JHAZ

Journal of Hazard Mitigation and Risk Assessment

An official publication of the National Institute of Building Sciences
Multihazard Mitigation Council

National Institute of Building Sciences: An Authoritative Source of Innovative Solutions for the Built Environment

Spring 2011

Building to Mitigate Risk

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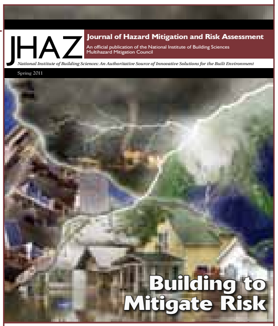

On the cover: Tornados, earthquakes, hurricanes and floods—these threats put millions of Americans at risk each year. The Multihazard Mitigation Council (MMC) is working to reduce the total costs associated with these disasters and other related hazards to buildings by fostering and promoting consistent and improved multihazard risk mitigation strategies, guidelines, practices and related efforts.

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Lessons Learned from Recent Damaging Earthquakes

By William T. Holmes

ACCORDING TO THE UNITED STATES Geological Survey (USGS), there were 22 major earthquakes—defined by seismologists as magnitude 7.0 or greater—in 2010. Several of these events caused significant damage, deaths and injuries. In particular, two events stand out: the magnitude 7.0 Haiti earthquake of January 12 and the magnitude 8.8 Chile earthquake of February 27. Was this seismic activity unusual? According to the USGS, statistically it was not (USGS, 2010).[1] However, USGS data presented in TABLE 1 indicate that the occurrence of 22 major events in one year is considerably above average and is the highest number of annual occurrences in any of the past 10 years.

The magnitude scale that is currently used, designated M_w and called moment magnitude, is based on the area of the fault slip and the distance moved. It is a measure of energy released. The moment magnitude is similar to the more commonly known Richter magnitude but is a scientifically superior measure, particularly for larger events. Major events with magnitudes of 7.0 or more release a high level of energy and are significant to geologists and seismologists. However, if they occur in remote areas where little or no damage is done, they may not be significant to seismic mitigation professionals, which includes engineers, emergency planners and social scientists.

Worldwide, earthquakes garner the attention of U.S.-based seismic mitigation professionals based on a combination of the following three interest factors:

- The extent of damage and losses;
- The similarity of the buildings and infrastructure in the area where the earthquake occurs to the U.S. building inventory; and
- A location in the United States or with reasonable access.

Several of the 2010 events are assessed in TABLE 2 using these factors. Although the rating scores shown are judgmental, the Baja, California, and Canterbury, New Zealand, events are of high interest due to the accessibility and applicability of scientific lessons, even though they were of relatively low consequence. Conversely, the earthquakes in Qinghai, China, and Papua, Indonesia, are of less interest due the inaccessibility of the regions and the lack of similarity to U.S. infrastructure and culture.

It is therefore no surprise that U.S. seismic mitigation professions have been involved in post-event reconnaissance missions not only to Haiti and Chile but also to the Baja, California, area (on both sides of the U.S./Mexico border) and the Canterbury area of the south island of New Zealand. Pertinent data from these four events are shown in TABLE 3.

By far, the remarkable destruction in Haiti stands out as the most significant consequence of seismic activity in 2010. The official number of deaths ranks somewhere between the fourth and seventh highest in recorded history (depending on the source of statistics) but the actual number is probably even higher. A long history of ineffective governments not only created a largely impoverished population but also an impoverished building stock and infrastructure. The result was buildings that were highly vulnerable to seismic damage due to the lack of modern building codes and practices.

Perhaps more significantly, the earthquake in Haiti reflects the growing recognition that the lack of effective

Table 1: The Number of Earthquakes Worldwide

Magnitude	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Longer Term Annual Average
8.0 to 9.9	1	1	0	1	2	1	2	4	0	1	1	1[1]
7.0 to 7.9	14	15	13	14	14	10	9	14	12	16	21	15[1]
6.0 to 6.9	146	121	127	140	141	140	142	178	168	141	148	134[2]

[1] Since 1900

[2] Since 1990

Table 2: Comparison of U. S. Interest Factors for Several Major 2010 Earthquakes

Events[1]				U. S. Interest Factors: 1 low, 5 high			
Locations	**Date**	**M_w**	**Deaths**	**Location**	**Extent**	**Applicability**	**Total**
Haiti	1/12	7.0	222,570	4	5	1	10
Chile	1/30	8.8	577	4	5	4	13
Baja, California	4/4	7.2	2	5	2	5	12
Qinghai, China	4/13	6.9	2,968	1	4	1	6
Indonesia	6/16	7.0	17	1	2	1	4
Canterbury, New Zealand	9/4	7.1	0	4	2	4	10

[1] Data from USGS, Deaths from Earthquakes in 2010: http://earthquake.usgs.gov/earthquakes/eqarchives/year/2010/2010_deaths.php

