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GEOTECHNICAL LESSONS LEARNED FROM EARTHQUAKES

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ABSTRACT

Geotechnical earthquake engineering is an experience-driven discipline. Field observations are particularly important because it is difficult to replicate in the laboratory, the characteristics and response of soil deposits built by nature over thousands of years. Further, much of the data generated by a major earthquake is perishable, so it is critical that it is collected soon after the event occurs. Detailed mapping and surveying of damaged and undamaged areas provides the data for the well-documented case histories that drive the development of many of the design procedures used by geotechnical engineers. Thus, documenting the key lessons learned from major earthquake events around the world contributes significantly to advancing research and practice in geotechnical earthquake engineering. This is one of the primary objectives of the Geotechnical Extreme Events Reconnaissance (GEER) Association. Some of GEER's findings from recent earthquakes are described in this paper. In particular, the use of advanced reconnaissance techniques is highlighted, as well as specific technical findings from the 1999 Kocaeli, Turkey earthquake, the 2007 Pisco, Peru earthquake, the 2010 Haiti earthquake, and the 2010 Maule, Chile earthquake.

INTRODUCTION

There have been major improvements in scientific understanding and subsequent advances in geotechnical engineering in the aftermath of significant natural and human-made disasters in urbanized and industrial areas. For example, events that have significantly influenced earthquake engineering include the 1964 Niigata, 1964 Alaska, 1985 Mexico City, 1989 Loma Prieta, 1994 Northridge, 1999 Kocaeli, and 1999 Chi-Chi earthquakes. Other extreme events that have influenced geotechnical engineering include the 1963 Vaiont Dam landslide, the 1966 collapse of the Aberfan colliery spoil tip, the 1976 Teton Dam failure, and the 2001 collapse of the World Trade Center Towers. More recently, the profession has learned much from studies conducted in the aftermath of Hurricanes Katrina (2005) and Gustav (2008), the 2011 Lower Mississippi River floods, as well as the 2010 Haiti, 2010 Chile, 2010-11 New Zealand, and 2011 Japan earthquakes. Each major disaster potentially provides critical lessons that can save lives in a future event.

Fortunately, severe hazards that have the potential to kill people and destroy infrastructure occur relatively infrequently. Hence, they are referred to as "extreme events." However, they occur frequently enough with the capacity for such severe consequences that society cannot ignore them. Instead, we must learn from them and develop the understanding that will allow engineers to evaluate and to mitigate the effects of future extreme events, such as earthquakes.

In this paper, some of the recent efforts of the U.S. National Science Foundation (NSF)-sponsored Geotechnical Extreme Events Reconnaissance (GEER) Association are chronicled. GEER is one of the world's leading reconnaissance organizations. Although originated as a NSF-funded activity in the United States, GEER includes members worldwide and works closely with other reconnaissance organizations to capture perishable data following an event so the profession can later learn from it.

GEER

The NSF-sponsored GEER Association organizes and supports reconnaissance efforts by geotechnical researchers and practitioners after severe natural and human-made disasters (i.e., "extreme events") and develops techniques to capture perishable data to learn from these events. It distributes findings from these reconnaissance efforts through GEER web-reports, peer-reviewed papers, and technical seminars. The primary objectives of GEER are:

1. Document geotechnical engineering and related effects of important extreme events to advance research and practice.
2. Employ innovative technologies for post-event reconnaissance.
3. Advance the capabilities of individuals performing reconnaissance of extreme events.
4. Train individuals to perform effective reconnaissance and facilitate access to equipment required for sensing and data collection.
5. Develop a coordinated response for geo-researchers to form effective reconnaissance teams and work effectively with organizations that focus on other disciplines.
6. Promote the standardization of measurement and reporting in reconnaissance efforts.
7. Disseminate timely and accurate post-event web-based reports and data.

Since its formation, GEER has made significant advancements with respect to these objectives. Additionally, GEER serves the NSF by identifying important geotechnical issues to study through observing and documenting geotechnical effects in the field after extreme events.

