A COMPUTER-AIDED SEMI-QUANTITATIVE SEISMIC RISK ASSESSMENT TOOL FOR SAFE SCHOOL BUILDINGS

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ABSTRACT

Risk assessment is the first step in making schools safer against seismic hazards like ground shaking, liquefaction, tsunami and landslide. It is important that such risk assessments involve the primary stakeholders such as school administrators and officials, but the tools utilized by the agency responsible for such assessments, the Department of Public Works and Highways (DPWH) are limited to screeners with a good background of engineering. Employing a semi-quantitative risk assessment that assesses qualitatively the school building's assets, seismic hazards and vulnerabilities to the various hazards would allow the school administration and staff to participate in the decision-making process. A seismic risk index, defined as the product of these three factors categorizes the school buildings to be at low risk, medium risk or high risk to a specific seismic hazard. Through the computed indices, the school buildings in a specific compound are ranked and prioritized for further detailed inspections and possible repair or retrofitting. Mitigation procedures are recommended based on the identified vulnerabilities to reduce the risk. This paper presents the conceptual framework of the research and the semi-quantitative risk assessment methodology.

Keywords: Hazards, Vulnerability, Risk Assessment, Schools, Safety.

1. INTRODUCTION

Worldwide, the risk of school facilities and more importantly, the children against seismic hazards is very high especially in countries situated in the Pacific Ring of Fire such as the Philippines. 875 million school children, who are among the most vulnerable groups in societies, enter schools which are situated in high seismic areas regularly (INEE & GFDRR, 2009). Seismic hazards such as ground shaking, landslide, soil liquefaction and tsunami could significantly disrupt teaching functions of educational facilities. Thus, the One Million Safe Schools and Hospitals Campaign was launched by the United Nations International Strategy for Disaster Reduction (UNISDR) to advocate for risk reduction in such facilities, assure continuity of its functions and more importantly, to protect the lives of the people.

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To promote safe school facilities against seismic hazards, seismic risk assessments must be conducted by government institutions such as the Department of Education (DepEd) and Department of Public Works and Highways (DPWH) for the Philippines. But, the risk assessment must not only involve inspectors, but also primary stakeholders such as school administrators and officials. In fact, UNISDR launched a global campaign during last 2006, entitled "Disaster Risk Reduction Begins at Schools", giving emphasis to the role of the school administration in risk reduction. *The first step to risk management is the conduct of risk assessments, involving the primary stakeholders in the risk management team* (DepEd, 2008).

For the school administrators to participate in the decision-making process and be aware of the risks of their school buildings, a semi-quantitative risk assessment is proposed. That is, the assessment would involve qualitative observations with some minimal calculations which are quantified through a methodology developed by the Federal Emergency Management Agency (FEMA). The seismic risk is defined through the assessment of the school building's assets, hazards and vulnerabilities using FEMA 428 (FEMA, 2003). With the initial assessment of the school buildings through a computer-aided risk management tool, the school administration would be able to determine and prioritize high risk buildings for further inspections to DepEd and DPWH.

2. FRAMEWORK OF SEMI-QUANTITATIVE RISK ASSESSMENT

A semi-quantitative risk assessment procedure was adopted in the study which involves three main factors: asset, hazard and vulnerability. Each of these factors has weighted parameters which would define the rating of the school building's asset, hazard and vulnerability. Risk is then defined as the product of these three risk factors:

$$\textbf{Risk} = \textbf{Asset x Hazard x Vulnerability} \quad (1)$$

Figure 1 shows a summary of the framework. The asset value may be defined as the population in the structure, its functions and processes, or its importance rating depending on the risk assessment priority defined by the user. The hazards are the seismic risks: ground shaking, landslide, soil liquefaction and tsunami which were quantified based on the earthquake source and the site condition. Lastly, vulnerability is the degree of susceptibility of the structure and the people in the building which is divided into three: Structural, Non-structural, and Social Vulnerability.

