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GLOBAL SEISMIC RISK REDUCTION PROGRAMS: INTERNATIONAL PERSPECTIVE ON THE SUCCESSFUL APPLICATION IN ISTANBUL

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ABSTRACT

Worldwide, a large percentage of school and hospital buildings in areas of high seismicity, constructed of unreinforced masonry or non-ductile concrete, have been vulnerable to damage from earthquake and have suffered disproportional damage and collapse resulting in loss of life and in particular injuries and fatalities.. The performance of school buildings in past earthquakes has typically been worse than typical residential and commercial buildings which is in contrast of what the population believed before the event. To address seismic vulnerability of public and school buildings, the World Bank has initiated several projects in the past decade assessing seismic vulnerability in several vulnerable and heavily populated locations such as Istanbul, Philippines, and Haiti. These programs follow a national-international partnership and are comprised of several components including: a) seismic vulnerability assessment, b) prioritization and cost-benefit analysis, c) development of seismic retrofit guidelines, d) emergency preparedness planning, e) stakeholder communication management, and f) seismic retrofit implementation. As a corollary to such programs, it is expected that the overall level of technical expertise in both design and construction sectors will be enhanced and thus result in construction of better buildings besides schools. A successful application of such a World Bank project is the seismic retrofitting of public school buildings in Istanbul. The government of Istanbul, under the auspices of the World Bank has developed the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, with the main objective of providing life safety performance for as many buildings as possible under the available funding. As part of the project, a comprehensive seismic assessment and retrofit guideline was developed by national engineers and international experts. Extensive, multi-layer design reviews and construction inspections are conducted. To date, over 1500 buildings have been retrofitted and the effort is on-going. The success of Istanbul project has resulted in similar programs being considered elsewhere and using the Istanbul project as a template. In Metro Manila currently data is being collected and both a seismic retrofit guideline and a state of art prioritization methodology have been developed. In the next phase the first batch of 200 buildings considered most vulnerable are slated for more in-depth investigation and seismic retrofit.

INTRODUCTION TO ISMEP

The 1999 magnitude 7.6 Izmit (Kocaeli) and magnitude 7.2 Duzce earthquakes caused extensive damage. Fatalities exceeded 18,000 while casualties exceeded 50,000, with a direct financial loss of

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over US $6 billion. High ground accelerations were recorded. Many vulnerable structures collapsed or were severely damaged during these earthquakes, The historic city of Istanbul is Turkey's largest city. More than 20% or the country's population lives in Istanbul and the metropolitan area generates a large portion of Turkey's GDP. The city has grown substantially since the 1999 earthquakes. It is located in an active earthquake region. Its seismicity is comparable to California and Japan. Similarly to these areas, there is a high probability of a major earthquake occurring in the next 20 to 40 years. Without extensive building strengthening throughout the city, such an earthquake will result in high casualties and tremendous economic losses. These factors served as the background for the World Bank project described here.

The government of Turkey and the International Bank for Reconstruction and Development (IBRD) entered into a loan agreement implementing the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The goal was to improve the city of Istanbul's preparedness for a future earthquake. Seismic retrofit of school and hospital buildings vulnerable to earthquake damage is of great political and social importance in Turkey. The last two major earthquakes in the region have shown the vulnerability of these buildings in particular and of the built environment in general.

As part of this effort Guidelines for seismic retrofit of schools and hospital facilities in Istanbul, has been developed. The aim of the proposed is to implement a procedure that leads to safeguarding Istanbul school and hospital buildings against a future earthquake in the area. The project scope is intended to protect as many buildings as possible, use cost-effective methodologies, produce on-schedule and high-quality construction, and ensure that the buildings meet their performance objectives. Fully implemented, the Guidelines describe retrofit methods that would significantly improve the seismic performance of school and hospital buildings in Istanbul. To remain cost-effective, a certain level of building damage is considered acceptable for school buildings, but Immediate Occupancy and Life Safety performance is highly likely. In this Guideline, supplements to Turkish Earthquake Code (herein referred to as TEC2007) are proposed for use specifically under the scope of ISMEP. These supplements are intended to increase confidence that collapse is prevented and damage is limited. The overall objectives are to minimize the retrofit cost, achieve acceptable earthquake performance, and to allow more buildings to be evaluated.

