NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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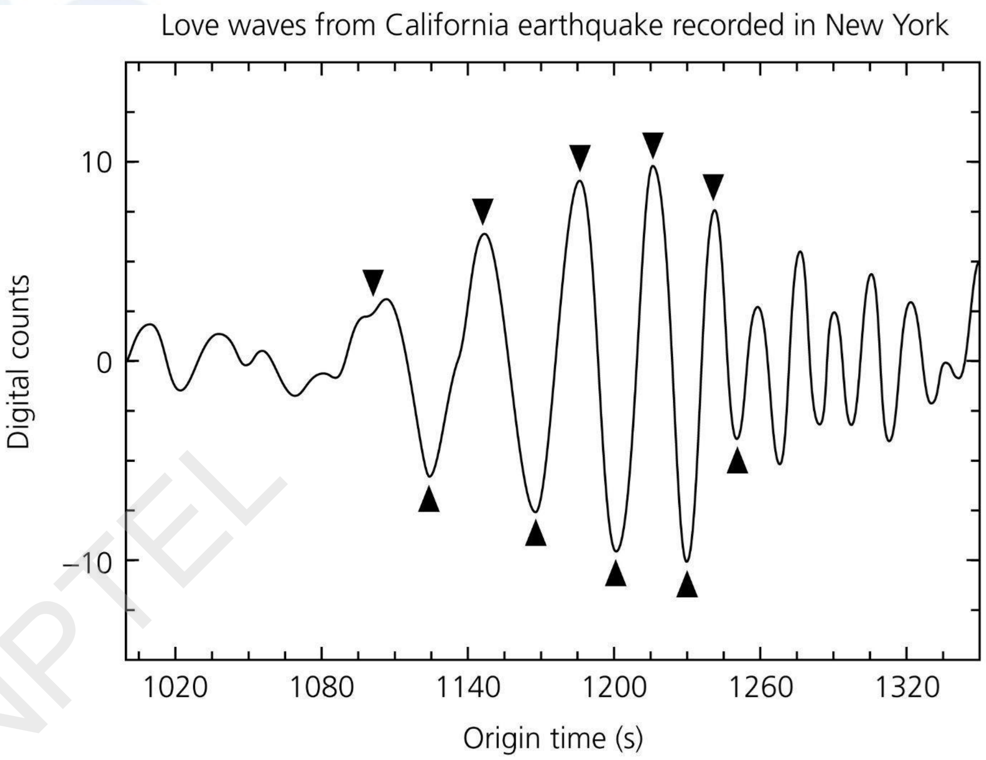
Module 03 : Surface Waves and Dispersion
Lecture 05: Dispersion example in the Earth and Tsunamis