SIGNIFICANCE OF EARTHQUAKE ENGINEERING RECONNAISSANCE

Much of the data and information generated by an earthquake is perishable and therefore must be collected within a few days or weeks of the event. The removal of debris during recovery operations and restoration of transportation networks and lifelines quickly obscures observable significant damage, and hence, it obscures critical data that could advance the state-of-the-art. Earthquake professionals must respond effectively to earthquakes so that potentially critical lessons are not missed. Additionally, because case histories form the cornerstone of geotechnical engineering more so than other disciplines, geotechnical engineers are uniquely poised to work with other professionals after a major earthquake to document its effects so that we can learn from it and turn information gathered following the disaster into knowledge.

Documenting and compiling the key lessons learned from earthquake events constitutes an important task for advancing research and practice in geotechnical earthquake engineering. For example, the Seismic Hazards Mapping Act, which became operative in the State of California in 1991, is a model for identifying and mitigating potential earthquake hazards. The stated purpose of the Act is "to protect public safety from the effects of strong ground shaking, liquefaction, landslides, or other ground failure, and other hazards caused by earthquakes" (California Division of Mines and Geology 1997). The California State Mining and Geology Board, Geological Survey, and advisory committees are implementing this legislation with the assistance of the U.S. Geological Survey and with the benefit of the results from prior research from the U.S. National Earthquake Hazards Reduction Program. The successful implementation of these types of laws and regulations is of paramount importance to society.

Many of the currently employed analytical methods utilized to evaluate geotechnical hazards, such as the effects of strong shaking (especially in the near-fault region and for soft soils), liquefaction and ground failure and their effects on building performance, seismically induced landslides, and the effects of surface faulting on structural systems and lifelines are in need of updating. Often the recommended evaluation and mitigation procedures in engineering practice are based on previously documented case histories that describe seismic performance during significant events. For example, prevalent liquefaction triggering procedures are based primarily on the empirical methods delineated in Youd et al. (2001), Seed et al. (2003), and Idriss and Boulanger (2008). Simplified seismic slope and embankment displacement procedures (e.g., Bray and Travasarou 2007, and Rathje and Antonakos 2011) are not used by engineers until they have been shown to capture the observed performance of earth/waste structures during earthquakes. These and other commonly employed engineering procedures require constant re-evaluation and revision as important case histories are reported.

Even more importantly, new unanticipated observations from significant events often define alternative research directions. As an example, the results of recent studies of soil liquefaction, especially those involving soils with a significant amount of fines, have been largely motivated by observations of liquefaction and ground softening documented by NSF-sponsored GEER reconnaissance efforts after earthquakes in Turkey and Taiwan. The careful documentation of liquefaction following the 1999 Kocaeli earthquake (Bray and Stewart 2000) provided much of the data that advanced the profession’s understanding of liquefaction/ground softening of fine-grained soils and led to important new criteria for evaluating the liquefaction potential of these soils (e.g., Bray and Sancio 2006). Additionally, observations in Taiwan by Stewart (2001) have supported research by Chu et al. (2004) on the liquefaction of fine-grained soils.

If the geotechnical engineering profession is not prepared to look for and find new “geotechnical insights” following future events, important research insights and opportunities will be lost. Additional case histories are required to enhance the profession’s understanding of critical geotechnical phenomena, such as the consequences of liquefaction-induced ground failure on structures, factors that contribute most to spatial variations in earthquake ground shaking, and the roles of seismic demand and resistance in seismic slope stability. Important advancements are possible through research of these effects in future earthquakes if their consequences are captured carefully and comprehensively.

The geotechnical engineering profession has a rich tradition of understanding the need to develop and to apply new technologies and techniques that document in detail the effects of earthquakes on urban infrastructure. The significant experience of geotechnical engineers in documenting the effects of earthquakes and their leadership in implementing new technologies in reconnaissance activities, positions them to work closely with other professionals to document the effects of earthquakes and to advance earthquake engineering through learning the lessons from these disasters.