Figure 1 depicts a vulnerable building in Istanbul taken during a recent site visit and condition-assessment survey. For this building, the walls terminate above the first floor to allow for parking. This introduces a soft-story mechanism at this level and can lead to collapse in a future earthquake. Once such dangerous buildings are identified, it is important that steps be taken to address the vulnerabilities. Many thousands of school, hospital, and government buildings in Istanbul use reinforced concrete moment frames. There are over a dozen sub-groups within the same design group. The main differences between the various subgroups are the layout of the frames, geometry of the structures, and presence of URM walls. The most common type (see Figure 2) is a three or four story, regularly configured building, with a basement, and an emergency staircase attached to the short sides of the structure.

Figure 1. A vulnerable structure

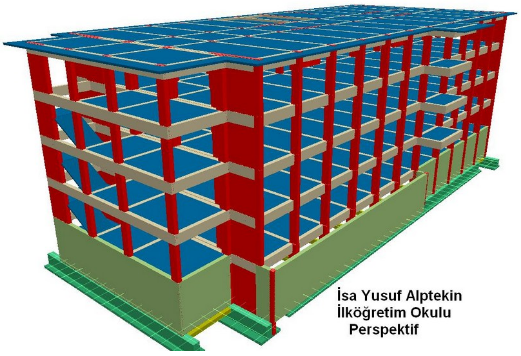

Figure 2. Schematics of a building

The primary goals of the project, as listed by IPCU are:.

- Increasing emergency preparedness and response awareness
- Retrofitting/Reconstruction of priority public buildings; Vulnerability inventory and project design for cultural and historical heritage assets
- Taking supportive measures for the efficient implementation of building codes.

The cost breakdown for the above tasks is approximately as following: Enhancing emergency preparedness (18%), Seismic risk mitigation and retrofitting/reconstruction (78%), enforcement of building code (2%), and project management (2%).

RETROFITTING AND RECONSTRUCTION OF PUBLIC BUILDINGS

Task organization

In order to ensure the successful implementation of the project, a collaborate effort between domestic and international consulting engineering companies was required and established. This arrangement took advantage of the strength of both groups. The local engineers are familiar with the in-situ designs and construction practices and can readily identify vulnerable structures. The international consultants, mostly from other well known earthquake-prone countries, are well-versed in the science and art of seismic rehabilitation and can more readily identify deficiencies in proposed retrofits, given their expertise and extended background in earthquake engineering rehabilitation practice. The international consultants also typically have extensive earthquake retrofit experience around the world and are familiar with the latest and most cost-effective retrofit techniques. Academics from Turkey were also involved in the review of the completed designs, as well as assisting in the development of criteria and guidelines for the work.

Rehabilitation Guidelines

The objectives of this project are to identify, evaluate, and retrofit/reconstruct as many vulnerable structures as possible with the available funding. To ensure that the project would strengthen and/or rebuild cost-effectively as many structures as possible, the project participants developed guidelines for selection and rehabilitation of vulnerable structures. The guidelines (IPCU 2007) are based on the provisions of the Turkish code (TEC 2007) with input from ASCE 41 (2006) and other relevant publications from around the world. While the Turkish code is written for new construction, the Guidelines are intended for retrofit work. In order to ensure that the project would encompass as many structures as possible, the Guidelines are less stringent than the current Turkish code. Certain levels of damage are deemed acceptable in the provisions. The key provisions of the Guidelines are as follows:

- Condition assessment. Data are gathered in sufficient detail to identify structural and nonstructural components that participate in resisting lateral loads, and potential seismic deficiencies in load-resisting components. As-built condition evaluations should utilize construction documents and testing, among other resources.
- Seismic deficiencies. Common structural deficiencies, such as irregular configuration, non-ductile reinforcement detailing and URM infill walls are identified.
- Seismic hazard. The seismic demands are defined in terms of design response spectra or suites of acceleration time histories. The hazard due to earthquake shaking is defined on either a probabilistic or deterministic basis.
- Analytical procedures. Acceptable procedures, ranging from simplified static to nonlinear dynamic analyses, is allowed based on structural configuration and retrofit..
- Structural performance levels. Various performance levels are defined and the level of damage for each level is described. The appropriate performance level for a given earthquake intensity is identified. More detail is provided below.
- Retrofit. Both conventional and innovative techniques are described. Innovative, but generally accepted methodologies are encouraged.

The Guidelines strenuously attempt to address and correct the weaknesses of recent and current general Turkish earthquake engineering and construction practices while incorporating state-of-the art practices from around the world, and particularly from countries that have conducted extensive and systematic strengthening of structures in earthquake regions over many years. This also includes considerations related to other systemic issues, such as engineering education and licensing. Many of the buildings that have already been strengthened were constructed relatively recently.

Specified performance levels

A key feature of the provisions is the use of performance based engineering (PBE). In PBE, three structural performance levels are considered: Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). These performance levels relate to damage states for elements of lateral-force-resisting systems and have specific drift limits as shown in Figure 3. The IO limit state implies that only limited structural damage has occurred. The basic vertical- and lateral-force-resisting systems of the building retain nearly all their pre-earthquake strength and stiffness. The LS damage state implies that significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. The CP performance level implies that the post-earthquake damage state of the building is on the verge of partial or total collapse. However, all significant components of the gravity-load-resisting system continue to carry their load. Although the retrofit objectives are project specific, typically it is expected that the retrofitted buildings will attain IO, LS, and CP, for the service, design, and extreme earthquakes, respectively. Such performance levels are expected from the rehabilitated (strengthened) public buildings in Istanbul.

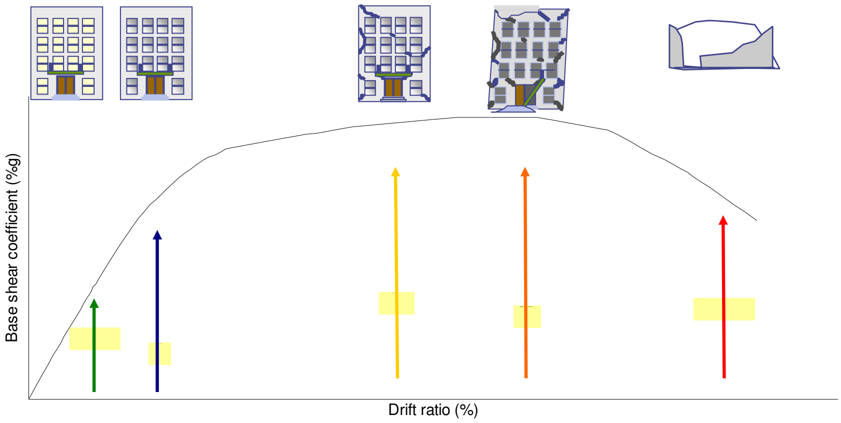

Figure 3. Performance Levels

Retrofitted buildings would satisfy the LS performance level if both of the following conditions were met.

- Not greater than 40 % of the primary beams should be in the “Severe Damage Zone” for any direction of earthquake loading. If at least 75% of the total base shear force for any direction of loading can be carried by shear walls, the performance of the beams can be ignored.
- The ratio of the sum shear force carried by the columns and shear walls in the “Severe Damage Zone” to the total shear force at any storey for any direction of loading should be less than or equal to 0.4 for the top storey, and 0.2 elsewhere.

