# *[S06 ] Shear Wave Resonances in Sediments on the Deep Sea Floor*

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# Abstract

Shear wave resonances at frequencies between about 0.1 and 10Hz are a ubiquitous feature of ambient noise and controlled source seismic data acquired on sedimented sea floors. They are a major factor in the ambient noise field and mask many useful seismic arrivals. For controlled source experiments shear wave resonances are a major source of incoherent, signal generated noise and coda. The peaks of the ambient noise spectra associated with the resonances, however, can be used to infer the sediment rigidity and thickness. The theory of Godin and Chapman (1999) has been used to infer shear velocity and sediment thickness from the resonance peaks in horizontal component power spectra for two sites in the Pacific. At ODP Site 843B (OSN-1), about 225km southwest of Oahu, the sediment thickness is known from drilling and we can infer from the resonances that the uppermost shear velocity is about 24.5m/s. At the Hawaii-2 Observatory (H2O) Site, half-way between Hawaii and California, we predict a sediment thickness above the first chert layer of about 13m by assuming the same uppermost shear velocity as at OSN-1. Work was funded by The National Science Foundation and the Free University of Amsterdam.

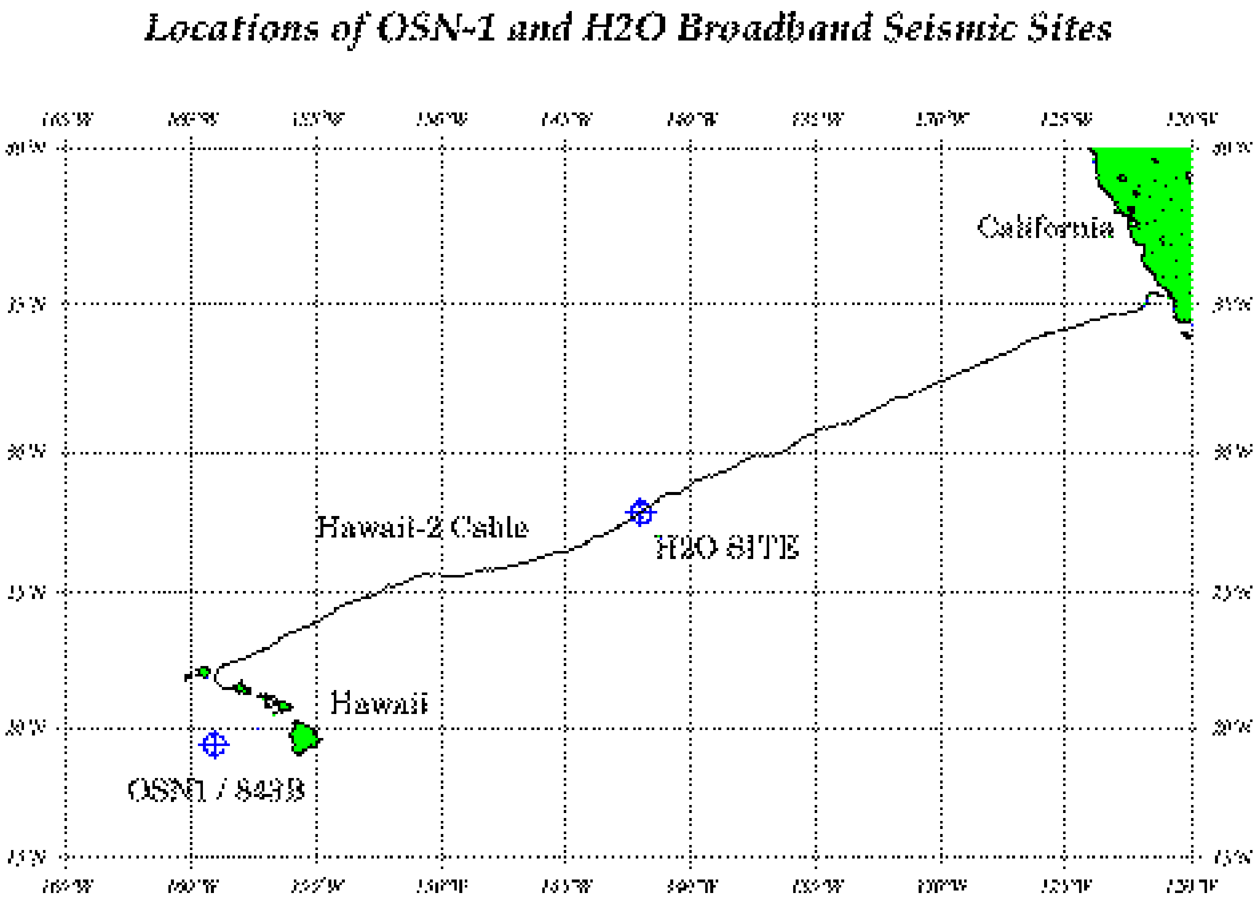


***Figure 1***: The Ocean Seismic Network Site (OSN-1) is 225km southwest of Oahu in 4407m water depth (Stephen et al, 1999; Collins et al, in press). The Hawaii-2 Observatory (H2O) is half-way between Hawaii and California on the retired Hawaii-2 telecommunications cable and is in 4970m water depth (Duennebier, 2000; Chave et al, 1997).

