\,z^{0.3}$

$c_w = 1500$ m/s, $\rho_w = 1000$ kg/m^3

Jensen, Kuperman, Porter and Schmidt, *Computational Ocean Acoustics*, p. 38, (2000).



Shear Properties of Rock

Table 1. Density, shear-wave velocity, quality factor and attenuation determined in samples of rocks and synthetic materials

Test sample	Density (g/cc)	V_S (m/s)	Q_S	α_S (dB/cm)
Rock samples				
Rhyolite	2.471	2994	116.75	0.7806
Granite (Hyderabad)	2.676	3345	70.10	1.1637
Granite (Kudankulam)	2.692	3173	56.32	1.5269
Granitoid gneiss	2.718	2992	51.40	1.7743
Hypersthene granite	2.724	3385	66.27	1.2164
Charnockite	2.863	3662	82.58	0.9023
Synthetic materials				
Processed wood	0.695	1582	76.30	2.2605
Perspex	1.202	1382	78.78	2.5062
Ebonite	1.444	1555	74.43	2.3576
Teflon	2.121	441	26.65	23.2171
Concrete	2.200	2365	40.36	2.8586

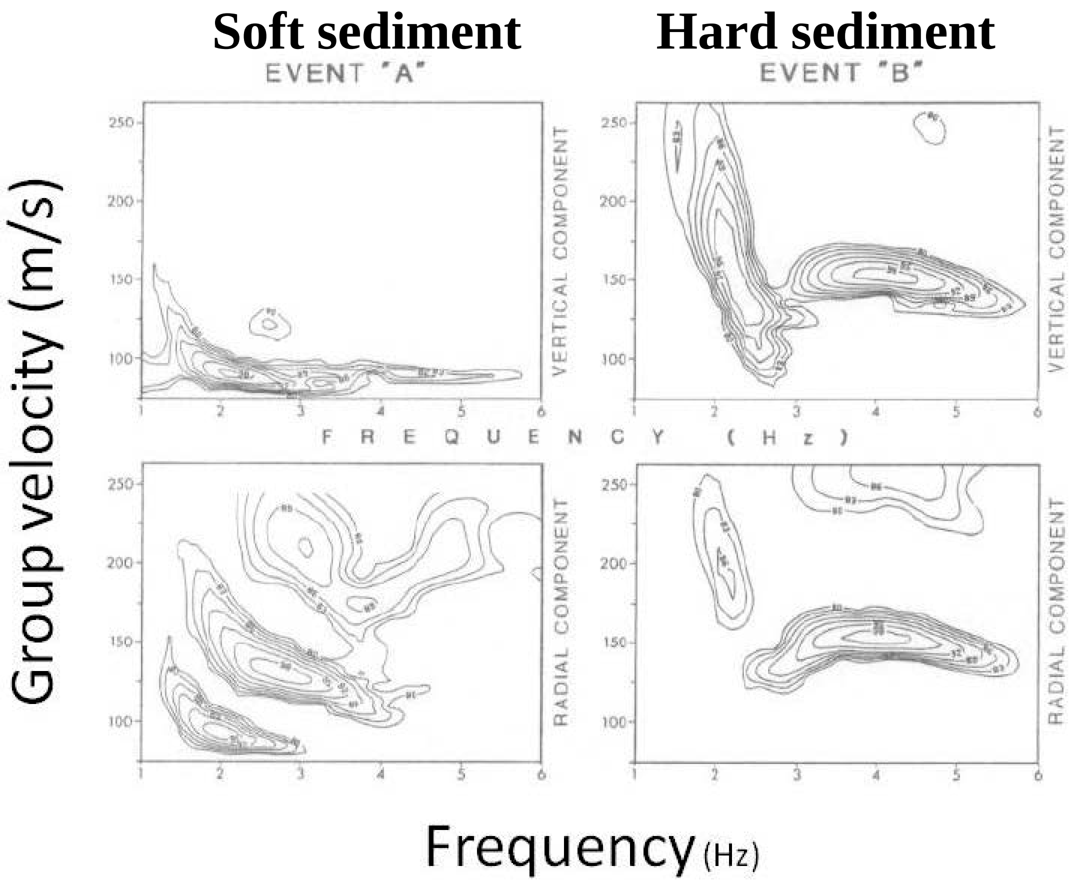
M. V. M. S. Rao* and K. J. Prasanna Lakshmi, Shear-wave propagation in rocks and other lossy media: An experimental study," CURRENT SCIENCE, VOL. 85, NO. 8, 25 OCTOBER 2003

Shear Measurement methods

- Direct measurements (probes-shear wave transducers or cone penetrometers)
- In the lab using probes
- In situ measurements are limited in depth, time consuming and often require support from divers or submersibles.
- Laboratory measurements have consistently shown lower values than in situ measurements (due to disturbance during collection, transportation and storage and reduction in confining pressure.
- Probes typically (especially lab ones) make measurements at frequencies higher than at which shear conversion is significant.

Osler and Chapman, Canadian Acoustics, 24(3), 11-22, 1996

Dispersion of interface waves



Dispersion of interface waves generated in a 'soft bottom'(Event A) and 'hard bottom' (Event B).

Top panels show the vertical particle velocity bottom panels show radial particle velocity

[Figure from Rauch, 1985]

- Scholte wave speeds are usually of the order of some tens to few hundreds of m/s in soft sediments as opposed to 1200 m/s to 1500 m/s in the case of hard sediments.

- Dispersion is comparatively stronger (with several modes) in softer sediments due to the regular sedimentary layering with strong parameter gradients.

- In the case of hard sediments, dispersion is strongly dependant on the actual layering present and usually dispersion less pronounced.

- Scholte waves are attenuated strongly in softer sediments due to higher medium losses. Harder sediments have low losses and hence lower attenuation.

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Shear Measurement: Using Scholte Wave Dispersion

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

- Consequently, a broadband Scholte waveform propagating in such an environment will undergo normal dispersion with the degree of dispersion determined by the shear-speed gradient.

- Conversely, the 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.

