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Development of a Scoring Framework and Rapid Tool for Novice Screeners to Estimate the Seismic Risk of Damage in Low-Rise Concrete Buildings in the Philippines

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Abstract – *Low-rise concrete buildings in the Philippines have been frequently damaged in past earthquakes, underscoring the need for effective seismic risk assessment. As a preliminary step toward distinguishing buildings with high seismic risk, simplified screening tools that do not require users to be specialists or expert structural engineers are commonly used, reserving the time and expense associated with full structural engineering assessments. This paper proposes an improved scoring framework and a corresponding rapid tool for screening called SCREEN, based on the probable loss that estimates the seismic risk of damage in low-rise concrete buildings in the Philippines using parameters that can be conveniently gathered by screeners who are novices, i.e., not structural engineers but have backgrounds in building design or construction. The simplified SCREEN scores were derived to approximate the results of analysis of computational models of 128 buildings with variations in seven parameters including potential ground shaking intensity, type of occupancy, shape of structure, vintage of structure, builder of structure, main material whether CHB or reinforced concrete, and width of walls between supports. For validation, SCREEN was compared with two locally developed seismic screening tools using a sample set of six (6) concrete hollow block buildings and eleven (11) reinforced concrete buildings, demonstrating high sensitivity in identifyng buildings needing engineering assessment. Meanwhile, its specificity in excluding low-risk buildings has not yet been as good. To minimize the risk of overlooking buildings with high seismic risk, this study prioritizes high sensitivity. It is recommended to test SCREEN further on a larger, diverse set of low-rise concrete buildings with independently assessed seismic risk.*

Keywords: *concrete hollow block, reinforced concrete, sensitivity, specificity*

I. INTRODUCTION

Recurring earthquakes in the Philippines have highlighted the prevalence of damage among concrete hollow block structures and reinforced concrete frame structures with one to three stories, or broadly speaking, low-rise concrete buildings, to seismic damage. Many of these structures are not formally engineered. Ironically, their resonance frequency often matches the predominant frequencies of near-field earthquakes, amplifying the effects of the ground shaking they experience. In 2013, the Bohol earthquake caused widespread failures in residential structures, revealing construction deficiencies [1]. Six years later, the Luzon earthquake of 2019 led to the destruction of numerous concrete houses in Porac [2]. That same year, the Cotabato earthquake series inflicted extensive damage on concrete buildings [3]. More recently, the 2022 Abra earthquake severely affected Northern Luzon, where common failures in concrete hollow block and reinforced concrete frame buildings were observed. However, despite post-earthquake observations in the Philippines indicating a high prevalence of damage among low-rise concrete buildings, it is crucial to acknowledge that not all such buildings have high seismic risk.

To effectively manage risk, owners and occupants of low-rise concrete buildings should be aware of the seismic risk associated with the buildings they own or occupy. This typically involves an engineering assessment conducted by a structural engineer. While this assessment provides a comprehensive understanding of the seismic risk, the time and expense associated with this process make it impractical for many buildings.

Therefore, simplified tools have been developed that do not require structural engineering expertise to screen the seismic risk of buildings. These tools serve as preliminary screening mechanisms to identify buildings that may necessitate a more detailed assessment by a structural engineer.

In the Philippines, FEMA-154 [4] and its updated version, FEMA P-154 [5], RCAsT [6, 7, 8, 9], and How Safe Is My House [10], have been used as seismic screening tools. A more detailed discussion of these screening tools and their limitations is provided in the literature review section. However, while they are collectively termed screening tools in contrast with engineering assessments, they differ in the assumed level of technical expertise they require for their users. Moreover, some of these tools lack the adaptability to assess diverse building types found in the country. These limitations pose challenges for large-scale screening campaigns or areas with limited structural engineers. Therefore, there is a pressing need for an intuitive and accessible screening tool that empowers individuals who are not experts in seismic risk assessment. These individuals can be categorized as either novices or laypersons [11]. In the context of seismic risk assessment, novices are those with basic training in building design or construction but who lack the expertise of structural engineers. With additional training, they can develop their skills for conducting rapid and reasonably accurate screening. Laypersons, on the other hand, are those with no formal training in building design or construction. In this study, novices in seismic risk assessment are referred to as individuals who have taken an undergraduate-level course on the design of reinforced concrete. Further discussion on this distinction and its implications for seismic screening tools is provided in the literature review.