GEOTECHNICAL RECONNAISSANCE METHODS

The last decade or so represents a time of unprecedented advancement in the technologies used to document earthquake damage (e.g., Frost and Deaton 2000; Deaton and Frost 2002). The innovative use of personal digital assistants (PDAs) to record earthquake damage resulting from the 1999 Kocaeli, Turkey earthquake allow engineers to collect systematically and analyze carefully observations in a consistent manner. The ground-based LIDAR (LIght Detection And Ranging) mapping technology proved useful in documenting ground failure resulting from the 2004 Niigata-ken Chuetsu, Japan earthquake before reconstruction efforts erased physical evidence that proved critical to understanding the potential failure mechanisms involved at many sites with ground failure (e.g., Kayen et al. 2006). Additionally, the use of GoogleEarth^{TM} is revolutionizing the way engineers and scientists merge and convey information. Recent GEER reports have included geo-referencing of photographs and observations of damage using GoogleEarth^{TM}. KMZ files provide an intuitive way to share key data.

Emerging technologies that will continue to be implemented in future reconnaissance efforts include satellite imaging using various techniques, coordinated military flyovers using advanced imaging capabilities, digital mapping equipment for establishing accurate documentation of ground failure case records, coordinated use of GPS (Global Positioning System) devices and digital cameras in aerial surveys followed by complementary ground surveys, and survey equipment for documenting the effect of ground failures on constructed facilities. It is anticipated that the utilization of technologies, such as inexpensive ground motion sensors and 3D imaging technologies, will expand significantly in the coming years.

Best practices for performing effective reconnaissance have been delineated in a manual for GEER reconnaissance teams that was developed by Robert Kayen and other members of the GEER Steering Committee (GEER 2012). It is crucial soon after an earthquake to identify the primary opportunities the earthquake holds for advancing the profession, while maintaining the flexibility required to adjust a team's focus based on early observations. Areas to investigate in greater depth are identified, and GoogleEarth^{TM} is used to coordinate and record team member activities and their field observations. The data and information that can be collected by post-earthquake reconnaissance teams includes high quality digital photographs of damage from aircraft and from the ground. Aerial photographs taken after the event can be compared to those from existing databases to help define damage patterns that can provide invaluable insights (e.g., Bray and Stewart 2000). Reconnaissance activities may include geologic and damage mapping, shear wave velocity profiling using the multi-channel analysis of surface waves (MASW) technique, and dynamic cone penetration tests (DCPT) at liquefaction sites, as shown in Fig. 1. All observations can be documented digitally and positioned accurately using GPS coordinates allowing integration of reports.

Fig. 1. Field activities in Haiti: geologic and damage mapping, MASW testing, and DCPT testing.

Besides photographic documentation that records images of damaged and undamaged facilities and systems, advanced techniques, such as LIDAR, can be used to help document more completely ground deformation across wide areas (Kayen and Collins 2012). Ground-based LIDAR has been used successfully to document ground failure in several earthquakes as well as after other extreme events. For example, aerial photography and ground-based LIDAR were used to document the Shiroiwa (White Rock) landslide that resulted from the shaking of the 2004 Niigata-ken Chuetsu, Japan earthquake (see Fig. 2). This large landslide adversely impacted a major road and adjacent bridge (Rathje et al. 2006). Another example is the detailed depiction of a failed highway overpass embankment in Chile, as shown in Fig. 3.

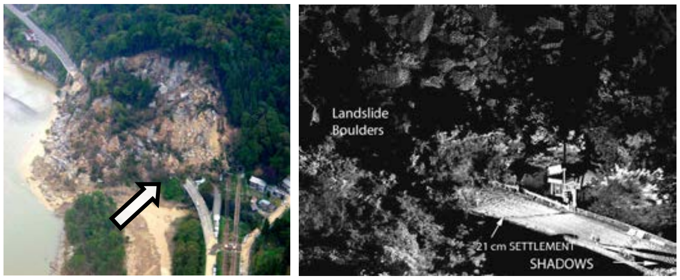

Fig. 2. The reconnaissance for the 2004 Niigata Ken Chuetsu earthquake in Japan provided geo-engineers an opportunity to use new technologies in their field studies. Aerial photography and terrestrial LIDAR were used to document earthquake-induced landslides, such as the Shiroiwa Slide, which is shown here (Rathje et al. 2006).

Fig. 3. Ground-based optical and LIDAR images of a failed overpass embankment on Ruta 5 as a result of the 2010 Chile Earthquake (courtesy of Kayen/GEER).