Relevant parameters that contribute to the rating of asset, hazard and vulnerability are identified and enumerated in a checklist. For each parameter related to asset, hazard and vulnerability, the assessor identifies the parameter's attribute as low, medium or high risk which has a corresponding nominal value of 1, 2 or 3, respectively. A description of the various attributes of the parameters is given to guide the assessor in deciding which attribute to choose. The nominal scores for each jth parameter for asset, hazard and vulnerability are defined by the variables: $\mathbf{A_{Pj}}$ (Asset value for parameter j), $\mathbf{H_{Pj}}$ (Hazard value for parameter j) and $\mathbf{V_{Pj}}$ (Vulnerability value for parameter j), respectively. To obtain the aggregate rating for asset, hazard and vulnerability, each parameter is multiplied by a weight ($\mathbf{w_{aj}}$, $\mathbf{w_{hj}}$, $\mathbf{w_{vj}}$ = weights for asset, hazard and vulnerability parameter j, respectively). Following the FEMA 455 (2009) methodology, the parameters are weighted depending on their importance to the factor which can be assigned or determined through a survey from experts. Each parameter is categorized as of low, medium, high or very high importance. FEMA 455 assigns nominal values for the importance rating: Low (1), Medium (2), High (4), and Very High (8). The weight of the parameter is obtained by normalizing the importance rating such that the sum of the weights for the set of parameters for asset, hazard and vulnerability is equal to 1. Multiplying the nominal scores of each parameter by its corresponding weight and taking the sum will result to the rating for asset, hazard and vulnerability as defined by the equations:

- Asset value rating for hazard i: $\mathbf{A_i = \Sigma w_{aj} \times A_{Pj}}$ (2)
- Hazard rating for hazard i: $\mathbf{H_i = \Sigma w_{hj} \times H_{Pj}}$ (3)
- Vulnerability assessment rating for hazard i: $\mathbf{V_i = \Sigma w_{vj} \times V_{Pj}}$ (4)

The product of the ratings of the three factors would result to the seismic risk index for each hazard (ground shaking, landslide, soil liquefaction and tsunami):

$$\mathbf{R_i = A_i \times H_i \times V_i} \quad (5)$$

The risk index per seismic hazard is then classified based on a range of values as low risk, medium risk and high risk.

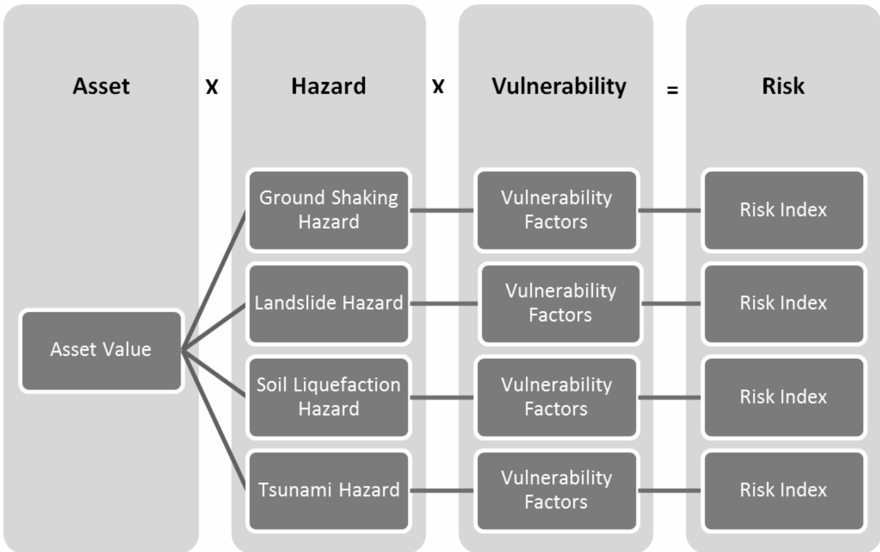

Figure 1: Seismic Risk Assessment Framework

3. DESCRIPTION OF SEISMIC RISK FACTORS

3.1 Asset Value

The asset value is the rating associated to the school building depending on the three parameters: population, function and importance. **Box 1** shows a summary of the Asset value parameters.

3.2 Seismic Hazard Rating

The seismic hazard rating depends on the earthquake source and site parameters. The earthquake source parameters are the fault location and the earthquake source type. For each type of earthquake hazard, there are relevant site hazard parameters. **Box 2** shows the seismic hazard source parameters and site hazard parameters.

