Large Scale World Bank Seismic Risk Reduction Program for Public Buildings

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Abstract

Under the auspices of the World Bank, a multi-step risk assessment project has been recently completed for Metropolitan Manila, Philippines, the country's primary commercial and business center, the 11th most populous metropolis in the world, with 12 million (13% of the national population). This area is susceptible to multihazard natural disasters such as earthquakes, floods, and typhoons. To address the vulnerability to natural disasters, a comprehensive risk assessment and mitigation program was undertaken and showed that the earthquake exposure was the key hazard to mitigate. A prioritization and seismic retrofit program was developed and focused on public schools and hospitals that have suffered disproportional damage and casualties in past disasters worldwide. The key steps in the program were to: a) prioritize vulnerable structures, b) conduct cost-benefit analysis to assess retrofit options, and c) prepare a seismic retrofitting guidelines including design examples and details. Approximately, 4,000 structures were evaluated using the available database of school and hospital buildings. The probabilistic evaluation platform was based on the global best practice, incorporated structural loss and fatalities. Cost-effective retrofit options were developed for use of national engineers based on the state of art but simple seismic retrofit methods and modified for local construction. Analysis showed that by cost-effective retrofit of only a part of vulnerable structure stocks total fatalities can be significantly reduced.

Introduction

As evidenced by the M7.2 Bohol earthquake on October 15, 2013, and Super Typhoon Yolanda on November 8, 2013, the Philippines is considered to be a natural hazards global hot spot—ranking eighth among the most exposed countries in the world. Geographically positioned on the Ring of Fire in the Southeast Asia region of the Pacific Ocean, the Philippines is particularly vulnerable to natural hazards such as earthquakes, typhoons, floods, volcanic activity, and tsunamis. In addition to the risk of human life loss and suffering, it is estimated that 85% of the national GDP activity occurs in at-risk areas, such as Metro Manila (MM), which further emphasizes the need for a robust natural hazards risk mitigation program.

Project Overview

Natural Disasters Effects in MM

Given its geographic and geologic conditions, the Philippines is particularly vulnerable to damaging socioeconomic impacts from a number of natural hazards.

- The 1976 M7.9 Mindanao earthquake caused an estimated death toll of up to 8000. Moreover, the 1990 Luzon earthquake had a magnitude of 7.7 and caused more than 1620 fatalities. Recent studies Wong, Dawson, and Dober, (2010) have shown that central Luzon, where Metro Manila is located, will continue to experience large earthquakes.

- Seasonal monsoon rains, typhoons, and devastating tropical storms such as Bagyong Ondoy (September 2009) and, more recently, Bagyong Gener (August 2012) contribute to widespread flooding and property damage throughout Metro Manila. Such storms have generated sustained winds of up to 130 kph and wind gusts of up to 160 kph.

- In the past few centuries, movement of the Manila Trench has resulted in two tsunamis hitting Metro Manila, causing major rivers to overflow and damaging vast areas.

- Within the past 35 years, three volcanic eruptions have occurred: Taal, Mayon, and Mount Pinatubo.

A large percentage of the Philippine population resides in the greater MM area (approximately 13%), and MM is the major commercial hub of the country (30% of the Philippine GDP), a natural disaster would have substantial human and financial impacts.

Risk assessment and Mitigation for MM

To address the vulnerabilities stated previously, it was vital to develop a multihazard evaluation and strengthening program for this important metropolitan area. The key components of the program were:

- Hazard assessment
- Development of an appropriate mitigation and strengthening solution
- Prioritization, of public buildings for earthquake strengthening and hazard mitigation. Such prioritization is necessary to help ensure that available funds are optimally allocated.

The multihazard and risk assessment and prioritization components were based on accepted principles of risk management and relied on the expertise of engineers and peer reviewers. Meetings with stakeholders were held to identify the socioeconomic importance of key buildings and to collect available information from various agencies

Key data for the purposes of risk assessment included information such as occupancy type, construction date, number of stories, number of occupants, and building type (including the lateral-force-resisting system), and other important parameters. Experience has shown that certain types of buildings (for example, nonductile reinforced concrete frames and reinforced concrete frames with partial height unreinforced infills) are highly susceptible to damage from earthquakes.

Data collection from the initial pool of buildings included site visits, visual surveys, and photos of the buildings for documentation. The data was then reviewed, assessed, and categorized, and then aggregated with available facility and structural data from the various agencies. The data was then assembled into a database and processed by using risk assessment algorithms—based on generally accepted methods in the United States and other countries—that correlate earthquake hazards to probable loss (that is, fatalities), and a ranking for each building was developed.

The information from the database was then used to develop effective earthquake strengthening methodologies for these types and other types of vulnerable structures in the pool of buildings. Retrofit techniques (such as adding shear walls or braced frames, and improving the existing component detailing) and innovative methods were investigated and presented. The selection of upgrade techniques incorporated both earthquake engineering and risk management (in terms of cost-benefit analysis), and were specific to the building types identified in the pool that are known to be vulnerable to earthquake damage. Finally, an implementation program was provided that outlined the next steps in advancing a multihazard risk mitigation program, using the findings, methodologies, and guidelines developed by this project team.

Furthermore, for effective implementation of this project, a robust communication campaign was important so that the findings are disseminated to a large group of stakeholders, including the public at large. Because many of these individuals and organizations are not experts in the field of earthquake engineering, a different, nontechnical approach should be used. For example, seminars can be conducted; informational pamphlets can be provided on the web for download; and the media can be included in briefings that report on the progress of the project and provide a means for educating the public. Such approaches, based on the tools that are used in the United States, Haiti, Turkey, and Romania for similar programs, are outlined in the communication plan presented herein.

The overall approach to the multihazard prioritization process used for this study is summarized and presented in Figure 1.