CONCEPTS COVERED

- Dispersion studies in the Earth
- Tsunami dispersion
- Summary

Dispersion studies in the Earth

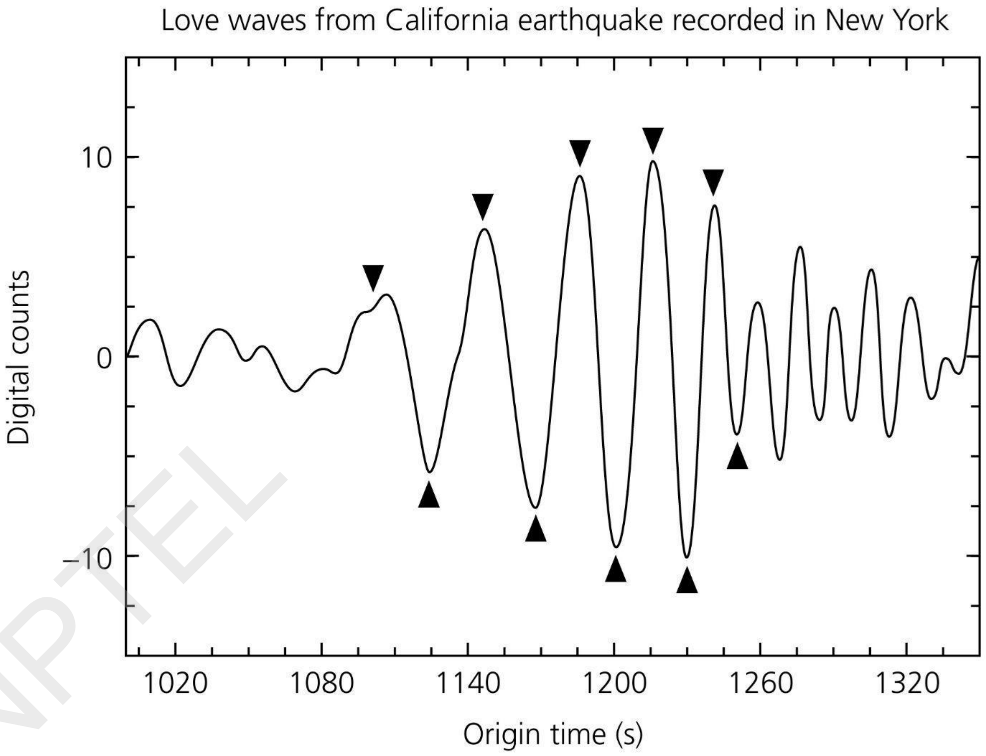
- Group velocities are relatively easier to measure.
- Because they are the velocities at which a wave group visible on seismogram travels.
- As shown by the Love waves in the figure, the period can be measured from the time between successive peaks or troughs.
- Generally, the waves with longest periods travel fastest, and therefore appear first on seismograms.



- **The group velocities are found by dividing the distance between the source and the receiver by the travel time of the wave group.**

  For example, the wave group with a period of about 45s arrived about 1145s after the earthquake , and thus has a group velocity of about 3.7 km/s (4200 km in 1145s).

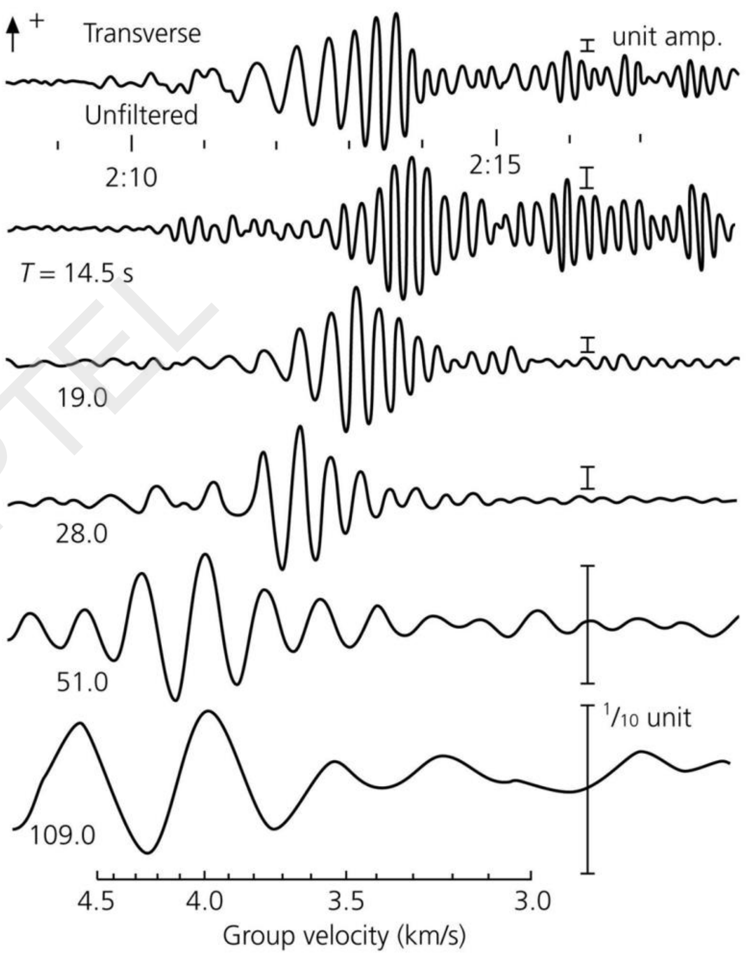
- **This is done in more sophisticated manner using Fourier transform to filter a seismogram at a successive narrow frequency bands to clearly visualize the different group velocities.**



Here's a plot from S&W in that shows Love waves over various frequency bands from a Mongolian earthquake recorded in Japan. You can see the dispersion quite well.

