NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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Module 10 : Brief on Earthquake geodesy
Lecture 02: Coseismic deformation

CONCEPTS COVERED

- **Coseismic deformation**
- **Static displacement due to strike slip fault**
- **Infinite fault**
- **Finite fault**
- **Buried fault**
- **Static displacement due to dip slip fault**

Recap

- Geodetic methods using signals from space permits all three components of position to be measured to sub-centimeter precision.

- The popular geodetic technique to measure ground deformation are: Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Global positioning system (GPS).

- GPS uses a constellation of satellites transmit coded timing signals on a pair of microwave carrier frequencies synchronized to very precise on-board atomic clocks.

- GPS data can be obtained for continuous period of time or short period of time (survey mode). Survey mode is cheaper.

- The biggest limitation of geodetic data for earthquake studies is that the positions of geodetic markers before the earthquake are needed.

Recap

- For radar, d is the antenna length, so a radar a distance r above the earth’s surface could resolve objects of size x, where $$\theta_d = \lambda/d = x/r$$

- The phase difference between radar signals with wavelength λ reflected from the Earth’s surface and recorded by antennas at position A_1 and A_2 is $$\phi = (4\pi/\lambda)(r_2 - r_1)$$

  r_i is the range from the antenna at A_i to the reflection point.

- If differences in satellite positions between the measurements are removed, a vector surface displacement D causes a phase change

$$\phi \approx (4\pi/\lambda)\delta r, \quad \delta r = (D.\hat{r}),$$

where δr is the projection of the vector displacement along the look direction connecting the satellite and reflection point.

Coseismic deformation

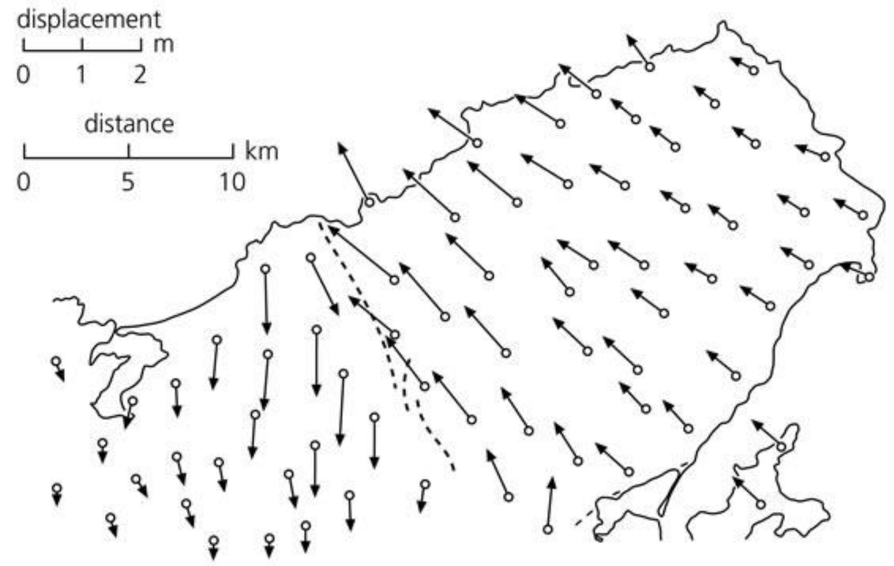
- ➔ The radiation pattern of static coseismic displacements from earthquakes are analogous to the propagating wave displacements.

