Faulting, Afterslip and Deformation Associated with the 24 August 2014 South Napa Earthquake (M 6.0)

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USGS network update
provided on behalf of Dan Determan and Aris Aspiotes
Nancy King retired

USGS SoCal Network UASI Upgrades Completed

– Total GPS/GNSS stations
  • Before UASI = 104
  • After UASI = 142+

– Total co-located w/ seismic
  • Before = 23
  • After = 64+

– Real-time telemetered GPS/GNSS stations
  • Before = 96
  • After = 134+
USGS Status – Before UASI
USGS Status – After UASI

(41 RTX’s; of these 34 at SoSAFz ‘zipper’, 7 at new UASI sites)

6 Topcons at new UASI sites
26 more to go in this year
Space geodesy, satellite & airborne imagery are powerful new methods for repair & recovery

- GPS is central to providing an absolute reference frame for correlating pre- to post-event imagery and observations.

- Geo-referenced pre-event imagery requires GPS control so that image-derived products showing changes may be highly accurate; we develop geodetic-quality differencing of LiDAR, EO and InSAR imagery through use of GPS global networks.

- Global sharing of GPS ground control station data in real-time facilitates disaster response.

- Global sharing of imagery makes rapid disaster response applications of imagery possible.

- USGS contributes to domestic & international efforts to use imagery to support response efforts (e.g., following earthquakes).
Northridge Co-Seismic Displacements

Hudnut et al.  
BSSA, 1996
Northridge 1994

In 1994, GPS was still being tested vs. previous methods.

The GPS constellation had just achieved Initial Operational Capability.

Leveling was GOOD!
Northridge Earthquake GPS

• Initial focal mechanism – but fault rupture could have been on either plane; no surface rupture
  – 1971 dipped north, what about 1994?
  – Aftershocks of Northridge in first several days did not clearly delineate one plane or the other

• GPS displacements showed a strong preference for a deeper hypocenter and a south-dipping fault plane; NORT moved SE and up – anomalous?
  – Displacement of station NORT proved not to be the only influential station in the solutions
  – Confidence in a south-dipping plane came from geodesy
Northridge Co-Seismic Displacements

Hudnut et al.
BSSA, 1996
Northridge Co-Seismic Displacements

fault plane dips south beneath San Fernando Valley

Hudnut et al.  
BSSA, 1996
Northridge Co-Seismic Displacements

Caltrans, MWD & LADWP needed vertical deformations

tilt of 40 cm in 10 km

Impacts – Water!

Affects of Coseismic Ground Movement on Water Systems

- Pre-earthquake: water flows normally
- Post-earthquake: ground tilt affects water flow
Geodetic Observations
1989-1994 leveling
1993-1994 GPS
Subsidence corrections based on 1971-1989 surveys

Restored Geodetic Network in the San Fernando, Santa Clarita, Simi Valleys and no. Los Angeles Basin
New Coordinates and Heights for 1074 leveling and 206 GPS monuments

Numerical Earth Model
Rectangular dislocation in an elastic halfspace
Variable slip on a planar fault

Computer Runs
Inversions to find fault geometry and slip
Statistical tests to accept/reject trials

Best-Fit Fault
Fault model minimizes [observed-predicted] geodetic residuals
Fault model consistent with seismic observations

Predicted Vertical and Horizontal Deformation at all points (see map and tables)
BM in rock, soil, or fill
BM in engineered structures
100-year flood plains

Disturbed BMs
Identify role of surface faulting, landslides, or liquefaction on movement of BM
Located on map and in tables

Disturbed BMs
Identify type of structure
Locate on map, give driving directions to BM
Recommend Engineering Inspection

Flood Plain Displacement
Calculate change in land slope at flood plain
Calculate resulting flood plain displacement
Identify significant changes
Damage and Restoration of Geodetic Infrastructure Affected by the 1994 Northridge, California, Earthquake
24 August 2014; S. Napa Eq. M 6.0

• Epicenter near Cuttings Wharf (south end)
• Rupture propagated towards the northwest and came up shallower on the fault as it went
• This resulted in energy being directed at the City of Napa, so damage was concentrated
• Fault rupture through residential suburban neighborhood of Browns Valley caused extensive damage that is still being repaired
• Critical lifeline infrastructure damage occurred along the surface rupture; identified by initial aerial recon
Maximum Fault Offset 46 cm
Two days ago (Tues., 9/30/2014) new observations of rupture next to house (Buhman Ave.)
Overview of Surface Faulting
Need to assess afterslip

Fault is continuing to slip; predictable but uncertain. Could a gas pipeline break?
Map of alignment arrays installed across surface ruptures of the M6.0 South Napa Earthquake that occurred at 3:20 AM PDT on Aug. 24, 2014.