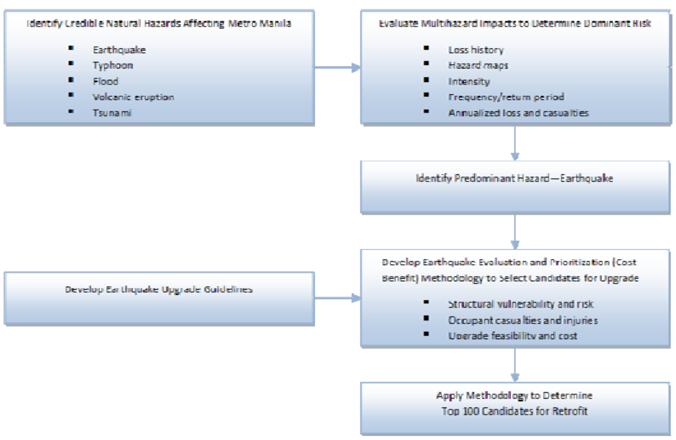

Figure 1. Multihazard prioritization process

Multihazard Prioritization

Metro Manila public schools and hospitals have different levels of vulnerability to earthquakes, floods, typhoons, tsunamis, and volcanic eruptions. One of the tasks of this project was to develop a prioritization methodology to help identify the highest-risk structures for upgrade and risk reduction. Following is a summary of the key natural hazards that affect Metro Manila and their resulting impacts.

Typhoon and Flood

The Philippines and its surrounding seas are affected by an annual average of 19 tropical typhoons, of which 10 make landfall each year. Typically, five are of typhoon strength Aquino (2005). These typhoons bring about strong winds, heavy rainfall, storm surges, floods, landslides, and mudslides. In recent years, Metro Manila has been directly affected by severe windstorms, most notably Typhoon Milenyo in September 2006, Typhoon Ondoyin September 2009, and a heavy southwest monsoon rain event in August 2012. The latter was associated with Typhoon Haikui, which passed through north of Taiwan. In MM, Typhoon Milenyo was said to have reached a recorded maximum sustained wind speed of 35 m/s and a gust speed of 45 m/s Pacheco et al. (2006). These numbers were lower than the basic gust wind speed of 55 m/s for MM as prescribed by the 2010 National Code ASEP (2010). This, therefore, puts the Milenyo wind speeds in Metro Manila as equivalent to approximately a 20-year return period wind speed, following the procedure in the ASCE/SEI 7 commentary (2010) for hurricane-level winds. The amount of damage, as well as death and injury, caused by the winds of Typhoon Milenyo was among the worst in more than a decade, particularly for Metro Manila, with approximately US$24 million in damage and about 200 deaths.

Typhoon Ondoy brought about the highest rainfall and flooding in the history of Metro Manila, causing more than 2 m in floodwaters in the span of just a few hours in some locations. It was actually only a tropical storm (maximum sustained wind and gust speeds of no greater than 28 m/s and 31 m/s, respectively) when it affected the Philippines; it became a typhoon only when it approached Vietnam. It can be said that Ondoy, as a windstorm, represents only a 1- or 2-year return period event for MM, but the rainfall that it brought is estimated to be 100 to 150 years in terms of return period Liongson and Tabios (2009). Deaths resulting from Ondoy totaled 465 for all of the Philippines.

It should be noted that Ondoy had a measured 24-hour rainfall at the PAGASA Science Garden Meteorological Station of about 455 mm, although 348 mm of rainfall had already been recorded in just a 6-hour period. By using current rainfall models, it could be said that Ondoy brought a 320-year return period rainfall. By using current flood models, the flooding that Ondoy brought represents approximately a 13,500-year return period event. It should be mentioned, however, that the highest flood event ever measured, since recording began in 1958, did not exceed even the 30-year return period design flood event. Therefore, the Ondoy floods can be considered only as a flood event with a return period greater than 100 years. Similarly, the Ondoy rains can be considered only as a rainfall event with a return period greater than 150 years Liongson and Tabios (2009).

The Habagat storm of 2012 brought perhaps the second-worst flooding in MM since Typhoon Ondoy in 2009, but the rains spread over a few days (instead of hours) and also caused landslides in one part of Metro Manila. In one area of Metro Manila, the floodwaters reached a height of approximately 1.8 m because of Ondoy, but only about 1.5 m because of the Habagat storm. In other areas, for both storm systems, floodwaters climbed to at least 3 m high. The maximum 24-hour rainfall brought by the Habagat was 472 mm—higher than the same 24-hour total for Ondoy. If the Ondoy rainfall were a 320-year return period event, the Habagat rainfall would be about a 430-year return period event. Considering the limitations of current rainfall modeling, however, the Habagat can be thought of only as a rainfall event with a return period greater than 150 years.

The rate at which rain fell during the Habagat was not as high as for Ondoy. The Habagat brought 1007 mm of rainfall over a 72-hour period. Ondoy's intense rainfall lasted only 24 hours, and mostly within a 6-hour period. By ratio and proportion and by using the current flood model, the Habagat flooding could be considered a 1950-year return period flood event. But again, because of current modeling limitations, the Habagat flood is considered only as a flood event with a return period greater than 100 years.

Typhoon Pablo of 2012 made landfall on the southern island of Mindanao as a Category 5 super typhoon, with winds of 175 mph. It was one of the costliest reported typhoons ever to strike the Philippines, and caused over US$600 million in damage and 1020 deaths NDRRMC (2012). The costliest typhoon is Super Typhoon Yolanda of 2013. It made landfall in the Visayas (Central Philippines) with Cat-5 winds and 5-6 m storm surges, killing 6,201 and caused over US$850 million in damage NDRRMC (2012).

These typhoon events caused flooding and wind damage at Metro Manila schools and hospitals. Based on interviews of DepED and hospital staff, deaths and injuries at schools and hospitals from these events were minimal—and schools are sometimes used as shelters in these events.

