Geotechnical & Earth Sciences Projects

• Geotechnical Projects:
  – RAPID: Geotechnical Engineering Reconnaissance of the March 11, 2011, Tohoku Earthquake, Japan
  – RAPID: Cone Penetration Testing (CPT) and Spectral Analysis of Surface Waves (SASW) Testing at Seismograph Stations with Liquefiable Soils Affected by the Tohoku Earthquake, Japan
  – RAPID: Observations of Sediment Scour and Deposition in the Vicinity of Ports and Harbors from the 11 March 2011 Japan Tsunami

• Earth Sciences Projects:
  – RAPID: Real-Time Investigations of the Tohoku and Darfield Earthquake Sequences
  – RAPID: Recording Fault-Zone Trapped Waves from Aftershocks of the M6.3 Christchurch Earthquake Sequence in New Zealand to Document the Subsurface Damage Zones
  – Evaluation of the potential of large aftershocks of the 2011 Off the Pacific coast of Tohoku earthquake

RAPID: Geotechnical Engineering Reconnaissance of the M 9.0 Japan Earthquake of March 11, 2011

PIs: Ross W. Boulanger, UC Davis, and Nick Sitar, UC Berkeley
GEER Team: 25 team members across 10 topic-oriented teams partnering with Japanese colleagues and other US organizations (EERI, PEER, FHWA, USGS).
Japanese Counterparts: 26 primary collaborators from universities, government agencies, and companies in Japan. Lead collaborators include Masanori Hamada; Kenji Ishihara; Takaji Kokusho; Kazuo Konagai; Kohji Tokimatsu; Takahiro Sugano; and Ikuo Towhata.

Objective: Facilitate partnering of US and Japanese teams in documenting perishable data at high-value case history sites, assisting in characterization of sites, & establishing long-term collaborations. Focus on unique opportunities stemming from the extensive network of recording stations, the unique characteristics of this large event, the large geographical area affected, and the modern infrastructure throughout the affected areas.

Dr. Kayen with Prime Minister Hatoyama
Key Findings

- Teams investigated site response, liquefaction, levees, dams, ports, bridges, lifelines, recovery, and surface rupture (April 11 earthquake).

Key Findings – Cont’d

- Quantity & detail of compiled data: (1) provides opportunity to test bias & dispersion in prediction of responses for broad range of systems, and (2) identifies some unexpected behaviors that require further study.
- Initial reports & data published at the GEER website. Analyses of data in collaboration with Japanese colleagues are ongoing.
RAPID: CPT and SASW Testing at Seismograph Stations with Liquefiable Soils Affected by the Tohoku Earthquake, Japan

US Team: Dr. Brady Cox (PI), Dr. Ross Boulanger, Dr. Nick Sitar, Dr. Robert Kayen, Mr. Clinton Wood, Dr. Robb Moss, Dr. Dimitrios Zekkos, and Dr. Ben Mason

Japan Team: Dr. Kenji Ishihara, Dr. Kohji Tokimatsu, Dr. Akio Abe, Mr. Kazushi Tohyama, Mr. Kota

Rapid Objective: Characterize strong motion stations (SMS) with liquefiable soils Cone Penetration Testing (CPT) and shear wave velocity ($V_s$) profiles from Spectral Analysis of Surface Waves (SASW) Testing. Measure $V_s$ for various ages of fill within the City of Urayasu to investigate the effects of aging within man-made fills and its impact on liquefaction resistance.

Key Findings

- Surface wave $V_s$ profiling was conducted at 56 liquefaction/no liquefaction sites (including 10 key SMS) in November 2011.
- CPT testing at select SMS are currently being planned with our Japanese colleagues using the results from the $V_s$ profiling to screen potential sites.
- $V_s$ profiling in the city of Urayasu was conducted in various age fills. The older 1968 fill is observed to have a slightly lower median near-surface stiffness than the younger 1978-1980 fills, indicating slightly lower liquefaction resistance. However, at depths greater than 10 m the older fill is stiffer.

PIs: Jonathan Bray, UC Berkeley, Thomas O’Rourke, Cornell U, & Russell Green, Virginia Tech
GSRs: Josh Zupan, UCB; Clint Wood, U. Arkansas; Brad Wham & Serozhah Milashuk, Cornell U.
International Students: Merrick Taylor, Simona Giorgini, Kelly Robinson, & Duncan Henderson, U. of Canterbury
Stakeholders & Partners: Christchurch City Council, CERA, EQC, NHRP

Objective: Surveying the re-occurrence of liquefaction, documenting cases of liquefaction-induced ground movements, and evaluating the effects of liquefaction on lifelines and buildings provide invaluable information that will advance our understanding the effects of earthquakes.

