Shear in the west part of the North Aegean Trough in a 100+ years scale

Stathis Stiros, Fanis Moschas and Vasso Saltogianni*
Dept of Civil Engineering, Patras University, Greece
* GFZ, Potsdam, Germany
The question:

Are slip rates along major active strike slip faults constant?

The answer from a theoretical point of view is YES

However,
- it is not known what happens at the edges of major strike slip faults
- there is no direct long-term geodetic evidence
  - GPS data currently cover up a to few tens of years

A related question:

How major strike slip faults terminate?
“Are slip rates along major active strike slip faults constant?”

An opportunity to contribute in an answer to this problem, focusing on

- the west edge of the North Aegean Trough (NAT), an active strike slip fault at the continuation of the North Anatolian Fault (NAF)
- expand the observations record to 100+ years using triangulation data (conventional geodetic data, rarely available) and GPS data
- examine seismological evidence
● The North Aegean Trough (NAT) at the continuation of the North Anatolian Fault (NAF):
● a >1000m deep major marine basin,
   narrow and **simple** to the east, wider and **diffuse** to the west
● A tectonically active strike slip zone
   Several major (M>6.0) strike slip earthquakes since the 1960’s
   (the 2014 Mw6.7 earthquake precisely modeled using GPS, teleseismic & accelerometer data)
● Earthquakes spread in the wider region
Slip vectors from the HEPOS GPS network indicate:

- A characteristic slip discontinuity around NAT
- Clear shear deformation in the central and east part of the NAT (till the coast)
- But deformation pattern tends to change to the west, in the mainland
  - Kinematic pattern changed in the mainland - no clear shear discontinuity

Displacement Field along the NAT: Evidence from the HEPOS GPS network (only homogeneous data)

GPS Slip vectors computed using only:
- uniform hardware
- continuous stations
- high accuracy data
- representative data sets
- data with common noise
- uniform processing
Data double checked to avoid errors (changing positions, etc.) - all dubious stations rejected.

Measurements from point on top of mountains peaks → limited atmospheric noise.

Very precise: average values from >24 valid sets of measurements, lasting weeks/months.

Precision in angles better than 0.00016 grads.

Very accurate: control through misclosure errors in several triangles (ideally, sum of 180°).

Maximum misclosure error in 76 triangles: 0.0002 grads (Stiros 1993).

Triangulation measurements

Survey 1, 1890-1892
Survey 2, 1929-1930
Survey 3, 1950-1966

Examine only measurements from stations stable/common in all surveys.
Shear from triangulation data

Triangulation data cannot describe well displacements, but describe excellently angle changes & shear

Typical shear deformation
$\rightarrow$ angle change

Shear deformation accurately deduced from slight changes of angles in a triangle

- Estimates of shear $\gamma$ (or of shear rate $\dot{\gamma}$), of its direction $\psi$ & of their uncertainties computed using only approximate coordinates and angle measurements

\[
\dot{\gamma} = f(\text{angle changes, approximate coordinates of triangulation stations, time})
\]

(algebraic formula in symbolic form)

- Precision/accuracy in estimates of shear increase with number of triangles
- No need for assumptions, approximations, etc.
  - results precise & reliable
**Results:** Estimates of shear strain rate at the west edge of the NAT

<table>
<thead>
<tr>
<th>Between surveys</th>
<th>1 to 2</th>
<th>2 to 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time interval</strong></td>
<td>1890/1892 to 1929/1930</td>
<td>1929/1930 to 1950/1966</td>
</tr>
<tr>
<td>(\dot{\gamma} , (\mu\text{rad/yr}))</td>
<td>0.05±0.04</td>
<td>0.48±0.10 (a few cm/yr/50km)</td>
</tr>
<tr>
<td>(\psi (^\circ))</td>
<td>-40.5(^\circ)±12.9(^\circ)</td>
<td>30.2(^\circ)±0.6(^\circ)</td>
</tr>
</tbody>
</table>