Volcanic Activity

The Philippines is an archipelago of more than 7100 islands. Most of these islands are of volcanic origin. There are 37 volcanoes in the Philippines, of which 18 are active. The rest are dormant and not expected to erupt in the near future. The most well known volcanoes in the Philippines are Mount Pinatubo (80 km northwest of Manila), Mount Banahaw (60 km southeast of Manila), and Taal (40 km south of Manila)—all of which are on the northern island of Luzon.

The last major eruption (the second largest of the 20th century) was Mount Pinatubo in June 1991. Evacuation zones 10 to 40 km (affecting a population of about 40,000) from the volcano's summit were established before the eruption, thereby significantly reducing casualties. A reported 847 people were killed by the eruption, mostly by roofs collapsing under the weight of accumulated wet ash, a hazard that was amplified by the simultaneous arrival of Typhoon Yunya. Some schools in the evacuation zone were damaged by the ash fall, thereby disrupting education (Martí and Ernst 2005). Metro Manila was well outside the 40-km evacuation zone and reported only minor damage and injuries. The impact to Metro Manila schools and hospitals was similarly light.

Earthquake and Tsunami

Because the Philippines is located along the Ring of Fire, earthquake and tsunami are major risks. Significant earthquakes in 1976 (Mindanao, M7.9) and 1990 (Luzon, M7.7) killed up to 8000 Soloviev, Go, and Kim (1992) and 1666 people Rantucci (1994), respectively. West of Metro Manila is the Manila Trench, which can generate large subduction-type earthquakes that can cause destructive tsunamis. Major tsunamis, with waves of 1.0 to 1.5 m, struck Metro Manila in 1677, 1744, 1824, 1852, and 1863 Nakamura (1978).

The MMEIRS project JICA et al. (2004) estimated losses from a M7.2 earthquake on the West Valley Fault (which runs through Metro Manila, MMEIRS Model 08) at 168,300 heavily damaged buildings, 33,500 deaths, and 113,600 injured. Ten percent of schools and hospitals are expected to sustain significant damage or collapse, and 25% are expected to have moderate damage. Tsunami risk was analyzed by using Model 13, a M7.9 subduction faulting event on the Manila Trench. Under this scenario, tsunami waves of 2 to 4 m are expected to reach Metro Manila in 70 minutes.

Both the 1976 Mindanao and 1990 Luzon earthquakes damaged schools, but because they struck in the evening when school was not in session, these earthquakes caused few deaths. The MMEIRS estimates are also based on an evening earthquake scenario, when schools are not in session. A daytime event would be catastrophic. With recent local education reforms to add the 11th and 12th grades, 2 million additional students will fill existing schools in two years. This will dramatically increase the number of two-shift schools, which in turn makes a daytime earthquake the likely scenario.

The construction vulnerability of Philippine schools is similar to that in China (which killed 19,000 students in the 2008 M8.0 Sichuan earthquake, or a little over 1% of the student population in the region Swiss Re (2009). For Metro Manila, 1% of the estimated 2.15 million students would be 21,500 children.

Prioritization Approach

Computer models, such as FEMA HAZUS (2001), to estimate portfolio losses from different natural hazards. The results are used for disaster response planning, policy making, and other planning exercises. For this project, a prioritization methodology was developed to highlight the disaster impacts at a qualitative level, with the goal of showing that, if earthquake upgrades are not performed, earthquake-caused life losses will be orders of magnitude greater than from other natural disasters. A first-order analysis of the natural hazards and potential consequences to schools and hospitals is presented in Table 1 and Table 2, respectively, which highlight the significantly greater threat that is presented by earthquakes. The consequences are based on a review of Philippine natural hazard loss history, which was summarized earlier in this chapter.

The Philippines is struck by major floods and typhoons frequently, so its people are prepared and buildings are generally resistant to major damage from these events (most damage is nonstructural). Most schools and hospitals are constructed of reinforced concrete—one of the most typhoon- and flood-resistant structure types—so structural damage in these events is rare. Also, both typhoons and floods give warnings, so citizens can prepare for and/or evacuate to avoid them. For major typhoons, schools are typically closed but are sometimes used as shelters. Typhoon and flood casualties in, and property damage to, Metro Manila public schools and hospitals have historically been low, as is reflected in Table 1 and Table 2, since the number of sites affected is low (less than 5%).

Table 1. Natural Hazard Impact to MM School Campuses

	Earthquake	Tsunami	Typhoon/ Flood	Volcanic
Property Damage	High	Mod.	Mod.	High
Business Interruption	High	Mod.	Mod.	High
% of Sites Affected	>50%	≈30%	5–10%	0%
Injuries	High	Mod.	Low	Low
Deaths	High	Mod.	Low	Low

Table 2. Natural Hazard Impact to MM Hospital Campuses

	Earthquake	Tsunami	Typhoon/ Flood	Volcanic
Property Damage	High	Mod.	Mod.	High
Business Interruption	High	Mod.	Mod.	High
% of Sites Affected	>50%	≈30%	5–20%	0%
Injuries	High	Mod.	Low	Mod.
Deaths	High	Mod.	Low	Mod.

The three known "active" volcanoes, Taal, Mount Banahaw, and Mount Pinatubo, are 40, 60, and 80 km from the Metro Manila area, respectively. These volcanoes are too far away to cause lahar damage (the greatest hazard from volcanoes) to the region and also are not expected to deposit significant amounts of ash

(that is, enough to cause structural damage or failure) on public school or hospital buildings in Metro Manila. Property damage and injury risk are high next to an erupting volcano, but Metro Manila schools and hospitals are far away; therefore, property damage and injuries are expected to be low (0% of sites affected).
Earthquake-induced tsunamis from the west will impact coastal areas. After a major earthquake on the Manila Trench, tsunami waves could reach Metro Manila in about 70 minutes, so low coastal areas would have some time to evacuate. As seen in Japan from the M9.0 earthquake-induced tsunami in 2011, property damage can be significant. However, in the Japanese event, reinforced concrete buildings performed much better than did other building types when struck by tsunami waves (Figure 5-2). For the limited number of properties (about 30%) along low-lying coastal areas near Metro Manila, moderate damage is expected. Casualties are expected to be low, as well.