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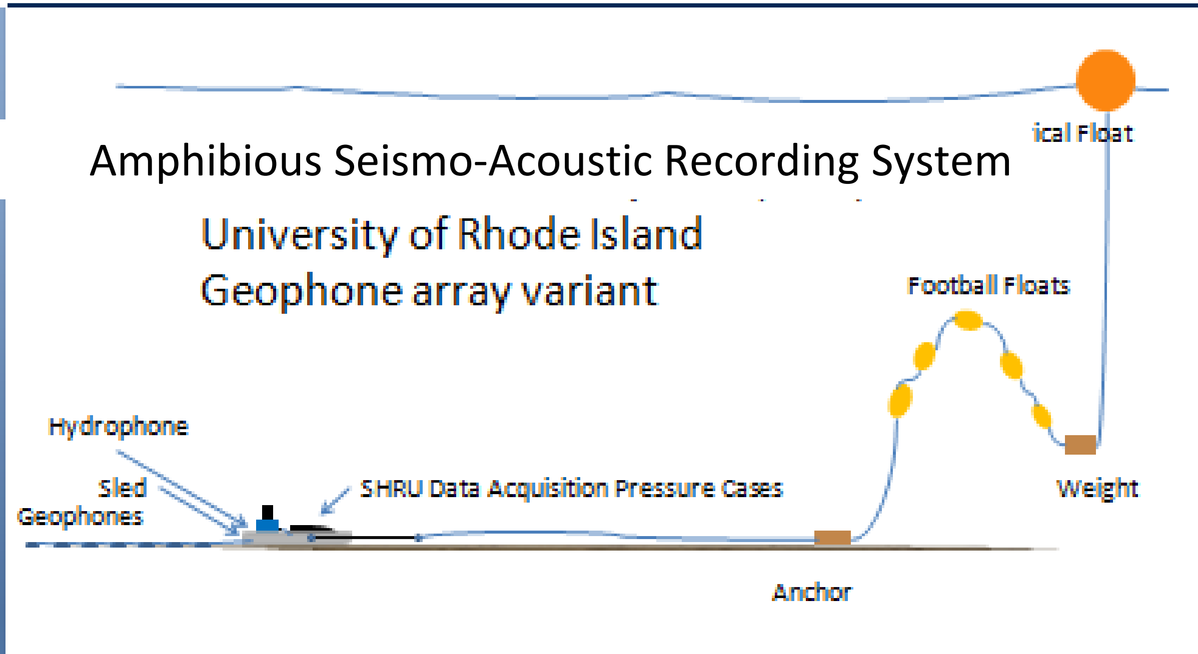
Amphibious Seismo-Acoustic Recording System



Approach: Use the dispersion of the interface waves to estimate the shear wave speed

The proposed equipment consists of two Several Hydrophone Receive Unit (SHRU), geophone and a sled to house the data acquisition system

Available (eight) channels will be used to acquire data using geophone/ hydrophone combinations.

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Sensors Used in ASARS

- Geospace PV-1 Dual Vertical Axis Gimbaled Geophone and Hydrophone

- Geospace Sea Array 4 3-axis Gimbaled Geophone (three mutually perpendicular geophones) and Hydrophone

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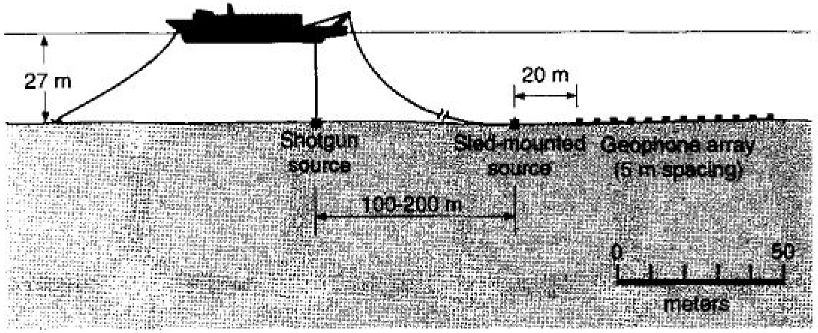
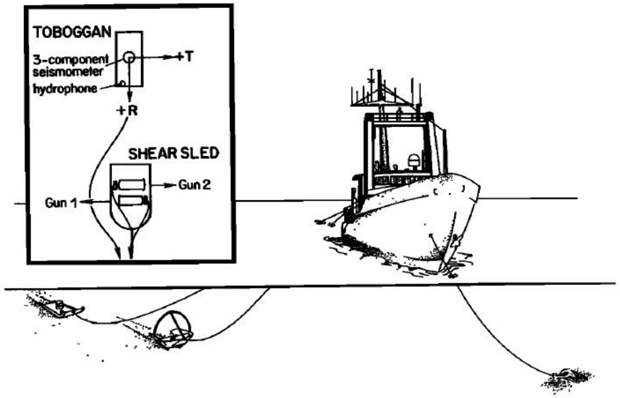
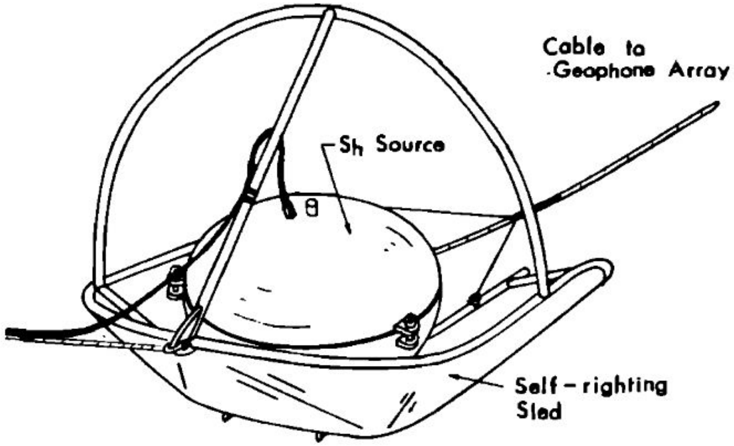
Geophone Specifications

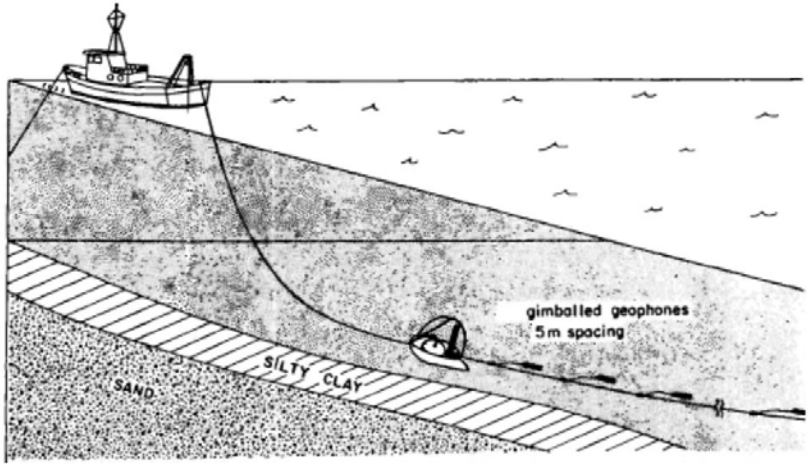
- **Velocity Sensor**
  - 2 each GS-30CT:
  - Natural Frequency 10 Hz ± 2%
  - Sensitivity 2.55 volts/in/sec ± 2%
  - Damping .70 ± 2% (.686 to .714)
  - DC Resistance 3677 ohms ± 4%
- **Pressure Sensor**
  - Natural Frequency 10 Hz ± 15%
  - Sensitivity 6.76 volts/bar ± 1.5 dB
  - Sensitivity change at operational depth less than 3 dB
  - Damping .70 typical (.60 to .80)
  - DC Resistance 871 ohms ± 5%
  - Operational Depth: 1 - 656 ft.
- **Dual Sensor Physical Dimensions**
  - Length: 14.25 in (36.20 cm)
  - Diameter: 2.50 in (6.35 cm)
  - Weight: 4.50 lb (2.04 Kg)

Sled design – proven and effective









John Ewing, Jerry A. Carter, George H. Sutton, and Noel Barstow, Shallow water sediment properties derived from high-frequency shear and interface waves, Journal of Geophysical Research 97 (1992), no. B4, 4739{4762.