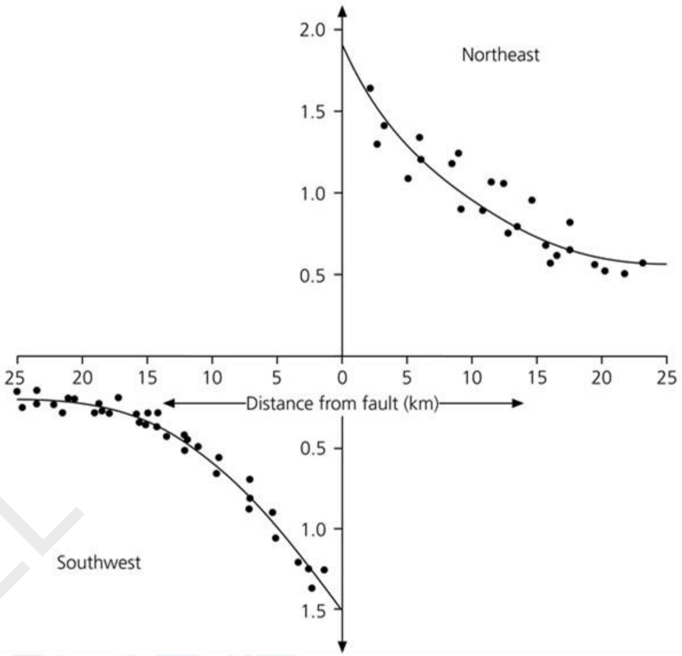
- ➔ Static coseismic displacements can provide information about the fault geometry and slip.

- ➔ Static coseismic displacement decays $\propto 1/r^2$ compared to
  While, seismic propagating waves $\propto 1/r$ terms for the propagating waves.
  Thus, static coseismic displacement decays rapidly with distance from the earthquake.

- ➔ That is why, we typically describe the static displacements using Cartesian coordinates near a fault, rather than the spherical coordinates used for teleseismic waves.

Figure 4.5-4: Static displacements for the 1927 Tango, Japan, earthquake.





- ➔ **Here is an example of the static displacements of 1927 M_s 7.5 Tango, Japan, earthquake.**
- ➔ **Displacements change direction across the fault.**
- ➔ **Displacement directions show that the earthquake involved left lateral strike slip.**
- ➔ **Right figure shows that the displacement decays rapidly with distance from the fault.**

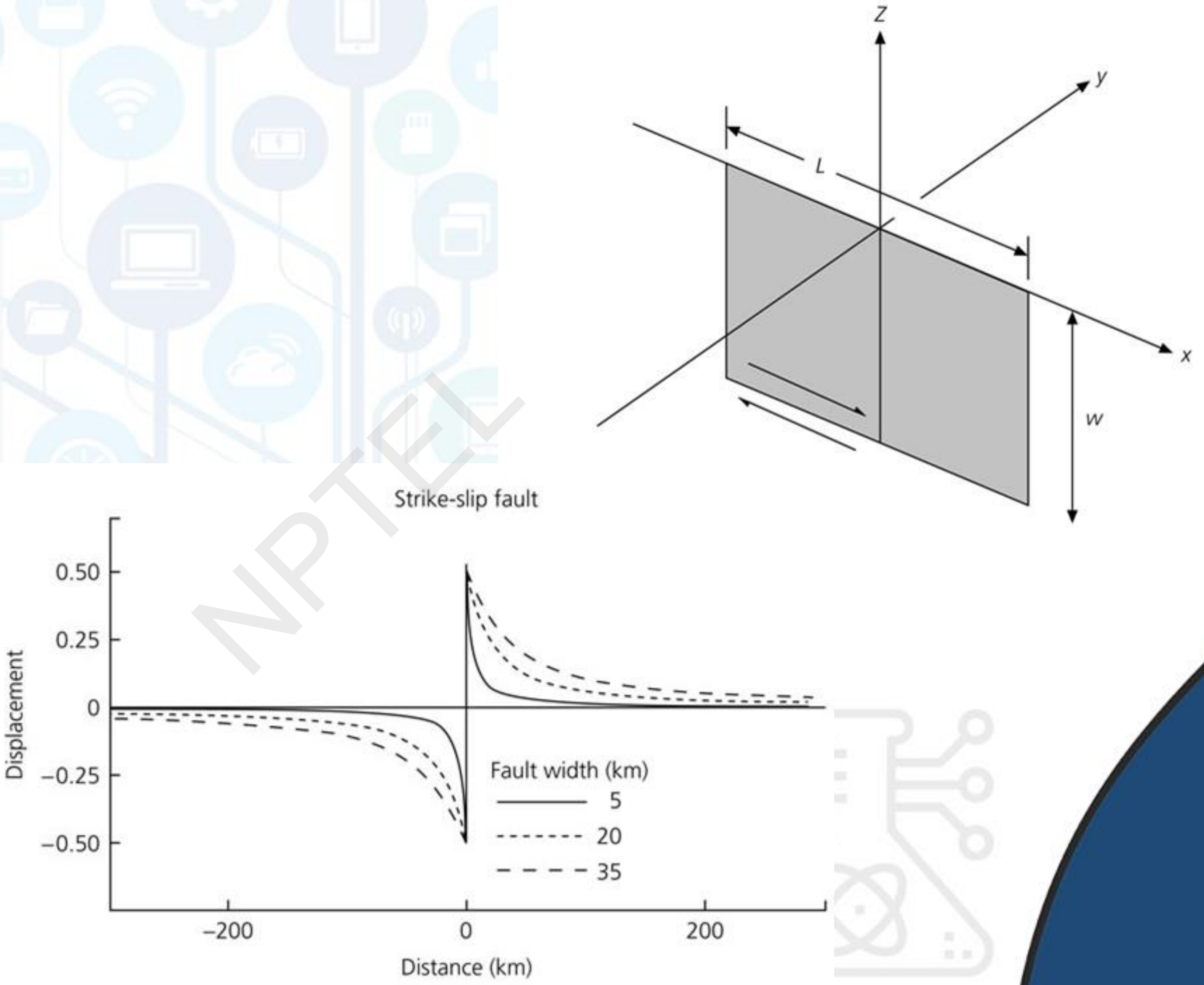
Static displacements due to slip on the fault: Infinite fault