Table 3: Comparison of Four Selected 2010 Events[1]						
Location	**Date**	**M_W**	**Local Time**	**Deaths**	**Population Exposed**	**Economic Loss (in millions)**
Haiti	1/12	7.0	4:53 pm	222,570	5,000,000	$7,800
Chile	1/30	8.8	3:34 am	577	12,000,000	$30,000
Baja, CA (Mexico)	4/4	7.2	3:40 pm	2	1,000,000	$425
Baja, CA (US)	4/4	7.2	3:40 pm	0	90,000	$91
Canterbury, NZ	9/4	7.1	3:40 am	0	375,000	$3,000
[1] *All data from (EERI, 2010, 2010a, 2010b, 2010c, 2010d)*						

governance in a country will prevent or significantly delay effective recovery despite all efforts of assistance from the rest of the world. If the world community is to be better prepared to assist after future disasters, the mitigation community needs to focus attention on identification of other countries with similar governance issues. A more detailed description of the specific damage in Haiti can be found in EERI, 2010[2] and 2010a.[3]

The emergence of performance-based design, a procedure for designing buildings for specific performance rather than mere code compliance, eventually may facilitate improved communication between owners and engineers.

On the other hand, the largest magnitude event of the year, the massive 8.8 earthquake in Chile, caused damage over an area approximately 62 miles (100 km) wide and 310 miles (500 km) long (FIGURE 1). This led to strong ground shaking for a period of 60 to 120 seconds but only caused 577 deaths, many from the accompanying tsunami. In Chile, strong governance led to general compliance with seismic codes and standards and facilitated effective emergency response and more rapid recovery. Although there were highly publicized failures of mid-rise concrete buildings, including one collapse, the very large overall inventory of these buildings generally protected the life safety of the occupants.

However, marginally or completely irreparable damage to a few of these buildings highlighted the issue of identifying acceptable damage from rare events (FIGURE 2). Codes in the United States are primarily intended to protect life safety in rare events with no specific goal related to control of damage or economic loss. Is this life safety goal acceptable or is the public expecting low economic loss as well? Except in special cases of buildings with occupancies critical to the public or to the building owner, it is probably not cost-effective to provide seismic protection to achieve low economic losses for rare events. A concise definition of the expected performance of buildings designed to meet U.S. seismic code requirements has been difficult to define due to the large number of building types used and the wide range of potential earthquake shaking intensities. The emergence of performance-based design, a procedure for designing buildings for specific performance rather than mere code compliance, eventually may facilitate improved communication between owners and engineers.

The shaking in Chile was strong, covered a huge area and produced a wide array of damage, including collapsed bridges, damaged freeways, closed hospitals and universities, damaged wineries and other businesses, and destruction of older, sometimes historic, adobe and masonry villages and neighborhoods. The results of the earthquake were also a reminder of the devastating effects of the tsunami. This earthquake was a subduction zone event similar to that expected somewhere along a similar subduction zone in the Pacific Northwest of the United States. Detailed

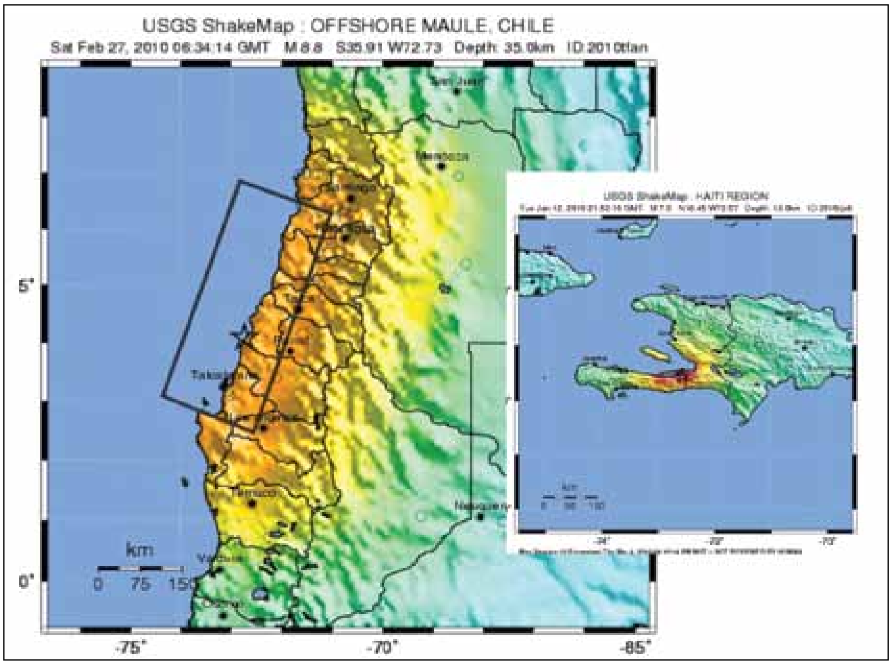

Figure 1. A comparison of the areas affected by the 2010 earthquakes in Chile (large diagram) and Haiti (inset).