A. Caiti, T. Akal, and R.D. Stoll, Estimation of shear wave velocity in shallow marine sediments, IEEE Journal of Oceanic Engineering 19 (1994), 58{72.

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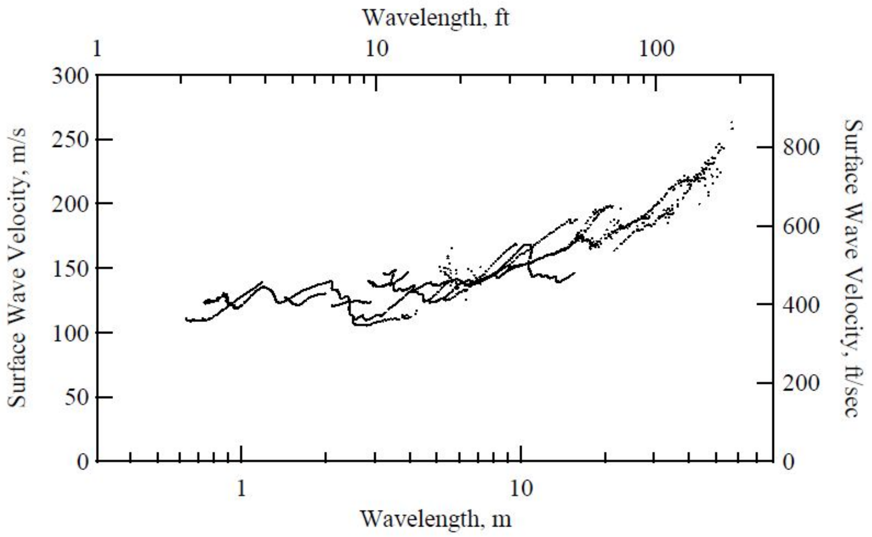
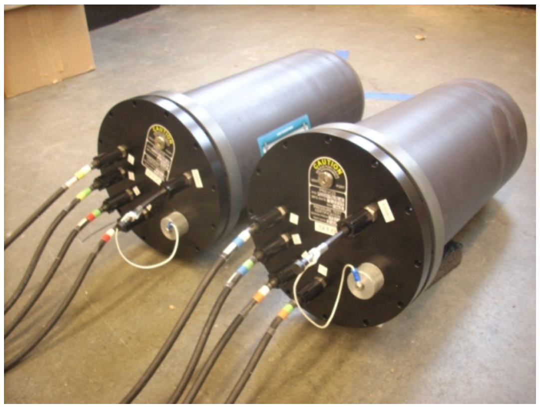
Terrestrial test validation: spectral analysis of surface waves

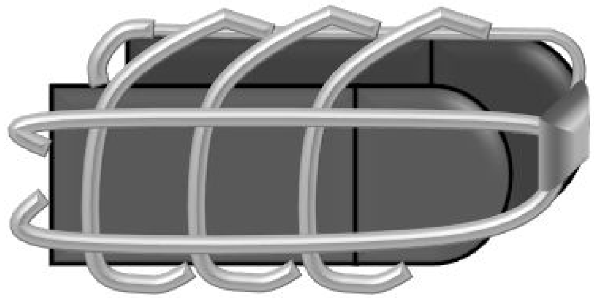
- non-destructive, non-intrusive technique
- evaluates in situ stiffness profiles
- Output is a dispersion curve
  - Rayleigh wave phase velocity versus wavelength or frequency.
- Shear wave velocity profile derived from curve using an inversion process
- Inversion - forward modeling process



James Bay, Je Gilbert, Kwangsoo Park, and Inthorn Sasankul, Shear wave velocity proling using spectral analysis of surface waves (sasw) at williams street park and coyote creek borehole san jose, ca.

ASARS DESIGN





- Low-profile cage – aluminum tubing
- Design based around DAQ component – SHRUs
- Geophone/hydrophone array – 8 channels, possible additions