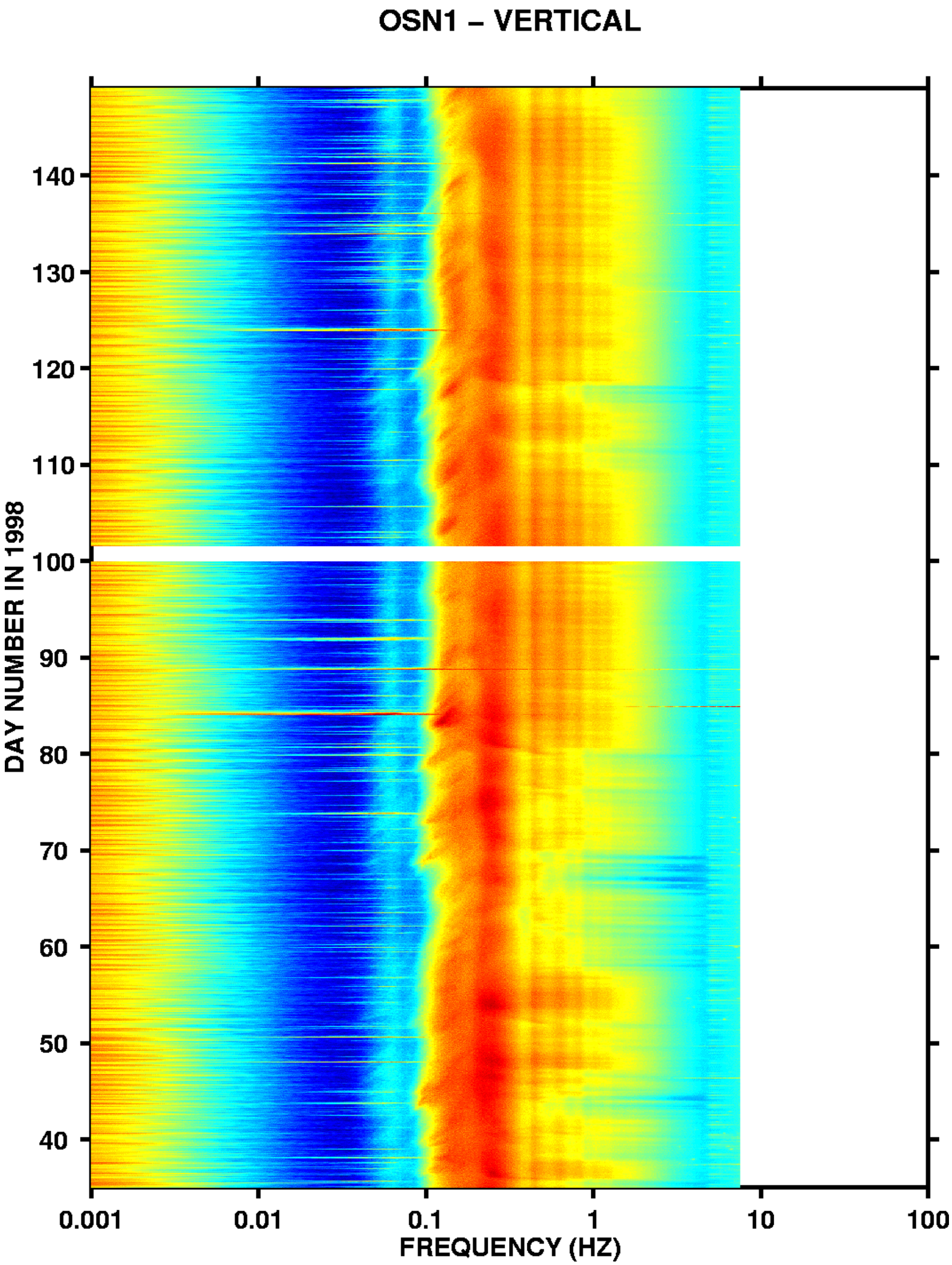


***Figure 2***: This true amplitude spectrogram summarizes the vertical component ambient noise in the band 1mHz to 7.5Hz for over 110days of the broadband borehole seismometer deployment at OSN-1. The constant frequency bands between 0.2 and 1Hz correspond to shear modes or reverberations within the sediment column.

