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SEISMIC RISK REDUCTION PROGRAM FOR SCHOOL AND HOSPITAL BUILDINGS IN METRO MANILA, PHILIPPINES

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Abstract

Metropolitan Manila in Philippines is the country's primary commercial and business center and is the 11th most populous metropolis in the world, with 12 million. This area is susceptible to multihazard natural disasters such as earthquakes, floods, and typhoons. To address this vulnerability, under the auspices of the World Bank, a multi-hazard risk assessment and mitigation program project has been recently completed. 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. The probabilistic evaluation platform was utilized and retrofit options were developed based on the state of art but simple seismic retrofit methods and modified for local construction.

Keywords: Seimic risk assesment; Schools and Hospitals; Seismic retrofit, multihazard assessment, cost-benefit prioritization

1 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 a natural hazards global hot spot—ranking eighth among the most exposed countries in the world. 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.

To address such vulnerabilities, a multihazard evaluation and strengthening program for this area has been developed. The key components of the program were: a) Hazard assessment, b) Development of an appropriate mitigation and strengthening solution, and c) Prioritization, of public buildings for earthquake strengthening and hazard mitigation. This prioritization is necessary to help ensure that key buildings are targeted for retrofit given the limit of available resources. The overall project approach is summarized in Fig. 1.

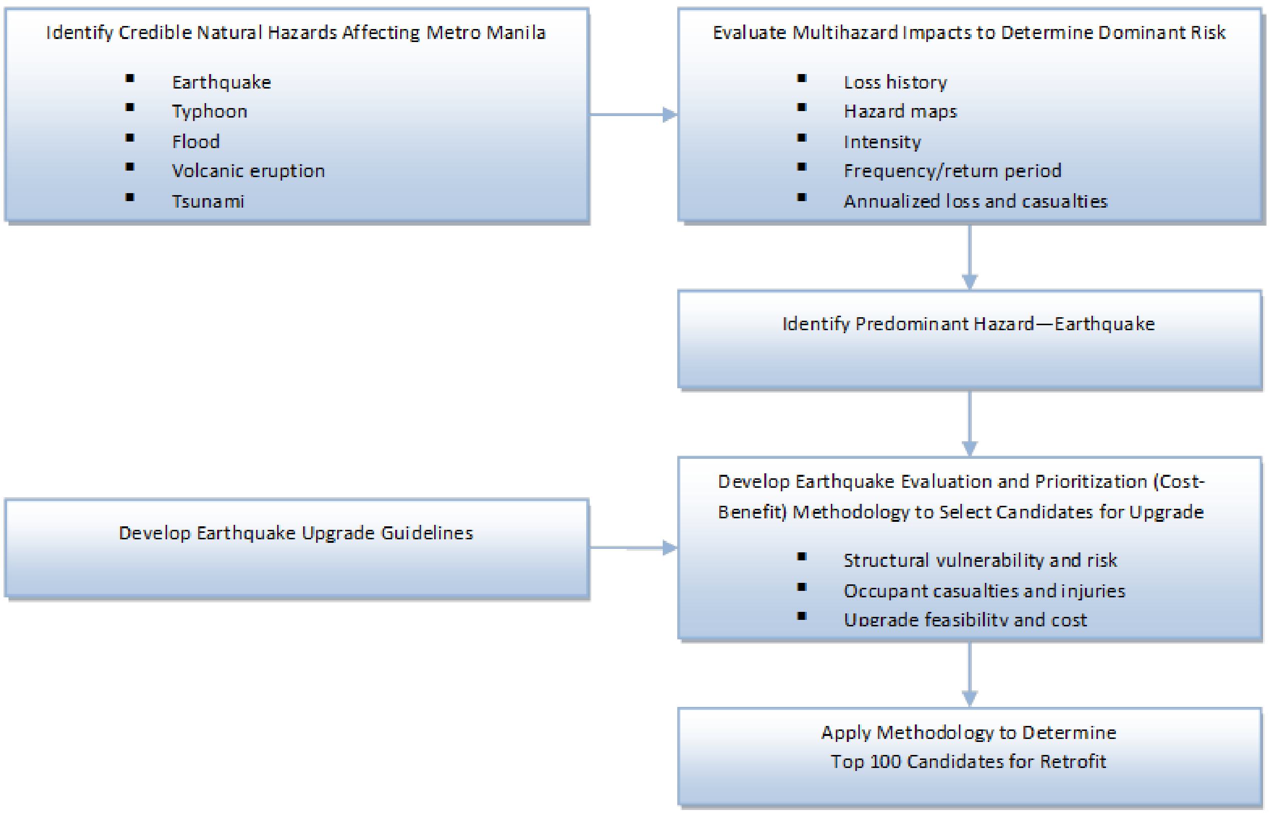

Fig. 1 Multihazard prioritization process

To store and process the multiple layers of data associated with the buildings and natural hazards under consideration, the ArcGIS platform was used. Building data was received for approximately 3700 buildings on 770 school campuses, and 70 buildings on 20 hospital campuses. This data was supplemented by site visits and a data collection program loosely based on the FEMA P154 methodology. 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 assembled into a database to be processed by a 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.

2 Prioritization Approach

Computer models, such as FEMA HAZUS [1], estimate portfolio losses from natural hazards. The results are used for disaster response planning, policymaking, and other planning. 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 is presented in Table 1 -, which highlight the significantly greater threat that is presented by earthquakes [2] and [3] and [4]. The consequences are based on a review of Philippine natural hazard loss history.