Box 1. Asset Value Parameters and Their Attributes

a. School Population (FEMA, 2002)

- Low = Below 100 people;
- Medium = 101 to 1000 people; and
- High = Over 1000 people.

b. Consequences to Functions and Processes (FEMA, 2003; CSSC, 1999)

- Low = Slight impact on core functions and processes for a short period of time: the school facility remains operational for teaching and serving as an evacuation center although utility service may be provided by emergency sources;
- Medium = Moderate to serious impairment of core functions and processes: utility service may or may not be available but the building is available for normal occupancy as an evacuation center; and
- High = Major loss of core functions and processes for an extended period of time: utility service is not available and many services would not function, thus the building is not available for normal occupancy.

c. Critical Components/Information Systems (FEMA, 2003)

- Low = The building houses the sports facilities, vocational equipment (shops), laboratories, custodial functions and the library;
- Medium = The building houses food service, temporary classrooms, administrative functions, security equipment, clinic, transportation facilities and utility systems associated with shelter; and
- High = The building houses the IT/Communication systems, designated shelter, power generators and school/student records

3.3 Vulnerability Assessment

The vulnerability assessment is the susceptibility of the school building's assets against specific seismic hazards. It is divided into three categories: structural, non-structural and social vulnerability. For every seismic hazard, there are significant structural vulnerability parameters. **Box 3** shows some the structural vulnerability parameters of school buildings related to ground shaking.

Box 2. Earthquake Source & Site Hazard Parameters & Their Attributes

Source Parameters :

a. Fault Location (Banatin et al., 2009; UN-Habitat et al., 2013; ASEP, 2010)

Reference: *http://www.phivolcs.dost.gov.ph/index.php?option=com_content&view=article&id=78&Itemid=500024*

- Low = Over 10 km-15 km to the fault line;
- Medium = Over 5 km-10 km to the fault line; and
- High = 5 km and nearer to the fault line.

b. Earthquake Source Type (ASEP, 2010)

Reference: *Philippine Institute of Volcanology and Seismology (PHIVOLCS)*

- Low = The magnitude of the earthquake is less than 6.5 (Source Type C);
- Medium = The magnitude of the earthquake is from 6.5 to 7.0 (Source Type B); and
- High = the magnitude of the earthquake is 7.0 or higher (Source Type A).

Site Parameter for Ground Shaking Hazard

a. Soil Foundation (ASEP, 2010; INEE & GFDRR, 2009; FEMA, 2007)

- Low = Hard Rock; Rock (S_A & S_B);
- Medium = Very Dense Soil and Soft Rock; Stiff Soil Profile (S_C & S_D); and
- High = Soft Soil Profile (S_E & S_F).

Box 3. Structural Vulnerability Parameters for Ground Shaking & Their Attributes

a. Construction Date (FEMA, 2002)

- Low = 1992 and beyond (Post-benchmark);
- Medium = Between 1972 and 1992; and
- High = Before 1972 (Pre-Code).

b. Plan Irregularity (PAHO, 2008)

- Low = Shapes are regular, structure has uniform plan, and there are no elements that would cause torsion;
- Medium = Shapes are irregular but structure is uniform; and
- High = Shapes are irregular and structure is not uniform.

c. Vertical Irregularity (PAHO, 2008)

- Low = Stories of similar height (they differ by less than 5%); there are no discontinuous or irregular elements;
- Medium = Stories have similar heights (they differ by less than 20% but more than 5%) and there are few discontinuous or irregular elements; and
- High = Height of storeys differs by more than 20% and there are significant discontinuous or irregular elements.

d. Building Proximity (PAHO, 2008)

- Low = Separation is more than 1.5% of the height of the shorter of two adjacent buildings;
- Medium = Separation is between 0.5% and 1.5% of the height of the shorter of two adjacent buildings; and
- High = Separation is less than 0.5% of the height of the shorter of two adjacent buildings.

3.4 Risk Factor Computation

Before combining the scores of the appropriate parameters of each risk factor to obtain the rating for asset, hazard and vulnerability, each score is multiplied by a normalized weight. The parameters are first assessed depending on their importance to asset, hazard or vulnerability. Following FEMA 455, a qualitative rating is also used. The qualitative rating with their corresponding importance scores are: Low (1), Medium (2), High (4), and Very High (8). The assignment of the importance can be based on a survey of experts. The normalized weight for each parameter is then obtained by dividing its importance score by the sum of the importance scores of all parameters for the risk factor. **Table 1** shows a sample computation for the weights of the seismic hazard parameters related to ground shaking. The normalized weight for the parameter fault location in Table 1 is equal to 4/16 or 0.25. Assuming that the assessment for the Hazard parameters is as follows: Fault Location: Medium (2), Earthquake Source Type: High (3) and Soil Type: Low (1), then the Ground Shaking Hazard Rating is computed as 0.25 x 2 + 0.50 x 3 + 0.25 x 1 = 2.25.

