SOEE2212 Tectonophysics Lab 4

Viscoelastic Coupling Model of the Earthquake Cycle:

The North Anatolian Fault

Tim Wright, University of Leeds

Note this is an assessed lab. Please hand in the lab report by 2pm, 1 May.

1. Theory / Introduction

Geodesists commonly consider steady slip on a screw dislocation embedded within an elastic half-space to model interseismic deformation (Savage and Burford, 1973, Wright et al., 2013). In this model, the surface velocities, *v*, are a simple function of the distance from the fault, x, the slip rate, *s*, and the locking depth, *d*:

$$v = \frac{s}{\pi} \tan^{-1}\left(\frac{x}{d}\right) \tag{1}$$

In reality, observations of rapid postseismic deformation show that the velocities are not constant through the earthquake cycle. The viscoelastic coupling model of (Savage, 2000, Savage and Prescott, 1978) is a relatively simple model in which periodic earthquakes occur in an elastic layer above a viscoelastic half space. The amount of time variation observed in the model depends primarily on the ratio, τ_0, between the inter-event time, *T*, and the Maxwell relaxation time of the viscoelastic layer, $2\eta/\mu$, where η is the viscosity and μ is the shear modulus.

2. Aims of the lab

1. To find the best fitting elastic dislocation model for interseismic GPS data acquired prior to the 1999 Izmit and Duzce earthquakes on the North Anatolian Fault (Turkey).
2. To determine the parameters of the viscoelastic coupling model that best match the observed interseismic deformation late in the cycle.
3. To determine the parameters of the viscoelastic coupling model that best match the observed postseismic deformation immediately following the 1999 Izmit and Duzce earthquakes.
4. To discuss how to reconcile the discrepancy between the parameters found for interseismic and postseismic deformation

3. Data sets

I have extracted two data sets containing GPS data for the area of the North Anatolian Fault that was struck by two M7+ earthquakes in 1999 (Figure 1):

interseis.dat contains GPS velocities measured late in the earthquake cycle, in the period 1988 to 1997, from (McClusky et al., 2000).

postseis.dat contains instantaneous velocities estimated in February 2000, 6 months after the 1999 Izmit earthquake, by (Ergintav et al., 2009).

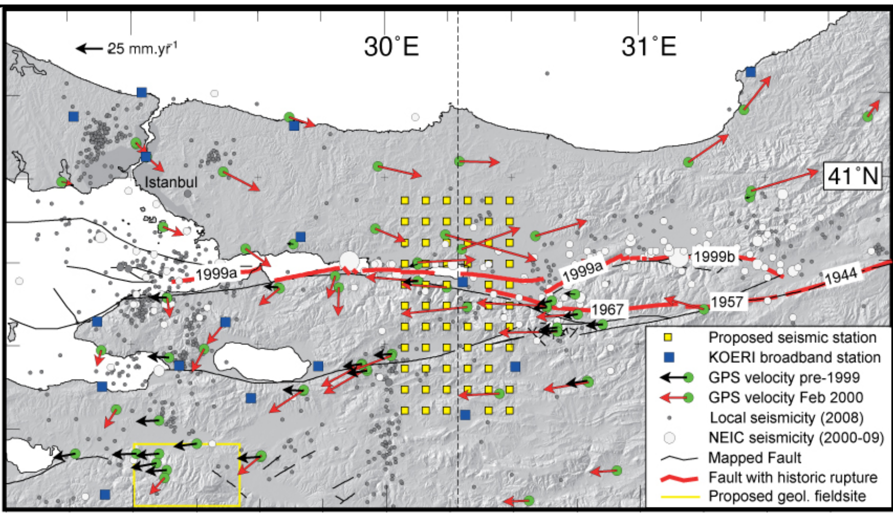

Figure 1: Location Map for GPS data (symbols defined in figure). Yellow squares show location of seismic stations installed by University of Leeds across main NAFZ in the area of the 1999 Izmit earthquake (dates of historic ruptures indicated). GPS deformation velocities before and after the 1999 earthquakes are shown. The dashed line (30.27E) gives the location of the geodetic data used in this lab.

I have projected the GPS data onto the dashed line (30.27E) shown in Figure 1. The files contain the fault-parallel (E-W) velocities for all sites within 50 km of the profile line.

The data files have three columns in the format:

[Distance from fault (km)] [Fault-parallel velocity (mm/yr)] [1 sigma velocity error (mm/yr)]

The data are in a fault-centred reference frame (i.e. the velocity at the fault is 0 mm/yr).