Remote sensing, via spaceborne or airborne sensors, is another tool that has emerged as a crucial component of documenting the effects of natural disasters, including earthquakes. Remote sensing represents the acquisition of data using sensors not in direct physical contact with the area being investigated, and includes optical satellite imagery, synthetic aperture radar (SAR), and LIDAR. Commercial optical satellites routinely obtain sub-meter imagery that can be used to assess the geographical distribution of earthquake damage. Satellite imagery is georeferenced to standard cartographic projections, and thus observations from the imagery can be fused with ancillary information such as geologic maps, topographic maps, or any other information that has been georeferenced. Very high resolution (VHR) satellite imagery was used to document the distribution of landslides from the 2004 Niigata-ken Chuetsu earthquake (Rathje et al. 2006) and to investigate the influence of geologic, topographic, and seismologic conditions on urban damage patterns from the 2010 Haiti earthquake (Rathje et al. 2011). Another example is the integrated documentation of geotechnical damage along the primary north-south highway in Chile (Ruta 5) following the 2010 Chile earthquake by Frost and Turel (2011).

SAR represents an active remote sensing technique in which the reflections of transmitted radar signals are measured. Because of the active source, SAR can acquire imagery at night or through clouds, which are attractive features for acquiring data as quickly as possible after an earthquake. In addition to the collected imagery, SAR data allows for advanced analytical techniques, such as radar interferometry (InSAR), which can provide precise measurements of ground deformation. Specifically, InSAR has been successful in measuring aseismic and coseismic slip across faults (e.g., Sandwell et al. 2002) and documenting the spatial and temporal distribution of landslide movements (Hilley et al. 2004).

Detailed mapping is possible with differential GPS devices, such as total stations, as illustrated by the survey of ground deformation associated with surface fault rupture observed after the 1999 Chi-Chi earthquake as shown in Fig. 4. The importance of detailed mapping and surveying of damaged areas relative to general damage surveys cannot be overemphasized, as they provide the data for well-documented case histories that drive the development of many of the empirical procedures used in geotechnical earthquake engineering practice. Geologic maps, topographic maps, soil reports, and damage reports can be collected from various sources to help complete the picture of what happened and prepare for later support studies that allow the profession to discern why it happened.

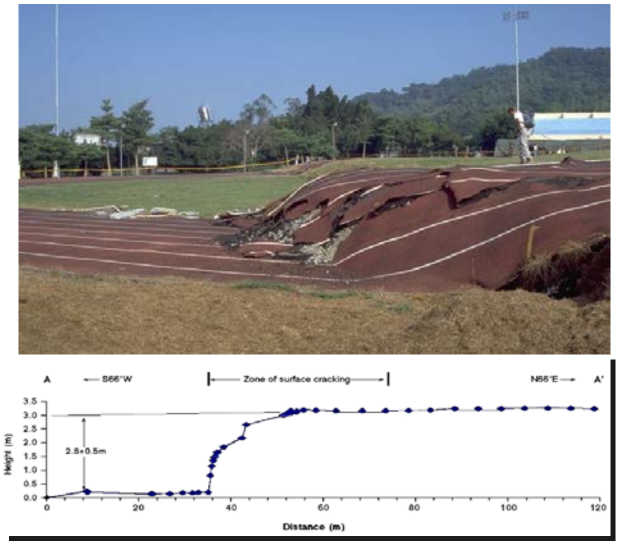

Fig. 4. Detailed mapping of surface fault rupture from the 1999 Chi-Chi, Taiwan earthquake that shows 2.8 m of vertical offset over a 20 m wide zone of deformation. This information is being used to develop mitigation design strategies for engineered systems, such as buried pipelines, that must cross active faults (Kelson et al. 2001).

Field observations, detailed mapping and measurements, and remote sensing technologies provide diverse data at different spatial and temporal scales, yet together they offer opportunities to develop more comprehensive observations of earthquake damage. Additionally, the fusion of observations from different sources can lead to more comprehensive assessments of failure mechanisms and earthquake effects.

The data can also be integrated with other types of geospatial information, such as geologic maps, topographic maps, and Shakemaps of ground motion, to explore the relationships between earthquake damage and these important conditions. This integration is facilitated by the fact that currently all damage observations, whether made in the field or via remote sensing techniques, are geo-referenced to standard cartographic projections using GPS.