Earthquake presents the greatest risk of death to occupants of Metro Manila schools and hospitals. The M7.2 West Valley Fault (WVF) earthquake scenario has a return period of 200 to 400 years, and the last earthquake on WVF was over 300 years ago Daligdig et al. (1997) and JICA et al. (2004). Therefore, the WVF M7.2 earthquake can strike at any time. This impending hazard also affects particularly vulnerable building stock— reinforced concrete–frame buildings. Metro Manila school and hospital construction is mostly reinforced concrete frame, and many of these structures are of the nonductile variety, which has caused the highest death rates in past earthquakes; see Figure 2 JICA et al. (2004).

. In summary, the fatalities from earthquake are approximately 200 deaths per year from earthquake hazard. By contrast, fatalities from flood, hurricane, and volcanic hazard are approximately 10 per year. As such, the earthquake hazard is the main risk that needs to be investigated for MM.

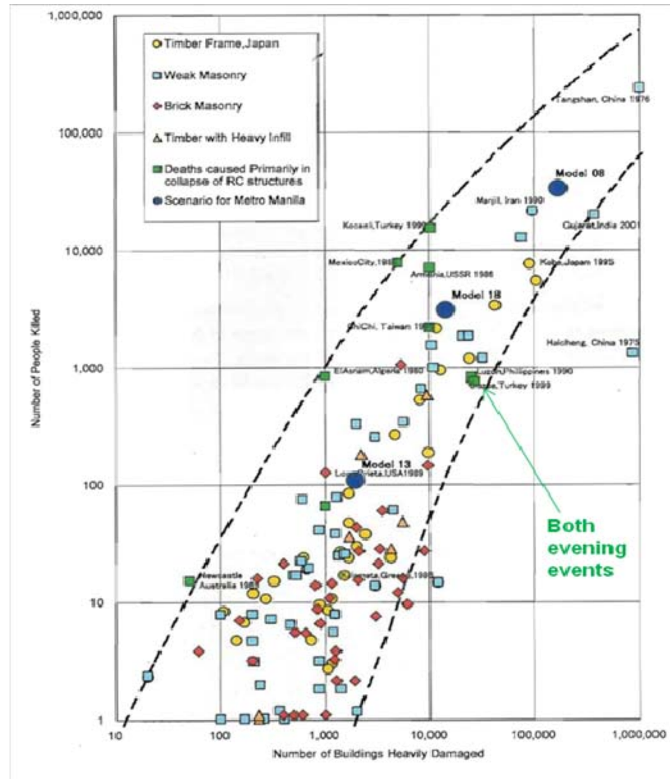

Figure 2. **Reinforced concrete structures kill the greatest number of people in earthquakes (JICA et al. 2004)**

Evaluation of Buildings for Seismic Hazard

Building construction

Typical school and hospital buildings are comprised of reinforced concrete–frame construction with infill walls. For some public buildings reinforced concrete shear walls are used. Figure 3 presents a typical school building.

Elevation and plan view for a typical school building is shown in Figure 4. As shown in the figure, school buildings are comprised of row rows of classrooms and a walkway in the longitudinal direction. Individual classrooms approximately measure 26x26 ft in plan, the walkway is approximately 10-ft wide and typical floor height is approximately 10 ft tall.

Figure 3. **Typical school building**

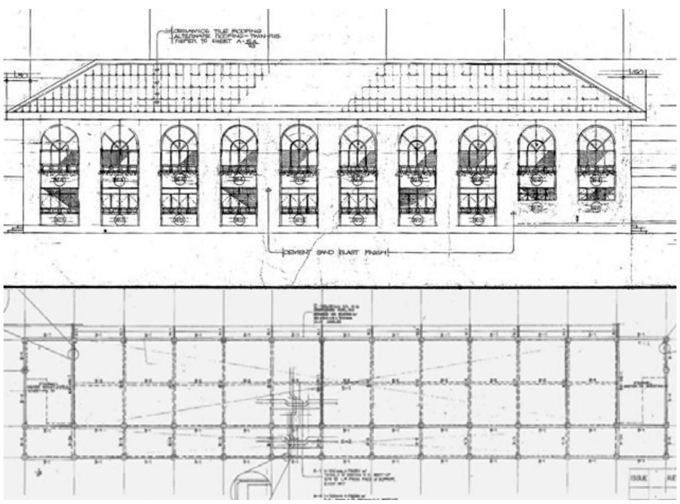

Figure 4. **Elevation and plan view**

Building codes

In the Philippines, the governing code for the design and construction of buildings is the National Building Code of the Philippines (NBCP). A set of accompanying Implementing Rules and Regulations (IRRs) assigned what was then the 1st edition of the National Structural Code for Buildings (NSCB), prepared by the Association of Structural Engineers of the Philippines (ASEP) and approved by the the governing structural design code. The NBCP as well as the NSCB 1st edition were actually both adopted from the 1970 Uniform Building Code. The NSCB contained provisions for minimum design loads (including dead loads, live loads, earthquake loads, and wind loads) as well as for reinforced concrete, steel, and timber design.

The NBCP has since evolved into the National Structural Code of the Philippines (NSCP) and National Structural Code of the Philippines (NSCP); Vol. 1: Buildings, Towers, and other Vertical Structures, and has been revised five times. Similar to the first edition, the second through sixth editions of the code has also been adopted from later UBC editions, prepared by ASEP, and approved by the Department of Public Works and Highways. In essence, the NSCP seismic design provisions have likewise been historically based upon those in the UBC; see Table 3

Table 3. History of seismic codes for Philippines

Ed.	Issued	Title	Code basis
1	1972	NBCP	UBC 1970
1	1977		
2	1982	NBCP	UBC 1979
3	1987	NSCP	UBC 1985
4	1992	NSCP Vol. 1	SEAOC 1988 UBC 1988
4	1996		
5	2001	NSCP Vol. 1	UBC 1997
6	2010	NSCP Vol. 1	UBC 1997

Cost-Benefit Analysis for Earthquake Retrofitting

Objectives

Perform cost-benefit analysis (CBA) and apply the algorithm to the database of buildings to prioritize the buildings based on the expected number of fatalities. In addition, prepare an estimate of cost associated with earthquake strengthening of vulnerable buildings.