This study proposes SCREEN, a new scoring framework and rapid screening tool for novices designed to improve upon existing tools by 1) differentiating structures by vintage and construction standards, 2) developing the Risk Score that explicitly incorporates the exposure of the building to seismic risk, 3) calibrating the estimation of the probabilities of collapse of structures found in the Philippines, and 4) developing the SCREEN score that is intuitive and practical for novice screeners. This study focused on low-rise concrete buildings with up to three stories and up to five bays, specifically addressing reinforced concrete frame buildings and concrete hollow block structures commonly found in the Philippines [12, 13]. Moreover, this study does not cover hazardous facilities and heritage structures, as they would require specialized considerations beyond its scope.

Furthermore, the study is limited to buildings for which visual and easily obtainable parameters can be used, relying on onsite observations and publicly available data. Previous studies conducted a series of surveys among structural engineers and civil engineers to determine which parameters required by the three tools, FEMA P-154, RCAsT, and How Safe

Is My House, could be conveniently gathered by novices [14, 15, 16]. The studies recommended fifteen (15) parameters and categorized them according to the Hazard-Exposure-Vulnerability Model of Disaster Risk [17]. These parameters are incorporated in SCREEN as shown in Figure 1.

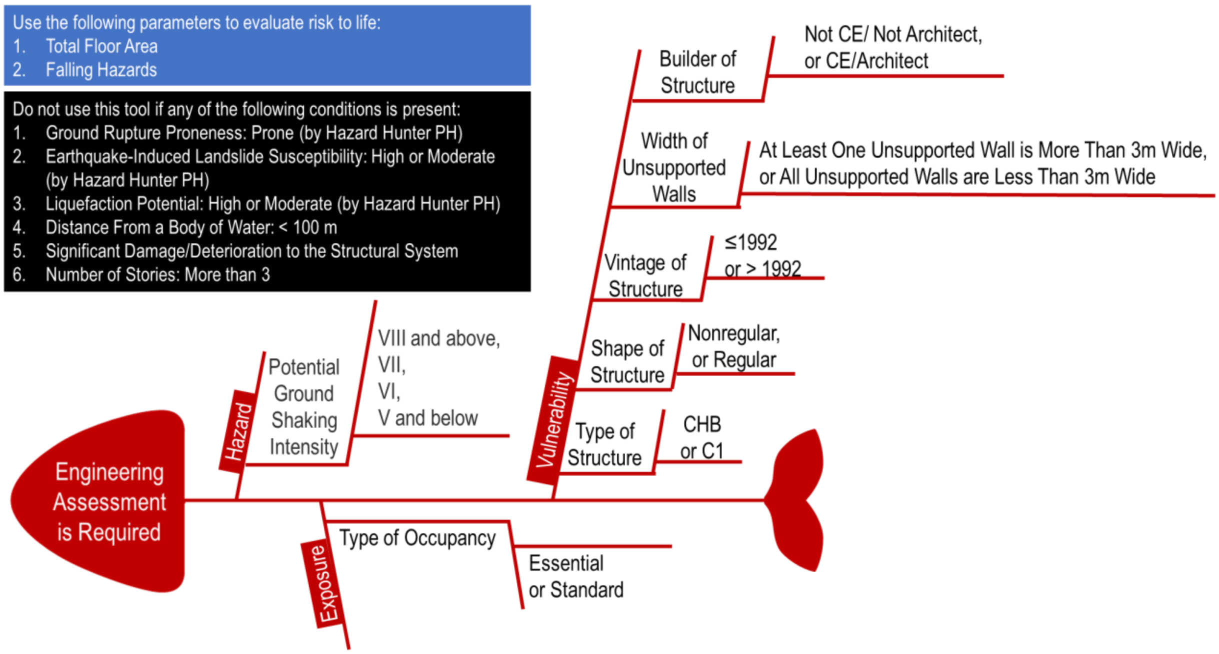

Figure 1. Fishbone Diagram of SCREEN to determine if engineering assessment is required