Retrofitted buildings would satisfy the IO performance level if both of the following conditions were met.

- Not greater than 20 % of the primary beams should be in the “Severe Damage Zone” for any direction of earthquake loading. If at least 75% of the total base shear force for any direction of loading can be carried by shear walls, the performance of the beams can be ignored.
- All the columns and shear walls should be in “minimal damage zone” for any direction of earthquake loading.

Implementation

To successfully implement the project and to transfer as much technology as possible, the international consultants work closely with the local engineers. To ensure that the retrofits are properly designed and constructed, international consultants review both the design and construction phases. They also often participate directly in the engineering designs. Their findings are submitted to IPCU as individual project reports. In the design phase, structural plans and calculations are reviewed to ensure that the retrofit is effective, it does not introduce structural irregularities, a clear load path is defined, and the response of the existing structural members is accounted for. In the construction phase, the consultants visit the site to survey the retrofit work first hand. During their site visit, they determine if the construction is following what has been prescribed in the plans, and whether the retrofit as proposed and implemented is robust enough.

In addition to the reviews at the design level, two additional design reviews are conducted. A World Bank earthquake engineering consultant reviews the general quality and direction of the project work while an earthquake engineering consultant to the IPCU reviews further many specific projects. The IPCU spends much of its time assuring the quality of both the designs and the construction. This redundant system for quality assurance is a primary factor in the success of this complex and large project.

To date, over 1500 structures have been strengthened or reconstructed (completely rebuilt) and vulnerability assessment of selected cultural buildings have been undertaken (WB 2014) . The bulk of the effort has been concentrated on schools and hospitals. These type of high-occupancy and essential facilities have been vulnerable in the past and their poor performance has had tragic consequences. As such, they rightfully belong to the top echelon of the retrofit program. It is also noteworthy that roughly seven school buildings, for example, can be strengthened for every single building that is rebuilt completely.

Retrofit case study

The addition of shear walls (schematics shown in Figure 4 and construction photograph for a school building is shown in Figure 5) is the most widespread retrofitting method for the Istanbul strengthening work. This technique is attractive because of its effectiveness, relative simplicity of construction, and cost effectiveness. The key reason for effectiveness is that the additional shear walls are designed to resist a large portion of the lateral seismic loads, which significantly reduces the demand on the existing frame members. This technique has been widely used to retrofit a significant number of public schools and hospitals in Istanbul, as well as in California, Japan, New Zealand, etc.

The IPCU independent consultants reviewed in detail a number of proposed retrofits with new shear walls. To ensure proper design and construction, they have recommended that the following be revised/incorporated in the final designs:

- The walls must be designed and detailed to have adequate ductility.
- Connections between new and existing structural members should be properly designed.
- The existing members should be analyzed to ensure they could resist the imposed loads.
- Diaphragms, collectors, and diaphragm anchorage to the new walls should be evaluated.
- Connections between existing and new concrete components shall be checked.

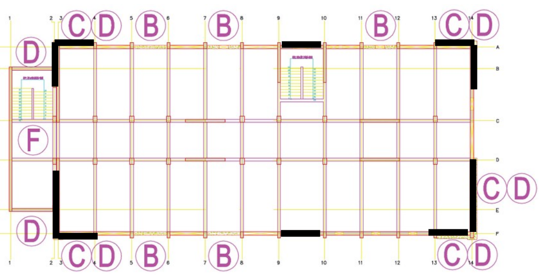

Figure 4. Example of retrofit with new concrete walls

Figure 5. Construction of exterior concrete walls for a school retrofit

APPLICATION OF THE ISTANBUL PROJECT TO METRO MANILA

Following the successful development and implementation of ISMEP, the WB and Government of Philippines are currently working on developing a similar program for Metro Manila. This project will use similar methodology as ISMEP; however, will utilize multihazard methodology for prioritization because Metro Manila is subject to a number of natural hazards.

