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GLOBAL EXPERIENCE: SEISMIC RISK REDUCTION AND DISASTER RECONSTRUCTION PROGRAMS

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Abstract: Nearly 40% of the largest cities in the world and hundreds of millions of people live in areas that can experience major earthquakes, resulting in large numbers of casualties, and placing a large burden on the regional and national economy. Earthquakes in Haiti and Christchurch have had long-term impact on society. The 2010 Haiti Earthquake affected 3 million people and over 300,000 people are still displaced. An unprecedented reconstruction effort, incorporating local materials and masons but based on international standard, is currently underway to repair and strengthen 120,000 damaged buildings, allowing people to return to safe homes and produce a seismically resilient community in this developing country. The 2011 earthquakes effecting New Zealand showed the need for seismic risk mitigation programs in developed countries. In New Zealand, older and newer buildings were damaged. The damage to these buildings was not unexpected because the building codes only focus on life safety rather than developing earthquake resilient communities. Over 50% of the 2400 buildings in the downtown area required demolition. Over $10 billion dollars in insurance loss is expected, resulting in a drop in the insurance capacity and threatening the country's investment environment. This issue is being dealt with by reducing the overall seismic risk for both public and private buildings. In Bangkok, where the effects of long distance and long duration of earthquakes are a serious concern due to soft soil, the commercial sector has initiated a seismic strengthening program for high rise buildings. A systematic seismic risk reduction program is critical, by understanding the limitations of the building codes. A seismically resilient community can be built if both public and commercial sectors rigorously participate in a broader program.

1. INTRODUCTION

The In the past several years, major earthquakes have affected both developed and developing countries. Although the consequences differ, the end result is similar because these events have caused casualties, affected local and national economies, and had long-term negative effects on communities. The adverse effects of earthquakes in developing and developed countries are attributed to different causes. In developing countries, the main culprit is the lack of an effective seismic code, education, licensing, and quality-control system. Buildings are designed and constructed without adequate provisions for seismic forces or a quality-control system. As a result, these buildings do not have a mechanism to resist earthquake loading and thus can be severely damaged or collapse in moderate or major seismic events. By contrast, in developed countries, the concept of seismic design is well developed and based on extensive research. However, the intent of the building codes in these countries is not to prevent damage but to provide a minimum of life safety. This philosophy is primarily due to financial constraints facing both private and public developers, and a lack of information. As such, in the event of major earthquakes, buildings in developed countries would likely not collapse. However, it is likely that these structures would sustain significant damage (as implied in the building codes) that would likely result in both financial losses and the need to replace or repair the buildings.

One common factor for Haiti, New Zealand, Japan, and similar recent events is that the earthquakes had magnitudes that were unexpected. In other words, the available design codes had underestimated and intensity of seismic events that could occur. This case was observed in China (2008), Italy (2009), Haiti (2010), New Zealand (2011), and Japan (2011), and it points to the need for either additional safety measures in design or better understanding of probable seismic events for a locale. Examples of earthquake damage and the consequences of such damage from two recent events are presented in the following sections.

2. OVERVIEW OF RECENT MAJOR EARTHQUAKES WORLDWIDE

2.1 2010 Haiti Earthquake

The catastrophic 2010 Haiti earthquake has had a tragic effect on the lives of more than 3 million people, including over 200,000 casualties, over 1,000,000 displaced people, and financial losses that crippled the country's economy.

Thousands of buildings collapse, including the United Nations (U.N) headquarters Port-au-Prince; as shown in Figure 1.

Figure 1 Collapsed UN building (UNDP Global 2010)

Similar to past and recent events in other developing countries such as Indonesia, Pakistan, and Turkey, the main causes of the devastation can be attributed to several factors. Among them: This earthquake caused devastation disproportional to its magnitude. If any form of standard of seismic design and construction had been used in Haiti, many lives and much of the economic loss could have been avoided. The main observed factors that exacerbated this tragedy were the following: a) Design and construction practices had not considered earthquake forces properly. In addition, many engineers and contractors had neither formal education nor experience in earthquake-resistant design methodologies. b) Absence of an accepted building or seismic engineering code, and proper quality control system in design, and construction. In addition, no formal building review process was in place. c) The rapid growth of low-income neighbourhoods due to migration into the city from outlying areas. In these neighbourhoods, unsafe housing had been built using substandard construction materials and practices. d) Lack of preparedness by the national government, local agencies, international organizations, emergency responders, and citizens for a major earthquake. Many of the structures in Haiti as well as other developing countries are constructed of either what is referred to as non-ductile concrete, unreinforced masonry (URM), or other stone-type block construction. These particular building types are seismically vulnerable and pose a life-safety hazard. An example of poor construction in Haiti is shown in Figure 2.