Key Findings

- Soil liquefaction in a substantial part of Christchurch damaged many multi-story buildings resulting in global and differential settlements, lateral movement of foundations, tilt of buildings, and bearing failures.
- Integrated GIS for water supply, wastewater, storm water, electric power, and gas distribution systems show spatial distribution of damage in all systems relative to transient motion (from seismometer data) and liquefaction-induced ground deformation (from LiDAR, air photo measurements, scan lines, and geodetic surveys) for three major earthquake events.
- Multiple episodes of liquefaction were clearly discernible in trenches cut through undisturbed sand boils. Trends in grain sizes both vertically and horizontally in the blow material are currently being quantified.
Geotechnical: Research Opportunities

- Case histories of unprecedented detail & quantity that enables: (1) evaluation of bias & dispersion in analysis procedures for PBEE, (2) addressing some unusual observations and fundamental challenges. Some examples follow.
- Estimates of SPT-based liquefaction-induced settlements in Urayasu do not agree with observed trends across fills of different fines contents and ages. Detailed study of CPT, SPT, $V_s$, and lab data required to understand these effects and improve predictive methods.
- Performance of various foundation and lifeline systems across a range of motions, ground deformations, and repeat liquefaction events provide basis to evaluate analysis methods and system fragilities.
- Levee performance across a range of geologic conditions and shaking intensities provide means to evaluate fragility development methods and repair/recovery strategies.
- Strong motion stations provide data to evaluate nonlinear site response models w/ and w/o liquefaction. Effect of long-duration shaking on liquefaction behavior is of particular interest.

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- Excellent performance of HDPE water mains (despite > 2m of ground movements in Darfield EQ) and MDPE gas distribution lines (no damage during all earthquakes) warrants detailed study, given implications for US practice.
- Reports of improved ground performance are favorable, with one major exception in NZ. Detailed study of these cases are need to improve confidence and reduce conservatism that increases costs.
- Paleo-liquefaction methods can be advanced by examining the episodic occurrence of liquefaction and its relation to the structure of liquefaction dikes and blows in NZ. The NZ experiences also provide unique data to evaluate how liquefaction potential of a deposit changes after liquefaction.
- Can we develop methods to predict, minimize, and design for tsunami-induced scour and damage to levees, dikes, and foundations?
- How can communities exposed to pervasive liquefaction hazards better protect and prepare themselves? Do design criteria appropriately recognize the risks to communities from large rare events? Issues include land use policies, public awareness, preparedness, recovery strategies, & insurance practices.
Motivation. On-going earthquake sequences in Japan and New Zealand are being observed by high-quality seismic and geodetic instrumentation.

Objective. We will use these data to improve the physical and statistical models that underlie time-dependent earthquake forecasting.

Goal. We seek a better understanding of how earthquake sequences unfold along active fault zones that can be used in operational earthquake forecasting.

Resources. At the initiation of these sequences, 106 earthquake forecasting models for New Zealand and Japan were under prospective testing by the Collaboratory for the Study of Earthquake Predictability (CSEP).

Collaboration. Organizations in Japan (ERI, DPRI, ISI), New Zealand (GNS), Italy (INGV), and U.S. (USGS, SCEC).
RAPID: Real-Time Investigations of the Tohoku and Canterbury Earthquake Sequences

- Project objectives:
  - Prospectively test earthquake forecasting models using the CSEP cyberinfrastructure
  - Develop and test forecasting models based on rate/state-dependent friction and Coulomb stress function
  - Evaluate the relative performance of dynamic and quasi-static earthquake triggering models

- Project activities in 2011:
  - Collaboration with GNS Science (Wellington) to process Canterbury sequence data
  - Visits by GNS personnel to SCEC CSEP testing center
  - Collaboration with ERI (Tokyo) to process Tohoku sequence data
  - Joint ERI-SCEC workshop at Stanford on Dec 10-11, 2011

RAPID: Recording Fault-Zone Trapped Waves from Aftershocks of the M6.3 Christchurch Earthquake Sequence in New Zealand to Document the Subsurface Damage Zones

**US Researchers:** Yong-Gang Li, University of Southern California

**International counterparts:** University of Canterbury, University of Auckland, Victoria University of Wellington

**Objective of RAPID:** In order to document the complicated subsurface rupture zones in the 2010 M7.1 Darfield and the 2011 M6.3 Christchurch earthquakes, we deployed 12 seismic stations in two cross-fault arrays to record fault-zone trapped waves generated by aftershocks in 2011. We use these FZTWs to address the magnitude of co-seismic rock damage along the Greendale fault and Port Hills fault at seismogenic depths as well as the post-mainshock fault healing.
Observations and 3-D finite-difference synthetics of fault-zone trapped waves (FZTWs) show a distinct low-velocity waveguide formed by severely damaged rocks along the Greendale fault, which likely extends across seismogenic depths. The damage zone is 200-300-m wide, within which seismic velocities are reduced by ~35-50% from wall-rock velocities, mainly caused by dynamic rupture of the 2010 M7.2 Darfield mainshock.