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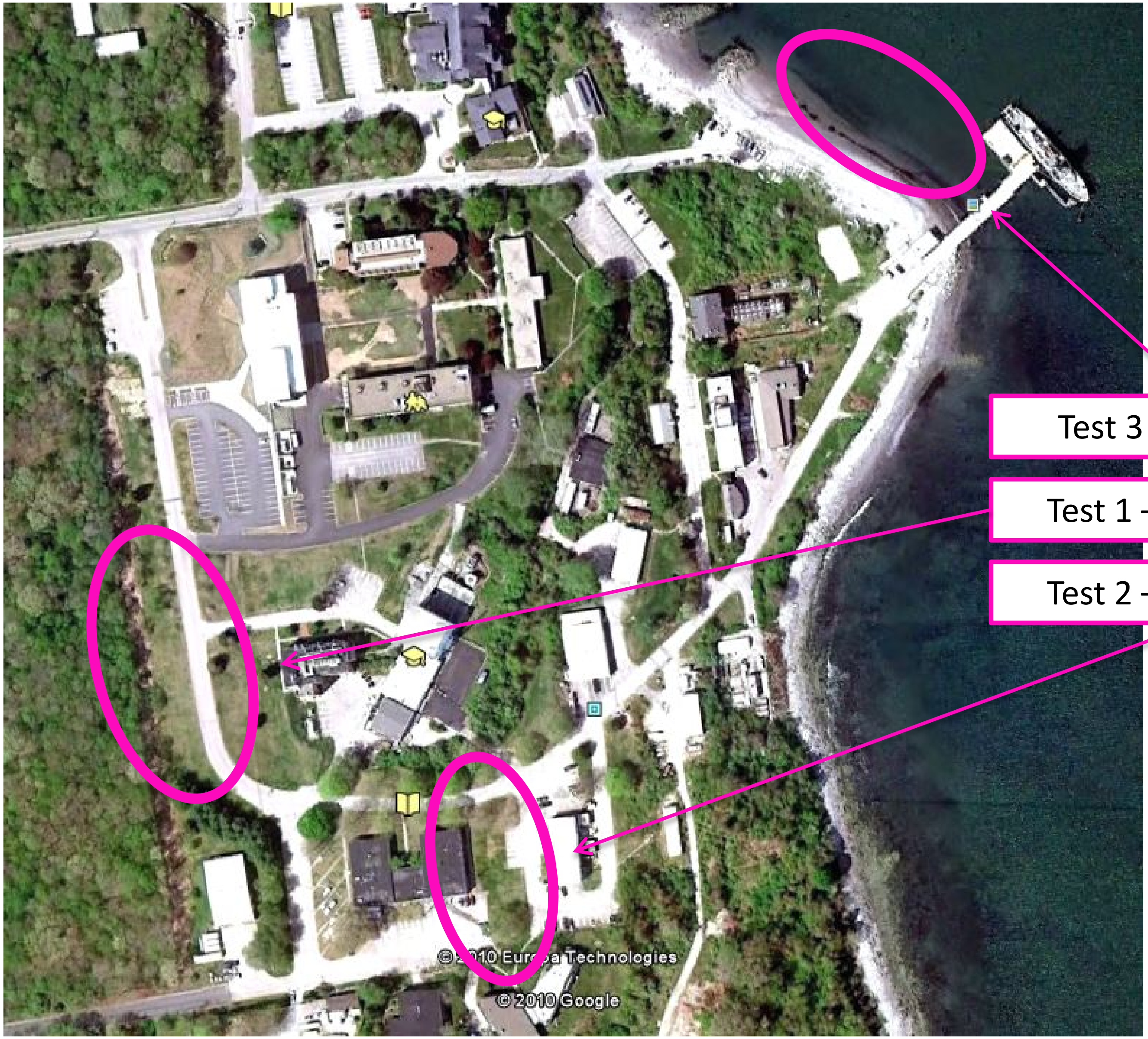
Testing overview