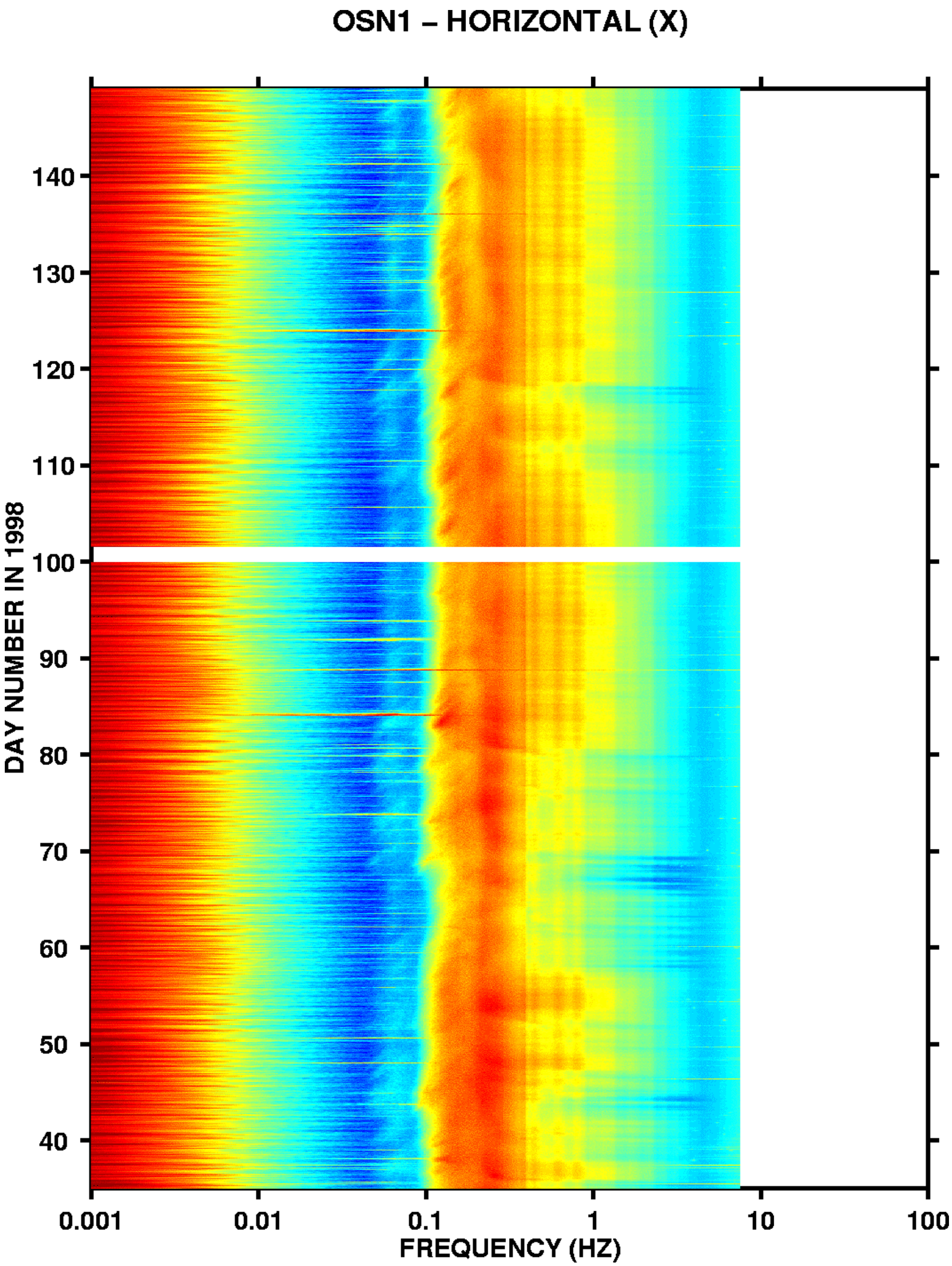


***Figure 3***: This true amplitude spectrogram summarizes the ambient noise on a single horizontal component similar to Figure 1.

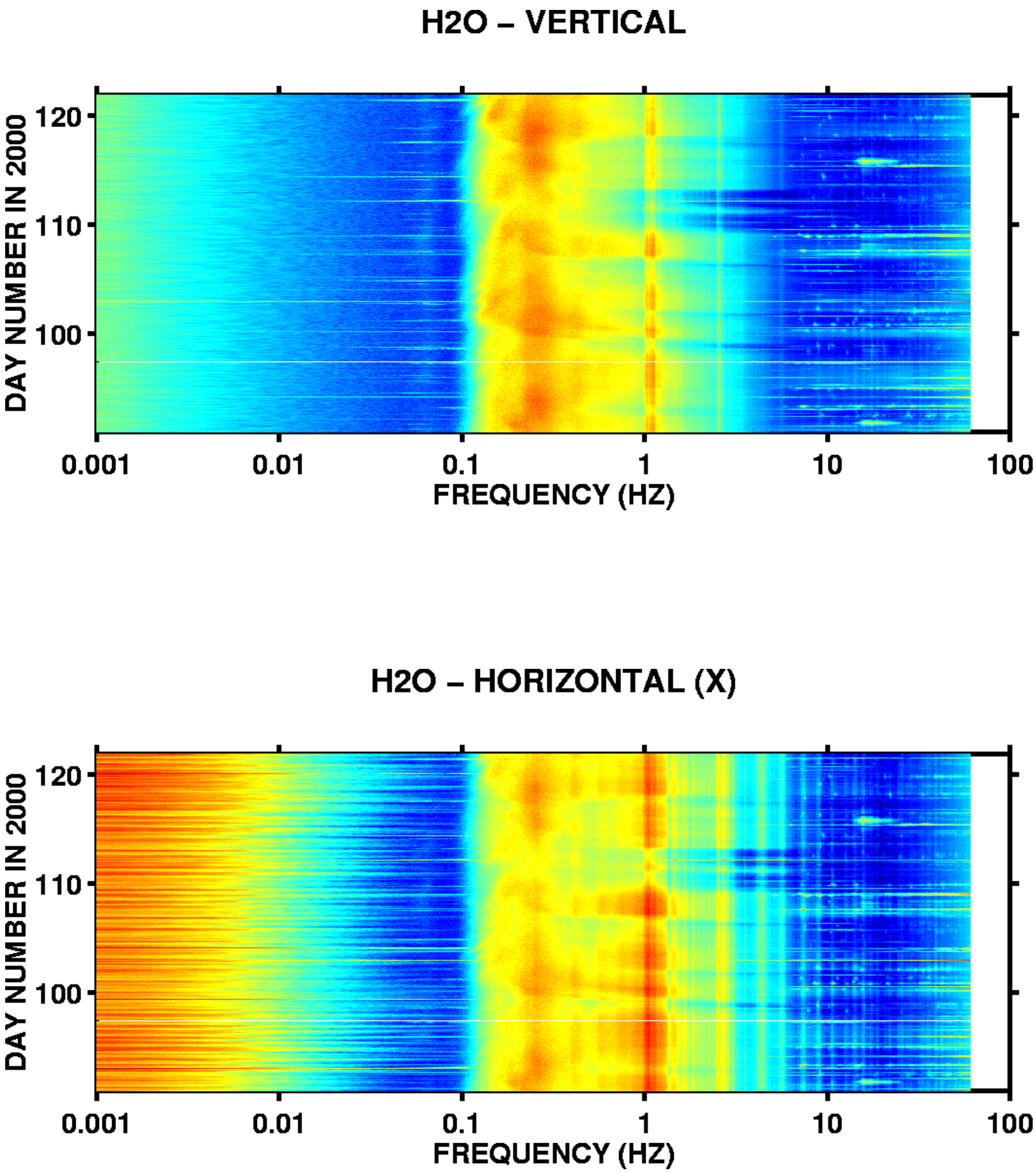


***Figure 4***: Vertical and horizontal (x) component spectrograms are shown for 1 month of data from the new Hawaii-2 Observatory site. These figures have the same time, frequency and color scales as Figures 2 and 3 for OSN-1. The sediment resonances are more clearly defined and extend to higher frequencies on the horizontal component data.