Table 1: Sample Weighting for Seismic Hazard Rating

Hazard Parameters	Importance	Weight	Normalized Weight
1. Fault Location	High	4	0.25
2. Earthquake Source Type	Very High	8	0.50
3. Soil Type	High	4	0.25
	Total	16	

Table 2 summarizes the complete list of parameters related to the risk factors (Asset, Hazard and Vulnerability). The table also lists the parameters for site hazard and vulnerability for the four seismic hazards – ground shaking, landslide, soil liquefaction and tsunami. As discussed in the

framework, each parameter has attributes corresponding to rating of low (1), medium (2) and high (3) for the guidance of the assessor.

Table 1: Asset, Hazard and Vulnerability Parameters

Asset Value			
1. School Population 2. Consequence to Functions and Processes		3. Critical Components/Information Systems	
Hazard Rating			
A. *Earthquake Source Hazard*			
1. Fault Location 2. Earthquake Source Type			
B. *Site Hazard*			
Ground Shaking	Landslide	Soil Liquefaction	Tsunami
1. Soil Type	1. Hill Setback 2. Hill Slope 3. Groundwater Table 4. Drain Condition and Discharge Capacity 5. Vegetation 6. Excavation/Cuts	1. Soil Profile 2. Water Table 3. Reclaimed Site 4. Ground Improvement 5. History of Settlement	1. Proximity to the Coast 2. Site Elevation 3. Vegetation 4. Dune Configuration 5. Building Surroundings 6. Historical Record
Vulnerability Assessment			
A. ***Structural Vulnerability***			
Ground Shaking	Landslide	Soil Liquefaction	Tsunami
1. Construction Date 2. Plan Irregularity 3. Vertical Irregularity 4. Building Proximity 5. Building Height 6. Structural System Material 7. Number of Bays in the Short Direction 8. Column Spacing	1. Construction Date 2. Number of Floors 3. Number of Bays in the Short Direction	1. Construction Date 2. Type of Foundation 3. Condition of Foundation	1. Construction Date 2. Building Material 3. Number of Stories 4. Ground Floor Plan 5. Type of Foundation 6. Number of Bays in the Short Direction
B. ***Non-Structural Vulnerability***			
1. Support of Ceiling Materials and Fixtures 2. Detail of Window Glass Panels 3. Support of Appendages		4. Support of Vertical Elements 5. Support of Partitions	
C. ***Social Vulnerability***			
1. Contingency Plan 2. Conduct of Drills 3. Access Routes 4. Open Space 5. Evacuation for Physically Challenged People		6. Emergency Exit System 7. Safety of Doors 8. Electrical System Backup 9. Water Supply System	

4. DESCRIPTION OF THE COMPUTER PROGRAM

The seismic risk assessment methodology is developed into a program with the aid of Microsoft Visual Studio and Microsoft Access for the database. The user inputs school buildings within their compound in the database providing some basic information such as name, address, zip code, building type, construction date, population and number of floors (Figure 2). A seismic risk assessment is then performed based on the initial inquiries on the main form.