Existing techniques can also be better utilized in a coordinated manner to obtain quantitative data on ground failure and building performance after an earthquake. For example, using a modified version of the Coburn and Spence (1992) rapid survey of structural damage and the ground failure index presented in Bray and Stewart (2000), reliable damage data were obtained in the city of Adapazari after the 1999 Kocaeli, Turkey earthquake before damaged buildings were razed or repaired. These data (an example is shown in Fig. 5) proved to be invaluable for focusing later in-depth studies. These data allowed investigators, such as described in Sancio et al. (2002), to correlate the occurrence of ground failure with particular ground conditions, as illustrated in Figure 6.

RECENT LESSONS LEARNED

Fine-Grained Soil Liquefaction

Until contrary evidence was obtained from well-documented observations after earthquakes that occurred over the last decade and a half (e.g., 1999 Kocaeli, Turkey and 1999 Chi-Chi, Taiwan earthquakes), engineers relied upon the so-called Chinese criteria, as recommended by Youd et al. (2001), to assess if fine-grained soils were potentially liquefiable. The liquefaction criteria of Bray and Sancio (2006) and Idriss and Boulanger (2008) have replaced the Chinese criteria largely as a result of observations made by GEER team members following recent earthquakes and research studies that followed from observations made during the initial reconnaissance efforts.

The Bray and Sancio (2006) criteria for identifying soils that are potentially susceptible to liquefaction are based primarily on cyclic testing of “undisturbed” specimens of Adapazari silts and clays. Research funding was provided for a comprehensive experimental program that included over 100 cyclic triaxial tests and 10 cyclic simple shear tests after field observations made following the 1999 Kocali earthquake could not be explained using the Chinese criteria (Bray et al. 2004). Cyclic testing of a wide range of soils found to liquefy in Adapazari during the Kocaeli earthquake confirmed that these fine-grained soils were susceptible to liquefaction. Bray and Sancio (2006) found that it is not the amount of “clay-size” particles in the soil; rather, it is the amount and type of clay minerals in the soil that best indicate liquefaction. Thus, plasticity index (PI) is a better indicator of liquefaction susceptibility. Bray and Sancio (2006) found that soils with PI ≤ 12 and with water content to liquid limit ratios (w_c/LL) ≥ 0.85 were susceptible to liquefaction when strongly shaken as evidenced by a dramatic loss of strength resulting from increased pore-water pressure.

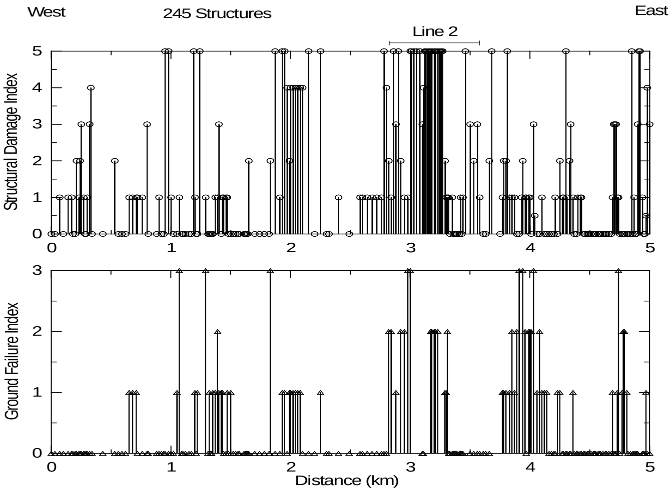

Fig. 5. Structural Damage Index, which Ranges from D0 (no observed damage) to D5 (complete collapse of a story or building), and Ground Failure Index, which Ranges from GF0 (no observable ground failure) and GF3 (significant building penetration of more than 25 cm or 3 degrees tilt) on Line 1 in Adapazari, Turkey (Bray and Stewart 2000).