Table 1 - Natural Hazard Impact to MM public buildings

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

3 Evaluation of Buildings for Seismic Hazard

3.1 Building construction

Typical school and hospital buildings are comprised of reinforced concrete–frame construction with infill walls. For a limited number of public buildings reinforced concrete shear walls (instead of moment frames) are used. Figure 2 and Figure 3 present a typical school building and its elevation and plan view. School buildings are regular; include row rows of classrooms and a walkway in the longitudinal direction. Individual classrooms approximately measure 10 x 10 m in plan, and 3 m tall.

Fig. 2 Typical school building

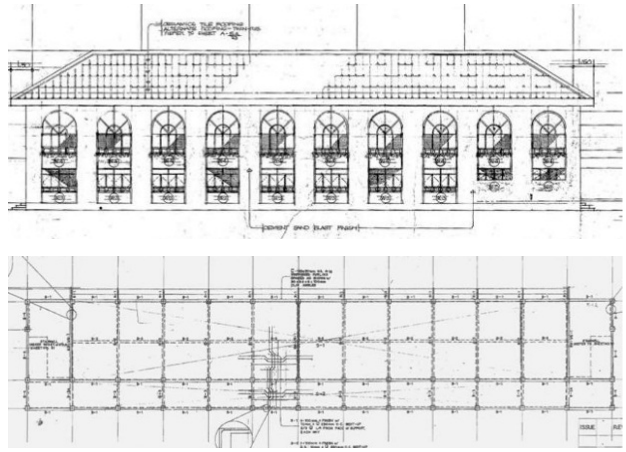

Fig. 3 Elevation and plan view

3.2 Building codes

In the Philippines, the governing code for the design and construction of buildings [5] 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 2

Table 2 - 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
4	1996		UBC 1988
5	2001	NSCP Vol. 1	UBC 1997
6	2010	NSCP Vol. 1	UBC 1997

4 Cost-Benefit Analysis for Earthquake Retrofitting

4.1 Overview

Cost-benefit analysis (CBA) was performed and used to rank (prioritize) the public buildings in the database of buildings. The benefit part of the equation was based on the lives saved (reduced expected number of casualties in a facility because of retrofit), whereas, the cost was monetary budget associated with earthquake strengthening of vulnerable buildings.

4.2 Description

The CBA used a modified version of the standard Boardman multistep approach. 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. 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 and costs associated with an earthquake strengthening program approach were quantified.

4.3 Earthquake Hazard Prioritization.

Earthquake hazard prioritization and selection of the highest-risk buildings for earthquake upgrade were based on building physical damage and expected casualties from the M7.2 West Valley Fault scenario earthquake. 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). Although developed for US, this approach is acceptable because buildings in MM were constructed using the provisions of US seismic codes. To estimate vulnerability and fatalities for a particular building, the following distinct parameters were used as input: a) Seismic hazard, b) Exposure, c) Building vulnerability, d) consequence function (casualty index). 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.