No significant shear

**Significant shear** at a direction compatible to the strike of NAT

▶ No evidence of shear strain before the 1930’s
West edge of NAT, correlation between seismicity & computed shear strain

1890-1930
no shear strain,
limited seismicity, M>6.0

1930-1966
shear strain,
important seismicity, M>6.0

1966-2017

No artefact of poor knowledge of seismicity before the 1930’s

Structural relationship between shear strain and seismicity?
Questions arising:

If the geodetic evidence for instability of shar is accurate (no reasons to doubt!),

what is the reason for the inferred change in the kinematic pattern in the west part of NAT after ~1930?

and what are its geodynamic implications?

First, a look at the tectonic structure of the NAT
Contrast between the east and west edge of the NAT

East part of NAT: a simple narrow deep basin at the continuation of the NAF, strike slip controlled

West part of NAT: structural complexity

Papanikolaou et al, 2002)
The west part of the NAT abuts to a system of raised Holocene and Quaternary shorelines, usually poorly developed/recognized (especially in the Sporades Isles) because of lithological and biological limitations.

Not a “typical” strike-slip environment

Holocene and Quaternary uplifted shorelines (Stiros et al 1992, 1994)
Summary:
In the *westernmost part* of the NAT
- complex tectonics (fault splaying & interaction?)
- evidence of *instability* in the displacement field (shear)

Possible explanations
Kinematics in this structurally composite area are likely to reflect
- cumulation of different tectonic processes at different time scales
- boundary effects / influence of adjacent tectonic provinces / fault interaction

Superimposition of short-term deformation rates from different sources
- *temporarily* obscure certain regional effects (e.g. shear from the east),
- emphasize transient effects
- lead to alternation of periods of strong earthquakes with relatively short aseismic intervals.
Conclusions

● In the west termination of the North Aegean Trough (NAT) we were able to expand the time scale of geodetic observations from tens of years (satellite data) to 100+ years (using triangulation data), and

● we found evidence of **shear strain instability** in periods of a few tens years, not recorded by shorter term GPS data, most likely correlating with changes in seismicity rates

The likely explanation:
● tectonic complexity at the termination of the fault
● influence from adjacent areas (boundary effects)
● superimposition of short and longer-term processes

A question/perspective
Similar pattern/effects in other major strike slip faults??
The table below summarizes the displacement rates and rotations for the network and the triangle 57-58-89 (NAT).

<table>
<thead>
<tr>
<th></th>
<th>epochs</th>
<th>I-II</th>
<th>II-III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>whole network</td>
<td></td>
</tr>
<tr>
<td>( \dot{\gamma}_1 ) (( \mu \text{rad/yr} ))</td>
<td>0.05±0.04</td>
<td>-0.42±0.09</td>
<td></td>
</tr>
<tr>
<td>( \dot{\gamma}_2 ) (( \mu \text{rad/yr} ))</td>
<td>0.01±0.05</td>
<td>0.24±0.10</td>
<td></td>
</tr>
<tr>
<td>( \dot{\gamma} ) (( \mu \text{rad/yr} ))</td>
<td>0.05±0.04</td>
<td>0.48±0.10</td>
<td></td>
</tr>
<tr>
<td>( \psi ) (°)</td>
<td>-40.5±12.9</td>
<td>30.2±0.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>triangle 57-58-89 (NAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \dot{\gamma}_1 ) (( \mu \text{rad/yr} ))</td>
<td>0.00±0.01</td>
<td>-0.34±0.24</td>
</tr>
<tr>
<td>( \dot{\gamma}_2 ) (( \mu \text{rad/yr} ))</td>
<td>0.00±0.01</td>
<td>0.09±0.40</td>
</tr>
<tr>
<td>( \dot{\gamma} ) (( \mu \text{rad/yr} ))</td>
<td>0.00±0.01</td>
<td>0.35±0.31</td>
</tr>
<tr>
<td>( \psi ) (°)</td>
<td>2.2±61.9</td>
<td>37.6±14.2</td>
</tr>
</tbody>
</table>