Description

The CBA used a modified version of the standard Boardman (2010) multistep approach, which is reproduced here:

- Specify the set of alternative projects.
- Decide whose benefits and costs count (standing).
- Identify the impact categories, catalog them, and select measurement indicators.

- Predict the impacts quantitatively over the life of the project.
- Monetize (attached dollar values to) all impacts.
- Discount benefits and costs to obtain present values.
- Compute the net present value of each alternative.
- Perform sensitivity analysis.
- Make a recommendation.

Given that the focus of this project is on public schools and hospitals in Metro Manila, the major stakeholders for this project include the Philippine Department of Education (DepED) and Department of Health (DOH), and the students, patients, employees, friends, and families associated with these institutions. Generally speaking, however, the Philippine government, the Philippine local government units (LGUs), and the Philippine citizenry at large are also stakeholders in this project. The main goal was to identify whether the buildings studied need to be retrofitted and, if so, what the costs and benefits would be. The status quo (no strengthening) was used as the baseline, and the benefits derived from an earthquake strengthening program and the costs associated with such an approach were quantified.

Fatality Calculations and Earthquake Hazard Prioritization

Earthquake hazard prioritization and selection of the highest-risk buildings for earthquake upgrade were based on building vulnerability and expected casualties from the M7.2 West Valley Fault scenario. Because most of the school and hospital buildings are of similar construction (reinforced concrete frame with masonry infill walls), the vulnerability ranking is directly correlated to the resulting casualties (that is, fatalities) from structural damage and collapse.

Vulnerability and fatality calculations were based on the probabilistic methods developed in ATC-13 and FEMA HAZUS (2001), and were used to rank the buildings under investigation. To estimate vulnerability and fatalities for a particular building, the following distinct parameters were used as input:

- Seismic hazard
- Exposure
- Building vulnerability
- Casualty index

For this project, a database of buildings was developed that incorporated these parameters. Following is a summary of the definitions and procedures that were used to determine these variables.

Seismic Hazard

The seismic hazard used in the analysis was based on the design response spectrum as defined in the National Code. This spectrum is similar to the "Scenario 8" (M7.2, West Valley Fault) event that was examined previously by the MMEIRS project team and was designated as the critical event for investigation.

Development of the elastic response spectrum was based on the procedure outlined in the National Code, and included factors such as the seismic zonation (equal to 4 for Metro Manila), the classification of subgrade soil at the site, and the shortest distance from the building site to the fault.

Data for the type of soil (typically Class D or E) at various campuses was determined from the available PHIVOLCS liquefaction maps.

Geographic coordinates (latitude and longitude) were provided in the database of school buildings that was furnished by DepED. Because the geometric coordinates of the West Valley Fault are known, the normal distance to the fault line was computed for each school campus. With this value, the near-field effects for various campuses could be computed.
The design spectrum for an individual building was then developed based on the procedure listed in the National Code, modified for the site class and near-field effects. The obtained site-specific spectrum comprised the seismic hazard for each building.

Exposure

The exposure for each building was based on its student population (used to estimate fatalities), floor area (in square meters), and construction characteristics used to estimate structural damage. The DepED database was based on an independent survey of 130 random buildings. The database entries were modified as follows:

- The campus population was distributed to individual buildings within the campus proportional to each building's floor area.
- The number of students in each building was updated by the ratio of the most recent estimate of the total student body divided by the aggregate building population indicated in the database.
- The floor area of buildings was factored by the ratio of the actual total floor area for the 130 buildings surveyed divided by the total floor area indicated in the database for the same 130 buildings.

Building Vulnerability

The structural vulnerability was based on fragility data from FEMA HAZUS, which shows the probability of exceeding a damage state as a function of the building drift ratio.

The parameters (means and variances of the lognormal curves) for the fragility functions of a given building were based on the following factors:

- Construction material
- Lateral-load-resisting system
- Number of stories
- Construction date
- Construction practices
- In this simulation, the default parameters from FEMA HAZUS were used and the following was noted:
- The buildings were almost exclusively constructed of reinforced concrete.
- Moment frames were the primary lateral-force-resisting system for the buildings.
- According to FEMA HAZUS definitions, the buildings were either low-rise (one to three stories) or mid-rise (four to seven stories).
- The buildings were constructed using the version of the National Code that was adopted at the time of their design and construction.

Thus, using the FEMA HAZUS methodology, the Metro Manila buildings were assigned the seismic design levels summarized in Table 4

Table 4. FEMA HAZUS Building Seismic Design Level Classifications

Construction Data	Code-Compliance Assignment
Post-2001	High Code
1991 to 2001	Low to Moderate code
Pre-1991	Pre Code

Damage states

The definitions of these damage states for a reinforced concrete moment–frame building (C1) are listed here:

- Slight Structural Damage: Flexural or shear-type hairline cracks in some beams and columns near or within joints.
- Moderate Structural Damage: Most beams and columns exhibit hairline cracks. In ductile frames, some of the frame elements have reached yield capacity, indicated by larger flexural cracks and some concrete spalling. Nonductile frames may exhibit larger shear cracks and spalling.
- Extensive Structural Damage: Some of the frame elements have reached their ultimate capacity, indicated by large flexural cracks, spalled concrete, and buckled main reinforcement. Nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns, which may result in partial collapse.
- Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse because of brittle failure of nonductile frame elements or loss of frame stability.

Figure 5 shows typical fragility functions that correspond to the various damage states.