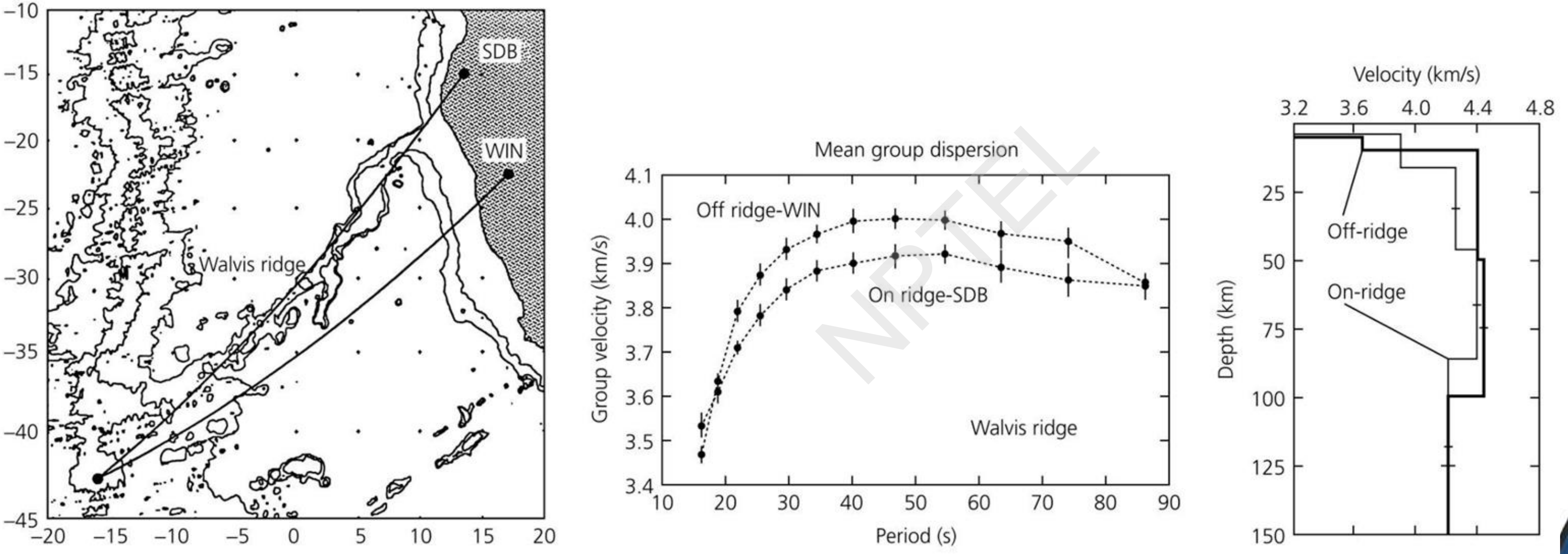
If we can use some means to measure this dispersion along a great circle path, and then compare the dispersion along other paths, then one can infer variations in velocity with depth along these paths.

Figure 2.8-4: Example of Love wave group velocity dispersion through bandpass filtering.



Here’s an example from S&W, figure 2.8-5.

