The Use of Real-time GPS and Accelerometer Data for Earthquake Early Warning and Rapid Response

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Earthquake early warning (EEW) has been shown to be a practical and effective way to reduce casualties and protect infrastructure during a large event, as evidenced by the successful early warning issued by Japanese authorities for the March 11, 2011 Mw 9.0 Tohoku-oki earthquake. EEW can be considered a form of earthquake prediction. Since radio waves travel much faster than seismic waves, a suitably designed real-time monitoring network can detect the seismic P-wave and issue an alert before the destructive S-wave arrives, for all areas except for a blind zone closest to the epicenter. A warning of even several seconds could be invaluable. In the ShakeOut scenario of a magnitude 7.9 earthquake nucleating at the southern terminus of the San Andreas fault, a warning of 70-90 seconds could be issued for the greater Los Angeles region. Earthquake response in terms of rapid estimates of magnitude and slip is also critical, especially for generating accurate and timely tsunami warnings.

Currently, EEW systems use only traditional seismic instruments, which have limitations in the near field during large earthquakes. Broadband velocity instruments will clip as occurred for the April 4, 2010 Mw 7.2 El Mayor Cucapah earthquake in northern Baja California, while displacements doubly integrated from strong motion instruments (accelerometers) are adversely affected by rotation and tilt. Accelerometer corrections are possible but they are subjective and result in the loss of the static offset. GPS instruments measure both static and dynamic displacements directly but have limited precision compared to inertial instruments, and have poor resolution in the vertical direction. Real-time GPS data are sufficiently precise to detect the S-wave, but that significantly increases the blind zone for EEW although they are quite useful for tsunami warning. Analyzed together using a Kalman smoothing algorithm (*Bock et al*., 2011), GPS displacements and raw accelerometer data at collocated stations provide a true broadband record of displacement across the entire frequency range of surface motion, including the static component at the higher rate sampled by accelerometers (e.g., 100 Hz), and with sufficient timeliness and precision to detect the P-wave. This was convincingly demonstrated for the El Mayor Cucapah earthquake for 12 locations in southern California where a high-rate GPS instrument and accelerometer were within 1.5 km of each other.

There is growing awareness for the need of an effective EEW system in the Western U.S. and that both seismic and geodetic instruments should be used. There are three areas of primary concern in our lifetimes: the Cascadia subduction zone which could experience an M=9 event similar to the March 11 Tohoku-oki earthquake and tsunami, and the southern and northern sections of the San Andreas fault which could experience up to an M=7.9 event. The EarthScope infrastructure in the Western U.S. is well suited to contribute to earthquake and tsunami early warning, including in Alaska, and there is a similar effort in Mexico focused on the Mexican subduction zone. Using EarthScope infrastructure for EEW requires an accelerated effort to upgrade PBO stations to real-time operations, consideration of adding accelerometers at PBO stations, a concerted effort to be able to estimate integrated displacement seismograms on-the-fly from both geodetic and seismic stations in response to a large earthquake, and coordination with the USGS and earthquake first responders.

Bock, Y., D. Melgar, and B. W. Crowell (2011), Total Displacement Waveforms from Geodetic and Seismic Networks, *BSSA, in review.*