4.4 Seismic Hazard

The seismic hazard used in the analysis was based on the design response spectrum as defined in the National Code. 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 [4]. 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.

4.5 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 used and supplemented by 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.

4.6 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 included the following factors: Construction material, Lateral-load-resisting system, Number of stories, Construction date, and 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.
- The buildings were low- (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.

4.7 Casualty Index

The FEMA HAZUS indoor casualty rates for concrete moment-frame low-rise (C1L) and concrete moment-frame mid-rise (C1M) buildings were used in this paper.

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, previous studies (MMEIRS) on the relationship between casualty and building damage for Philippines are quite different from HAZUS findings. The MMEIRS report shows that in Philippines, casualty numbers in unreinforced masonry buildings are actually between 5 and 100 (an average of 20) times those of reinforced concrete buildings. Therefore, the casualty numbers and the collapse rate were adjusted accordingly in this study to account for specific parameters in the study area.

5 Analysis Results

The geographic distribution of buildings based on the number of fatalities is shown in Fig. 4. In this figure as the legend indicates:

- Red dots correspond to buildings with fatalities of more than 20
- Yellow dots indicates fatalities of 5 to 20
- Green dots represent buildings with less than 5 fatalities

Fig. 5 presents the distribution of the number of fatalities associated with individual buildings. It is noted that there are a small number of most vulnerable buildings with the largest expected fatalities.

The buildings were next ranked based on the number of fatalities as shown in Fig. 6. The data in this figure are based on a pool of over 3800 structures with student population of approximately 2.15 million and are shown for a design-level earthquake, as defined in the building code struck Metro Manila. The key findings of this figure are summarized in Table 1.