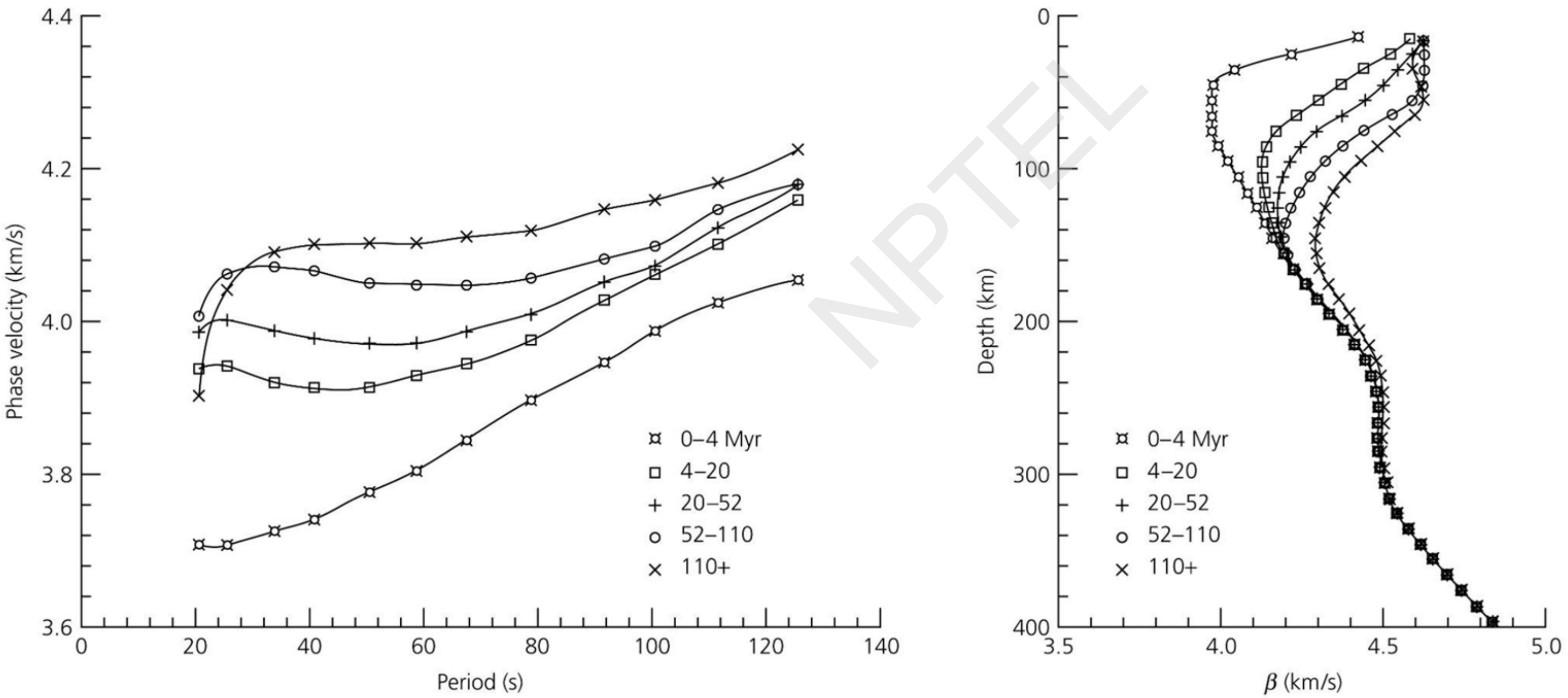
Figure 2.8-5: Rayleigh wave group velocity study of the Walvis ridge.



- Surface wave phase/group velocities are a function of V_P, V_S, and density.
- In practice they are most sensitive to V_S in the mantle, and can be converted to V_S after assuming few conditions.
- A great series of codes that will do this are available from Robert Hermann at St. Louis University (http://www.eas.slu.edu/People/RBHerrmann/CPS330.html).

This is a very famous figure of phase velocity vs. wave period, converted to S-wave velocity vs. depth for oceanic lithosphere of different ages. This is from Nishimura and Forsyth, 1989, and is one of the most commonly shown figures in seismology and related fields for five age provinces in the Pacific basin.

Figure 2.8-7: Rayleigh wave phase velocity dispersion as a function of oceanic plate age.