- It is complicated to derive static displacement due to slip on a fault.

- Just to have an idea, let's take an example of pure strike-slip faulting on an infinitely long vertically dipping fault.

- L is the fault length while W is the depth to which faulting extends, called the fault width.

Figure 4.5-5: Predicted fault-parallel static displacements for infinite strike-slip faulting.



- The fault-parallel displacement in the x direction, u(y), varies with distance from the fault y as

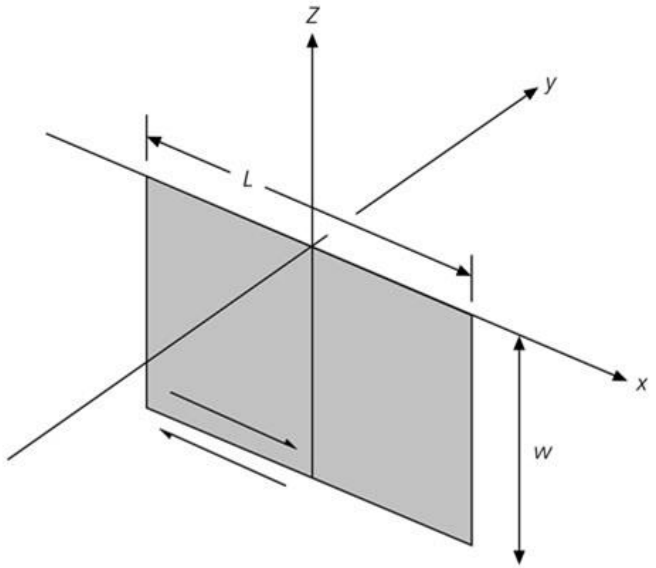
$$u(y) = \pm D/2 - (D/\pi)\tan^{-1}(y/W)$$

D: slip across the fault
W: width is the depth to which faulting extends, called faulting width

- The ±D term is positive for y > 0, negative for y < 0.

- Assumption: The slip is uniform all over the fault plane.