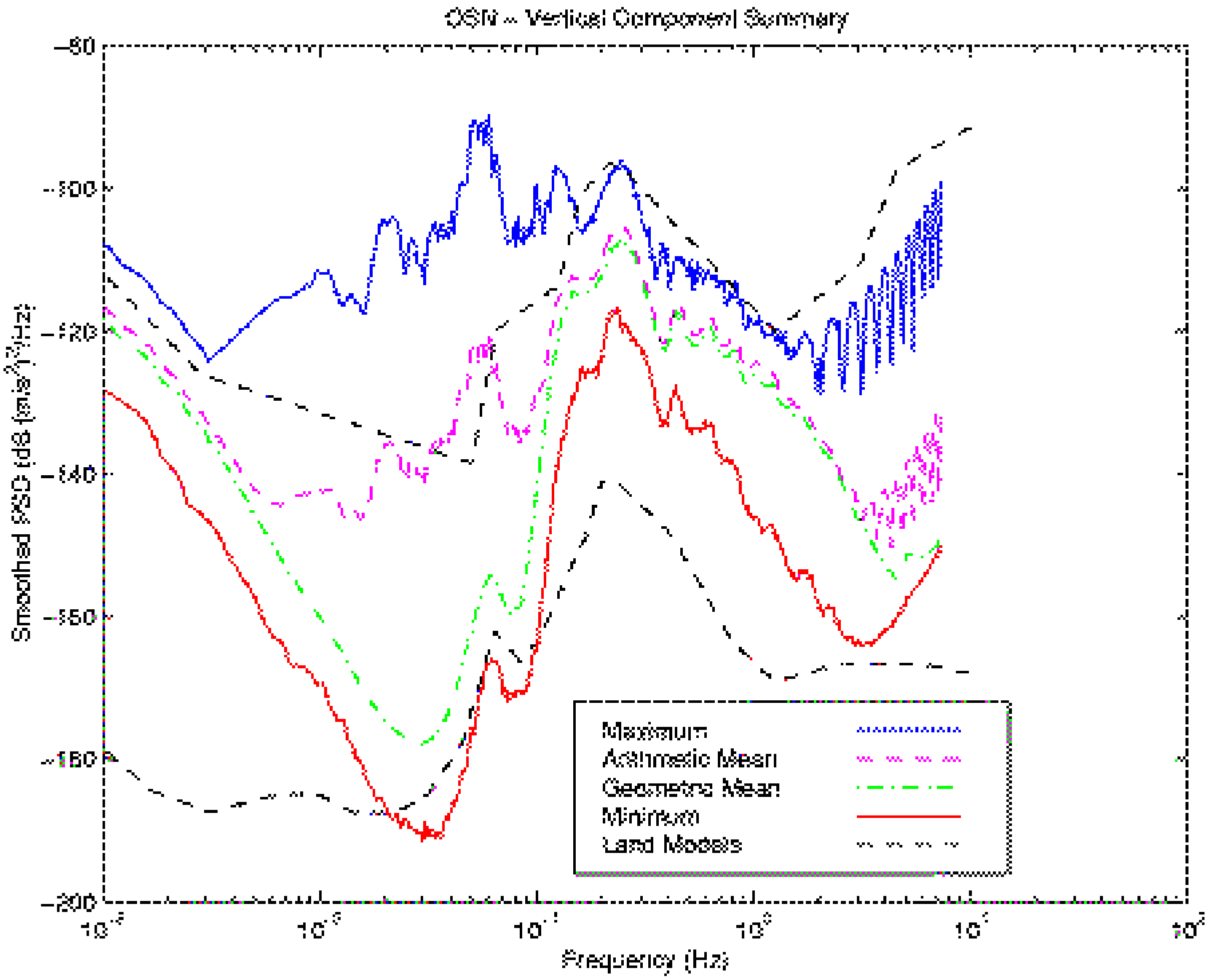


***Figure 5***: The geometric and arithmetic means of all of the spectra for the OSN-1 vertical component (Figure 2) are shown. Also shown are the largest and least spectral values at each frequency. The USGS high and low noise models (land models) are based on a synthesis of data from land and island stations. The very high levels from 3mHz to 0.2Hz are caused by the large (Mw=7.9) Balleny Islands earthquake on Julian Day 84/1998.