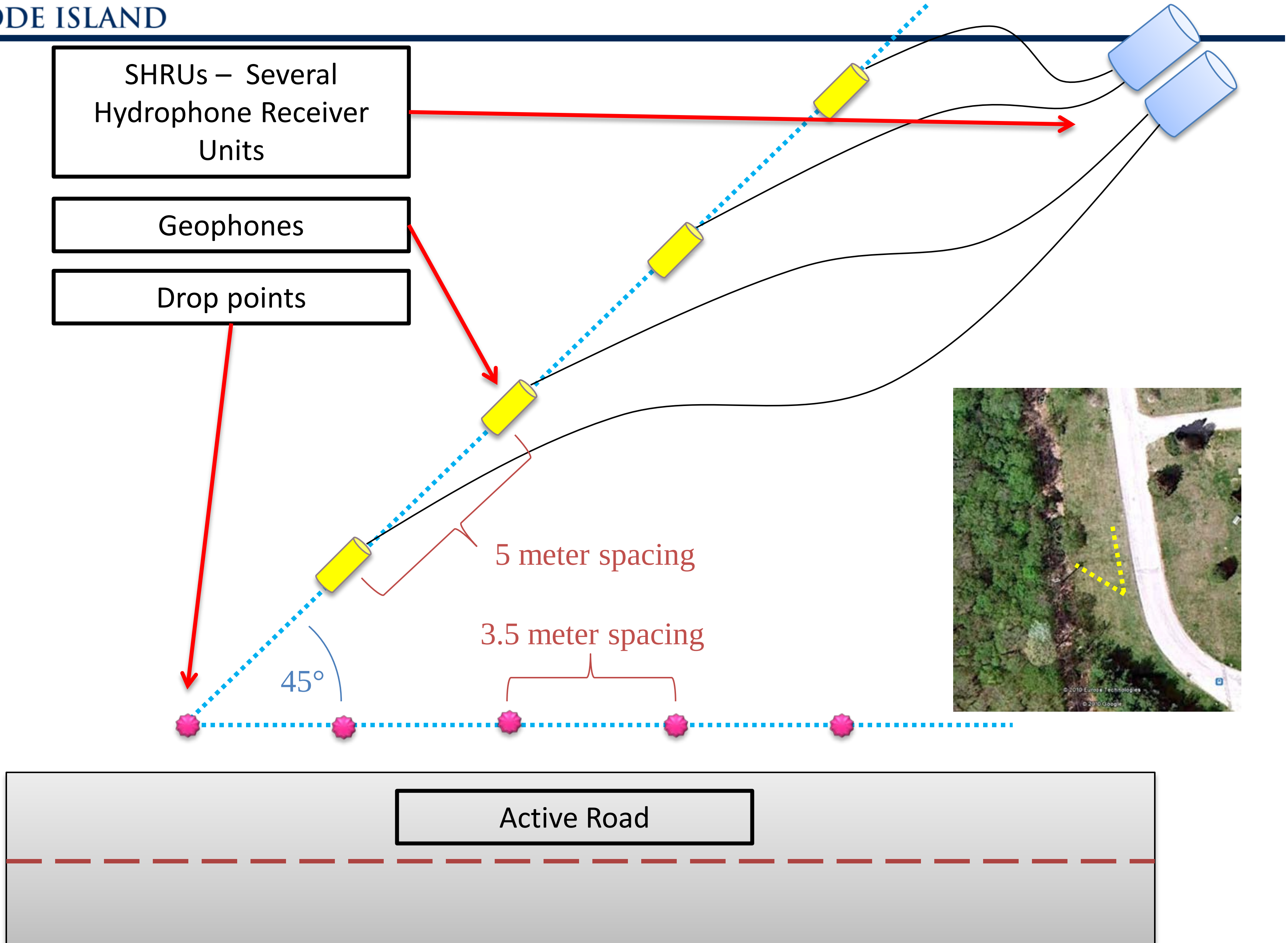


Test 3 – Beach Test

Test 1 – Ground Test

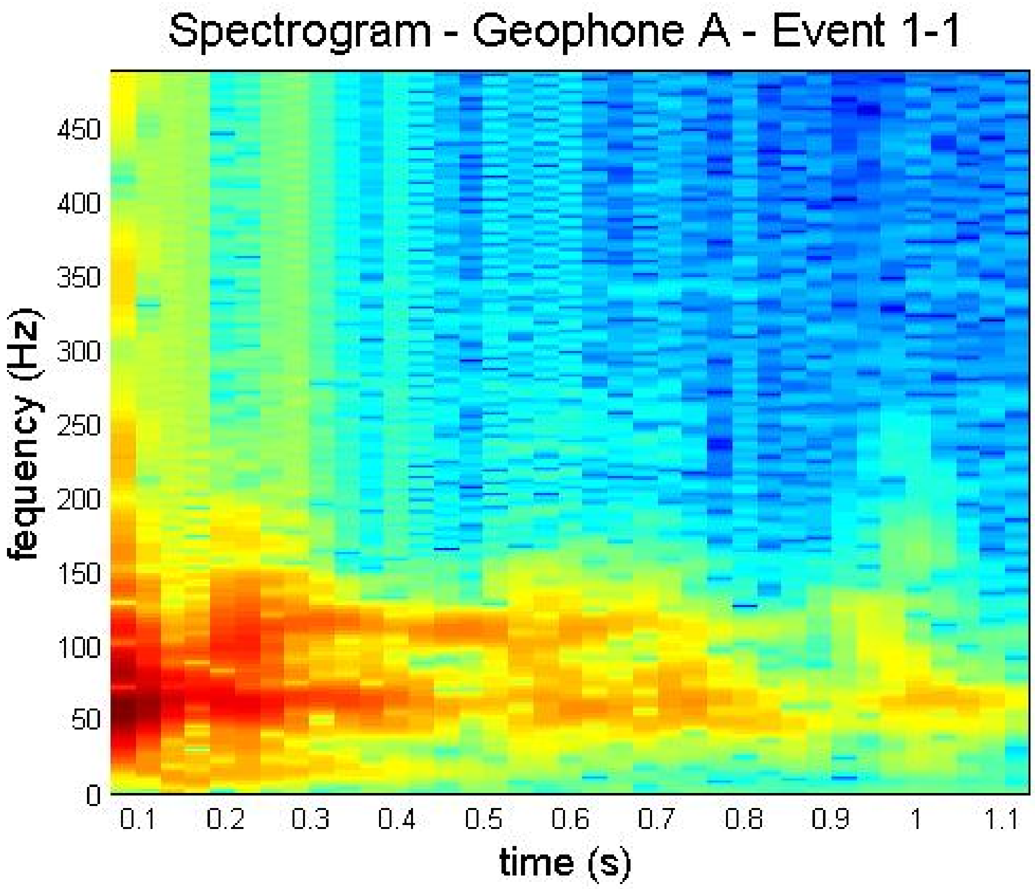
Test 2 – Ground Test

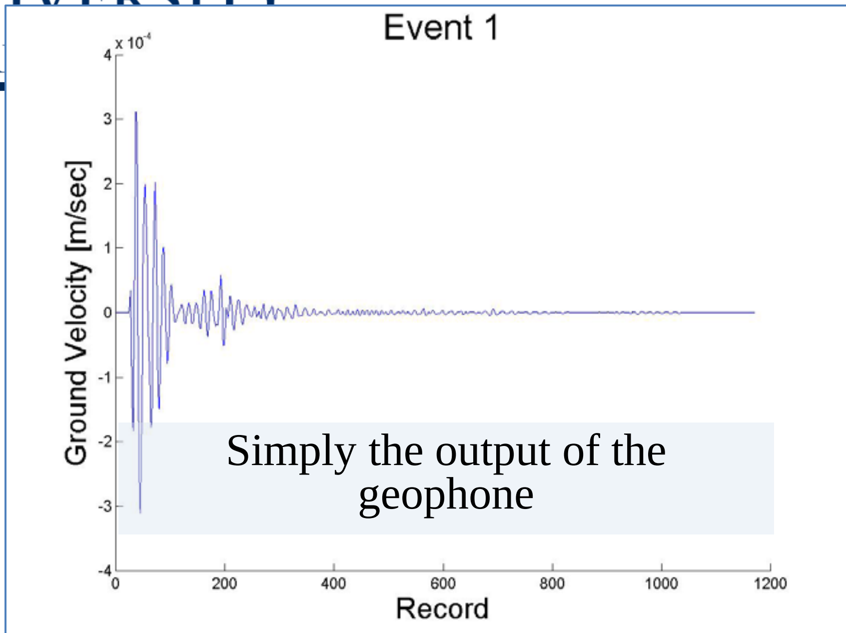
Ground Test 1

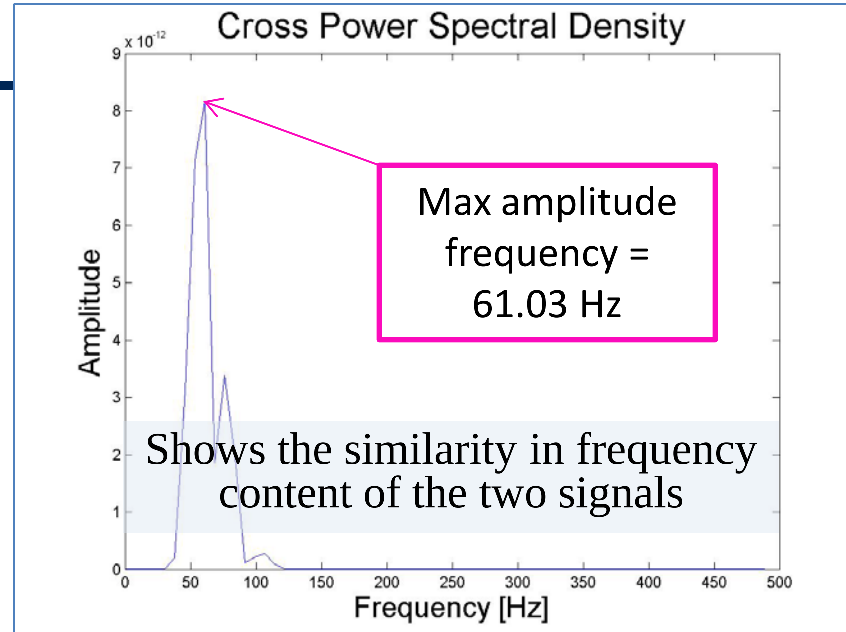


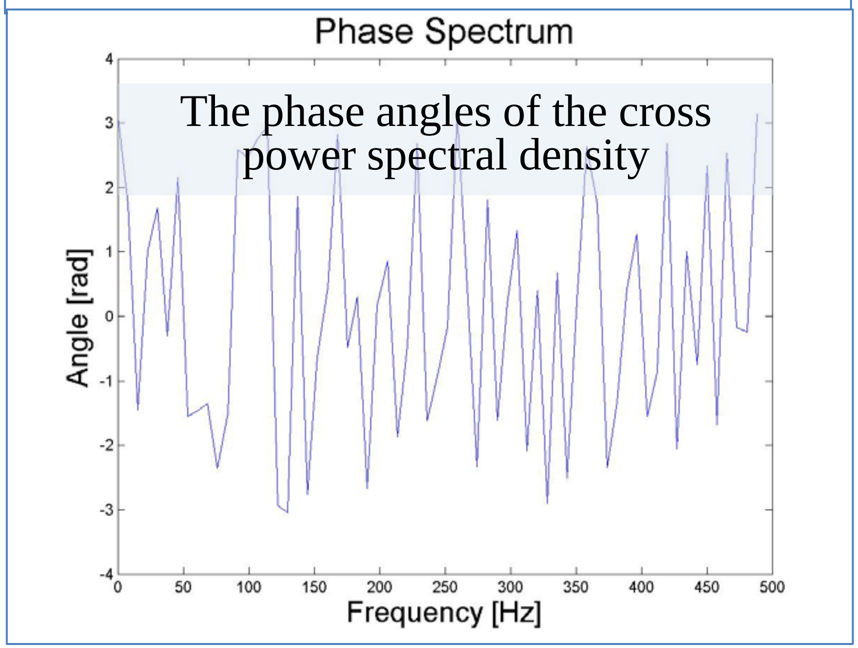
Spectrogram

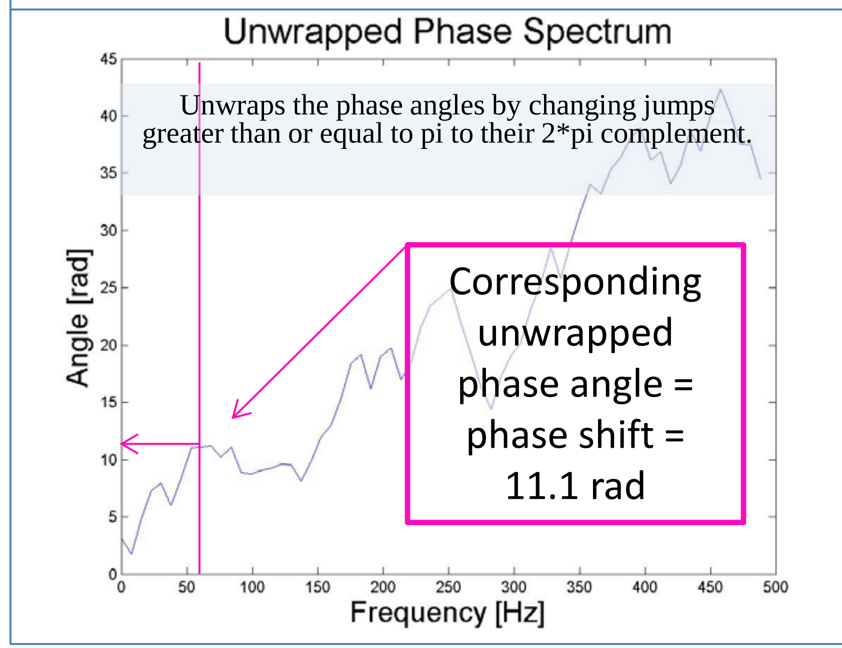
- Seismic signal created by dropping a heavy weight.




Event 1
x 10^-4
Ground Velocity [m/sec]
Record
Simply the output of the geophone


Cross Power Spectral Density
x 10^-12
Amplitude