Positive distances are south of the fault. Positive velocities are to the west.

4. Getting started

Download the zip file: http://see.leeds.ac.uk/~eartjw/data/tectonophysics/lab4.zip and unzip.

Open matlab and move into the lab4_files directory. Like in previous labs start a script and keep all your commands in that. Begin with some comments about what the script is, and then add mbin to the path.

> addpath mbin

Load the interseismic and postseismic velocities:

> load interseis.dat

> load postseis.dat

You can plot them with the command *errorbar*, e.g.

> *errorbar(interseis(:,1),interseis(:,2),interseis(:,3),'.')*

Note that the above command plots 1-sigma errors. Sometimes 2-sigma errors are plotted in the literature.

5. Task 1: Find the best fitting elastic dislocation model for interseismic GPS data acquired prior to the 1999 earthquakes

I have made a Matlab function *deepdisloc*, which uses equation (1) to calculate velocities at specified distances for a given slip rate and locking depth. Use

>*help deepdisloc*

to get the usage.

Create a vector of positions every 1 km from -100 to 100 km:

> *x* = [-100:1:100]';

Use *deepdisloc* to calculate the model predictions at these distances and plot them.

5.1 Play around with different values for slip rate and locking depth until you get a reasonable fit to the data in interseis.dat.

Geological data suggests that the long-term slip rate of the NAF is 24 mm/yr in this location.

Assuming this is correct,

5.2 find the locking depth that minimises the residual misfit (in a least squares sense) between the observed and model interseismic velocities.

Some hints on how to do this:

1. First make a vector of residuals, by calculating the model for the values of *x* where the interseismic velocities have been measured. Remember, residual = data minus model.
2. A quick method for calculating the root mean square misfit is to use the command *norm.* (e.g. *rms = norm(resid)*)
3. You may wish to create a for loop to calculate the residual for multiple values of locking depth, *d.,* e.g.

> *for d = [1:50]*

> *[CALCULATE RESIDUAL]*

> *[CALCULATE RMS]*

> end

4. Plot rms misfit as a function of locking depth, d.

Think about how well constrained the locking depth is by the data. What is an acceptable range of values for d?

6. Task 2: Determine the parameters of the viscoelastic coupling model that best match the observed interseismic deformation late in the cycle.

The matlab function *savage2000* will calculate surface velocities at a given snapshot within the earthquake cycle using the viscoelastic coupling model. It requires an input vector, *in*, which contains the following:

in(1) = slip_rate	velocity will have same units
in(2) = t	time since last earthquake (years)
in(3) = T	Earthquake recurrence time
in(4) = Tr	Relaxation (Maxwell) time ($2\eta/\mu$)
in(5) = D	depth of faulting
in(6) = H	thickness of elastic layer

For the North Anatolian Fault, you can consider the long-term slip rate as reasonably well known, at about 24 mm/yr, and the inter-event time as 200 years. Consider in this case only models where the earthquakes rupture the entire elastic layer (i.e. set D=H=Locking Depth). A good starting value is the locking depth, *d*, you found in task 1. The interseismic velocities are late in the cycle, ~5 years before the 1999 earthquake.

What Maxwell relaxation times match the observed interseismic velocity profile?

Do the data provide an upper bound on viscosity, a lower bound, or both?

If $\mu = 3 \times 10^{10}$ Pa, what viscosities are required by interseismic data if the viscoelastic coupling model is correct?

7. Task 3: Determine the parameters of the viscoelastic coupling model that best match the observed postseismic deformation early in the cycle.

Repeat the above procedure using the postseismic velocities in *postseis.dat*. These were observed 0.5 years after the start of the cycle. Note, it is harder to match the shape of the profile, partly because the earthquake was not infinitely long. Concentrate on matching the magnitude of the postseismic velocity.

Again answer these questions:

What Maxwell relaxation times match the observed postseismic velocity profile?

Do the data provide an upper bound on viscosity, a lower bound, or both?

What viscosities are required by postseismic data if the viscoelastic coupling model is correct?

8. Task 4: Discuss how to reconcile the discrepancy between the parameters found for interseismic and postseismic deformation

You will find that a single value for the viscosity cannot match both interseismic and postseismic velocities. In the lecture, I discussed some alternative models that are able to do this. References were given in the lecture handout. In the discussion section of your lab report, discuss these alternative models.

References

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