Geodetic estimates of crustal deformation in the central California coast region

Jessica Murray-Moraleda, Jerry Svarc, Wayne Thatcher, and Tiemi Onishi

U. S. Geological Survey

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How is strain partitioned in the central California coast region?

UCERF2
Field et al. (BSSA, 2009)

Probability of M≥6.7 Earthquakes

1. S. San Andreas - 59%
2. Hayward-Rodgers Creek - 31%
3. San Jacinto - 31%
4. N. San Andreas - 21%
5. Elsinore - 11%
6. Calaveras - 7%
7. Garlock - 6%
Clockwise rotation of crustal blocks causes plate boundary-normal compression.

Left transfer of right lateral slip causes compression subparallel to strike slip faults.

- Steep reverse faults between major strike-slip faults
- East-west escape tectonics
- Opposite trends of Hosgri and Rinconada-West Huasna slip rates

McLaren and Savage (BSSA, 2001)

Hardebeck (BSSA, 2010)
Central California Coast Region (CCCR) GPS station coverage

- CCCR defined by box
- Number of CGPS sites has gone from 4 to 18 since 2004
- Surveyed 27 SGPS sites 1 – 3 times from 2007 – 2010 to augment data
- Established 9 SPGPS sites

- Continuous (CGPS)
- Survey-mode (SGPS)
- Semi-permanent (SPGPS)
Contamination from earthquake-related signals

- Coseismic offsets and strong postseismic signals
- Many CGPS sites installed after earthquakes
- Corrections based on slip models can introduce bias into secular rate estimates
Time series analysis

\[ d_i = d_o + v_o t_i + \sum_{j=1}^{j_o} o_j H(t_i - T_j) + \sum_{m=1}^{m_o} [a_m \sin(2\pi f_m t_i) + b_m \cos(2\pi f_m t_i)] + \sum_{k=1}^{k_o} c_k H(t_i - T_k) + \sum_{k=1}^{k_o} A_k \log(1 + (t_i - T_k)/\tau_k) + r_i \]

Continuous (secular rate removed)

Survey-mode

Time series fit using realistic noise models that include colored noise (Langbein, 2004)
Mitigating postseismic effects when estimating GPS velocities

When possible, use full time series and estimate all terms (e.g., CGPS sites)

\[
d_i = d_o + v_o t_i + \sum_{j=1}^{j_o} o_j H(t_i - T_j) + \sum_{m=1}^{m_o} [a_m \sin(2 \pi f_m t_i) + b_m \cos(2 \pi f_m t_i)]
\]
\[
+ \sum_{k=1}^{k_o} c_k H(t_i - T_k) + \sum_{k=1}^{k_o} A_k \log(1 + (t_i - T_k)/\tau_k) + r_i
\]
Comparison of secular rates estimated using pre-earthquake data only and those estimated simultaneously with earthquake terms shows good agreement.
How to address sites without pre-earthquake data?

Previous studies (e.g., Rolandone et al., 2006; Johanson and Burgmann, 2010) have assumed that the postseismic signal due to San Simeon died off after about 1 year, but time series analysis shows otherwise.

Exponential decay with time constant assumed by Johanson and Burgmann (2010) predicts negligible signal within 1 year.

Estimated logarithmic decay shows continued displacement for several years.

Detrended time series for P278

Velocity bias if secular rate is estimated from post-2006 data
Mitigating postseismic effects when estimating GPS velocities

For SGPS sites with sufficient data, estimate velocities using pre-earthquake observations.
Central California Coast Velocity Field

Red: CGPS
Green: SGPS
Blue: SPGPS
Unfilled: increased uncertainties
Grey markers: determined from only two surveys
Central California Coast Velocity Field (close-up)

Red: CGPS
Green: SGPS
Blue: SPGPS
Unfilled: increased uncertainties
Grey markers: determined from only two surveys
Block models of regional crustal deformation

- **Software:** *defnode* (McCaffrey, JGR, 2005)
- **Model parameters:** block angular rotation, creep rate on faults, uniform permanent strain rate in blocks, and reference frame adjustment
- **Data:** Central Coast velocity field (this study) plus CMM4 and PBO GPS velocities

- Implicitly satisfies Pacific-North American relative motion
- Provides some kinematic constraint on covariance among fault slip rates
Block models of regional crustal deformation

- Null hypothesis: Region west of the San Andreas in central California is a single block (SALI)
- Data in southeastern portion of SALI inconsistent with geologically-inferred slip rate on San Andreas
- Large residuals throughout SALI
Large residuals in this area have been seen in other studies

• Inclusion of “Big Pine” block reduces residuals
• No corresponding mapped fault here
• Data favors extension along this boundary:
  • 5.5 +/- 1.5 right lateral strike slip
  • 2.3 +/- 1.0 normal slip
Block models of regional crustal deformation: Inclusion of Big Pine block

- Right lateral oblique extension on block boundary as seen by Meade and Hager
- Statistically significant improvement in fit to the data
- San Andreas slip rate is still lower than geologic estimates (34 +/- 3 mm/yr), but similar to McCaffrey (2005) estimate based on geologic slip rate and geodetic data.
Block models of regional crustal deformation: Inclusion of Oceanic block

- Statistically significant improvement in fit to the data
- Very little relative motion taken up across Oceanic fault; inclusion of strain in OCEN does not improve fit
- San Andreas slip rate is slightly higher.
The statewide consensus block geometry under development for UCERF3 will help constrain internally-consistent slip rate estimates throughout the San Andreas system, providing context for targeted studies like the one we are conducting in the central coast region.
Central California coast modeling, initial findings

- Little relative motion taken up on boundaries of proposed Oceanic block; its estimated Euler pole is consistent with that of the rest of the Salinian Block
- No certain evidence found in additional model runs for compression (either N-NW or E-NE) within the Oceanic block, but more study is warranted.

Next steps

- Use the UCERF3 consensus block model for California as a framework for our detailed block models of the central coast region
- Explore alternative block geometries and internal strain to reconcile anomalous velocities in southeast Salinian block and further assess the possibility of ongoing compression
- Assess the range of slip rates permissible on the Hosgri, Oceanic, and Rinconada-West Huasna faults, which observations most influence these estimates, and the sensitivity of results to choice of model geometry
- Incorporate geologic slip rate data
Mitigating postseismic effects when estimating GPS velocities

For newer CGPS sites, estimate velocity using more recent data and increase the uncertainties.
Magnitude of velocities estimated by fitting a trend to postseismic signal at CGPS sites (after removal of secular rate) is used to assess uncertainty for newer sites.