Figure 4.5-5: Predicted fault-parallel static displacements for infinite strike-slip faulting.



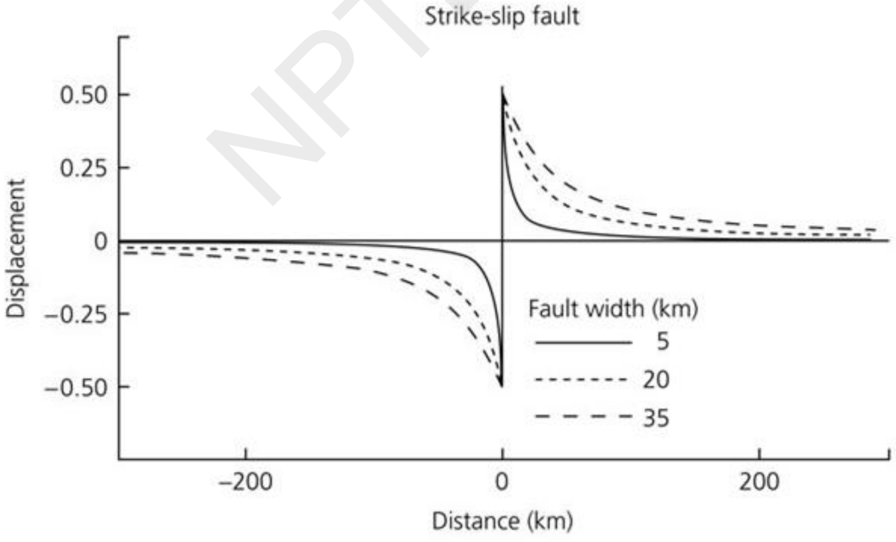
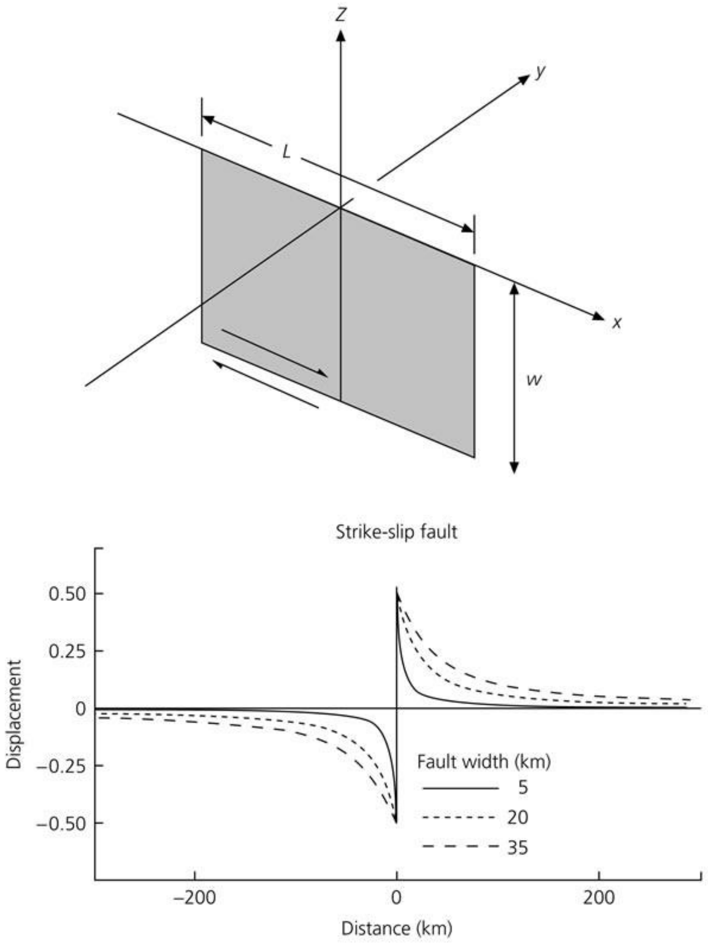


Figure 4.5-5: Predicted fault-parallel static displacements for infinite strike-slip faulting.