Tsunamis

- Dispersion is also observed in tsunamis, the water waves generated by earthquakes.

- Tsunami dispersion is similar to that of Rayleigh and Love waves.

- In tsunami dispersion, the waves with longer periods travel faster and thus arrive earlier.

- For tsunamis in which their wavelength is significantly longer than the ocean floor depth, there is no dispersion, and the phase velocities are essentially nondispersive and are given by

$$c = \sqrt{gd}$$

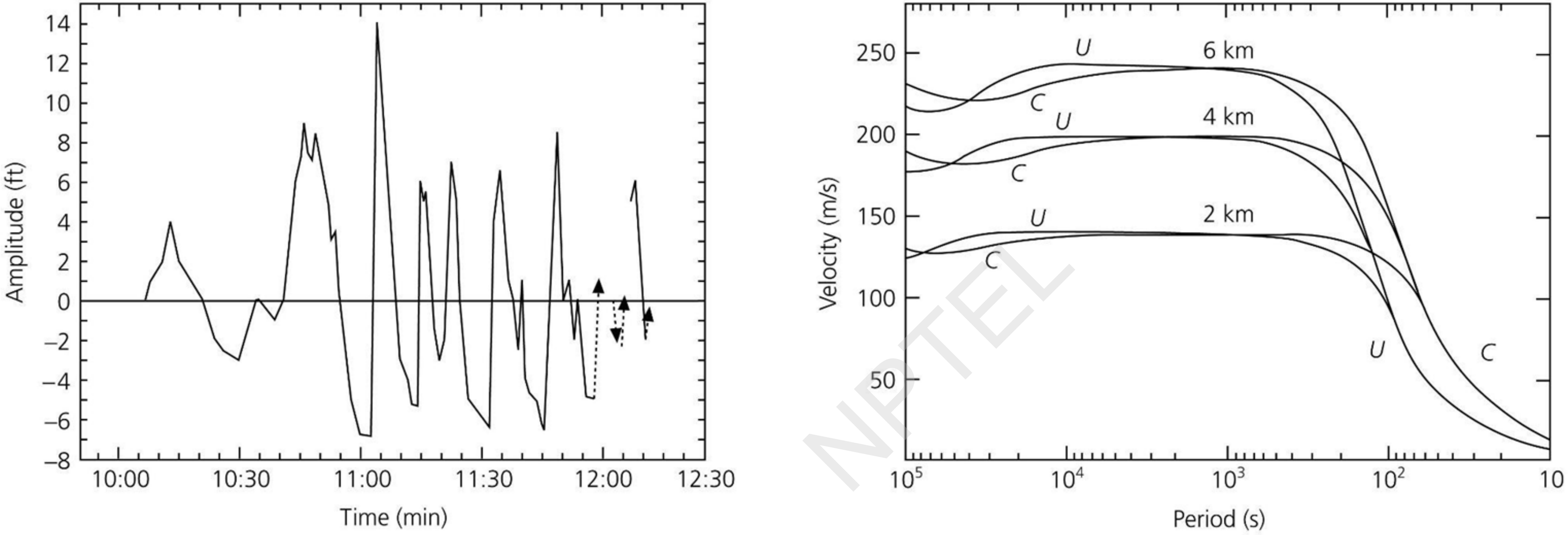
Here, 'g' refers to the acceleration due to gravity, and 'd' to the ocean depth.

This means tsunami velocities are sensitive to ocean floor topography, and at some locations multipathing means that energy comes in from a variety of directions and amplifies.