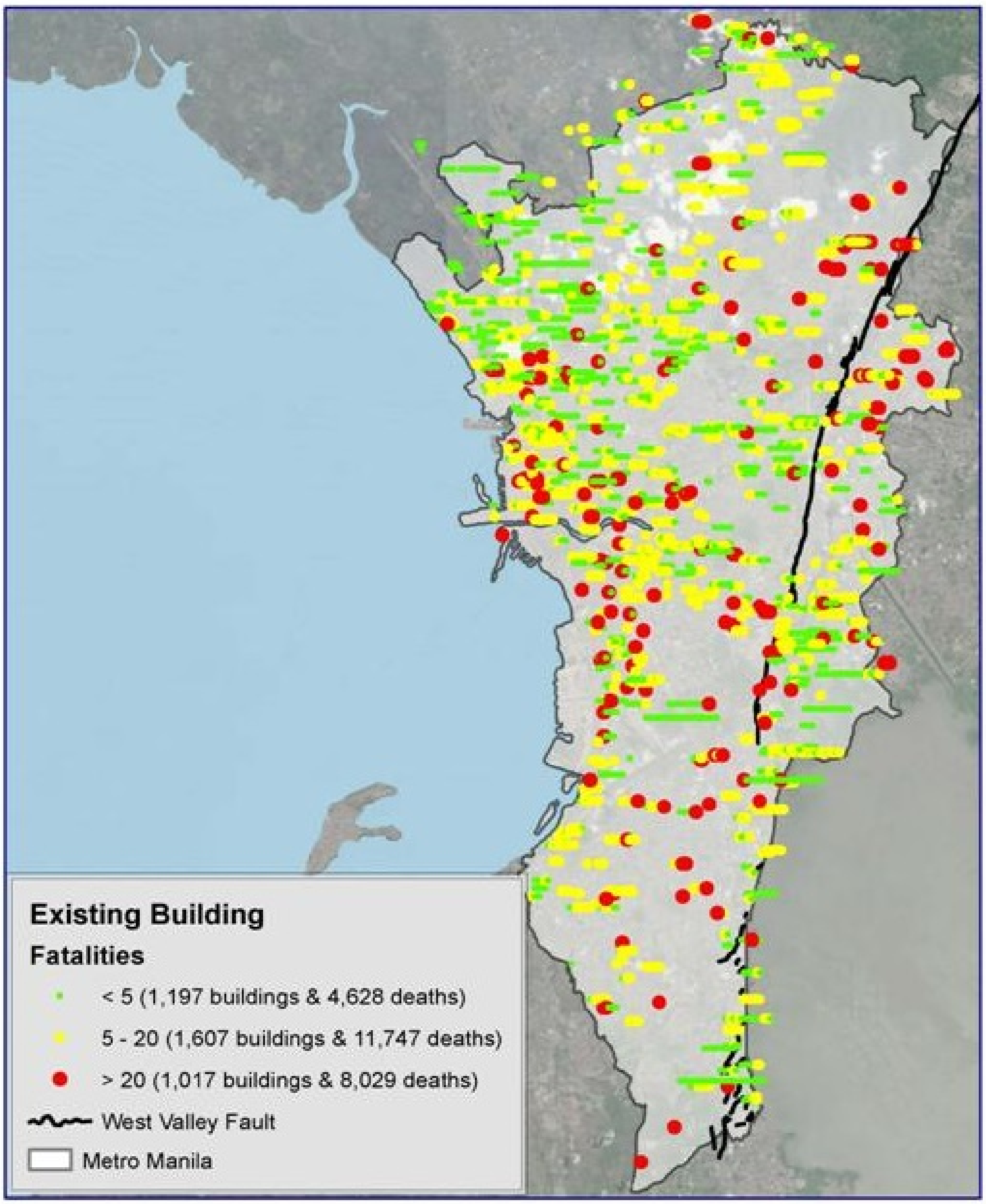

Fig. 4 Geographical distribution of schools based on the estimated fatalities

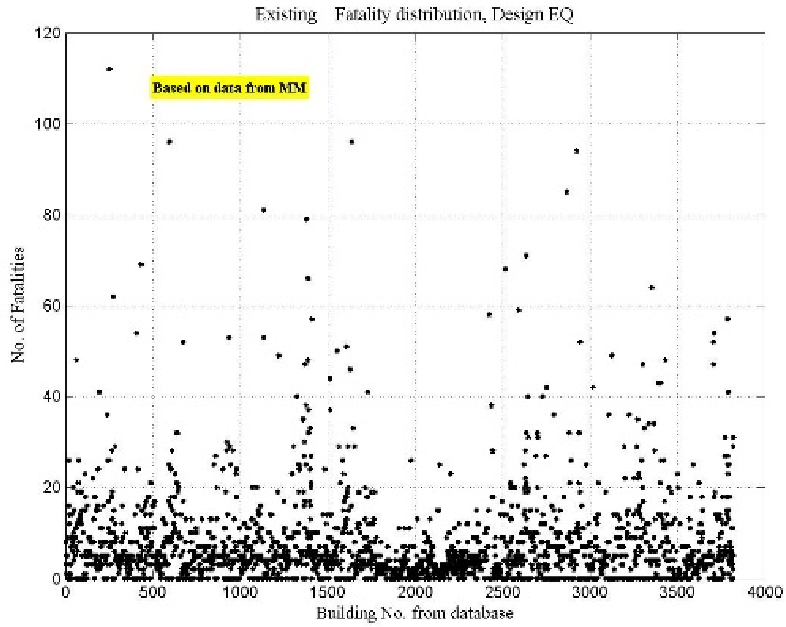

Fig. 5 Fatality distribution for school buildings

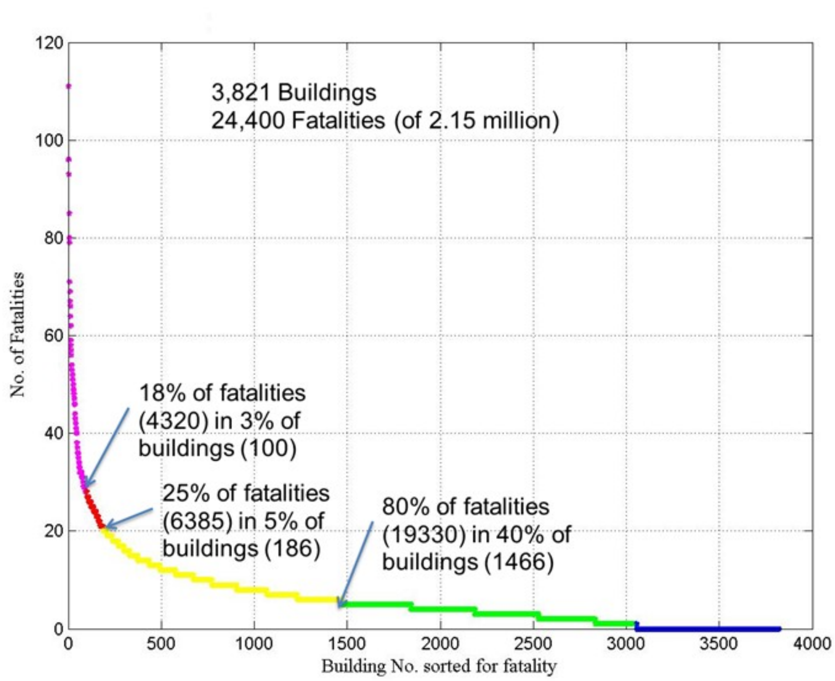

Fig. 6 Ranking of buildings based on the number of fatalities

Table 3 - Fatality values from probabilistic evaluation

% Number of buildings	% Fatalities
Worst 100 (Magenta)	18%
5% (186) (Red+)	26%
38% (Yellow+)	80%
100% (3821)	100% (24,000)

Note the following:

- By retrofitting the worst 5% buildings, fatality risk will be significantly reduced by 26%.
- By retrofitting the worst 38% buildings, fatality risk will be significantly reduced for 80% of population.
- Systematic seismic upgrade of certain vulnerable structures and will have a significant impact on casualty risk and damage

It was estimated that the total inventory (replacement) cost of all buildings to equal $US1.0 billion and the total loss anticipated from a design earthquake to be $US 820 million. By contrast, the seismic upgrade cost is significantly less as shown in Table 4.

Table 4 - Seismic upgrade costs from probabilistic evaluation

% Number of buildings	Seismic upgrade cost in $US million
Worst 100 (Magenta)	$US25-50
5% (186) (Red+)	$US40-80
38% (Yellow+)	$US180-360
80% (3000) (Green+)	$US300-600
100% (3821)	--

Therefore, as an example, seismic upgrade of the worst 100 buildings (3% of inventory) will cost $US25-50 million dollars. However, such program will not only result in saving of over 4,000 lives but also preserve the infrastructure that is substantially more valuable than the cost of the seismic upgrade. It is further noted that such a seismic upgrade will ensure that these facilities are available to serve as shelters for other natural disasters such typhoons. Furthermore, such an upgrade program can be expanded to the entire country.