Given its geographic and geologic conditions, the Philippines is particularly vulnerable to damaging socioeconomic impacts from earthquakes and other natural hazards. Because such a large percentage of the Philippine population resides in the greater Manila area (approximately 13%), and Metro

Manila is the major commercial hub of the country (30% of the Philippine GDP), a natural disaster could have substantial human and financial impacts. As such, it is vital to develop a multihazard evaluation and seismic retrofit program for this important metropolitan area. The key components of a well-designed retrofit program are:

- Multihazard assessment
- Development of an appropriate seismic retrofit guidelines
- Identification (prioritization) of buildings for retrofitting to ensure that available funds are allocated optimally

The *Guidelines for Seismic Retrofitting of Public Schools and Hospitals in Metro Manila* has 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 are to be used as a supplement to the 2010 edition of the Philippine Earthquake Code (ASEP 2010) whose 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. 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.
- This 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, provisions of Volume I will be used and the design examples and detailing provided in Volume III to be utilized. 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. Reinforced concrete–frame construction is prevalent in Metro Manila for most school buildings and many hospitals; therefore, this document focuses on that type of construction. The procedure specified in the Guidelines for a given building is as following:

- Determine the seismic hazard for the building per National Code
- Perform 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 limit drift ratio 1%. Provide detailing as presented in Volume III
- Check nonstructural component anchorage and nonbuilding structures such as water towers.

COST-BENEFIT ANALYSIS FOR METRO MANILA PUBLIC BUILDINGS

Cost-benefit analysis (CBA) was performed and applied to the database of buildings to prioritize the buildings based on the expected number of fatalities. In addition, an estimate of cost associated with seismic upgrade of vulnerable buildings was prepared. Given that the focus of this study is on public schools and hospitals in Metro Manila, main goal is to identify whether the buildings studied need to be retrofitted and, if so, what the costs and benefits are. The status quo (no retrofit) is used as the baseline, and the benefits derived from a seismic upgrade program and the costs associated with such an approach are quantified. The cost algorithm is based on fatalities and uses hazard, exposure, and building vulnerability as input; see Figure 6.