We observed the FZTWs at the array across the Greendale fault to record fault-zone trapped waves generated by aftershocks, where 4.5-m horizontal right-lateral slip (shown by fence offset) and 1.6-m vertical slip caused by the 2010 M7.1 Darfield earthquake. Many en echelon cracks were seen in a ~75m wide zone along the Greendale fault trace at surface.

Key Findings

- Observations and 3-D finite-difference synthetics of fault-zone trapped waves (FZTWs) show a distinct low-velocity waveguide formed by severely damaged rocks along the Greendale fault, which likely extends across seismogenic depths. The damage zone is 200-300-m wide, within which seismic velocities are reduced by ~35-50% from wall-rock velocities, mainly caused by dynamic rupture of the 2010 M7.2 Darfield mainshock.
- We observed the FZTWs at the array across the Greendale fault for aftershocks either on the Greendale fault or on the Port Hills fault, suggesting that the Darfield rupture zone likely connects the blind rupture zone of the 2011 M6.3 Christchurch earthquake at depth beneath a slip gap between them where the moment release was minimal in this earthquake sequence.
J-RAPID: Evaluation of the potential of large aftershocks of the 2011 Tohoku earthquake

Japan team (J-RAPID): Yo Fukushima, Shinichi Miyazaki, and Manabu Hashimoto (Kyoto Univ.)

US team (NSF): Paul Segall (Stanford Univ.) and Kaj Johnson (Indiana Univ.)

Objective: Re-evaluate of the recent and historic geodetic data to estimate the potential of future large aftershocks of the Tohoku earthquake.

Key Findings

No conclusions yet, but some findings at the moment:

- Purely elastic models considered in most previous studies can not explain the cycle of the megathrust earthquakes. Viscoelastic/elastic layered model is required. The rheological properties should be ideally constrained simultaneously with the evaluation of the future aftershocks.
Earth Sciences: Research Opportunities

• Is the M6.3 Christchurch earthquake of 22 February 2011 an aftershock or separate event from the ~6 month earlier M7.1 Darfield earthquake of September 4, 2010? To address this problem, we require a high-resolution image of subsurface fault segmentation and connection in this complicated region with multiple slips and simulation of dynamic ruptures.
• Fault-zone trapped waves recorded after the Christchurch earthquake can be used to delineate the spatio-temporal variations in rock damage along the rupture zones at seismogenic depth.
• Unique opportunity to illuminate the in-situ fault-zone rock damage and healing associated with two successive large earthquakes, the M7.1 Darfield and M6.3 Christchurch earthquakes in the same region.
• Likelihood of earthquake sequence in complicated slip regions with multiple faults at depth may be important for regions such as Southern California.

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• The wealth of available data can be used to advance earthquake physics. Geodetic data (pre-, co-, and post-seismic) enables tracking how the strain accumulated and released. Seafloor measurements are needed to understand the nature of subduction earthquakes.
• Can we estimate the potential for future earthquakes? Current theories of earthquake physics and observation data are generally insufficient for forecasting the nature of future earthquakes. Expectation is OK, but the uncertainty in the expectation should be taken into account.
• Engineering procedures for predicting ground motions and ground motion time series from subduction zone events can be updated and improved based on the compiled data.
• How is the April 11th 2011 M6.6 Hamadoori earthquake related to post main shock adjustments of the shallow crust in the hanging wall of the subduction zone?
Geotechnical & Earth Sciences: General Aspects of Research Opportunities

• Surprising &/or uniquely detailed observations have raised new geotechnical and earth science questions that require basic research.
• These earthquakes have produced a wealth of detailed geotechnical & earth sciences data that enable a range of problems to be addressed in ways that were not previously possible.
• These events have characteristics (sources, soil conditions, impacts) that are directly pertinent to earthquake hazard reduction efforts in the US and abroad. A focussed research program can be expected to produce significant advances in these fields, in the same way that research after other major events led to earlier advances.
• Vulnerable regions and communities in the U.S. are not well prepared to deal with larger than expected events or pervasive geotechnical hazards. The risks to these communities from such rare events need to be understood and recognized so that appropriate actions can be taken.

Japan and NZ Earthquakes RAPID and Research Needs Workshop
Arlington, VA   Feb 9 and 10, 2012