6 EARTHQUAKE STRENGTHENING Guidelines

The Guidelines for Earthquake Strengthening and Upgrading of Public Schools and Hospitals in Metro Manila have been published to assist in addressing the seismic design requirements and is intended to be used as a supplement to the 2010 edition of the Philippine Earthquake Code (ASEP 2010. The National Code is used for the design of new buildings. In the Guidelines, the Life Safety (LS) performance level at the design earthquake is used for evaluating existing buildings.

The Guidelines are divided into three volumes. The three volumes focus on:

- Volume I of the Guidelines provides a prescriptive methodology for evaluating and upgrading school and hospital buildings. The provisions in this document are suitable for a great majority of public buildings.
- Volume II of the Guidelines provides detailed background information, and advanced analysis and evaluation techniques, including the use of performance-based engineering. This is intended for a few nontraditional buildings.
- 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. As importantly, retrofit details are provided to assit local engineers.

Volumen III of juilines is the most practical for typical Buildings. The drawings from a school Building were used and mathematical model of the building was prepared; see Fig. 7. The example building was then analyzed and its seismic deficiencies identified using the procedures described in Volume I. Next the model was updated to incorpórate retrofit measures and analyzed; see Fig. 8. Finally typical details for implementation of seimic retrofit were presented; see Fig. 9.