For shorter wavelength waves, dispersion does occur: $c = \sqrt{\frac{\lambda g}{2\pi}}$

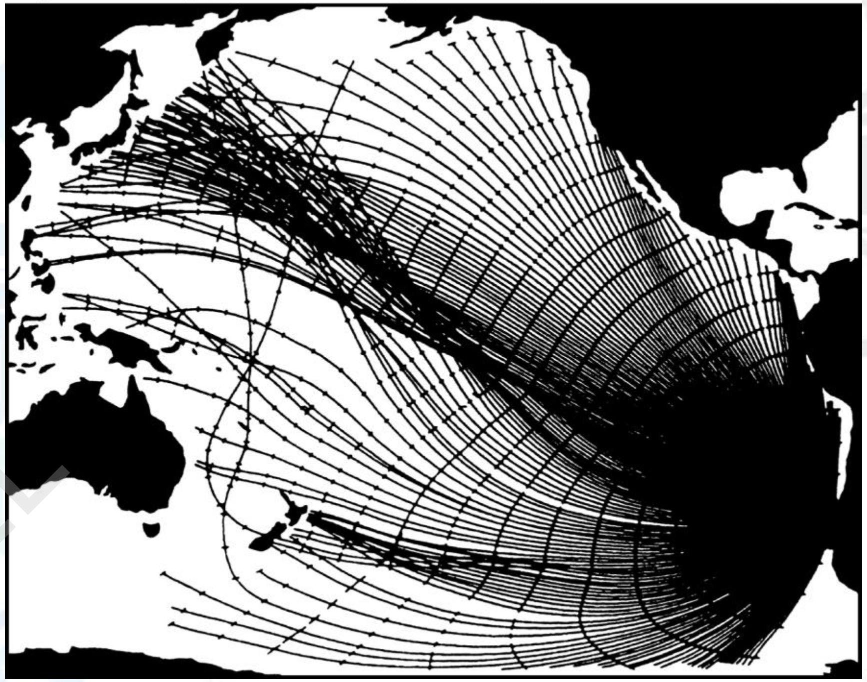
Hence, water wave group and phase velocities do not match. The figure below shows the tide gauge.

Figure 2.8-8: Dispersion example and curves for tsunamis.



- Like surface waves, tsunami travel across the earth's surface, so their amplitudes decay roughly according to $1/\sqrt{r}$.
- Due to lateral velocity variations, the path of surface waves and tsunamis deviate from the shortest great circle path.
- This effect is called "Multipathing" because waves arrive at the receiver from several directions and can cause large changes in the waves' amplitudes due to the effect of focusing and defocusing.
- Denser ray path show "focusing" and increasing amplitudes, whereas sparser paths indicate defocusing and lower amplitudes.
- Figure on the right shows focusing and defocusing for the tsunami, due to variations in ocean depth.

Figure 2.8-9: Ray paths for tsunami generated by the 1960 Chile earthquake.



Summary

- Surface waves energy spreads two dimensionally and decays with distance 'r' from the source approximately as r^{-1}, whereas the body waves spreads three dimensionally and decays approximately as r^{-2}.

- The two types of surface waves we are most concerned about in global and regional seismology are Rayleigh and Love waves.

- Love waves are inherently dispersive, results from SH waves trapped near the surface and need positive velocity jump or curved surface to exist with velocity varies from $\beta_1 < c_x < \beta_2$
- Rayleigh waves have P-SV motion. We see them on the vertical and radial channels of seismograms need no special conditions to exist

Summary

- Dispersion means that wave velocities are dependent on frequency i.e., $v = v(\lambda)$
- The velocity of the carrier wave is $v_{phase} = \frac{\omega}{k}$ and that of the envelope is slower $v = \frac{\delta w}{\delta k}$
- We refer to the former as "phase velocity", and the latter as the "group velocity". Typically, "c" is used to denote phase velocity, and U to denote group velocity. On average in the earth, c >U.
- If the medium is non-dispersive and the phase and group velocity will be the same.
- In the Earth, dispersion causes a range of different frequencies to travel at nearly common velocities.

Summary

- As an example, as energy propagates through the earth, it scatters off of velocity heterogeneities which creates ambient noise field.

- Another type of dispersive wave is tsunamis, in which their wavelength is significantly longer than the ocean floor depth, there is no dispersion, and $c = \sqrt{gd}$

- For shorter wavelength waves, dispersion does occur: $c = \sqrt{\frac{\lambda g}{2\pi}}$

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THANK YOU !