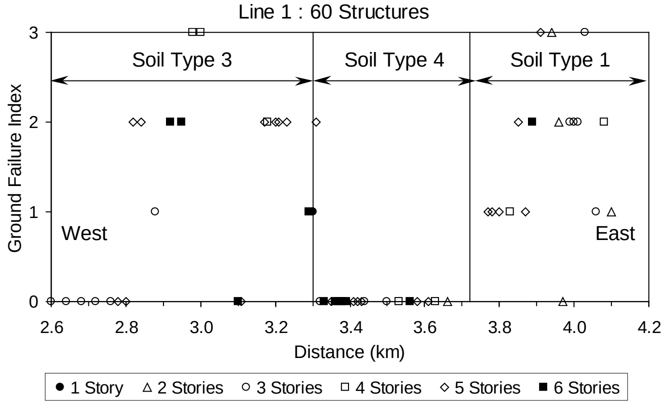

Fig. 6. Correlation of Ground Failure and Soil Type on Line 1 in Adapazari, Turkey. Soil Types 1 and 3 contain liquefiable silt deposits, but Soil Type 4 does not (Sancio et al. 2002).

2007 Pisco Earthquake

On August 15 2007, the M_w 8.0 Pisco earthquake shook the coastal region of central Peru. The city of Pisco suffered considerable damage, and the civil infrastructure in the entire region was significantly affected. In response to this event, GEER organized immediately a reconnaissance team to document the geotechnical aspects of the earthquake (Rodriguez-Marek et al. 2007). The Pisco earthquake was most significant for the amount of soil liquefaction and landsliding observed in the mesoseismal zone. The observations of the GEER team highlighted the fact that earthquake impacts extend over vast areas and have unique spatial signatures that are a function of regional-scale factors such as geologic setting, ground motion intensity, and land use patterns.

The observations of the GEER team led to a three year NSF-funded study on the geotechnical effects of the Pisco earthquake. This award enabled research employing remote sensing, subsurface geotechnical investigations, and traditional reconnaissance information to collect, process, interpret, and digitally archive ground failure events identified by the GEER team. In particular, landslides in the mesoseismal zone and a massive lateral spread complex on a marine terrace in Canchamaná were documented extensively (Cox et al. 2010).

Deformations of the Canchamaná lateral spread complex were evaluated using pre- and post-earthquake satellite images. The GeoEye-1 satellite was specifically tasked by the research team to obtain post-earthquake imagery and to collect a stereo pair of images to develop a detailed digital elevation model of the site. Using advanced image processing, the pre- and post-earthquake images were used to develop estimates of ground deformation. Results indicate that the observed deformations were not "lateral spreading" in the truest sense, since the movements did not extend all the way to the free face at the land-ocean contact. Rather, the movements seemed to be concentrated in areas with slightly higher slope angles. Lateral slumping appears to be a slope-type failure triggered by liquefaction of underlying soils and driven by static shear stresses from very small slope angles (i.e., less than 3% on average) without a nearby open face. Researchers concluded that lateral slumping should be considered in ground failure analyses for future earthquakes because traditional lateral spreading and slope stability analyses would not typically be performed for the circumstances documented in this work.

2010 Haiti Earthquake

The 2010 M_w 7.0 Haiti earthquake represents one of the most devastating earthquakes in history from a human impact perspectvie, with an estimated 200,000 or more deaths and millions left homeless. NSF supported a GEER team to investigate the influence of geotechnical conditions on the devastation in Haiti (Rathje et al. 2010). The team was able to take advantage of various remote sensing data sources during its reconnaissance, including high-resolution aerial photography and LIDAR acquired by the World Bank. They performed geologic and damage mapping, shear wave velocity profiling using the multi-channel analysis of surface waves (MASW) technique, and dynamic cone penetration tests (DCPT) at liquefaction sites.

The power of merging field data and observations from remote sensing was fully realized by the work done by the GEER team after the field reconnaissance. Damage data derived by UNOSAT (http://www.unitar.org/unosat/) from aerial photography was compared with the team's field damage data for accuracy assessment, then integrated with geologic, topographic, and shear wave velocity information to evaluate the influence of these conditions on the damage distribution (Fig. 7). Complex, but clear, relationships between geologic/shear wave velocity conditions and topographic conditions were identified, highlighting a real need to better understand these influences (Rathje et al. 2011).