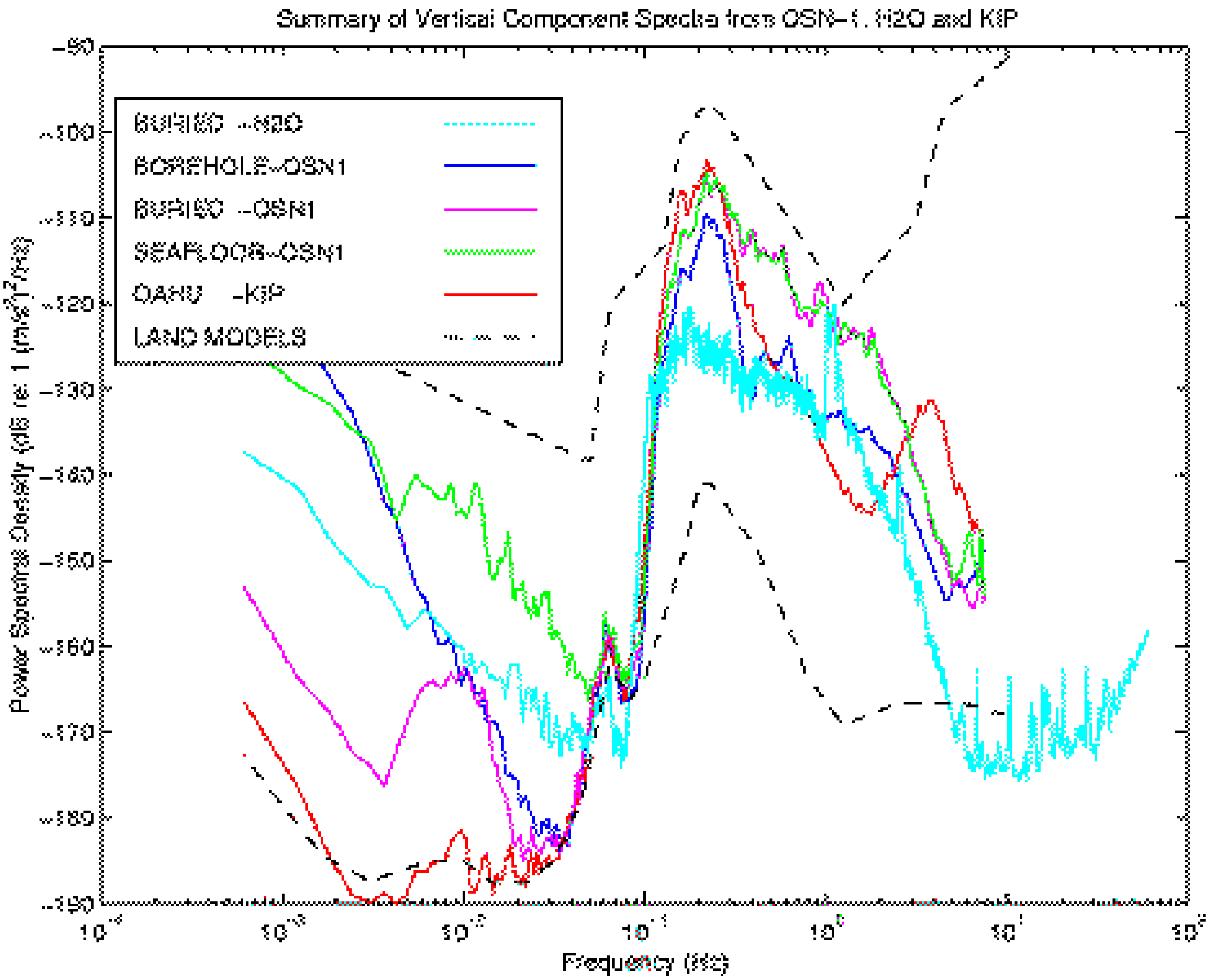


***Figure 6***: Vertical component spectra from the seafloor, buried and borehole installations at OSN-1 are compared with the spectra from the buried installation at H2O and the KIP GSN station on Oahu. H2O has extremely low noise levels above 5Hz and near the micro-seism peak from 0.1-0.3Hz. H2O has high noise levels below 50mHz. Otherwise H2O levels are comparable to OSN borehole and KIP levels. The sediment resonances at H2O near 1 and 3 Hz are very prominent.

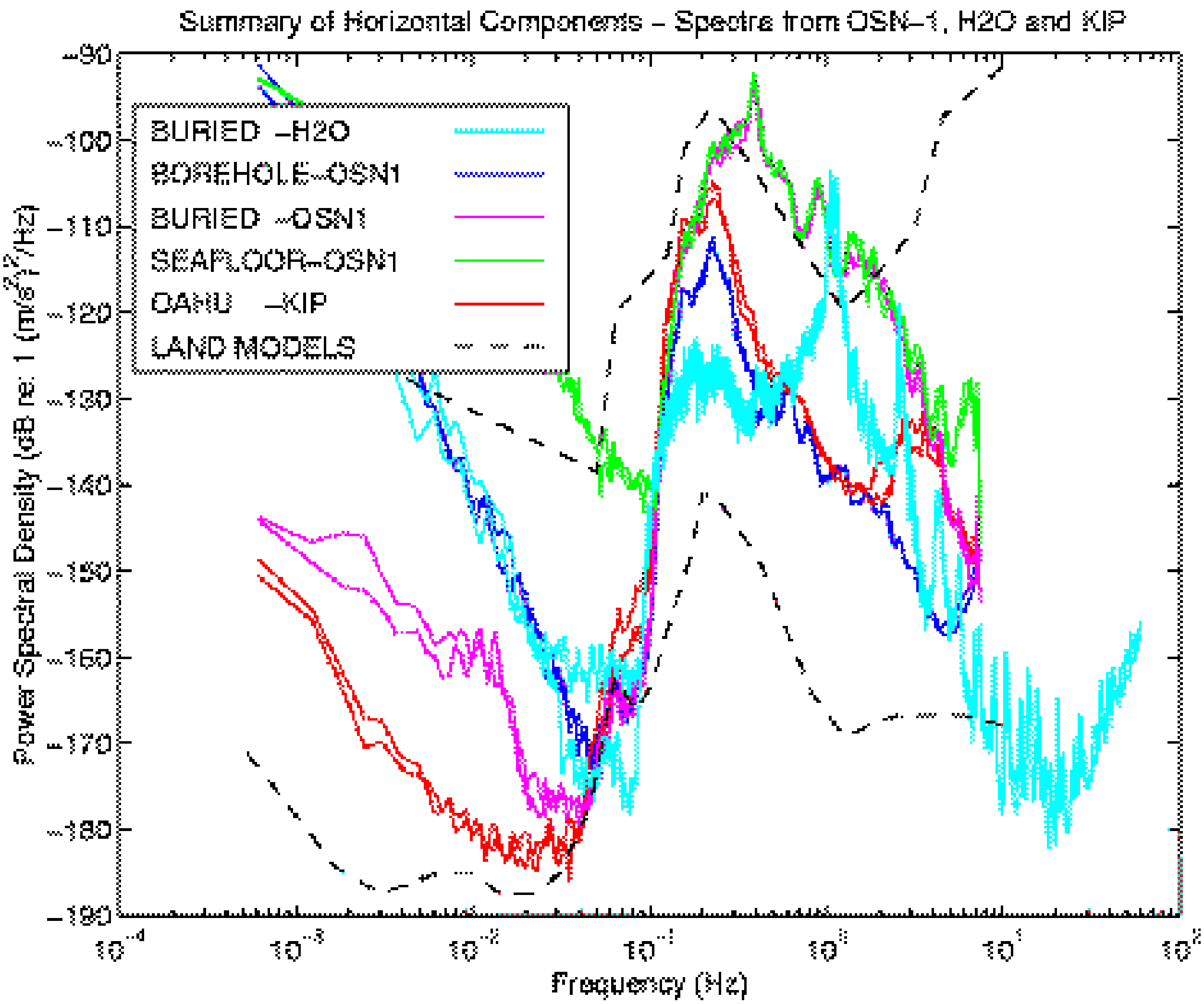


***Figure 7***: Horizontal component spectra from the seafloor, buried and borehole installations at OSN-1 are compared with the spectra from the buried installation at H2O and the KIP GSN station on Oahu. The sediment resonance peaks at H2O in the band 0.3-8Hz are up to 30dB louder than background and far exceed the microseism peak at 0.1-0.3Hz. That the resonant peaks are considerably higher for horizontal components than for the vertical component is consistent with the notion that these are related to vertically propagating shear wave multiples.