Figure 2. (Left) A toppled building in Concepcion, Chile. This failure is clearly unacceptable performance. But is the damage shown in the image on the right acceptable? It did not cause a collapse but the building is possibly unrepairable.

studies of the characteristics and consequences of such an event should be applied for planning purposes in this region. A more detailed description of the specific damage in Chile can be found in EERI, 2010b.[4]

The April 4, 2010, earthquake in northern Mexico, just 31 miles (50 km) below the U.S. border, created strong ground motion over a large area in the Southern California region that was previously struck by several earthquakes (El Centro, 1940 and Imperial Valley, 1979). Therefore, many of the worst buildings in this area may have been previously damaged and either removed or strengthened. In general, the existing building stock in the region protected life safety (there were no U.S. deaths), but it was again demonstrated that damage to the nonstructural components and systems in buildings can be costly to repair. Large-scale liquefaction and warping of the ground surface was noted in farmlands, mostly in Mexico. Some have voiced concern that not only have certain crops been ruined but the fertility of the land may have been affected and the irrigation patterns changed. Similar patterns were noted in the farmlands on the Canterbury Plains in the New Zealand earthquake in September. More detailed descriptions of specific damage from the Baja, California event can be found in EERI, 2010c.[5]

By the standards of 2010 seismic destruction, the earthquake of September 4, 2010, near Christchurch, New Zealand was relatively minor. However, the similarity of seismic construction standards for both infrastructure and buildings to those used in the United States made the event of high interest to U.S. seismic mitigation professionals. Although overall damage was moderate, two vulnerabilities were highlighted.

First, older and unreinforced masonry buildings, very much like many older U.S. buildings, are extremely vulnerable to damage, even in moderate shaking. The exterior walls of these buildings tend to fall away from the floors and roofs onto adjacent streets, sidewalks and buildings, creating severe life safety risks. No one was killed

Figure 3. A portion of this unreinforced masonry wall in Christchurch, New Zealand fell onto an outdoor café. Fortunately, no one was there. The U. S. has many buildings like this.

in this event because it occurred at 3:30 a.m., when no one was on the streets or sidewalks or in commercial buildings. Dozens of life threatening situations were noted and one significant injury was reported—from a masonry chimney falling into a residence **(FIGURE 3)**. Many areas of high and moderate seismicity in the United States should study ways to reduce the hazard from this building type.

The second vulnerability highlighted in New Zealand is the potential economic loss caused by liquefaction and other soil failures related to earthquake shaking **(FIGURE 4)**. Liquefaction occurs when certain water saturated sands "liquefy" during shaking. Buildings, bridges, pipelines and other infrastructure supported on such materials may move downwards (sinking into the liquefied soil), upwards (floating on the liquefied soil) or slide sideways (when near a slope). The movement normally causes damage to the structure and often creates secondary problems. For example, if a house sinks 6 inches (15 cm) or more into the ground, surface water that originally ran away from the building will now flow into the building. Similarly, gravity flow sewers or storm drains may flow the wrong way or have high points that prevent normal drainage.

As previously noted regarding the Baja, California, event, grade changes occurred near the fault line in New Zealand. They caused changes in stream flows and will probably disrupt irrigation patterns in farm land. In the future, this possibility should be built into U.S. regional seismic loss studies for areas where fault movement or liquefaction could effect farm land. More detailed descriptions of specific damage from the Canterbury, New Zealand, event can be found in EERI, 2010d.[6]

In summary, there were an above-average number of damaging earthquakes in 2010 but not a statistically unusual number. The tragedy in Haiti stands out as a historically high killer and points out the need for the world community to find a better way to offer assistance in such situations. For the United States, few new lessons were learned but many were re-emphasized.

Figure 4. Subtle but expensive damage from liquefaction in Christchurch, New Zealand. The house, relatively undamaged, has settled about eight inches, which will cause storm drainage from the entire lot to run to the house. Regrading the lot is not always an option due to the adjacent street elevations.

Earthquakes are still a serious threat to life safety in many communities with older, vulnerable buildings. Economic loss to individuals can be significant due to damage repair or the loss of the use of buildings. Economic loss to institutions or regions can be significant if important infrastructure is lost or weakened. Communities and regions can be made more resilient by combinations of mitigation and planning. But first, local vulnerabilities must be identified and recognized through educational programs and regional loss studies. ■

William T. Holmes has more than 40 years of practical experience in structural engineering. Since most of his work has been in California, seismic design has become his specialty. Holmes has also been active in local, national and international professional committees and workshops and in research and development in seismic engineering. He is currently Chair of the Institute's Building Seismic Safety Council.

Editor's note: This article was written before the 6.3 magnitude earthquake that struck Christchurch, New Zealand, on February 22, 2011, and the massive 8.9 magnitude earthquake and subsequent tsunami that occurred in Japan on March 11, 2011.

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