An outcome of this work is that part of the GEER team returned to Haiti in November 2010, under the support of the U.N. Development Programme, to share with the Haitian Ministry of Public Works the data collected and to give a two-day short course on geotechnical earthquake engineering. The short course was attended by over 50 engineers and geologists, and in a small way helped Haiti with its rebuilding efforts.

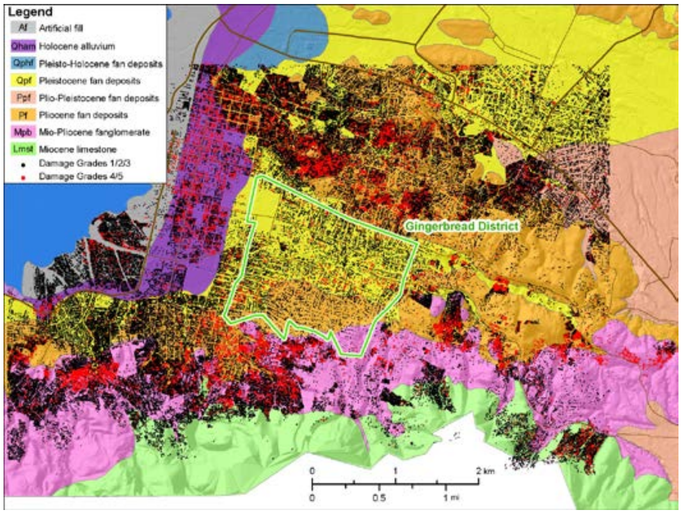

Fig. 7. Integration of geologic, topographic, and damage data for Port-au-Prince, Haiti (Rathje et al. 2011).

2010 Chile Earthquake

The February 27, 2010 Maule, Chile earthquake (M_w = 8.8) is the seventh largest earthquake to occur since 1900. Its effects were felt along 600 km of the central Chilean coast. Field observations suggest that tectonic displacement of the hanging wall produced uplift of over 2 m and subsidence of up to 1 m in coastal regions. The tsunami initiated by the rupture devastated parts of the coast and killed hundreds of people. Strong shaking lasted for over a minute in some areas, and widespread damage occurred in some cities. A large number of significant aftershocks contributed additional damage to an already fragile infrastructure.

Post-event reconnaissance conducted by GEER reported how soil liquefaction occurred at many sites, and often led to ground failure and lateral spreading (Bray and Frost 2010). Of special interest were the effects of liquefaction on the built environment. Several buildings were damaged significantly due to foundation movements resulting from liquefaction. Liquefaction-induced ground failure displaced and distorted waterfront structures, which adversely impacted the operation of some of Chile's key port facilities. Critical lifeline structures, such as bridges, railroads, and road embankments, were damaged by ground shaking and ground failure. The damage to some sections of Ruta 5, the primary North-South highway in Chile, was pervasive, which disrupted supply traffic following the event (Moehle and Frost 2012).

Most earth retention systems, such as retaining walls and basement walls, proved to be inherently robust. Landslides and other large earth movements were not pervasive, which appears to have resulted from native slopes that are generally composed of competent earth materials and the relatively low groundwater levels present at the end of the dry season. Most dams, levees, and mine tailings dams also performed well. Several key earth structures experienced some distress, and in one case a liquefaction-induced tailings dam failure produced a flow slide that killed four. Pre- and post-event satellite imagery of the tailings impoundment is shown in Fig. 8.

Fig. 8. Pre and post satellite images of failed tailings impoundment.

2010-11 Canterbury, New Zealand Earthquakes

The Canterbury, New Zealand earthquake sequence during 2010-2011 has yielded the most comprehensive data to date of the integrated effects of multiple earthquakes and liquefaction episodes, including the locations and types of damage for underground lifelines in Christchurch, thousands of residential structures, and scores of commercial buildings. Field observations are complemented by high-resolution airborne LIDAR measurements of lateral and vertical surface movements for multiple earthquakes and hundreds of liquefaction surveys and geodetic measurements. A key finding from the reconnaissance efforts was the documentation that HDPE water mains sustained no damage when subjected to more than 2 m of ground movement (O'Rourke et al. 2012).