# *The Godin-Chapman Method*

The Godin and Chapman method assumes a power-law profile for the shear speed in the sediments and it assumes that the sediments are underlain by a rigid boundary. The depth dependence of the shear modulus is given by: $\mu = \rho_0 c_0^2 z^{2\nu}, \nu > 0$ where $\rho_0$ is the density which is assumed constant, $c_0$ is the uppermost shear velocity, z is depth and $\nu$ gives the power law dependence. The two-way travel time for a vertically propagating shear wave in the sediment layer is: $2H^{1-\nu}/c_0(1-\nu)$ where H is the thickness of the sediment. The normalized frequency. $F = c_0(1-\nu)/(2H^{1-\nu})$ corresponds to the fundamental resonance when $\nu$=2/3. The relationship between the resonant frequencies, $f_n$, and their ordinal number, n, is approximately linear: $f_n = F(n + m/2 - 1/4)$ where m is related to $\nu$ by: $\nu = (2m+1)/[2(m+1)]$. From the slope and intercept of the resonant frequencies one can compute the ratio: $c_0 / H^{(1-\nu)}$. Then given either the sediment thickness or the uppermost shear velocity one can compute the other quantity.

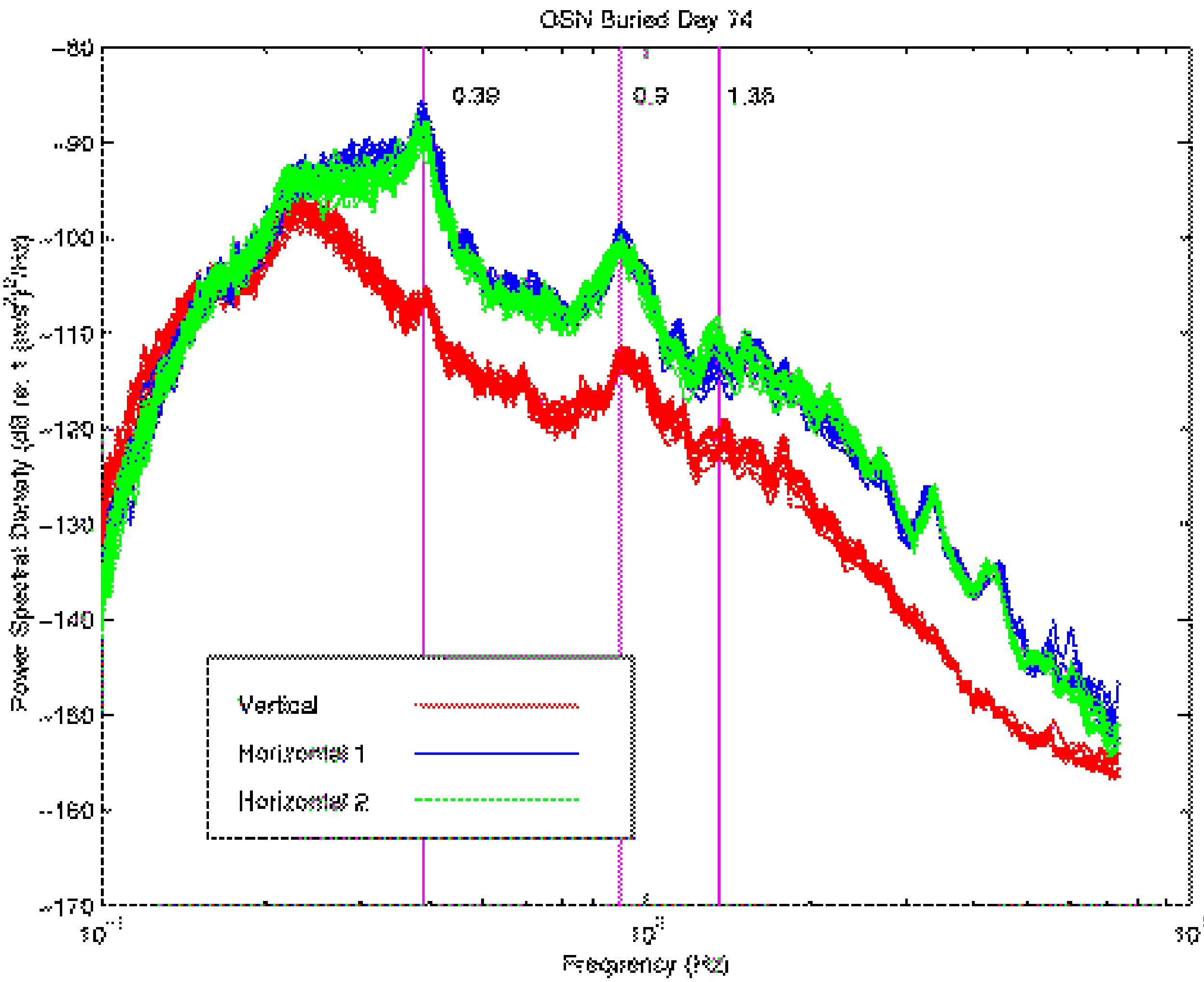


***Figure 8***: We can use the resonances at OSN-1 to compute a typical uppermost shear velocity for deep sea sediments because the sediment thickness at OSN-1 is known from drilling (242m). The resonant frequencies for OSN are 0.39, 0.90, and 1.36Hz as shown in this figure of the spectra for the buried seismometer at OSN-1.