Of the 15 parameters, two (2) parameters were recommended to evaluate the risk to life, as shown in the blue box in Figure 1. Six were identified as immediate indicators for recommending a full structural engineering assessment, as shown in the black box. Seven (7) of these parameters were considered in this study for the scoring of risk to property as a hazard parameter (potential ground shaking intensity obtained from HazardHunterPH), an exposure parameter (type of occupancy), or a vulnerability parameter (type of structure, shape of structure, vintage of structure, width of unsupported walls, and builder of structure).

1.1. Literature Review

In 2002, the Federal Emergency Management Agency published FEMA-154 [4], with a rapid visual screening procedure tailored for individuals familiar with building design or construction. Primarily used in the United States, its objective is to rapidly screen buildings for potential seismic risk by assigning scores based on observable features of buildings during a sidewalk survey. Although FEMA-154 has been used in the Philippines—most notably by the Department of Public Works and Highways to screen more than 4,900 government buildings in Metro Manila [18]—a key limitation is that its scoring system has yet to be validated for Philippine building types and construction practices. A limitation, as well as a strength, is that it relies completely on exterior visual assessment. In 2015, FEMA published an updated edition called FEMA P-154 [5], incorporating revised seismicity definitions, new building types, and recalibrated scores. However, it remained a sidewalk survey tool.

The Rapid Condition Assessment Tool (RCAsT) [6, 7, 8, 9], developed in 2013, predates FEMA P-154 and served as a rapid screening tool tailored for concrete structures in the Philippines, intended to be used by individuals who reached a senior level in the undergraduate civil engineering education. Designed to be more comprehensive than sidewalk survey tools, it provided a more detailed screening of seismic risk by incorporating structural condition, soil parameters, and material deterioration, with scores calibrated using fragility curves specific to Philippine concrete structures [13]. In 2014, it was used to estimate the seismic risk of 11 reinforced concrete buildings at the University of the Philippines Diliman [19]. Though large-scale adoption remains limited, its framework continues to serve as a basis for exploring more detailed screening methodologies. A key limitation of RCAsT is that, while it offers a more comprehensive screening than sidewalk survey tools, most of its parameters are likely to be unsuitable for novices [14].

Another screening tool has been developed in the Philippines for the screening of concrete hollow block (CHB) houses called How Safe Is My House [10]. Designed for owners or residents of CHB houses who may be unfamiliar with building design or construction, this tool simplifies seismic screening by using a checklist-based scoring system based on the provisions of the National Structural Code of the Philippines 2010 [20]. Its applicability is limited to CHB houses with one to two stories, making it unsuitable for other types of structures and number of stories.

