The 27 February 2010 Chile Earthquake:
Implications for U.S. Building Codes and Standards

A Meeting Held on 2 June 2010

Executive Summary

From an earthquake engineering perspective, large earthquakes are paradoxical events, deplorable due to the damage and harm they can inflict and yet valuable because of the lessons that can be learned from them. The powerful earthquake that struck Chile on 27 February 2010 is no exception. Lessons from this tragic event are highly relevant to the United States as well as to Chile, given that both nations face ongoing risks associated with having modern urban environments situated in seismically active regions, and both have implemented comparable building codes and standards to mitigate these risks.

On 2 June 2010, earthquake engineers from the United States and Chile met in San Francisco to discuss what can be learned from the Chile earthquake. The meeting was organized by the American Society of Civil Engineers (ASCE), the National Institute of Standards and Technology (NIST), and the Pacific Earthquake Engineering Research (PEER) Center to begin to analyze how U.S. model building codes, and the national design and construction standards referenced by those codes, can be improved in response to what occurred in Chile. Attendees noted that, in view of the commonalities among the codes, standards, and built environments in the United States and Chile, information sharing and research collaboration offer synergistic benefits for both countries, and the Chile earthquake has provided a unique opportunity to jointly evaluate and advance state-of-the-art seismic codes and standards for use worldwide.

The 21 meeting participants included Chilean engineers (practitioners and researchers), representatives from agencies participating in the National Earthquake Hazards Reduction Program (NEHRP), and members of post-earthquake reconnaissance teams sent to Chile by ASCE, the Earthquake Engineering Research Institute's Learning from Earthquakes (EERI LFE) Program, and the Los Angeles Tall Buildings Structural Design Council. During this full-day session, participants (1) shared observations about the effects of the Chile earthquake, (2) discussed potential research studies that could translate these observations into improved seismic provisions for building codes and standards, (3) identified the code- or standards-related issues that such studies should address, (4) delineated the data needed for such studies, and (5) specified and prioritized recommended research and data-collection efforts.

Effects of the 2010 Chile Earthquake

The Chilean attendees described numerous observations made and findings developed since the earthquake struck. An unexpected and sobering finding, for Chilean engineers and the public, is that some buildings that appear to have been designed and built in accordance with current Chilean codes did not behave as engineers expected and were extensively damaged. This has brought into question the adequacy of existing seismic standards at a time when Chilean engineers are being called upon to design new structures to replace those too damaged to repair, and to design repairs and retrofits for many salvageable buildings.

Ground motion monitoring records suggest that the earthquake comprised two overlapping ruptures moving from south to north, resulting in directional ground motions of long duration, which exposed buildings to repeated shaking. Cast-in-place, reinforced concrete buildings, often tall with numerous structural walls, emerged as the structures of most concern to Chilean engineers due to their prevalence and performance in the quake. Much of the damage sustained by these buildings appears to have been related to the configuration and reinforcement of structural walls, with damage concentrating near wall discontinuities and boundaries. There is also evidence implicating entire structural systems, however, which appear to have been more brittle than expected. Other design-related factors that may have influenced building performance include site-specific soil misclassifications, modeling uncertainties and assumptions, and the limitations of the software that has been available for simulating and predicting structural performance.

The EERI LFE and ASCE reconnaissance teams also emphasized structural walls in their observations about the damage caused by the earthquake. In particular, they noted the high axial stresses that the quake is likely to have imposed on the walls of many newer and taller buildings, the lack of adequately detailed transverse reinforcement in wall boundary elements, the unconfined lap splices observed in some damaged walls, and the prevalence of discontinuities and irregularities in wall configurations. Significant damage was also found among nonstructural elements such as exterior cladding, partition walls, and concrete and steel staircases. The teams identified important opportunities afforded by the quake, including chances to assess and improve performance simulation and evaluation techniques by comparing the predicted and actual performance of individual buildings; to evaluate how building performance is affected by ground-motion directionality and by the behavior of slabs, stairs, and other elements that have not been considered part of seismic-load-resisting systems; and to assess the adequacy of repair strategies employed following earlier earthquakes.

Recommended Research and Data-Collection Efforts

Participants discussed the relative urgency and relevance of more than 20 prospective studies related to the observed effects of the Chile earthquake. These potential investigations, which had been suggested by individual invitees in advance of the meeting, were intended to clarify how seismic codes and standards could be improved in response to the vulnerabilities revealed by this earthquake.

Based on this discussion and on the earthquake effects reviewed earlier, attendees distilled a list of potential areas of inquiry that, if pursued, could lead to improved seismic provisions in U.S. and Chilean building codes and standards. The list encompasses topics related to geotechnical issues, such as the effects of ground motions characterized by long duration or directionality; architectural issues, such as engineered restraints for nonstructural components and performance requirements for stairs; structural issues, such as wall boundary detailing and longitudinal reinforcement requirements for concrete walls; and issues related to existing buildings, such as the effectiveness of previous repairs.

To fully investigate these topics, U.S. and Chilean researchers will need data for meaningful samples of structures in the affected areas, including records of the ground motions that impacted the built environment. For individual buildings, needs include design drawings and specifications, data on the properties of building materials, geotechnical site data, and earthquake damage surveys. Several severely damaged structures are being scheduled for demolition, making some of the most valuable building-specific data perishable and the need for its collection more urgent. Legal and public-relations considerations, which can affect owners' willingness to share building data, may also pose challenges for data collection. Based on their reconnaissance findings, attendees identified more than three dozen specific buildings of interest located in Concepción, Santiago, Viña del Mar, and other communities.

Participants prioritized and consolidated the potential studies and areas of inquiry that they had discussed into 10 recommended research and data-collection efforts. Five of these were characterized as urgent, while the remaining five were regarded as less time-sensitive but nevertheless essential for making appropriate and optimal use of the Chile earthquake to improve building codes and standards. The activities considered urgent are summarized below.

- Systematically collect, synthesize, and analyze perishable building-specific data.
- Study the ground motions and displacements experienced at key sites and how they relate to the building designs and earthquake damage found at those sites.
- Conduct detailed studies of selected damaged and undamaged buildings to assess damage- and collapse-prediction capabilities and identify issues that are key to improving specific provisions of U.S. and Chilean building codes.
- Assess and improve design and detailing requirements for reinforced concrete structural walls.
- Establish an online post-earthquake clearinghouse for the Chile earthquake that provides convenient and comprehensive access to ground-motion records, building-specific damage and design data, and shared research findings.

Research efforts regarded as essential but less time-sensitive are summarized below.

- Develop and validate advanced numerical models and computational procedures that can be used to simulate the performance of buildings containing reinforced concrete structural walls over the complete range of wall behavior, from elastic response to collapse.
- Devise a comprehensive rehabilitation strategy for damaged shear wall buildings.
- Study and improve the behavior of anchors for structural and nonstructural building components.
- Improve procedures for estimating shaking intensity as a function of site or basin effects and for buildings subjected to shaking from subduction-zone fault ruptures.
- Improve seismic design and detailing procedures for building contents (including laboratory and other equipment) and for nonstructural components of buildings.