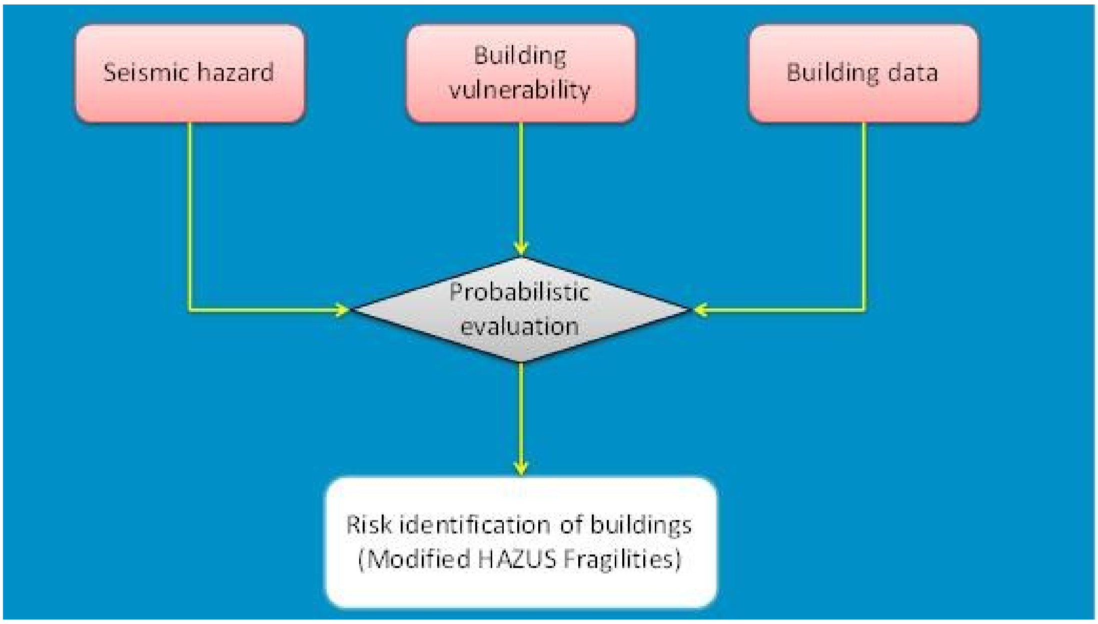

Figure 6. Prioritization process

- Seismic hazard. The seismic hazard map were input as a layered map for analysis. Data is based on the provisions of the National Code
- Exposure. A database that lists the number of occupants for the facilities under consideration. Field surveys have been conducted by the project team and data from these surveys were used to augment and modify the databases.
- Building Vulnerability. The risk analysis platform provides fragility information for various building types. In this project, the fragility were based on the recommended values of FEMA HAZUS (FEMA 2003) and modified for Metro Manila.

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Findings

The geographic distribution of buildings based on the number of fatalities is shown in Figure 7. 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