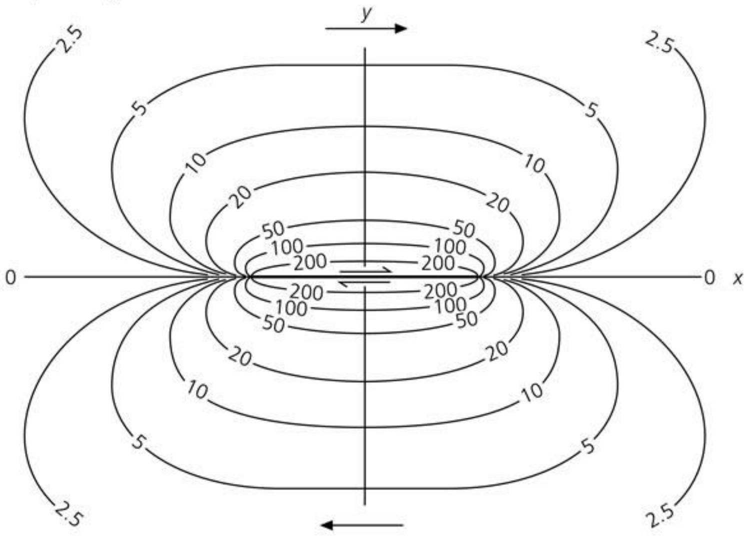


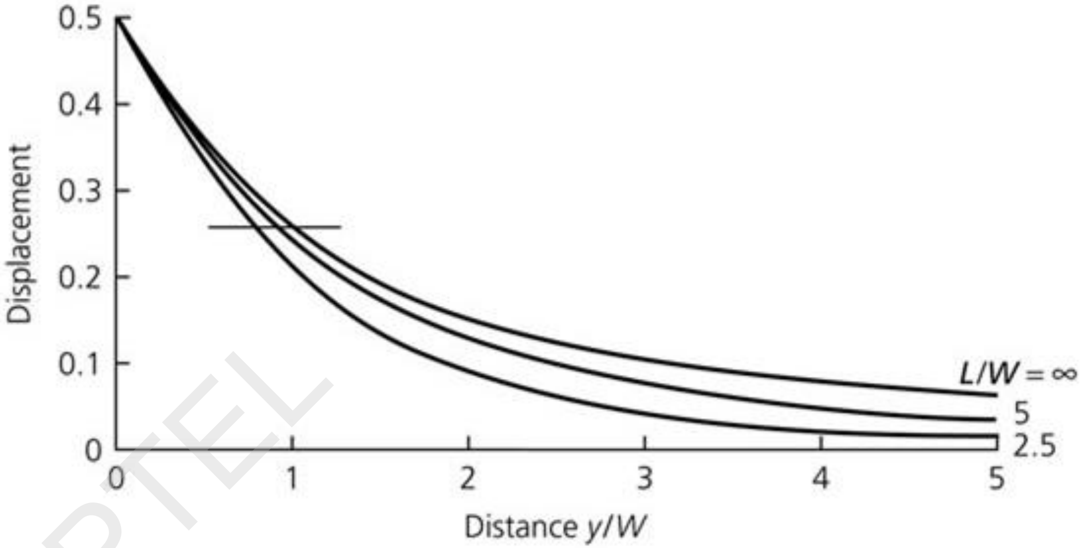
$$u(y) = \pm D/2 - (D/\pi)\tan^{-1}(y/W)$$

- **Near the fault i.e. y → 0 gives u(0) = ±D/2.**
- **The displacement decays away from the fault.**
  For example, When y = W, then u(W) = D/4.
- **Far from the fault, y/W → 0, and the displacement dies off.**
- **Hence, the distance over which the displacement extends gives information about the fault width.**
- **For this infinite fault, fault-parallel displacement extends to infinity along the fault.**