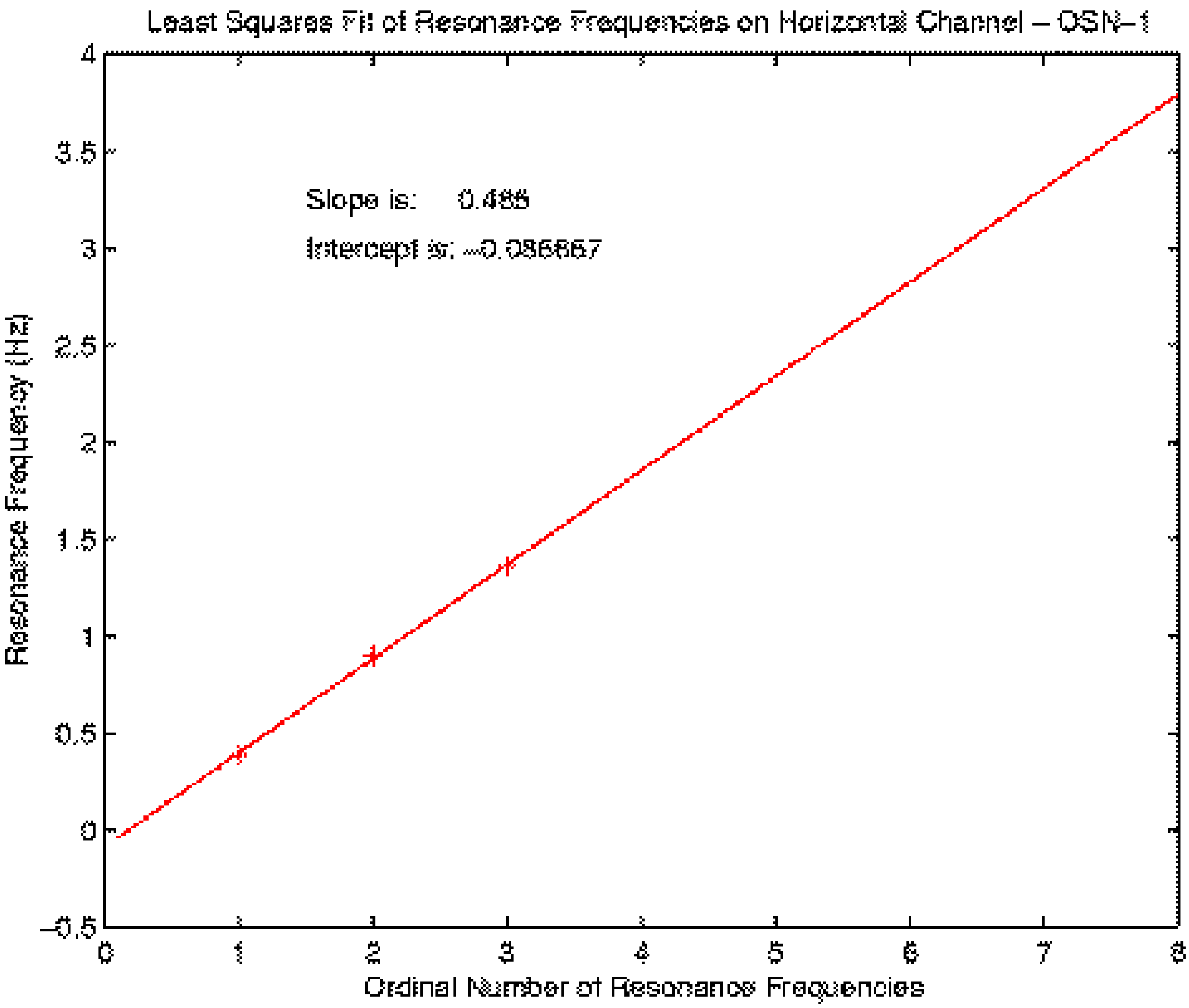


***Figure 9***: A plot of the resonant frequencies from Figure 8 versus ordinal number gives: F = 0.485, b = -0.087, ν = 0.562, ratio =2.22. Using the known sediment thickness at OSN-1 of 242m we can estimate the uppermost shear velocity as 24.5m/s.