While the existing tools used in the Philippines have significantly advanced seismic risk screening efforts, their application has revealed valuable opportunities to further enhance the practicality and effectiveness of screening methodologies. First, existing tools cannot easily differentiate among numerous concrete structures with various vintages and ambiguous standards. Mukhopadhyay and Dutta [21] pointed out that FEMA-154 cannot be used in non-engineered buildings in India, which are built using varying materials and construction practices. Second, the scoring in the previously stated screening tools did not consider the parameters that indicated the exposure of the building to seismic damage, such as the type of occupancy or building use. Third, the existing tools may not be sufficiently calibrated to estimate the seismic risk of the types of structures found in the Philippines, such that some doubt is cast on their findings. Wang and Goettel [22] proposed the refinement of the seismicity categories of FEMA-154 because there is a high variability in the probability of collapse within its seismicity categories. They also proposed recalculating the combinations of score modifiers in FEMA-154 because some combinations are mathematically out of bounds. Wallace and Miller [23] recommended accounting for the type and number of irregularities or nonregularities in the score calculation in FEMA-154 (2002). Regarding the use of FEMA P-154, Ishack et al. [24] developed a method to classify vertical irregularities or nonregularities. Several studies have pointed out that FEMA-154 and FEMA P-154 cannot be directly used for non-US types of structures [25, 26, 27]. Fourth, for certain people who are not experts in seismic risk analysis, the tools may be using parameters that are not practically convenient or scores that are not intuitively interpretable. After the 2010 Magnitude 7.1 Darfield, New Zealand earthquake, Marshall et al. [28] noted that many inspectors were not adequately trained in using ATC-20 Rapid Evaluation, a screening tool for post-earthquake assessment. Consequently, many buildings were tagged as red (unsafe) when they should have been tagged as green (inspected). Although the objectives of pre-earthquake and post-earthquake screenings are quite different, both highlight the need for individuals who are not experts in structural engineering to augment the ranks of structural engineering experts during wide-area campaigns for seismic risk reduction.

While various screening tools were developed to screen buildings without requiring structural engineering expertise, they still vary in the level of expertise in building design or construction they assume from users. Understanding this distinction requires defining expertise itself. Ericsson [29] defines expertise as outstanding performance in a given field, typically achieved through years of education and practice. Mieg [30] emphasizes expertise as s societal function, such as that of structural engineers, whose expertise is tied to their profession.

Individuals without expertise can be classified as novices or laypersons [11]. Novices are those in the process of acquiring expertise, while laypersons do not intend to develop expertise. In this study, individuals who have taken an undergraduate-level course on the design of reinforced concrete were considered to be novices. This classification aligns with Ericsson's definition [29], as they have begun developing expertise through education, and with Mieg's definition [30], as they have the potential to enter the profession of structural engineering.

There is a need to ensure that screening tools are explicitly designed with the abilities of their users in mind and calibrate scoring frameworks to produce more intuitive and accurate risk estimation. A user-centered tool and well-calibrated tool will not only enhance risk estimation but also empower a wider range of individuals to participate in seismic risk reduction, ultimately contributing to more resilient communities. The present study addresses the limitations observed in the previous tools by accounting for construction practices in the Philippines, incorporating the exposure of the building to seismic damage, and improving the scoring of seismic risk to be more practical for novice screeners.

II. METHODOLOGY

The development of the SCREEN scoring framework and corresponding rapid tool involved a multi-step process. First, the varying standards and construction practices in the Philippines were addressed by incorporating vintage and builder of structure as parameters to estimate seismic risk as discussed in Section 2.1. Second, the exposure of buildings to seismic risk is quantified by the type of occupancy as discussed in Sections 2.2 to 2.3. Third, a comprehensive review of the scoring frameworks used in FEMA P-154, RCAsT, and How Safe Is My House was conducted to gain insights on risk scoring and to facilitate easy conversion and comparison between SCREEN and the existing tools. These insights informed the development of calibrated probabilities of collapse specific to low-rise concrete structures in the Philippines, incorporating fragility curves generated through pushover analyses discussed in Sections 2.4 to 2.7. Fourth, from the Risk Score, the SCREEN Score was developed for use in the rapid tool, designed to be implementable during screening without the need for structural analyses discussed in Sections 2.8 to 2.9.

2.1. Incorporation of Builder of Structure to Consider Varying Construction Practices

To account for the variability in construction practices, this study incorporated the builder of the structure as an indicator of construction quality. This approach was informed by the methodology proposed by Ghasemi et al. [31], in which design code levels were assigned based on the time of construction and the quality of workmanship.