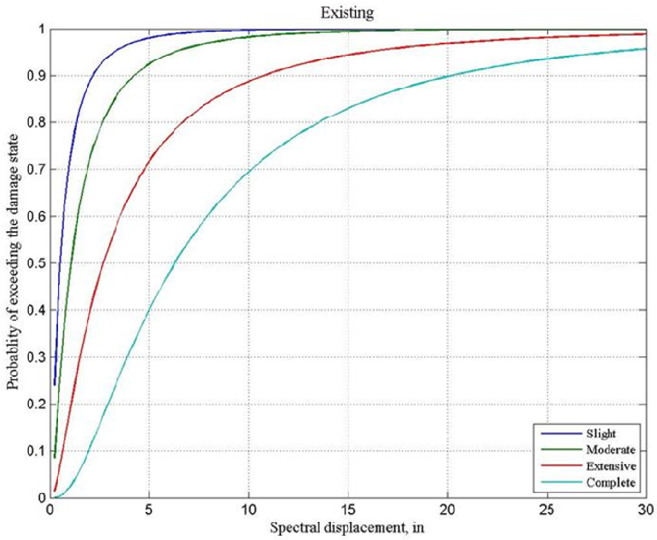

Figure 5. Sample fragility curves for various structural damage states

Casualty Index

The FEMA HAZUS indoor casualty rates for concrete moment-frame low-rise (C1L) and concrete moment-frame mid-rise (C1M) buildings are summarized in Table 5.

Table 5. FEMA HAZUS Indoor Casualty Rates for RCMF Buildings

	Complete Structural Damage		
Building Type	Fatality Rate, No Collapse	Fatality Rate, Collapse	Collapse Rate
C1L	0.01%	10%	13%
C1M	0.01%	10%	10%

FEMA HAZUS building collapse rates for "Complete Structural Damage" are 13% for C1L and 10% for C1M. Collapse rates for unreinforced masonry are 15% for URML and for URMM. FEMA HAZUS casualty rates are uniform across all building types, so casualty estimates must factor in the collapse rates. Based on this logic, casualty rates for reinforced concrete buildings should be slightly lower than for unreinforced masonry buildings. However, MMEIRS findings on the relationship between casualty and building damage are quite different from HAZUS findings. The MMEIRS report shows that casualty numbers in reinforced concrete buildings are actually between 5 and 100 times (an average of 20x) those of unreinforced masonry buildings. Therefore, the casualty numbers and the collapse rate were adjusted accordingly.

For each level of damage defined earlier, a percentage of the population was assigned as the casualty rate. For each building, the probable fatality ratio was then considered by aggregating the probability of exceeding a damage state and the fatality rate associated with that damage state. It should be noted that only indoor fatalities were used in this study. Fatalities outside of buildings due to falling hazards were not included, but can add 5% to 10% to the indoor casualty rates.

The following is a summary of the key steps for determining the top 100 candidates for earthquake strengthening, based on the prioritization process discussed earlier.

- For each building, compile the following information, as discussed earlier:
    - Building ID
    - Building coordinates
    - Seismicity
    - Occupants and area
    - Fragility parameters (mean and standard deviation) for each damage state
- Compute probabilistic values for damage states by using the fragility functions corresponding to the building construction type, lateral-load framing system, number of stories, and vintage.
- Compute fatality ratios by using the fatality rate for each damage state and the probability of exceeding that damage state.
- Compute earthquake strengthening costs by using the cost estimate per square meter and building floor area.
- For Metro Manila schools, use a student population of 2.15 million.

6.4 Analysis Results

The results of our analysis of the vulnerability of Metro Manila schools show that out of 3821 buildings identified in available databases, approximately 50% are high earthquake risks that will have significant damage or collapse in the M7.2 West Valley Fault scenario. The resulting fatalities will be approximately 24,400 students; see Figure 6.

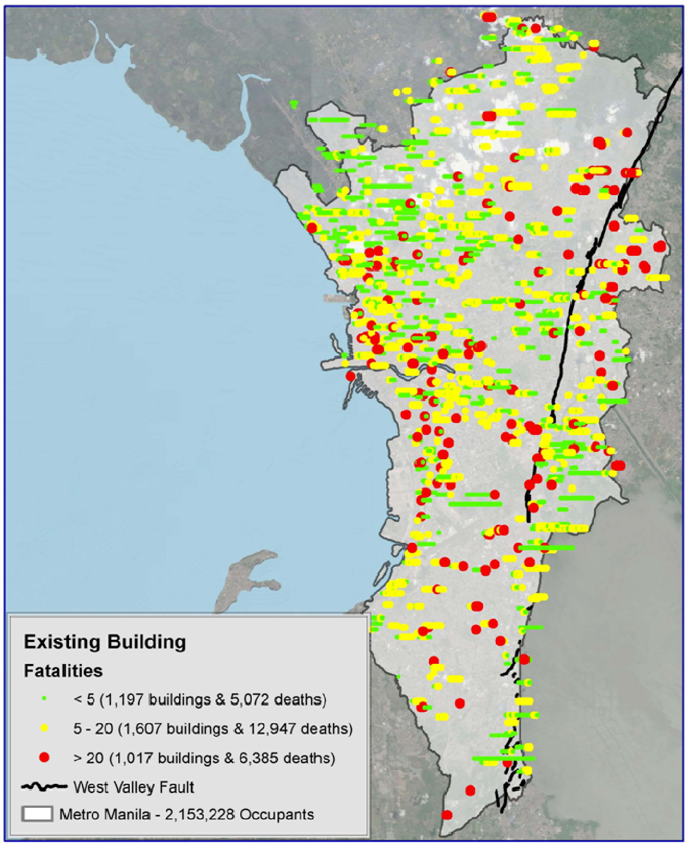

Figure 6. Student fatality distribution in MM

EARTHQUAKE STRENGTHENING Guidelines

The Guidelines for Earthquake Strengthening and Upgrading of Public Schools and Hospitals in Metro Manila (hereinafter referred to as "Guidelines") have been developed for Metro Manila by using state-of-the-art earthquake retrofit procedures that are tailored to local construction standards for these facilities.