Frequency [Hz]
Max amplitude frequency = 61.03 Hz
Shows the similarity in frequency content of the two signals


Phase Spectrum
Angle [rad]
Frequency [Hz]
The phase angles of the cross power spectral density


Unwrapped Phase Spectrum
Angle [rad]
Frequency [Hz]
Unwraps the phase angles by changing jumps greater than or equal to pi to their 2*pi complement.
Corresponding unwrapped phase angle = phase shift = 11.1 rad

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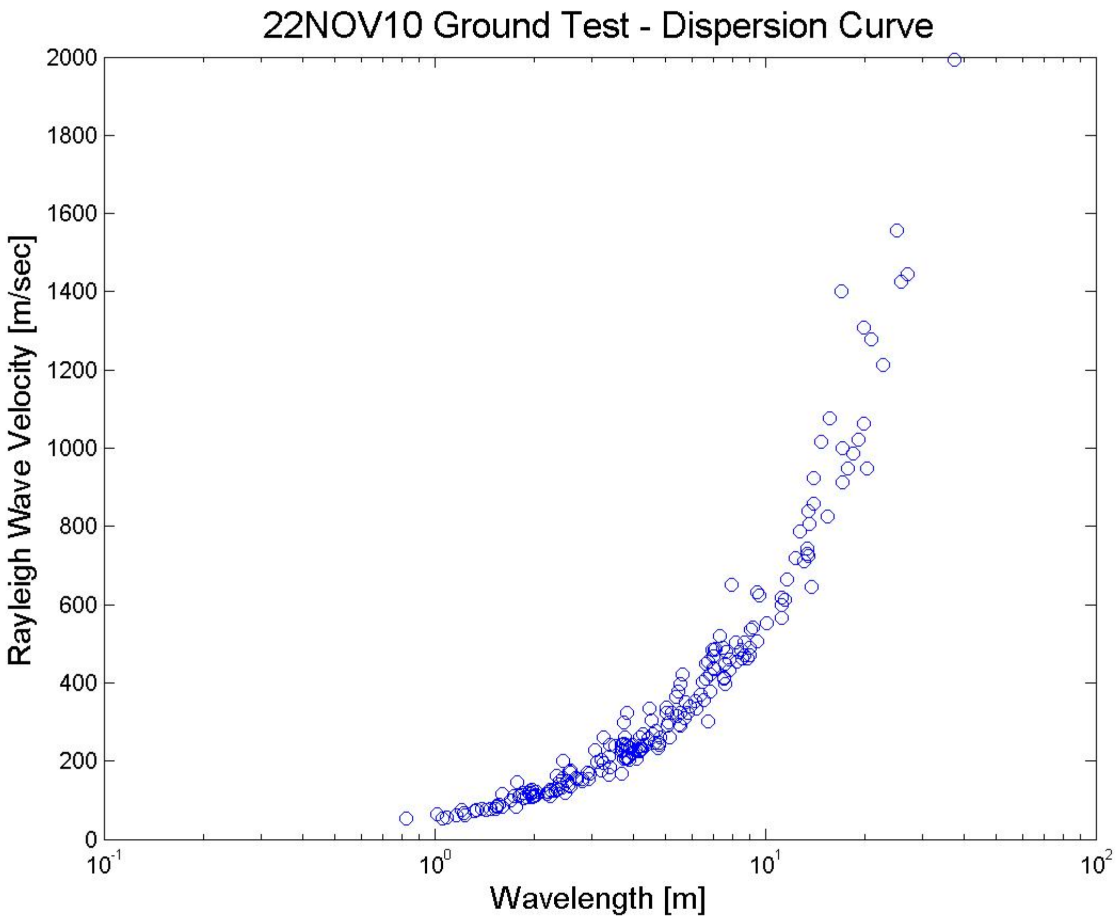
Dispersion curve