Observing static displacements due to slip on the fault: Finite length fault

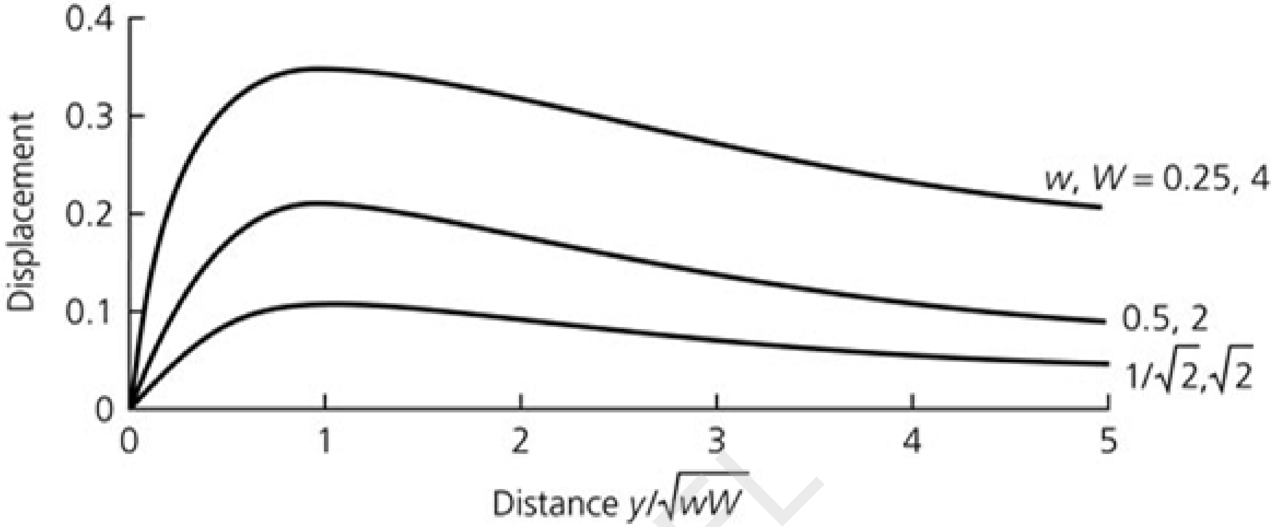
Figure 4.5-6: Predicted fault-parallel static displacements for finite strike-slip faulting.





Left Figure: **For finite length faults the displacement tapers off rapidly past the fault ends.**

Right Figure: **decay of displacement depends on the ratio of the fault width to fault length, W/L. Thus the fault width estimated from the decay depends on the assumed length.**



- If a fault is buried and extends from depth w to depth W, then displacement is given by

$$u(y) = (D/\pi)\left[\tan^{-1}(y/w) - \tan^{-1}(y/W)\right]$$

- In this case, the maximum surface displacement is less than half the fault slip and occurs a distance from the fault equal to the mean depth $(wW)^{1/2}$

- Thus the displacement fields of buried faults are smoother and lower amplitude versions of those for faults that reach the surface.

Why displacement fields of buried faults are smoother and lower amplitude versions of those for faults that reach the surface?