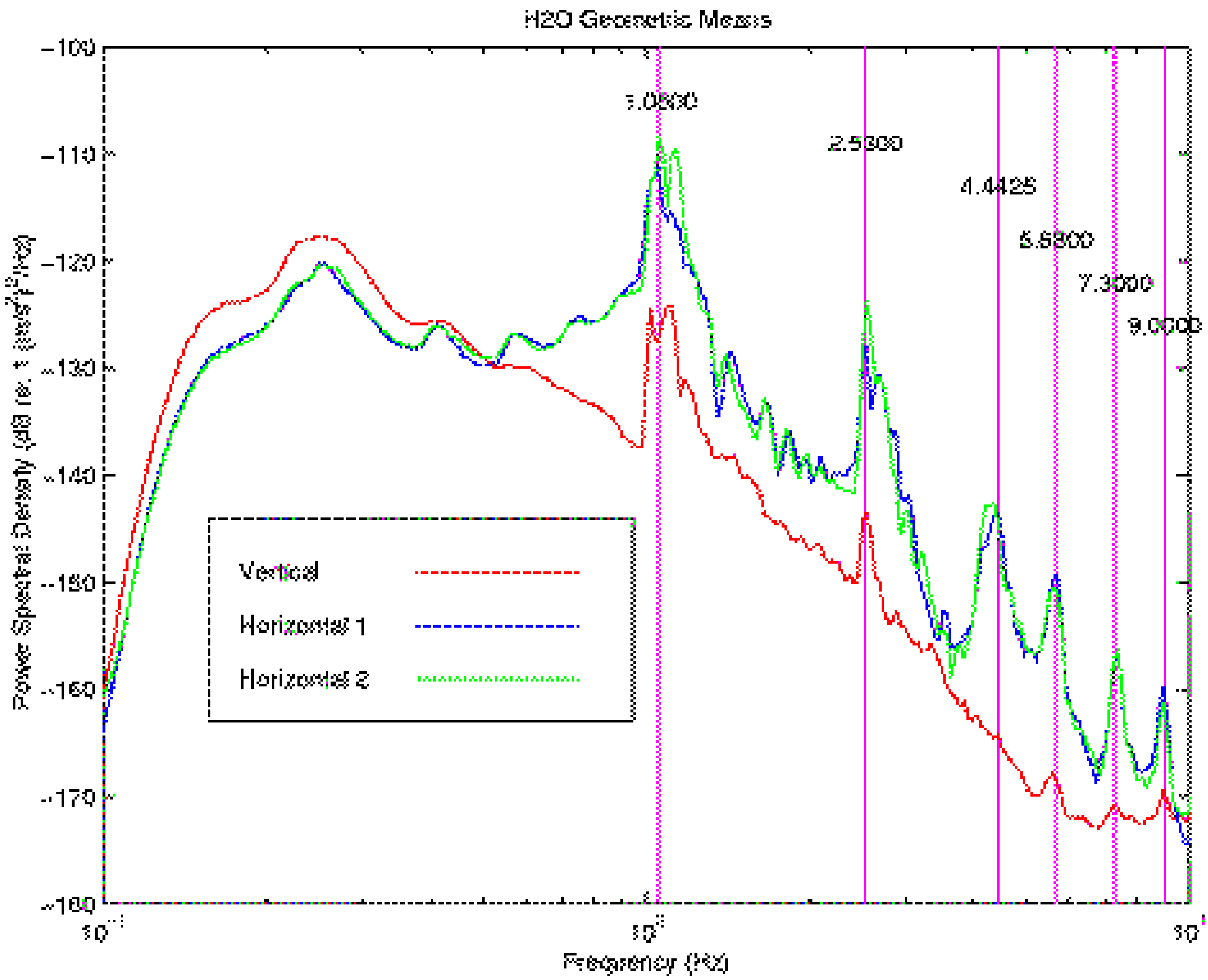


***Figure 10***: The sediment resonances at H2O are very well established and it is possible to pick six unambiguous resonant frequencies (1.06, 2.53, 4.44, 5.68, 7.30, and 9.00Hz) on the horizontal component data.

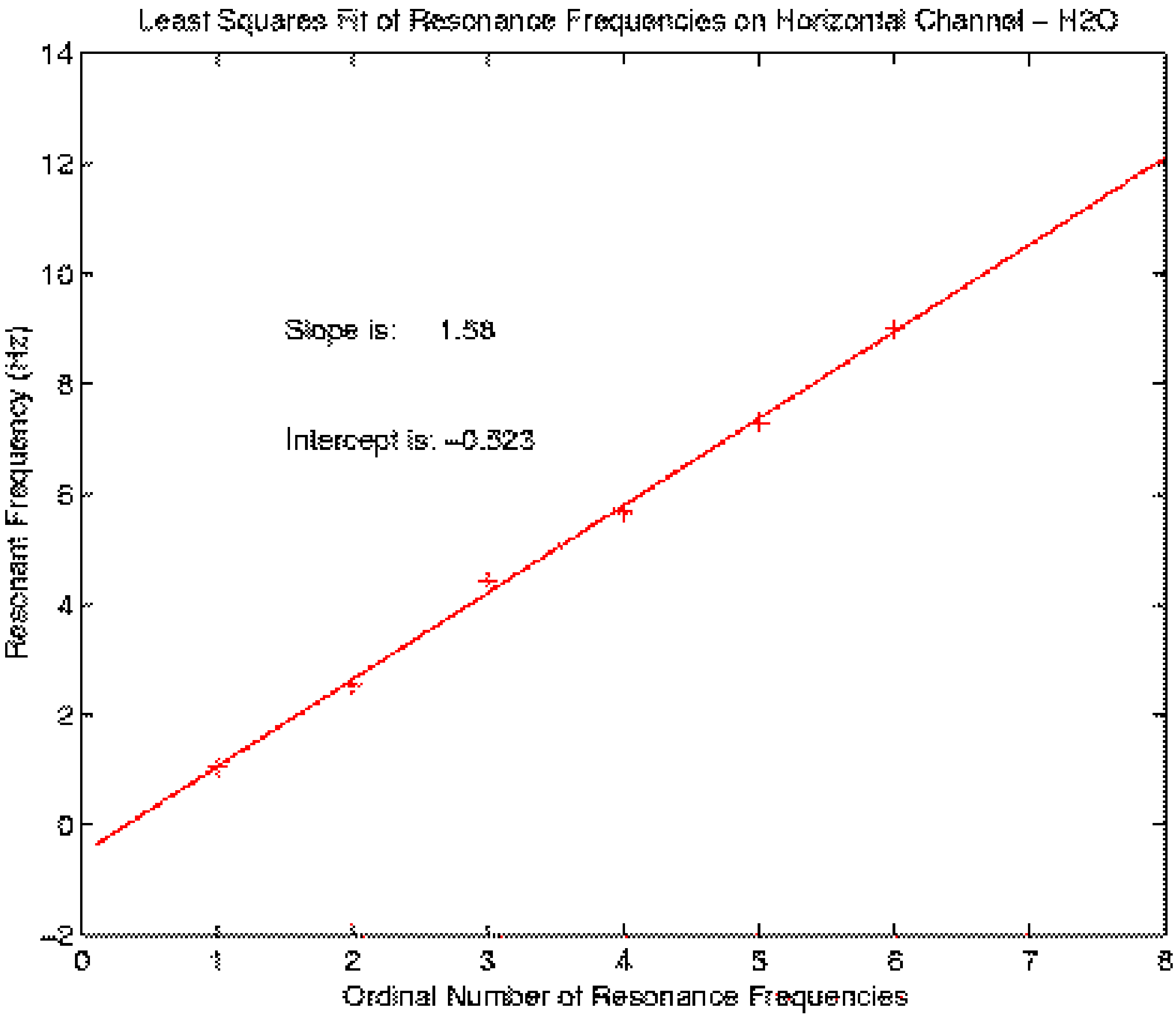


***Figure 11***; A plot of the resonant frequencies from Figure 10 versus ordinal number gives: F = 1.58, b = 0.52, ν = 0.40 and ratio = 5.28. Assuming that the uppermost shear velocity at OSN-1 is a good estimate of the uppermost shear velocity at H2O gives the sediment thickness at H2O of 13m. This is probably the thickness to the first interbedded chert layer.

# Conclusions

1) For shallow buried and seafloor sensors, shear wave resonances in the sediments are the dominant mechanism contributing to the ambient noise in the band 0.3-8Hz.

2) The resonance frequencies can be used to infer the shear velocity and thickness of the sediments using the model of Godin and Chapman (1999).

3) This technique is particularly useful in areas with thin sediment cover (less than 100m) where surface reflection seismology loses resolution.

4) For example, at the Hawaii-2 site we estimate the sediment thickness to be about 13m based on the sediment resonance technique.

## References:

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