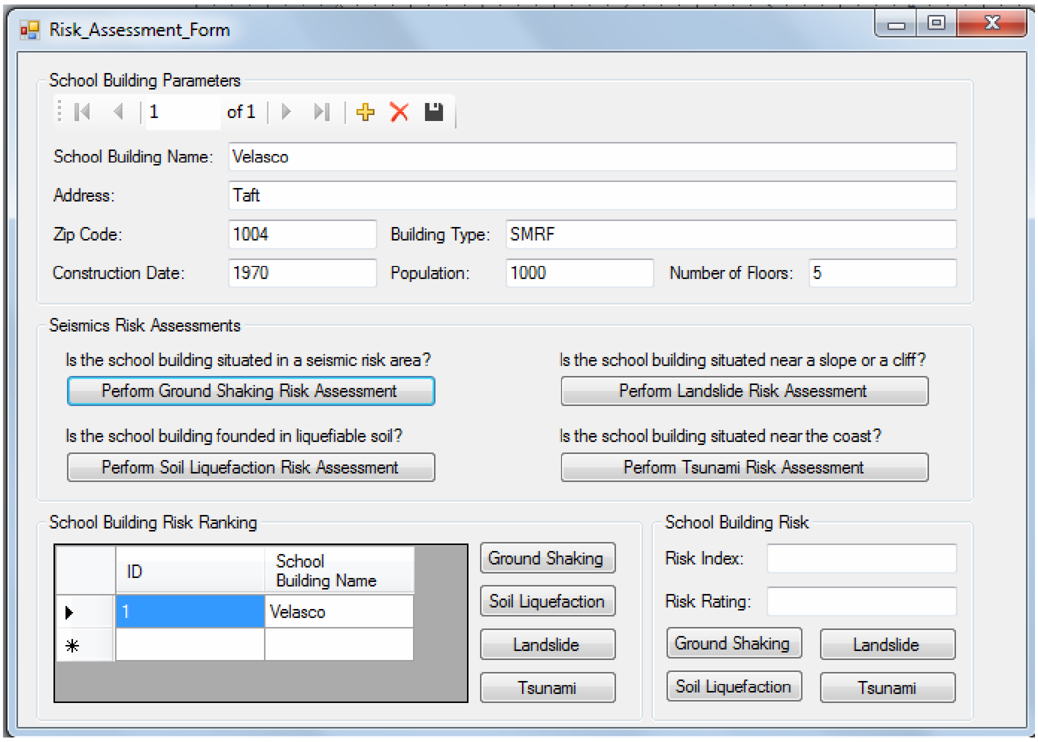

Figure 2: Seismic Risk Assessment Form

When a particular seismic risk assessment is performed, the assessor defines the asset value, hazard rating and vulnerability assessment of the school building. Each of these risk factors are rated in a particular form with guide questions presented including the criteria for the ratings (Figure 3).

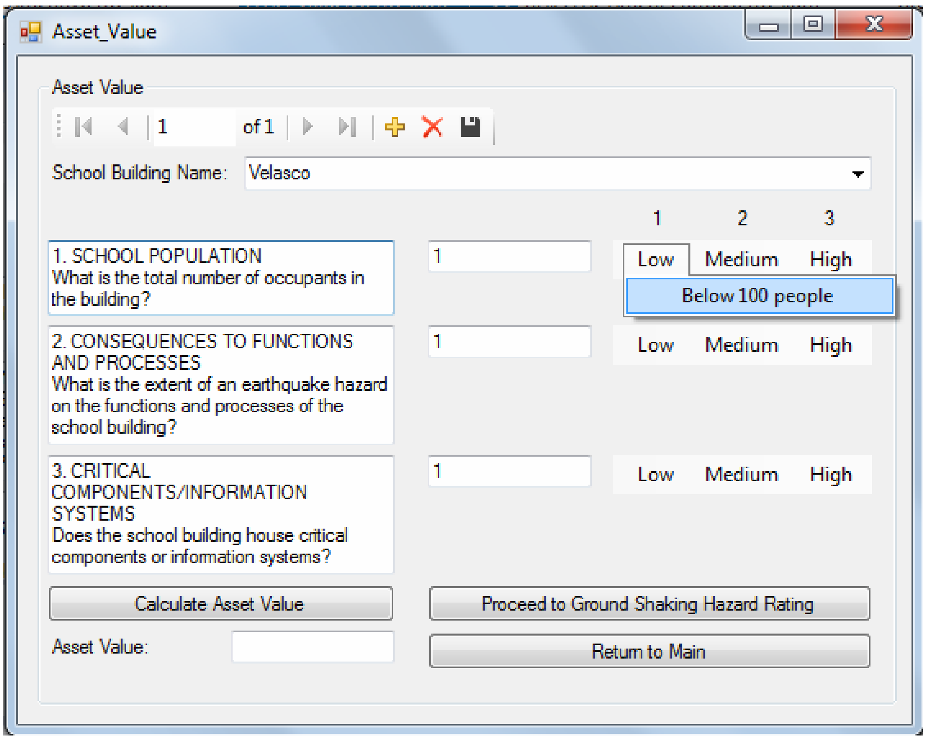

Figure 3: Asset Value Form

The risk assessment then results to a risk index which is rated as low, medium or high risk. Depending on the school building's index, the final output is the ranking of the most vulnerable building. Buildings which are categorized as high risk are given the highest priority and must be submitted to DPWH or DepEd building officials for detailed inspection. For the same risk group, the buildings are ranked according to their risk scores, the one with the highest score having the first priority in the group. Mitigation or retrofit procedures are then based according to the vulnerabilities found in the school buildings.

5. CONCLUSION

The simplified tool for a semi-quantitative seismic risk assessment allows school administrators and officials to be aware of the vulnerabilities of their school building, and thus participate in maintaining safe school communities. The methodology presented in this study would help develop seismic risk criteria based on qualitative observations of the buildings. Without the aid of engineers or technical personnel, they could be guided in identifying the most vulnerable school buildings in their compound and point the vulnerabilities of their structures. Once identified, further detailed evaluations are suggested to be conducted by the Department of Public Works and Highways (DPWH). In such manner, buildings are initially screened and thus, reduce its seismic risk.

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