The vintage of structure can be classified as Low-Code or High-Code. Low-Code refers to buildings constructed before or in 1992, while High-Code refers to buildings constructed after 1992. The year 1992 was used as a threshold because a paradigm shift was adopted, adding provisions for the ductile design of structures [32, 33].

It was assumed that if the builder was not a civil engineer or architect, the structure was effectively classified as Low-Code, regardless of whether it was built after 1992. This assumption aligns with the observation that the quality of construction in such cases often does not meet the standards associated with High-Code structures.

2.2. Calculation of Probable Loss with Consideration of Type of Occupancy

To incorporate the type of occupancy — being an exposure parameter — in the risk screening, hence anticipating the difference between a standard-occupancy building and an essential-occupancy building, the concept of probable loss was used. The probable loss was obtained using Eq. 1.

` $$\text{Probable Loss} = \text{Probability of Collapse} \times \text{Cost of Original Construction} \qquad \textbf{Eq. 1}$$

Essential-occupancy structures were understood to have a higher cost compared to standard-occupancy structures even for the same total floor area, as building code provisions mandate stricter requirements. To differentiate between essential-occupancy structures and standard-occupancy structures, the ratio of the cost of the standard-occupancy structure to the cost of the essential-occupancy structure was estimated.

The cost ratio in this study was calculated to ensure that the probable loss for essential- and standard-occupancy structures would be equal at their respective FEMA P-154 cutoff scores. For standard-occupancy structures, the cutoff for FEMA P-154 is 2.0, corresponding to a probability of collapse of 0.01 [5]. In contrast, the U.S. Army Corps of Engineers Civil Engineering Research Laboratory, in its screening of 11,500 buildings using FEMA-154, adopted a more conservative cutoff score of 2.5 for essential-occupancy structures, which corresponds to a probability of collapse of 0.003 [5], with the specific intent of using a more conservative approach for buildings that they deemed to be of essential occupancy. These probabilities of collapse were adopted in this study.

Therefore, the probable loss of an essential-occupancy structure would be equal to $0.003 \times \text{Cost}_{\text{Essential}}$. This would be equated to the probable loss of a standard-occupancy structure at $0.01 \times \text{Cost}_{\text{Standard}}$. From this equivalence, the ratio of the cost of a typical standard-occupancy structure to the cost of a typical essential-occupancy structure was estimated to be 0.3. This may be understood to include not only the direct cost of construction but also the indirect cost due to the potential consequences such as potential damage to contents and disruption of operations, which are particularly critical for essential structures.

2.3. Application of the Capacity Spectrum Method to the Computational Models of Low-Rise Concrete Buildings in the Philippines

The performance of low-rise concrete buildings was determined through the Capacity Spectrum Method [34]. Computational models of low-rise concrete buildings were generated based on the combinations of the values of four of the five vulnerability parameters shown in Figure 1. The combinations of those vulnerability parameters are listed in Table 1; these combinations are listed approximately in the order of descending vulnerability among combinations of low-rise concrete hollow block buildings, henceforth referred to as CHB, and among combinations of low-rise reinforced concrete frame buildings, henceforth referred to as C1, based on the scoring of previous seismic screening tools.

For novices, accurately assessing the presence and severity of vertical nonregularities can be challenging. To address this, FEMA P-154 recommended a conservative approach: if there is uncertainty about the presence of a vertical nonregularity, screeners should assume its presence [5]. This cautious stance minimizes the risk of overlooking structures with high seismic risk. Following the same approach, this study recommends assuming severe vertical nonregularity rather than requiring novices to judge its severity. Moderate vertical nonregularity as intended by FEMA P-154 is not considered in this study. Examples of severe vertical nonregularity include buildings with fewer walls or fewer columns on a particular story compared to the rest of the stories, a single story significantly taller than the others, setbacks from one floor to another, or columns that are noticeably narrower compared to the depth of the beams. However, Philippine construction practices may differ from those referenced in FEMA P-154, and a more detailed local or national study is recommended in the future to confirm the applicability of this classification to Philippine structures.