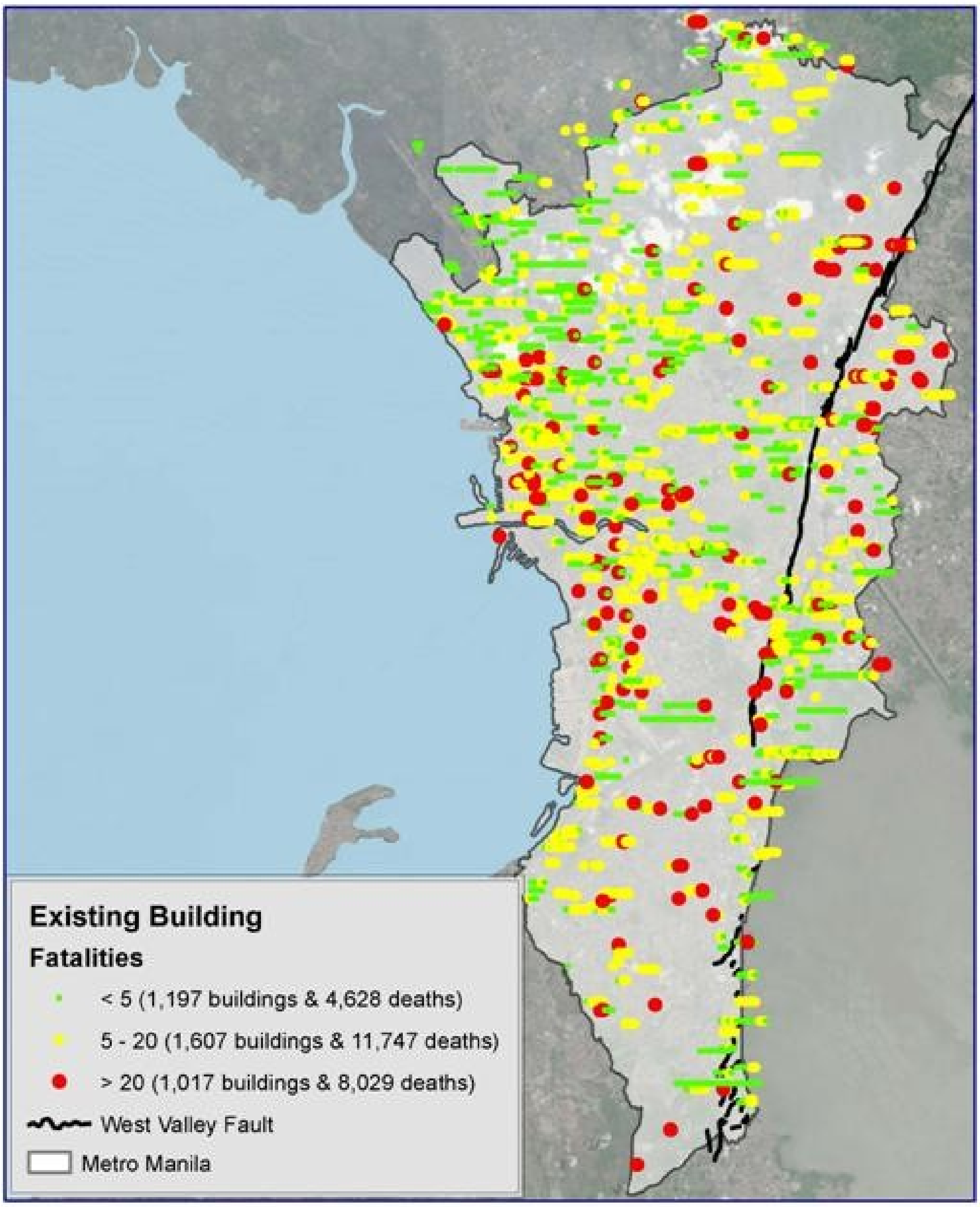

Figure 7. Geographical distribution of schools based on the estimated fatalities

The buildings can thus be ranked based on the number of fatalities, and indicate that the seismic upgrade of the worst 100 buildings (3% of inventory) will cost approximately $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.

Typical school 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 8 presents a typical school building.

Elevation and plan view for a typical school building is shown in Figure 9. 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 feet wide and typical floor height is approximately 10 feet tall.

Figure 8. Typical school building

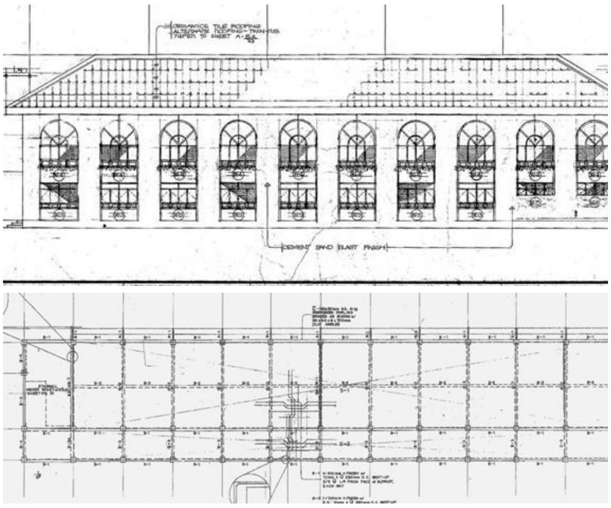

Figure 9. Elevation and plan view

CONCLUSIONS

The Istanbul retrofit project developed under the auspices of the World Bank and ISMEP is intended to be used to mitigate earthquake hazard for schools and hospitals in Istanbul. The success of this project has led to development of similar activities to be undertaken elsewhere including in Philippines.

- Istanbul provides an excellent example of cooperation between world and Turkish government agencies, local engineers, and world experts in mitigating earthquake hazards for essential buildings and for vulnerable structures. It is expected that when the project is fully implemented, it will significantly reduce damage from seismic hazard for the Istanbul schools and hospitals.
- The seismic guideline is primarily based on TEC2007. However, recent research data and knowledge from ASCE 41 is also implemented. The Guidelines can be used as an effective tool in assessing existing conditions, identifying vulnerable components, and devising cost-effective retrofits. The Guidelines used performance based engineering and hence can lead to a more realistic assessment.
- Given the high earthquake hazard present in Metro Manila and in Philippines and the large number of suspect buildings present in these areas, it is important to keep the lessons of recent devastating earthquakes in mind and use the Istanbul project as an example and address the vulnerable structures.
- In the initial phase of risk assessment and mitigation process, a ranking algorithm was developed to select the priority buildings in Metro Manila and a retrofit guideline was prepared to allow for systematic strengthening of vulnerable public school buildings in Metro Manila.

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