The Guidelines have been developed to assist in addressing the seismic design requirements for public hospital and school buildings in Metro Manila. It is recommended that the Guidelines be used as a supplement to the 2010 edition of the Philippine Earthquake Code (ASEP 2010), entitled National Structural Code of the Philippines (hereinafter referred to as the "National Code"). The National Code is the legal technical seismic design code in the Philippines. It was updated, with a new version issued in March 2010, and its seismic requirements closely follow the provisions of the 1997 Uniform Building Code (ICBO 1997). The National Code is used for the design of new buildings. Participating consultants should be intimately familiar with its specifications.

In the Guidelines, the Life Safety (LS) performance level at the design earthquake is used for evaluating existing buildings. This performance level is equivalent to the provisions of the National Code. Seismic performance of a building depends on the characteristics of the earthquake event. A sample construction might perform well when it is subjected to one class of earthquake, but experience substantial damage when it is subjected to another class. Therefore, it is imperative to determine the seismic hazard before attempting assessment or retrofit. The seismic hazard is based on the provisions of the National Code, and also depends on the soil conditions at the site and the proximity of the building to the earthquake source.

Seismic performance also greatly depends on a building's design and construction. Therefore, it is important to specify the requirements for detailed site investigations to quantify the critical existing building parameters. A review of school and hospital building construction drawings has shown that a large majority of the school buildings and many hospitals use reinforced concrete construction. The typical lateral-load-resisting system consists of reinforced concrete moment-resisting frames. In many of these buildings, hollow concrete block infill panels are used.

The most recent version of the National Code generally follows the principles and design requirements of modern seismic design. However, most of the reinforced concrete buildings that were constructed in accordance with the provisions of earlier editions of the National Code are considered nonductile or of limited ductility. Nonductile structures lack the detailing that is necessary to prevent brittle failures and collapse. Nonductile reinforced concrete structures are vulnerable to earthquake damage, and many have collapsed in recent earthquakes.

For this type of construction, the most economical and structurally viable strengthening option is the application of conventional retrofit techniques, such as the addition of new elements (for example, reinforced concrete shear walls) to carry the full seismic load. Using this approach, no strengthening of the existing elements would be required. Example designs and detailing for such retrofits are presented in the Guidelines.

The risk assessment and retrofit methods used in the Guidelines rely on the existing worldwide knowledge base and are further refined to address the specific conditions of the subject buildings in Metro Manila. A great majority of the buildings use reinforced concrete framing with hollow concrete block infill. These types of buildings are often large, high-occupancy facilities, and their collapse in future earthquakes could result in hundreds or thousands of casualties. Therefore, retrofit of these buildings is considered a high priority and is emphasized in the Guidelines.

The Guidelines provide strengthening methods that will significantly improve the seismic performance of school and hospital buildings in Metro Manila. To remain cost-effective, a certain level of building damage is considered acceptable, but greater life safety will be ensured and confidence will increase that building collapse will be mitigated. The overall objectives are to minimize the retrofit cost, achieve acceptable earthquake performance, and maximize the number of buildings to be rehabilitated. It is expected that the school and hospital buildings that will be strengthened in accordance with the Guidelines will meet their performance targets when they are subjected to the design earthquake for Metro Manila.

The Guidelines are divided into three volumes. The three volumes emphasize the following:

- Volume I of the Guidelines provides a prescriptive methodology for evaluating and upgrading school and hospital buildings.
- Volume II of the Guidelines provides detailed background information, and advanced analysis and evaluation techniques, including the use of performance-based engineering.
- Volume III provides design examples for use in evaluating typical Metro Manila school and hospital buildings. The examples show the upgrade methods prescribed in Volume I.

It is anticipated that for a great majority of the buildings, the provisions of Volume I and the design examples and detailing provided in Volume III will be used. Volume II is intended to be used for unique structures or when alternative approaches are required; for example, for buildings with irregularities for which the Linear Static Procedure is not allowed, or when alternative or innovative upgrade options that are not covered in Volume I have been selected.

Many technical sections of the Guidelines are based on the provisions of FEMA 356 (NEHRP 2000). Reinforced concrete–frame construction is prevalent in Metro Manila for most school buildings and many hospitals; therefore, the Guidelines focus on that type of construction.

The procedure specified in the Guidelines for a given building is as follows:

- Determine the seismic hazard for the building per the National Code.
- Perform a condition assessment.
- Perform linear static analysis.
- Assess the performance of the building.
- For inadequate buildings, design upgrade options as defined in Volume I, based on the procedures of the National Code to carry 100% of the lateral load and limiting story drift ratios to 1%. Provide detailing as presented in Volume III.
- Check nonstructural component anchorage and nonbuilding structures such as water towers.

Seismic Strengthening Approach

The proposed seismic strengthening scheme for the lateral force resisting system (LFRS) members is presented in Table 6.

For deficient buildings, either new reinforced concrete shear walls or BRBF systems are proposed. The use of

BRBF will limit the foundation upgrade and preserve the open space in front of the classrooms.

Table 6. Proposed upgrade matrix for vertical elements of LFRS

LFRS	Construction date	Stories	Option[*]
RC framing with or without CHB infill walls	Pre-1992	1–3	I
			II
	1992–2001	1–3	I
			II
	1992–2001	4+	I
	Post-2001	Any	I
RCSW	Pre-1992	Any	III
	1992–2001	Any	III
	Post-2001	Any	III

The schools and hospitals in MM use a wide array of nonstructural components. The proposed seismic strengthening for these elements is listed in Table 7

Table 7. Proposed upgrade matrix for non-structural components

Nonstructural element	Seismic strengthening
Heavy partition walls	Provide wall bracing and anchorage.
	Provide wall bracing and anchorage, and FRP partition walls.
	Remove and replace walls with lighter Sheetrock-type walls.
Ducts and piping	Provide support, bracing, and anchorage
Shelving	Provide bracing and anchorage to floors and/or walls.
Elevated TVs or monitors	Strap item to the mounts and bolt the mounts to the structure.
Mechanical and electrical	Provide proper anchorage to the structure.
Parapets	Provide bracing.
	Remove parapets.