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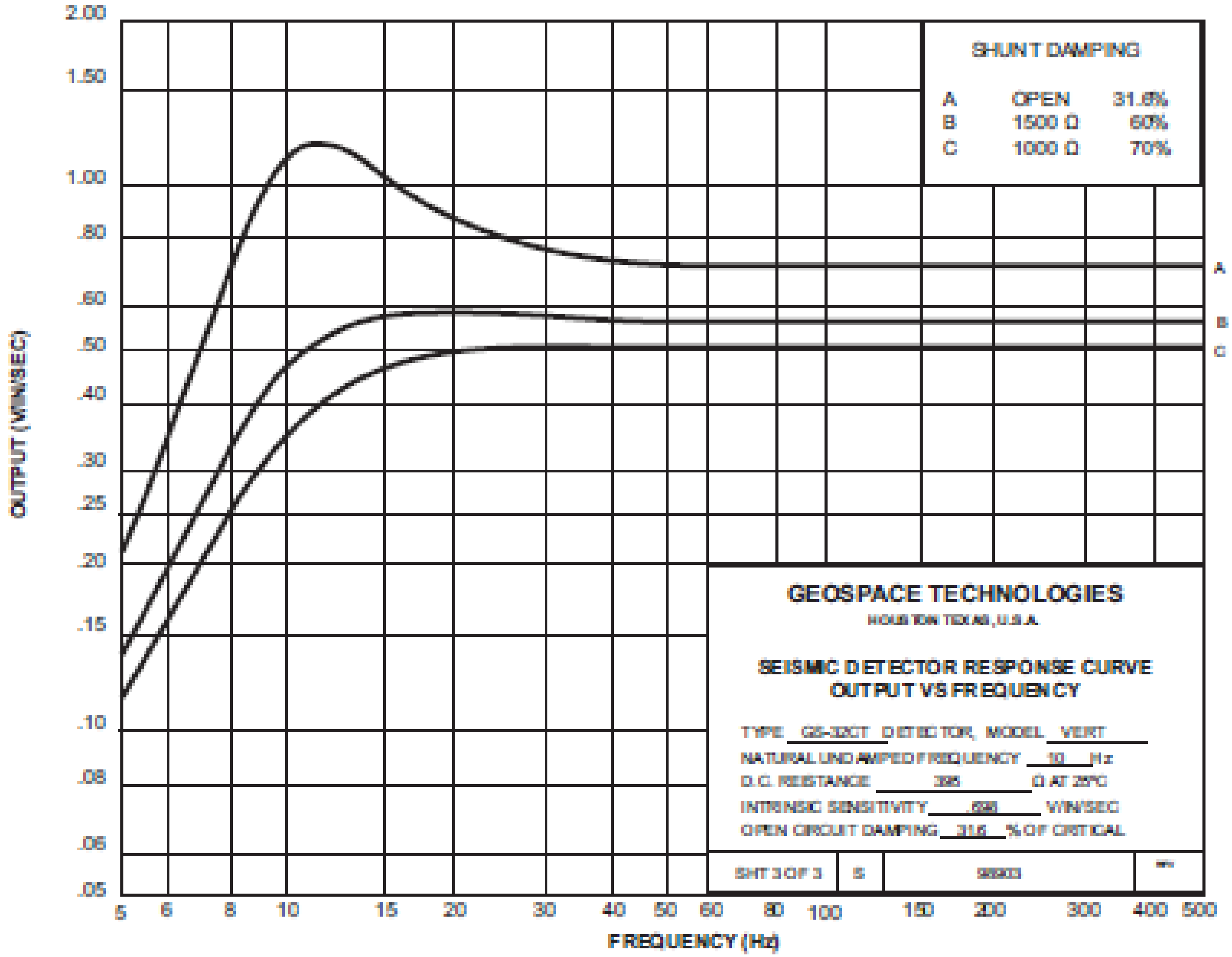
Possible Estuarine Experiment

- High frequency acoustics
- Multibeam sonar
- Seismo-acoustics
- Cores, in situ sensing
- Chirp sonar
- Ambient noise
- What else makes sense?

