Introduction to Geophysics

[ES 3004 / ES 7020]

Semester 2, AY2025–2026

Nanyang Technological University

Tutorial
Earthquake Location Using P–S Waves

1. Physical setting

Earthquakes release elastic energy that propagates through the Earth as seismic waves. The first arrivals on a seismogram are typically:

- **P waves** (primary waves), which travel fastest, and
- **S waves** (secondary waves), which travel more slowly.

Because P and S waves travel at different velocities, the time delay between their arrivals depends on the distance between the earthquake source and the recording station. By measuring this delay at multiple stations, the earthquake epicenter can be determined.

2. P– and S-wave arrivals on seismograms

A seismogram records ground motion as a function of time. In this tutorial, you will use synthetic seismograms and manually pick:

- the P-wave arrival time t_P,
- the S-wave arrival time t_S.

The difference

$$\Delta t_{SP} = t_S - t_P \tag{1}$$

is the key observable used for earthquake location.

3. Distance from S–P time difference

Assume a homogeneous Earth with constant P- and S-wave velocities V_P and V_S. In general, the arrival times recorded at a station include the earthquake origin time t_0:

$$t_P = t_0 + \frac{d}{V_P}, \qquad t_S = t_0 + \frac{d}{V_S}, \tag{2}$$

where d is the distance from the source to the station.

The difference between the S- and P-wave arrival times is

$$\Delta t_{SP} = t_S - t_P. \tag{3}$$

Substituting the expressions above gives

$$\Delta t_{SP} = \left(t_0 + \frac{d}{V_S}\right) - \left(t_0 + \frac{d}{V_P}\right) \tag{4}$$

$$= d\left(\frac{1}{V_S} - \frac{1}{V_P}\right). \tag{5}$$

The unknown origin time t_0 cancels out, which is why the S–P method does not require knowledge of the earthquake origin time.

Solving for distance yields

$$\boxed{d = \Delta t_{SP}\,\frac{V_P V_S}{V_P - V_S}}. \tag{6}$$

This equation allows the source–station distance to be computed directly from the picked arrival times.

4. Epicenter determination by triangulation

Each seismic station provides a distance estimate but not a direction. Geometrically, this corresponds to a *circle* centered on the station, with radius equal to the estimated distance d.

- With one station, the epicenter can lie anywhere on the circle.
- With two stations, two possible intersection points exist.
- With three or more stations, the epicenter can be uniquely constrained.

In this tutorial, you will:

1. Plot station locations on a map.
2. Draw distance circles for each station.
3. Visually identify the region where the circles intersect.

This provides an intuitive understanding of earthquake location before applying formal inversion methods.

5. Synthetic seismograms

You are provided with synthetic seismograms generated for a known epicenter and five seismic stations. The waveforms include:

- P waves,
- S waves,
- later-arriving surface waves,
- background noise.

6. MATLAB exercise: P–S picking and epicenter location

In this tutorial you will:

1. Load synthetic seismograms for three stations.
2. Manually pick P- and S-wave arrival times.
3. Compute S–P time differences and source–station distances.
4. Plot distance circles and visually estimate the epicenter.

Suggested velocity model:

- P-wave velocity: $V_P = 6.0$ km/s
- S-wave velocity: $V_S = 3.5$ km/s

8. Learning objectives

After completing this tutorial and assignment, you should be able to:

- Identify P and S waves on seismograms,
- Estimate earthquake distances from S–P times,
- Understand earthquake location as a geometric problem,
- Appreciate the role of velocity structure and uncertainty.