GEER teams responded to this sequence of earthquakes (Green and Cubrinovski 2010; Cubrinovski et al. 2011). As is typically the case with earthquakes outside of the United States, this effort was a collaborative partnership between New Zealand and U.S. researchers. As there is more to learn from this extensive database of observations gathered and fieldwork performed (e.g., thousands of cone penetration tests (CPTs) have been advanced by the New Zealand government to characterize the ground), it is likely that several follow-on research studies will yield important findings that will advance the state-of-practice in geotechnical earthquake engineering.

2011 Tohoku, Japan Earthquake

The 2011 Tohoku, Japan earthquake is another important event that is already shaping practice with the numerous ground motion recordings at sites throughout Japan for both the M_w=9.0 subduction event and its many aftershocks. U.S. GEER researchers partnered with Japanese researchers to conduct several focused surveys of damage (e.g., Ashford et al. 2011). Although Japanese researchers are carrying out the bulk of the research and will be sharing lessons to be learned over the next decade with the international community, several important Japan-U.S. research initiatives will also provide useful insights. For example, co-locating several CPTs with standard penetration test (SPTs) boreholes at liquefaction sites will enable the extensive Japanese database of borehole information with SPTs to be leveraged effectively to enhance CPT-based liquefaction triggering procedures. This research is critically important for examining the effects of duration from this large magnitude event. Detailed studies of seismic site response at sites that have recorded ground motions at the surface and within the profile will also provide useful insights.

CONCLUSIONS

The documentation of the geotechnical effects from the 1999 Kocaeli, Turkey earthquake in Youd et al. (2000), the 2007 Pisco, Peru earthquake in Rodriguez-Marek et al. (2007), the 2010 Haiti earthquake in Rathje et al. (2010), and the 2010

Chile earthquake in Bray and Frost (2010), among other fine efforts, are great examples of what effective post-earthquake geotechnical engineering reconnaissance can accomplish. These efforts succeeded in large part because of the value geotechnical engineers place on learning from earthquakes and on developing well-documented case histories that form the cornerstone of understanding for the profession.

Recent earthquakes in Japan and New Zealand re-emphasize society's need to improve its resilience. Unfortunately, extreme events will happen. It would be most unfortunate if the geotechnical engineering profession did not capture the perishable data that enables it to understand which design procedures result in good seismic performance and which procedures still need improvement. With this understanding and with robust empirical data, geo-professionals can advance the practice of geotechnical engineering. The formation of GEER and the willing participation of geotechnical engineers have allowed this goal to be realized for the benefit of the profession and society.

ACKNOWLEDGMENTS

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The GEER Association currently has over 230 members and 4 organizational partners. GEER is led by a Steering Committee (SC) that is currently composed of Jonathan Bray, Chair (UC Berkeley), David Frost, Co-Chair (Georgia Tech), Ellen Rathje, Co-Chair (Univ. of Texas at Austin), Robert Gilbert (Univ. of Texas at Austin), Laurie Johnson (Laurie Johnson Consulting|Research), Robert Kayen (USGS), Jeff Keaton (AMEC Environment and Infrastructure), and Nick Sitar (UC Berkeley). The GEER SC receives guidance from a broad-based Advisory Panel (AP) consisting of a larger group of prominent hazard engineers and scientists that includes members of organizations that participate actively in post-event reconnaissance (such as the U.S. Geological Survey, the Earthquake Engineering Research Institute, and the U.S. Army Corps of Engineers). Members of the GEER AP are: J.P. Bardet, D. Bloomquist, R. Borcherdt, R. Boulanger, L. Cluff, M. Crawford, R.E. Crippen, C. Edwards, R. Hanson, L.F. Harder, Jr., W. Holmes, T.L. Holzer, I.M. Idriss, A. Kammerer, S.L. Kramer, W. Lettis, R.J. Love, J.R. Martin, II, R.S. Olsen, T.D. O'Rourke, C Scawthorn, R.B. Seed, P. Somerville, J.P. Stewart, K. Tierney, H. Yeh, and T.L. Youd. The GEER Recorder, Nick Oettle, assists teams in performing reconnaissance activities and in preparing reports, develops website features and posts web-based reports, and maintains the records of the GEER Association. GEER is described further at: http://www.geerassociation.org/.

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