For the width of the structure, the threshold of 3 meters was adopted to be consistent with How Safe is My House [7]. The consideration of the vintage and builder of the structure is discussed in Section 2.1.

Table 1. Combinations of Vulnerability Parameters in the Computational Models

Combination	Type of Structure	Shape of Structure	Vintage of Structure	Width of Unsupported Walls
CHB-1	CHB	Nonregular	Low-Code	> 3 m
CHB-2	CHB	Nonregular	Low-Code	3 m
CHB-3	CHB	Nonregular	High-Code	> 3 m
CHB-4	CHB	Nonregular	High-Code	3 m
CHB-5	CHB	Regular	Low-Code	> 3 m
CHB-6	CHB	Regular	Low-Code	3 m
CHB-7	CHB	Regular	High-Code	> 3 m
CHB-8	CHB	Regular	High-Code	3 m
C1-1	RC	Nonregular	Low-Code	> 3 m
C1-2	RC	Nonregular	Low-Code	3 m
C1-3	RC	Nonregular	High-Code	> 3 m

C1-4	RC	Nonregular	High-Code	3 m
C1-5	RC	Regular	Low-Code	> 3 m
C1-6	RC	Regular	Low-Code	3 m
C1-7	RC	Regular	High-Code	> 3 m
C1-8	RC	Regular	High-Code	3 m

The computational models for CHB-5, CHB-6, CHB-7, and CHB-8 were generated. Computational models for C1-5 and C1-7 were adopted from a previous Philippine study [13]. For each computational model, a pushover analysis [35] was performed.

The experimental models used in the full-scale shaking table test prior to this study [12] were used as the basis for the computational model parameters in combinations CHB-5 and CHB-7 in this study as shown in Figure 2. CHB-5 was modeled based on Model B of that study, which represented CHB structures in the Philippines that are not compliant with the minimum requirements of the National Structural Code of the Philippines 2010 [20], which was considered low-code in this study. CHB-7 was modeled based on Model A of that study, which represented CHB structures constructed according to the minimum requirements of the National Structural Code of the Philippines 2010 [20], which was considered high-code in this study. The computational models for CHB-6 and CHB-8 were generated by reducing the width of the walls of CHB-5 and CHB-8, respectively, to 3 meters.