Courtesy of Jim Lienkaemper, USGS
Surface slip on alignment arrays, 24 Aug 2014 M6.0 South Napa Earthquake

Accumulated surface slip (cm)

Distance NW of mainshock epicenter (km)

POSTSEISMIC
COSEISMIC (~1 s)

Courtesy of Jim Lienkaemper, USGS
Airborne LiDAR Coalition formed rapidly as a result of California Earthquake Clearinghouse. DWR, PEER-GEER, CGS and USGS prioritized post-earthquake airborne LiDAR.
GPS is used to provide precise positions of airborne sensors so that highly accurate base geospatial data products such as high resolution terrain (elevation) data and ortho-rectified imagery can be produced efficiently. With pre- and post-event data difference products such as maps of vertical deformation, tilt and strain can be produced quickly and are useful for damage assessment.

Example of high resolution orthorectified imagery acquired in Partnership between USGS and other Federal, State, and Local government agencies.

Highly accurate terrain elevation data is replacing older, lower resolution data.
‘Phase I’ airborne LiDAR (9/9/2014)
Cost-share; DWR, CGS, PEER-GEER, USGS

A very limited area of coverage was all that could be acquired due to limited funds.
UAVSAR example interferogram (L-band)

Similar to satellite InSAR, but airborne so it has higher resolution and more control over flight planning for rapid response uses.
Aug. 2012 Brawley, CA Swarm – UAVSAR (NASA/JPL)
Airborne LiDAR pre- & post-earthquake difference

Courtesy of Mike Oskin, UC Davis
“Phase II” airborne LiDAR – why a larger AOI?

State agencies have concerns after they learned of more widespread effects

- bridge damage can be subtle (e.g., Northridge Eq. FEMA report)
- inspectors need aiding and guiding from imagery differencing in large area

- levee damage in Solano County at a greater distance (Grizzly Island)
- Sacramento River delta is susceptible to saline water, levees are crucial

Cost share in ‘Phase I’ seems to have depleted agency resources significantly

Identified a need for coverage of a larger area, but cost-share is a challenge

Uplift & subsidence pattern partially understood, more detailed info required

Stress change on faults such as the Green Valley fault and increased activity
Disaster vs. Catastrophe

- What made ‘Katrina’ a catastrophe? cascade of events …
- What if afterslip causes a pipeline rupture, or if a levee fails, or if another earthquake hits …
- Need to repair and restore geodetic infrastructure (as was done with GPS after 1992 Landers earthquake, GPS & leveling after 1994 Northridge earthquake, and with GPS & model by USMC after 1999)
Bridge and overpass damage, repairs and ongoing assessments by Caltrans, others
Levee damage at Grizzly Island; Solano County
Reported by Don Ryan, Solano County Sheriff / Emergency Management

He requests assistance in assessing levee damage

repaired overtopping location approximately one mile west of the Van Sickle Rd/Gum Tree Road intersection in Solano County - more subsidence suspected further west of repair
Looking NW from repaired location at suspected subsidence area

*needs further inspection*
Uplift (red) and subsidence (blue)

*heavy red line is surface fault rupture*

De-correlated in close proximity to the fault rupture zone; cannot see what happened
Triggered slip on Green Valley fault?

Coulomb stress imparted by the
24 August 2014 M=6.0 American Canyon Earthquake
resolved on UCERF3 Bay area faults (as of 28 Aug 2014: 1:00 am PST)

source: Ross Stein & Jian Lin
GPS & imagery for hazards management

• GPS and rapid imagery analysis (especially differential repeat pass) is an essential enabling technology for the mapping and precise monitoring needed to accomplish science missions in support of hazard warnings and other societal needs.

• In the aftermath of a significant disaster event, re-mapping and establishing a grid and geo-referenced incident data is essential in support of immediate response (e.g., Urban Search & Rescue) as well as for long-term recovery (e.g., organizing debris removal).
Before and after image differencing provides rapid characterization of earthquake ground deformation needed to assess patterns of subsidence, uplift and lateral shift that causes strain across pipelines.

- Application to assessing damage to storm drains, sanitation lines and all other gravity fed water systems; identify subtle damage.

- Application to assessing subtle damage to engineered structures such as bridges, overpasses, and lifelines.

- Application to assessing damage to levee system in western Sacramento River delta; close and fragile enough to be damaged, even though shaking was not very strong at this distance range; how widespread? Verify and validate claims.

- What is the expected tectonic fault slip signal? How much afterslip is occurring and after several years how much more will accumulate? Geodetic and geospatial information must be accurate, and extrapolated slip values must be accurate.