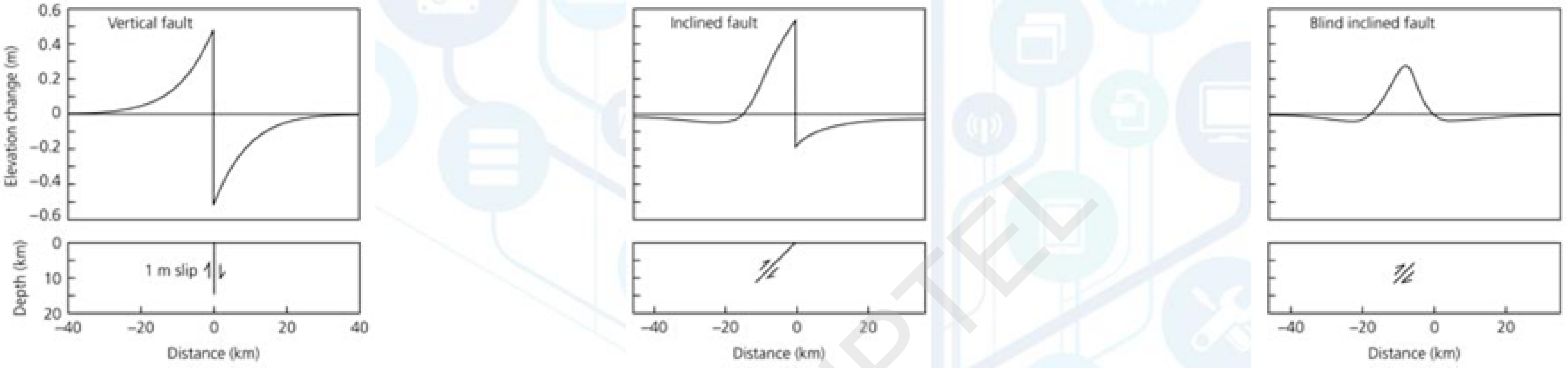
Two reasons

- **A buried fault is further away from each point on the surface, and the higher spatial frequencies (shorter wavelengths) in the displacement decay faster with distance, making the displacement smoother.**

- **There is a trade-off between the fault's down-dip dimension W – w and the coseismic slip D, and one is often assumed to determine the other.**

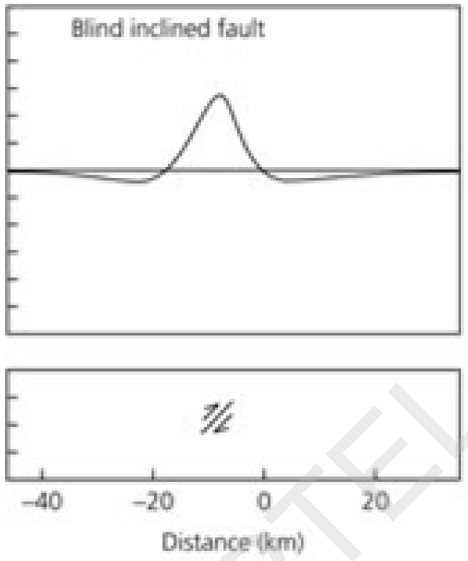
Observing static displacements due to slip on the fault: dip slip fault

The figure shows vertical component of static displacement as a function of distance from various pure dip slip faults.



- ➔ The solution for vertical slip looks like strike-slip solution turned vertically.
- ➔ For the non vertical dip, the displacement varies in magnitude as well as sign across the fault.
- ➔ The amplitude above the thrust fault is higher, on the hanging wall block.