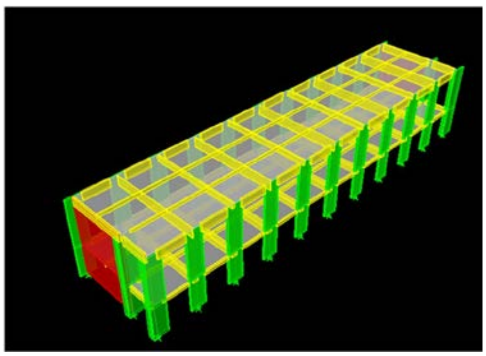

Fig. 7 Mathematical modle of example building

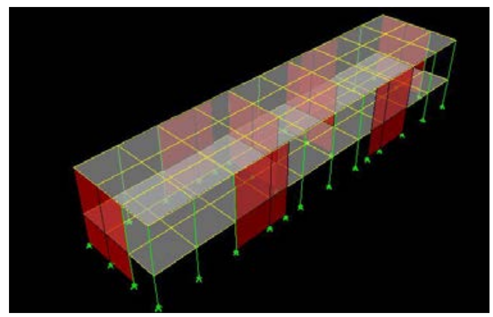

Fig. 8 Model of retrofitted building

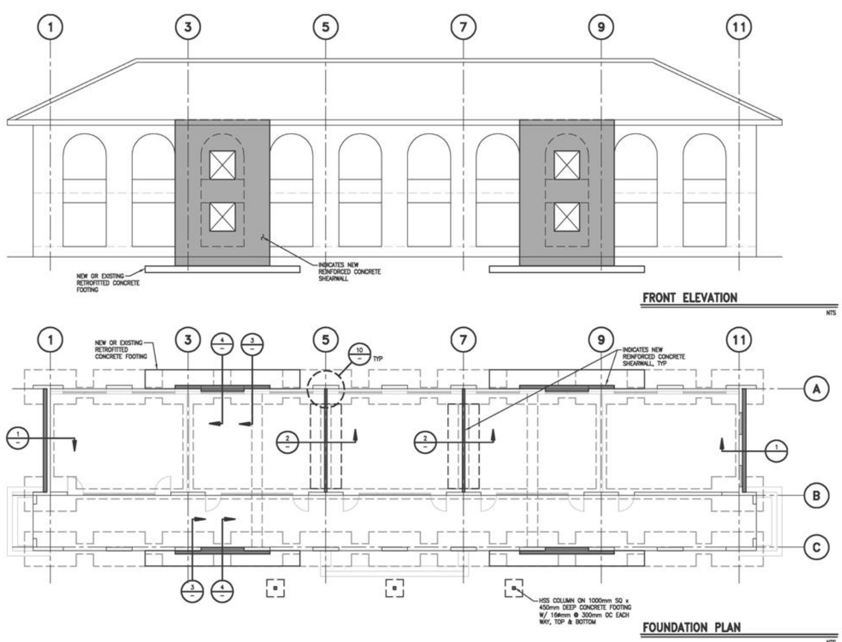

Fig. 9 Plan and elevation for added shearwalls

6.1 Seismic Strengthening Approach

The proposed seismic strengthening scheme for the lateral force resisting system (LFRS) members is presented in Table 5 -. For deficient buildings, either new reinforced concrete shear walls or BRBF systems are proposed; see Fig. 10.

Table 1. Proposed upgrade matrix for vertical elements of LFRS

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

Addition of new shearwall

Addition of BRBF

Fig. 10 Proposed seismic retrofit options

7 Conclusions

Metro Manila Philippines is one of the most populated cities in the world and the economic and commercial center in Philippines. 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% of population.
- A ranking algorithm was developed and implemented, using the available database from Philippines and data from field surveys. The fatality and structural loss were used as the ranking parameters of interest. The

* 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

algorithm showed that a subset of small number of buildings contributed the most to fatalities; approximately 25% of fatalities occurred in 5% of buildings.

- The strengthening of these 5% buildings can be achieved at accost of US $40-80 million and will result in saving over 6000 lives in a design earthquake.
- Guidelines for seismic strengthening were published. The document included strengthening details and design examples for local engineers.

8 Acknowledgements

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