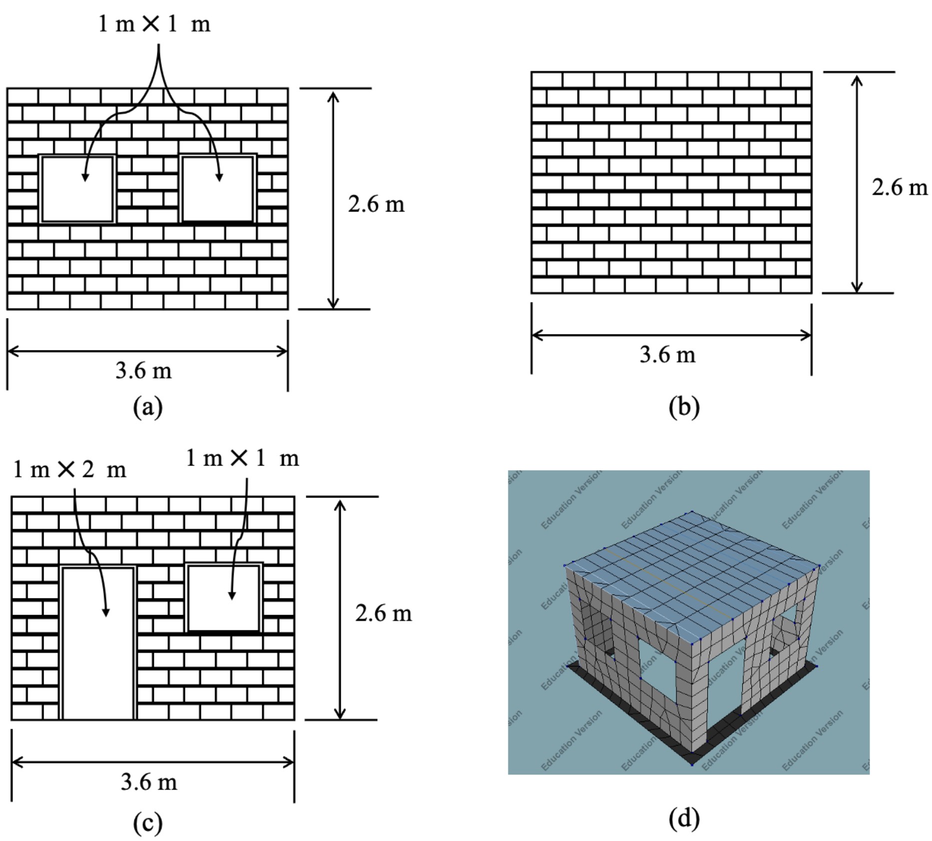

Figure 2. (a) North and South Elevation View of CHB-5 (b) West Elevation View of CHB-5 (c) East Elevation View of CHB-5 (d) DIANA Mesh of CHB-5

The pushover analyses for CHB-5, CHB-6, CHB-7, and CHB-8 were performed through DIANA [36, 37]. The material properties used for CHB-5 and CHB-7 are summarized in Table 2. The CHB elements were modeled as engineering masonry elements [37], while the reinforcing bars were modeled as uniaxial elastic perfectly-plastic elements [37]. The geometric properties of the CHB-5 and CHB-7 computational models are detailed in Table 3. All the nodes at the bottom of the model were fixed. The finite element mesh was made of hexahedron elements.

Table 2. Material Properties of Regular CHB Computational Models [12]

Modulus of Elasticity of CHB	1 GPa
Shear Modulus of Elasticity of CHB	0.385 GPa
Mass Density of CHB	1630 kg/m^3
Compressive Strength of CHB	1.5 MPa
Modulus of Elasticity of Rebar	200 GPa
Yield Strength of Rebar	230 MPa

Table 3. Geometric Properties of Regular CHB Computational Models [12]

Geometrical Property	CHB-5	CHB-6	CHB-7	CHB-8
Length of Side of Square Plan	3.6 m	3.0 m	3.6 m	3.0 m
Thickness of CHB Wall	100 mm	100 mm	150 mm	150 mm
Diameter of Rebar	6 mm	6 mm	10 mm	10 mm
Spacing of Vertical Rebars	900 mm	900 mm	400 mm	400 mm
Spacing of Horizontal Rebars	600 mm	600 mm	600 mm	600 mm

For the CHB building models, the determination of the performance point was done using FRACAS [38]. To be comparable with the results of a full-scale shaking table test performed in a previous study [12], the demand spectrum used was the JMA 1995 Kobe earthquake, scaled from 20% to 100% at a 20% interval.

For CHB-1 to CHB-4 and C1-1 to C1-4, being nonregular counterparts of CHB-5 to CHB-8 and C1-5 to C1-8, other approximate calculations were made, as discussed in Section 2.4.

For the regular C1 building models, both low-code and high-code, the performance points determined through ETABS [39] from the dataset obtained from RCAsT Structural were adopted [13].

2.4. Fragility Curve Fitting

The capacity spectrum method was repeated for each building model at different amplitude scales of the demand spectrum. The complete damage fragility curve, defined as a plot of the probability of complete damage versus peak ground acceleration, was generated for each building combination using the method outlined in a previous study [13].

Since the RCAsT Structural dataset lacked models for buildings with a length of bay equal to 3 m, the median of the fragility curve for C1-6 was estimated by extrapolating the value of the median of buildings with a 3-m length of bay from the plot of the medians of the fragility curve of all C1-5 models of RCAsT Structural with a 4-m length of bay and all C1-5 models of RCAsT Structural with a 5-m length of bay, as shown in Figure 3.

