Earthquake Fault Deformation Monitoring Program with Focus on Use of GNSS

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Overview

- USGS Natural Hazards Mission
- Shake Alert – Earthquake Early Warning Systems (EEWS)
  - EEWS – network based alerts
  - Major system components
- USGS Use Case for GPS/GNSS
USGS Natural Hazards Mission

• Every year in the US, natural hazards threaten lives and livelihoods and result in billions of dollars in damage.

• The USGS works with many partners to monitor, assess, and conduct targeted research on a wide range of natural hazards.

• Major natural hazards include:
  – Earthquakes
  – Volcanoes
  – Landslides
ShakeAlert
Earthquake Early Warning System

Network Based Alerts

P-wave ~ 3.5 mi/sec (felt waves)
S-wave ~ 2.0 mi/sec (damaging waves)
Alert ~ 186,000 mi/sec
Regional Network Alerts
Maximize reliability for warning time
Warning Time

Network alerts give most users more time

Onsite vs. Network Warning Times
Assumes 4 sec processing time for network & 1 sec processing time for on-site

Distance to Earthquake Epicenter (km)

Warning Time (seconds)

Onsite System  Network System
Big Earthquakes are on Long Faults

M 7.8 Scenario Fault Rupture

P-wave ~ 3.5 mi/sec
S-wave ~ 2.0 mi/sec
Rupture <2.0 mi/sec
M 7.8 Scenario Fault Rupture

P-wave ~ 3.5 mi/sec
S-wave ~ 2.0 mi/sec
Rupture <2.0 mi/sec
Long Rupture is like a chain of quakes

P-wave ~ 3.5 mi/sec
S-wave ~ 2.0 mi/sec
Rupture <2.0 mi/sec
Earthquake Begins

M7.8 SoSAFZ Scenario
Stations Sense Shaking

SCEC ShakeOut Simulation by R. Graves

Ground velocity magnitude
0.05 1 2 m/s
ShakeAlert Detects Event – Issues Alert

Size of “blind zone” depends on stations spacing and system speed.
Rupture Moves Up Fault
Strong Shaking Arrives – Palm Springs
Strong Shaking Arrives – San Bernardino

SCEC ShakeOut Simulation by R. Graves

Ground velocity magnitude

0.05 1 2 m/s
Strong Shaking Arrives – Orange Co.
La Habra quake:
M 5.1, March 28, 2014. 9:09 pm PDT

ShakeAlert Timeline
09:09:42.3 Origin time
09:09:43.3 (+1.0s) 1st P-wave
09:09:46.3 (+4.0s) 1st Alert

South Napa quake:
M 6.0, Aug. 24th, 2014. 3:20am PDT

ShakeAlert Timeline
10:20:44.4 Origin time
10:20:49.5 (+5.1s) 1st Alert

- Upgraded stations would be faster
- 4 stations required for alert
- Size of “zone of no warning” depends on # stations required to alert

Similar performance for:
M4.4 Encino Event of March 17, 2014
M4.2 Westwood Event of June 2, 2014
ShakeAlert: Major System Components

Sensor Networks

Field telemetry

Processing Alert Creation

Alert Delivery

User Actions
Network Telecommunications
Diverse Telecomm Strategy

• Cellular (multiple carriers)
• DSL, cable
• IP Radio
• Digital microwave
• Satellite
• Public Internet
• Partner systems

• Data telecomm from field sensors
Alert Delivery

- Create and send alert and data streams
- Data services (servers, cloud)
- IPAWS alert authority
  - TV, radio, WEA, FIA, etc.
- Mass notification integration
- FM radio, VSAT, push, pubsub
- New EEW products
- Smartphone Apps
- Social media, etc.

Sensor Networks

Field telemetry

Processing Alert Creation

Alert Delivery

User Actions
Two User Categories

**People** (the public)
- Social Science R&D
- Alert content, sounds
- Ongoing education
- Messaging, “branding”

**Things** (automated)
- Automated actions
- Situational decision-making capabilities
- User-specific applications

Sensor Networks → Field telemetry → Processing Alert Creation → Alert Delivery → User Actions
USGS GPS/GNSS ‘use case’ (1)

- USGS Earthquake Program operates over 100 real-time GNSS stations to monitor the San Andreas and other faults in Southern California.
- Real-time GNSS station position data at cm level accuracy are streamed into the earthquake early warning system (EEW), Shake Alert, that issues alert messages for public safety in case of a major earthquake.
- The GNSS component of the Shake Alert system augments the inertial and seismic sensors - especially important for the largest earthquakes.
- Real-time, **uninterrupted GNSS signals are required, without interference, at all times**
  - temporary black-out of data at from stations could thwart effectiveness of the EWS
  - Critical impact if one or more stations are close to the epicenter of a major earthquake.
  - Loss of data due to RFI could increase the “blind zone” and delay delivering or degrade the accuracy of the Shake Alert message to the public.
GPS/GNSS Network
Southern California
USGS GPS/GNSS ‘use case’ (2)

- USGS high precision application for Earthquake Early Warning (EEW) requires the broadest spectrum so as to fully utilize the GNSS signals, including side bands, for achieving the highest station position accuracy possible in real-time.

- The 100+ stations operated by USGS in real-time are only part of a much larger collaborative inter-agency partnership.

- In all, over 1000 high precision GNSS stations, called the Plate Boundary Observatory (PBO), are operated by UNAVCO for the National Science Foundation
• PBO GNSS station data are streamed in real-time and soon will be included into the EEW system.

• Added benefit is plan for inclusion of real-time GNSS data from PBO into the NOAA tsunami alert system and USGS volcano alert system.

• Working with JPL/NASA, the EEW will benefit from the IGS global array of GNSS stations for Precise Point Positioning with Ambiguity Resolution PPP(AR) processing using highly accurate GNSS orbit and clock corrections.
Japanese EEW system

- Spent ~$600M on EEW after the M7.2 1995 Kobe earthquake killed 6,400
- Public warnings since Nov. 2007
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Thank you