Laurea Magistralis in Physics Academic year 2013-2014

Theoretical Seismology

Fabio Romanelli - romanel@units.it

Dept. Mathematics and Geosciences - University of Trieste,

SAND Group - ICTP

Fundamentals of vibrations and waves

Presentation and outline of the course

1DOF systems: Harmonic oscillator

2&N DOF systems: Coupled oscillators

- Discrete propagating systems
  - "Free" modes

The wave equation

- Transverse waves on a string
  - Harmonic waves
- Sound waves
  - Harmonic waves
  - Energy in waves
    - Intensity (Decibels)

Wave phenomena

- Superposition principle
  - Interference
  - Beats
- Superposition principle
  - Progressive and stationary waves
  - Modes of a string with fixed ends
  - Modal summation

Wave propagation

- Heterogenous string
  - Impedance, reflection and transmission coefficients
- Snell's law with Huygens and Fermat principles

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Elasticity and seismic waves

Elasticity

- Stress and strain tensors
  - Static equations
- Theory of elasticity
  - Elastic constants
- Equations of elastic motion
- Navier equations
- Body waves (P and S)
  - Helmholtz's theorem
- P and S: longitudinal and transverse
- Energy of harmonic waves
  - Geometrical spreading

Body waves and boundary conditions

- Free surface
  - Horizontal apparent velocity
  - Wavenumber decomposition
- Reflection coefficients
- Body waves at discontinuity interfaces

Rays in flat layered media

- Traveltimes in 1D media
  - Direct, reflected and refracted arrivals
  - Ray Parameter

Rays in spherical layered media

- Traveltimes in 1D media
  - Direct, reflected and refracted arrivals
  - Ray Parameter

Free surface

- Horizontal apparent velocity (revisited)
  - Boundary condition
- Surface waves
  - Rayleigh waves in a halfspace

Dispersion, surface waves and free modes

Dispersion

- Group and phase velocity
- Flexural waves (stiff systems)
- SH waves in plates
- Plates & rods (extensional and torsional waves)

Surface Waves in layered media

- Waves in layer over a halfspace
  - Love waves
- Waves in a liquid layer over a halfspace
  - Rayleigh (dispersed) waves
- Phase and group velocity
- Phase and group velocity measurements

Free modes

- Laplacian in cylindrical coordinates
- 2D: free modes of a membrane;
  - Bessel functions

Free modes of the Earth

- Laplacian in spherical coordinates
  - Separation of variables
  - Azimuthal and polar dependence
- Spherical harmonics: Zonal; Sectoral;Tesseral
- Torsional & spheroidal modes
- Eigenvalues and eigenfunctions
- Omega-l plane; splitting; modal synthesis

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Seismic sources and their representation

Seismic sources 1: faulting

- Rupture process
- Faults and their geometry
  - Strike, dip, rake and slip
- Brittle deformation and stresses
  - Shear fracture and Coulomb criterion
  - Frictional sliding
    - Byerlee's law
- Stresses and faulting
  - Stress cycle & Stick slip

Seismic sources 2: faults and body forces

- Elastodynamic basic theorems
- Elastodynamic Green function
- Representation theorem
  - Equivalent body forces
  - Moment density tensor
  - Shear Dislocation
- Far source condition
  - Moment tensor
  - Seismic moment
  - Double couple
- Faults and moment tensor components
  - Application to a specific case

Linear systems and Green's function

Linear systems theory

- Impulse response & Transfer function
- Transformed domain
- Convolution theorem

Elastodynamic Green function

- Spherically symmetric problem
- Lamè theorem
- GF in a isotropic and homogeneous medium
  - Near and far field
- Response to a double-couple
  - Near, intermediate and far field

Seismic sources, their spectra and size

Seismic sources 3: focal mechanisms and source spectra

- Faulting and radiation pattern
  - Basic fault plane solutions
- Faults and plates
- Haskell model
  - Rupture time
  - Directivity
- Source spectra

Seismometry

- Damped & forced oscillators
  - Q factor
  - Resonance
- Inertial instruments
  - Mechanical and electromagnetic instruments
  - Response curves
- Broad band instruments
  - Feedback & Force balance
- Digital signals
- Sampling
- Time bandwidth

Seismic sources 4: earthquake size

- Intensity
- Magnitude: M_L, m_b, M_S.
- Saturation
- Moment Magnitude

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Theoretical Seismology

Anelasticity and attenuation

Anelasticity

- Rheology
- Viscoelasticity
  - Maxwell
  - Kelvin-Voigt
- Standard Linear Solid
  - Relaxed & Unrelaxed Modules
  - Debye peak
- Complex modules
- Attenuation & Q in the Earth
  - Material dispersion

Scattering

- Scattering and absorption
  - Coda waves
  - Scattering and attenuation

Some applications

Waves in layered media

- Equation of motion in 1D halfspaces
- Thomson-Haskell method for layered halfspace
  - Love & Rayleigh waves; Double-couple excitation

Application

- Computation of "spectral" quantities
  - Phase velocity; Group velocity;
  - Eigenfunctions and energy integral; Attenuation
- Computation of synthetic seismograms
  - Radiation pattern; displacement, velocity, acceleration

Dispersion in layered media

- FTAN: frequency-time analysis
  - floating filters
- Inverse problems in seismology
  - Seismic tomography
  - PREM
  - Body and Surface tomography

References:

1) Scales, J., and Snieder, R., 1999.
What is a wave?, Nature, 401, 739-740;

2) Pain, H., 1993.
The physics of vibrations and waves, Wiley, 479 pp.

3) Graff, K., 1975.
Wave motion in elastic solids, Ohio State University Press, 649 pp.

4) Stein, S., and Wysession, M., 2003.
An introduction to seismology, earthquakes, and earth structure, 498 pp.

5) Aki, K., and Richards, P., 2003.
Quantitative Seismology, 2nd edition. USCI

6) Lay, T., and Wallace, T., 1995.
Modern Global Seismology, Academic Press.

Some links:

http://www.walter-fendt.de/ph14e/ **(physics applets)**

http://www.acs.psu.edu/drussell/demos.html **(animations)**

http://www.iris.edu/hq/programs/education_and_outreach/animations **(animations)**

http://www.du.edu/~jcalvert/waves/wavhom.htm **(waves)**

http://epscx.wustl.edu/seismology/book/ **(S&W book)**

http://earthquake.usgs.gov/earthquakes/map/ **(Earthquakes facts and stats)**

http://earthquake.usgs.gov/learn/glossary.php **(Earthquake glossary)**

http://www.geophysik.uni-muenchen.de/~igel/ **(Heiner Igel lectures)**