Figure **2** Example of poor construction in Haiti

2.2 2011 New Zealand Earthquake

The magnitude-6.3 February 2011, New Zealand, earthquake caused more than 160 deaths and damage costing over US$20 billion. Many buildings were damaged; over 30% of the brick and stone buildings in the central business district (CBD) either collapsed or sustained major damage (see Figure 3) resulting in total closure of the CBD for period of several months because many of the remaining buildings were considered unsafe (Miyamoto International 2011).

Figure **3** Collapsed masonry buildings in the CBD

As of this writing, the CBD is still partially closed, resulting in severe economic losses. In addition, the unprecedented damage has brought the construction industry to a halt because of the difficulty in obtaining insurance. Most of the deaths from this earthquake occurred after people had been buried under collapsed buildings, such as nonductile concrete structures downtown (see **Error! Reference source not found.**). This was a shallow (5-km epicentral depth) earthquake, and its epicenter was less than 6 km from the east side of Christchurch. As such, it caused significantly more damage and casualties than did the magnitude 7.0, September 2010 earthquake (which had no direct fatalities). The 2011 Earthquake caused extensive liquefaction and ground failure, which also led to widespread loss of water and electricity. The severity of this earthquake was unexpected in Christchurch and points to the same problem that exists in many other urban areas that are close to active faults. The level of damage to modern (post-1980) construction was alarming. Over 50% of the building stock—more than 1,300 buildings—are expected to be claimed as total losses. Many of these buildings were designed and constructed using modern seismic codes. Nonetheless, they sustained significant structural and nonstructural damage, and many have to be demolished. Similar observations were made following the 2010 Chile earthquake. In both countries, modern seismic codes are advanced and local engineers are quite capable, and there are tight construction standards. It is important to note that the building codes likely did what they were intended to do: that is, to provide life safety and prevent collapse. However, the codes do not have provisions for either the building condition after an earthquake or financial losses as a result of an earthquake.

Figure 4. Collapsed nonductile concrete building in the CBD

3. RESPONSE TO THE RECENT EARTHQUAKES

In the aftermath of the subject earthquakes, the authors and other engineers mobilized as part of the response teams. The primary goals of the teams were to:

- Develop methodologies for seismic risk reduction,
- Devise robust and resilient reconstruction methods. In the following sections, the approach and results to date are summarized.

3.1 Response to the Haiti Earthquake

Immediately after the earthquake, the team was mobilized with the primary goal of evaluating and/or repairing as many buildings as possible to allow citizens to leave temporary camps and return to their houses (Miyamoto, Gilani, and Wong 2011). A two-step procedure was undertaken: (a) perform damage assessment of approximately 400,000 buildings, and (b) develop earthquake-resistant, cost-effective, and robust reconstruction techniques. Key components of these programs were having international engineers educate and train local Haitian engineers, and having international construction experts train local Haitian masons. In addition, training manuals were developed, and emphasis was placed on local materials and techniques to additionally stimulate the local economy.

Table 1 summarizes the results of the damage assessment program. Over 50% of the buildings were tagged as green, or safe for occupancy. This allowed hundreds of thousands of people to return home.

Table 1. Results of damage assessment

Category	**Green**	**Yellow**	**Red**
No. of buildings	213,000	102,000	80,000
Percentage	54%	26%	20%

The seismic rehabilitation of thousands of buildings that is currently under way (see 0) will allow many more thousands to return home, and provide a safe and seismically resilient community for citizens. At the time of this paper, over 9,000 houses have been reconstructed under various programs; see 0.

Figure 5. Example of acceptable reconstruction in Haiti

Table 2. Results of damage assessment

Program	Description	Houses
PADF	Leogane Haiti Emergency Shelter Rehabilitation	1,200
OFDA	Pilot program	1,200
OFDA	Extension	2,000
ADORATION	Yellow Houses Repairs	200
DAI	Yellow Houses Repairs	200
OTI-USAID	Haiti Recovery Initiative Yellow Houses Repairs	125
UNOPS	Shelter Repair	800
PADF	Yellow Houses Repairs	3,839
Total		9,564

3.1 Response to the Christchurch Earthquake

New Zealand has one of the most advanced seismic codes in the world. However, the city of Christchurch was not ready for the earthquake that hit it, and the engineering community was unprepared to deal with the aftermath of the event. As such, the initial decisions were to demolish all buildings that had been deemed unsafe, and either reconstruct the areas deemed unsafe or leave them as open space. Experience has shown that many vulnerable structures can be upgraded to comply with the current seismic standards using systematic rehabilitation methods. The first step in this process is condition assessment. This key component is currently missing in New Zealand. To address this issue, the authors are developing a risk assessment algorithm that is uniquely suitable for New Zealand construction but relies on worldwide knowledge in seismic assessment and rehabilitation. The objective of this program is to characterize risk for individual buildings, and thus to present owners with the financial cost of doing nothing, rehabilitating the structure, or demolishing and reconstructing the structure. Experience has shown that the assessment-reconstruction alternative is the preferred and the optimal (as related to benefit-cost ratio) option for many structures.