Many schools and hospitals in MM use structures that are classified as non building. For example, Figure 7 shows a water tower (note the size of steel members and the poor anchorage) and Figure 8 shows an entrance canopy (cantilevered and heavy). Many of these structures also require seismic strengthening. The proposed strengthening for non-building structures is listed in Table 8

Figure 7. Water tower with inadequate anchorage and small steel members

Figure 8. Cantilevered entrance canopy

[*] I: Add new RCSWs in the transverse direction and BRBFs in the longitudinal direction; II: Add new RCSWs in the transverse and longitudinal directions; III: Add new shotcrete or concrete and boundary elements, if necessary.

Table 8. Proposed upgrade matrix for Non-building structures

Component	New elements
Water tower	Strengthen members, connections, and anchorage.
Gym/auditorium, self-supporting	–
Gym/auditorium, non-self-supporting	Provide an independent vertical- and lateral-load support mechanism.
	Check building connections and strengthen them for displacement and load transfer.
Entrance canopies/ awnings	Create an independent vertical- and lateral-load support mechanism.

Summary and Conclusions

Metro Manila Philippines is one of the most populated cities in the world and the economic and commercial center in Philippines. The area is also subject to frequent natural disasters with grave consequences. To assess the natural hazard risk and advance mitigation schemes, a risk assessment and management program was undertaken. The results showed that:

- .The earthquake hazard is the governing risk for the area resulting in annualized fatality rate of 1% ort population; an order of magnitude larger than any other natural hazard for the area.
- A ranking algorithm was developed and implemented using the available database from Philippines supplemented by field surveys. The fatality and structural loss were used as the ranking parameters of interest. The algorithm showed that a subset of small number of buildings contributed the most to fatalities; approximately 25% of fatalities occurred in 5% of buildings.
- It is projected that the strengthening of these 200 buildings can be achieved at accost of US $40-80 million and will result in saving over 6000 lives in the event of the design earthquake.
- Guidelines for seismic strengthening were developed. The guidelines included strengthening details (drawings) and examples based on MM construction for use by local engineers.

References

American Society of Civil Engineers (ASCE), 2010. ASCE/SEI 7-10: Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, Reston, VA, USA.

Aquino, R.E.R., 2005. “Philippine Wind Information for Engineering, Research, and Mitigation.” COE-TPU Country Report. http://www.wind.arch.t-kougei.ac.jp/info_center/APECwind/philippines.pdf.

Association of Structural Engineers of the Philippines (ASEP), 2010. National Structural Code of the Philippines, Volume 1: Buildings, Towers, and Other Vertical Structures, Quezon City, Philippines.

Boardman, A.E., Greenberg, D.H., Vining, A.R., and Weimer, D.L., 2010. Cost-Benefit Analysis: Concepts and Practice, 4th ed., Prentice Hall, Upper Saddle River, NJ, USA.

Daligdig, J.A., Punongbayan, R.S., Besana, G.M., and Tungol, N.M., 1997. “The Marikina Valley Fault System: Active Faulting in Eastern Metro Manila.” PHIVOLCS Professional Paper 01, Quezon City, Philippines.

Federal Emergency Management Agency (FEMA), 2001. HAZUS-MH 2.1, Multi-hazard Loss Estimation Methodology, Earthquake Model, Washington, DC, USA.

International Conference of Building Officials (ICBO), 1997. 1997 Uniform Building Code, Vol. 2: Structural Engineering Design Provisions. International Conference of Building Officials, Whittier, CA, USA.

Japan International Cooperation Agency (JICA), Metropolitan Manila Development Authority (MMDA), Philippine Institute of Volcanology and Seismology (PHIVOLCS), 2004. Earthquake Impact Reduction Study for Metropolitan Manila, Republic of the Philippines (MMEIRS).

Liongson, L.Q., and Tabios, G.Q., 2009. "Typhoon Ondoy (Ketsana) and the Marikina River Flood of September 26, 2009." UPCOE-ICE-NHRC Public Presentation.

Nakamura, S., 1978. "On Statistical Tsunami Risk of the Philippines." Southeast Asian Studies, Vol. 15, No. 4, March 1978.

National Disaster Risk Reduction and Management Council (NDRRMC), December 16, 2012. Update No. 29 re Effects of Typhoon "Pablo" (Bopha). http://www.ndrrmc.gov.ph/attachments/article/835/29%20Update.pdf.

Pacheco, B.M., Aquino, R.E.R., Tanzo, W.T., and Rosaria, N.E., 2006. "Wind Loads and the Wind Environment in the Philippines: Recent Developments in 2006." Proceedings of the 3rd Workshop on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies (APEC-WW-2006), New Delhi, India.

Rantucci, G., 1994. Geological Disasters in the Philippines: The July 1990 Earthquake and the June 1991 Eruption of Mount Pinatubo. Dipartimento per l'Informazione e l'Editoria, Presidenza del Consiglio dei Ministri.

Soloviev, S.L., Go, Ch.N., and Kim, Kh.S., 1992. Catalog of Tsunamis in the Pacific, 1969–1982. Soviet Geophysical Committee, Academy of Sciences of the USSR.

Swiss Reinsurance Company, Ltd. (Swiss Re), 2009. "Natural Catastrophes and Man-Made Disasters in 2008," T. Hess, ed. Swiss Reinsurance Company, Ltd., Zurich, Switzerland.

Wong, I., Dawson, T., and Dober, M., 2010. "Evaluating the Seismic Hazards in Metro Manila, Philippines."