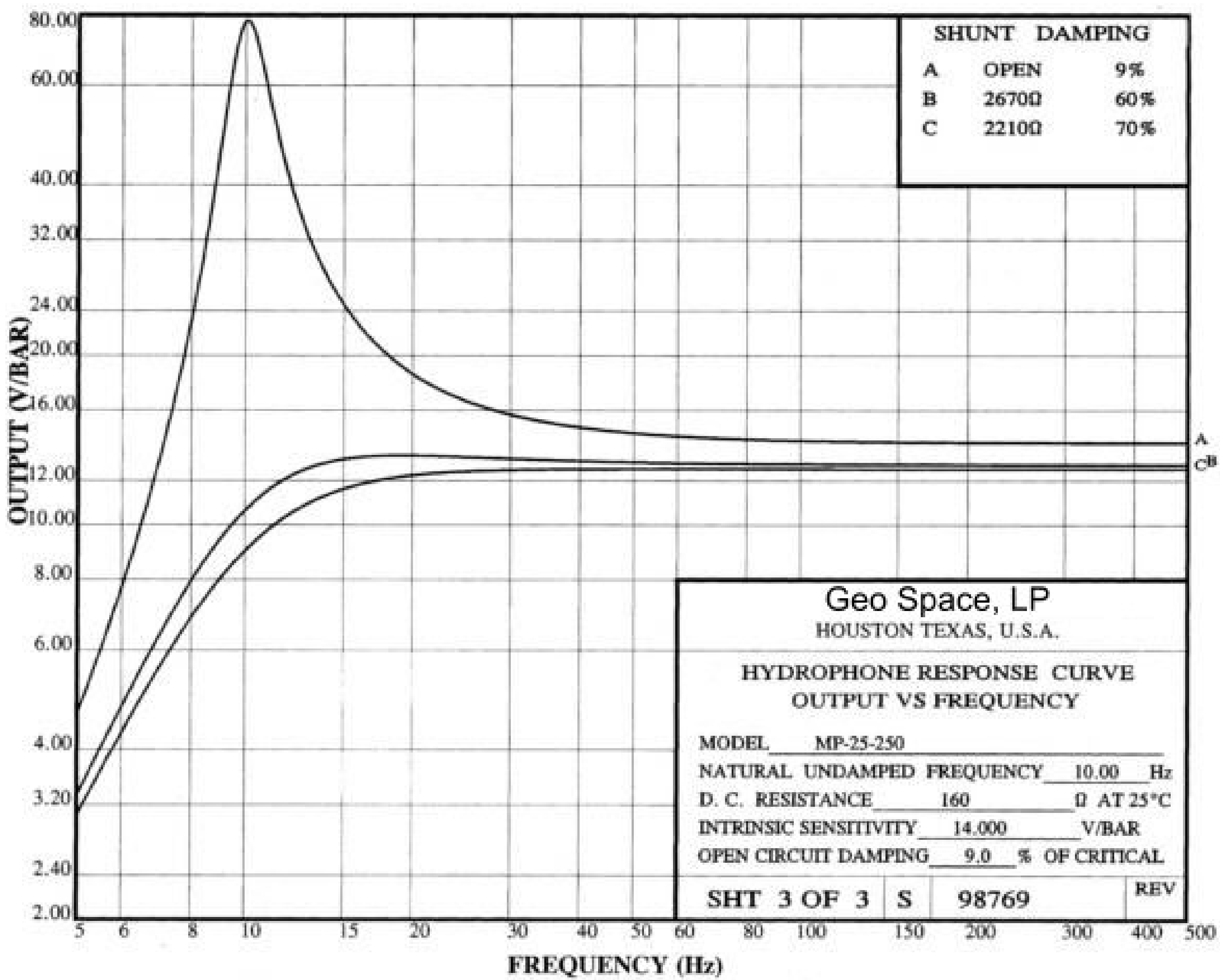
Summary and Future Work

- Effect of shear on modal dispersion could provide some information about the shear speed in the sediment.
- This could be developed as an inversion tool or could be used as valuable background data for our regular sediment inversions.
- Develop techniques for the estimation of shear speed using interface wave dispersion.
- Deploy and test the Amphibious Seismo-Acoustic Recording System. Collect data using the source being developed at ARL-UT (Preston Wilson)

Geophone: GS-32



Hydrophone: MP-25



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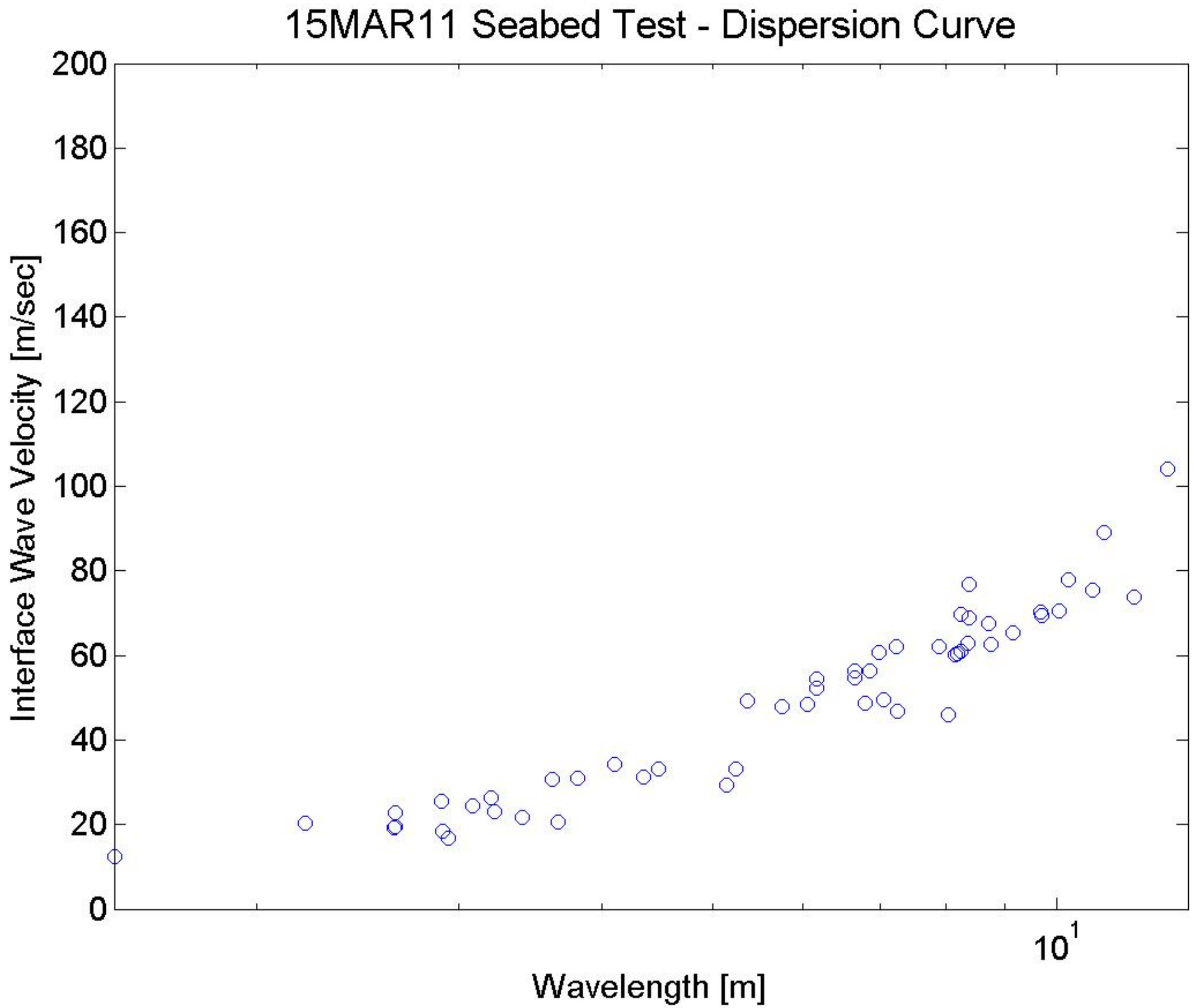
Sea-test – Narragansett Bay



f=100/10=10 hz

Hydrophone: HTI-94-SSQ

HTI-94-SSQ SERIES -

SENSITIVITY:

without preamp

- -198 dB re: 1 V/uPa
- 12.6 V/Bar

with preamp

- (max) -165 dB re: 1 V/uPa
- (max) 562 V/Bar
- (min) -240 dB re: 1 V/uPa
- (min) 0.1 V/Bar

FREQUENCY RESPONSE: 2 Hz to 30 KHz

EQUIVALENT INPUT SELF NOISE:

RMS from 1 Hz to 1000 Hz

- 75 dB re: 1 uPa
- 0.06 uBar

Spectral

- 54 dB re: 1 uPa/sq.root Hz @ 10 Hz
- 40 dB re: 1 uPa/sq.root Hz @ 100 Hz
- 38 dB re: 1 uPa/sq.root Hz @ 1000 Hz

MAXIMUM OPERATING DEPTH: 20,000 feet (6096 meters)

SIZE: 1.50 inches (3.8 cm) length X 1.25 inches (3.2 cm) diameter