4. COMPONENTS OF RISK ANALYSIS AND RESILIENT RECONSTRUCTION

One of the disturbing observations in recent earthquakes has been the damage to modern buildings that had been designed according to modern seismic codes. Although these buildings have survived, the level of damage and the associated cost of the damage and repair have been high. Consequently, the current building code approach (that is, prevent collapse but tolerate damage) has been questioned. Performance-based engineering (PBE) provides an alternative to code-based prescriptive design. PBE involves selecting various targets or desired objectives for a given intensity of earthquake input. Such an approach relies on sound engineering judgment, involves direct communication between structural engineers and owners, and requires that the structural performance and the seismic hazard be known with a certain level of confidence. The concept of PBE directly ties to managing seismic risk: The owner is given the option of choosing the level of risk that can be tolerated and the cost associated with that level. For example, 0 presents a typical PBE matrix. The rows correspond to the intensity of a seismic event, and the columns indicate the expected level of performance. In this matrix, the limited, standard, and enhanced objectives for seismic rehabilitation are shown as red, yellow, and green entries, respectively.

Table 3 PBE matrix

Seismic event	Operational	Immediate Occupancy	Life Safety	Collapse Prevention
Typical				
Design				
Rare				

In risk management language, this matrix is also directly related to what is commonly referred to as “probable maximum loss” (PML). PML implies the level of damage (casualties, financial loss, and loss of income) that can be expected for a given building at a given level of earthquake. As shown in 0, seismic rehabilitation and/or reconstruction should be such that this example building whose analyzed performance was above acceptable PML level and thus inadequate—would be strengthened so that its post-retrofit damage index is below the PML threshold resulting in significant risk reduction. The low level of PML in this example was achieved by using an innovative seismic protective device (such as isolators and dampers) which protect structural and nonstructural components. The concept of PML is especially relevant to developing countries and for critical facilities in these countries. In many instances in these countries, the level of seismic hazard and the risk associated with it are not well known. By conducting a preliminary (often referred to as a “phase I”) analysis, an approximate but accurate estimate of the PML for a given structure and/or group of buildings in a facility can be determined quickly. This PML estimate can then be used to prioritize the buildings for further analysis and possible retrofit within the allocated budget.

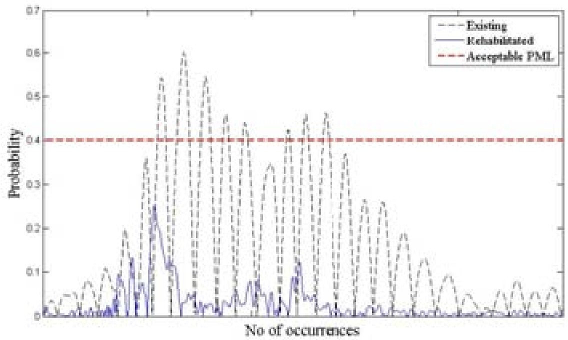

Figure 6. Example of PML analysis

5. ADDED VALUE TO INTEGRATIVE RISK MANAGEMENT

The lessons learned from earthquakes such as those in Haiti and New Zealand and the concepts presented in this paper have global applications. For example, under the auspices of the World Bank (WB), a multiyear program was developed and managed to ensure the systematic upgrade of essential facilities in Istanbul, Turkey. As a result, by the end of the program, over 2,000 critical buildings were retrofitted or reconstructed, including schools that now provide safety to students. Schools have been noted as one of the most vulnerable building types in past earthquakes, causing thousands of casualties. Similar to the program in Turkey, a new rehabilitation guideline and training manual is currently under development in Romania. This document is based on state-of-the-art research and knowledge in the United States and incorporates specific considerations for Romanian design and construction. It will be used to make communities more resilient in Romania.

CONCLUSIONS

Recent earthquakes have caused damage worldwide and have demonstrated the vulnerability of many cities in both developing and developed countries. To address such vulnerability and reduce the global seismic risk, the following are recommended:

- Educate private and public entities on the limitations of code-based design. As an alternative, investigate the application of PBE, which relates probabilistic performance to seismic hazard and can assist in decision making by stakeholders.
- Building codes, by definition, count on select components and modes of response to dissipate seismic energy. Although effective in preventing collapse, this approach, by definition, implies damage to these components. Seismic protective devices are readily available to protect structures and mitigate such damage.
- Vulnerable buildings such as nonductile concrete and URM structures are well-known; effective and inexpensive retrofit concepts are also known. It is important to train engineers in developing countries and undertake a systematic program of rehabilitation and reconstruction for this group of vulnerable structures.
- For developing countries, risk assessment and PML are critical tools because it is not feasible to retrofit all vulnerable structures, given the limited resources. PML and the ensuing benefit-cost analysis can be used to rank buildings for assessment and possible upgrade to help maximize protection of life and infrastructure.

REFERENCES

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