Observing static displacements due to slip on the fault: dip slip fault

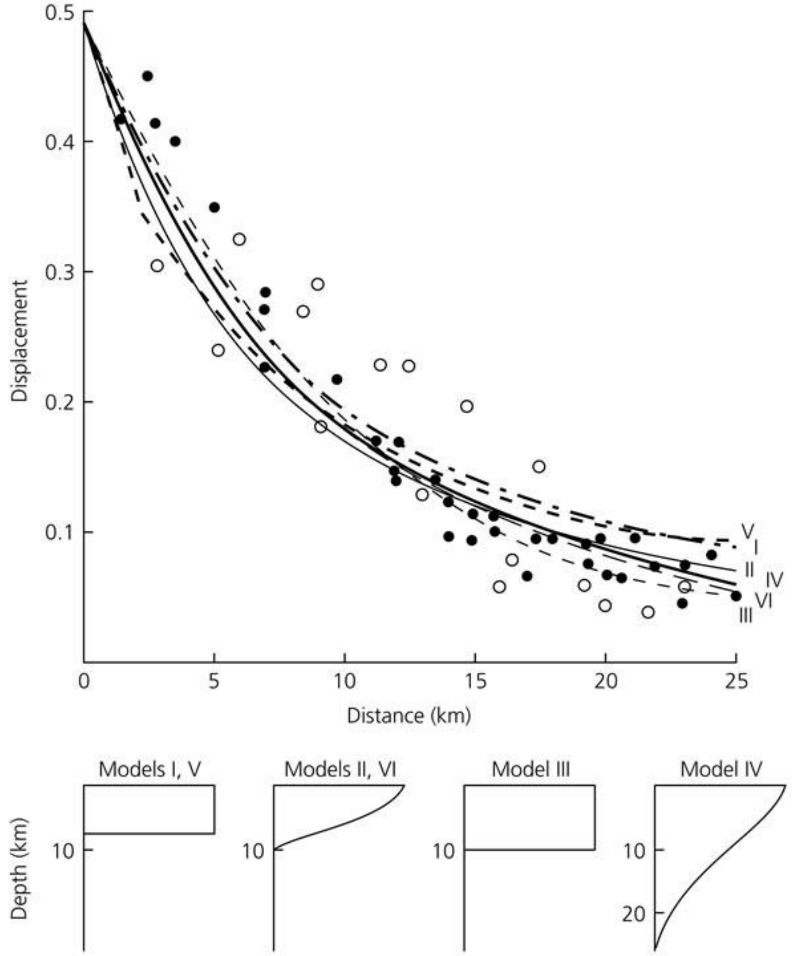


- A fault that does not reach the surface, the displacement is both reduced in amplitude and varies more smoothly with distance than it would for a fault extending to the surface.

- Such buried dip-slip faults are sometimes called “blind” faults, because they do not appear at the surface and may not be recognized until an earthquake occurs.

Non uniqueness of geodetic determination of fault parameters

Figure 4.5-8: Modeling the coseismic deformation from the 1927 Tango, Japan, earthquake.



Estimation of fault parameters using geodetic data is an inverse problem with highly non-unique solution as various combinations of fault parameters predict similar deformation.

Let's have an example of Tango earthquake, we have six solution with all having reasonable fits to the Tango earthquake data.

Model I is an infinite fault with uniform slip at depth, model II is an infinite fault with slip tapering to zero at depth, and models III and IV are finite faults with uniform and variable slip, respectively

Model V is the most complicated, in that it assumes that the material near the fault is weaker than that further away

Summary

- **Static coseismic displacement contain $1/r^2$ terms, compared to $1/r$ terms for the propagating waves. Thus, it decay more rapidly with distance from the earthquake.**

- **For infinite length fault, the fault-parallel displacement in the x direction, u(y), varies with distance from the fault y as**

$$u(y) = \pm D/2 - (D/\pi)\tan^{-1}(y/W)$$

- **For finite length faults the displacement tapers off rapidly past the fault ends. If a fault is buried and extends from depth w to depth W**

$$u(y) = (D/\pi)\left[\tan^{-1}(y/w) - \tan^{-1}(y/W)\right]$$

- **A fault that does not reach the surface, the displacement is both reduced in amplitude and varies more smoothly with distance than it would for a fault extending to the surface.**
- **Estimation of fault parameter using geodetic data is an inverse problem and has highly non unique solutions.**

REFERENCES

- Stein, Seth, and Michael Wysession. An introduction to seismology, earthquakes, and earth structure. John Wiley & Sons, 2009.
- Lowrie, William, and Andreas Fichtner. Fundamentals of geophysics. Cambridge university press, 2020.
- Kearey, Philip, Michael Brooks, and Ian Hill. An introduction to geophysical exploration. Vol. 4. John Wiley & Sons, 2002.
- https://geologyscience.com/geology-branches/structural-geology/stress-and-strain/
- Seismology course, Professor Derek Schutt, Colorado State Univ., USA.

THANK YOU !