Similarly, the median of the fragility curve for C1-8 was estimated by extrapolating the value of the median of buildings with a 3-m length of bay from the plot of the medians of the fragility curve of all C1-7 models with a 4-m length of bay and all C1-7 models with a 5-m length of bay, as shown in Figure 4.

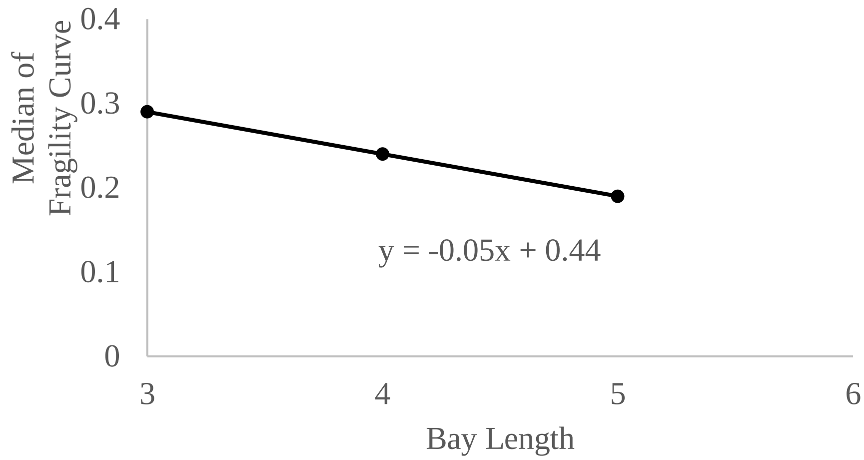

Figure 3. Median of Fragility Curve vs Bay Length of C1-5 Models

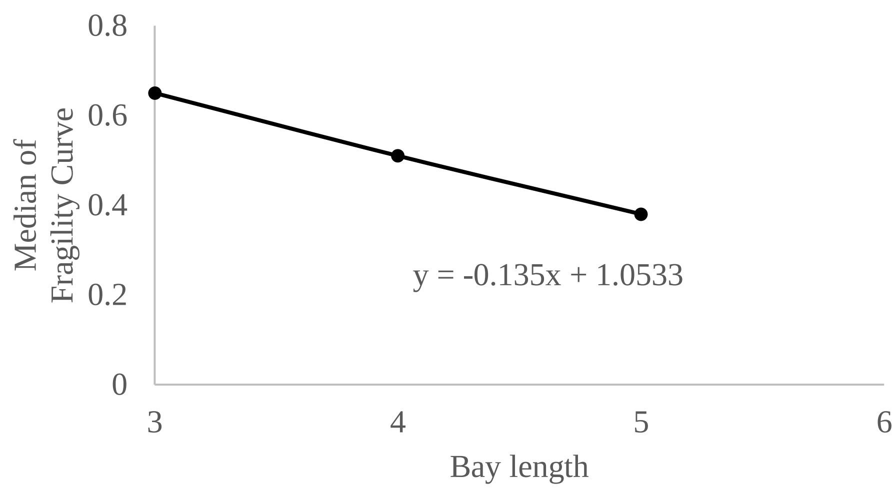

Figure 4. Median of Fragility Curve vs Bay Length of C1-7 Models

Following the approach of FEMA P-155 [40] in converting the fragility curves of regular structures to nonregular structures, the median of the fragility curve was approximated by applying a reduction factor of 0.69 to the corresponding median of the fragility curve of the counterpart regular structure for combinations CHB-1, CHB-2, CHB-3, CHB-4, C1-1, C1-2, C1-3, and C1-4.

2.5. Ground Motion Intensity Conversion

Before any calculation of the probability of collapse, the measure of ground motion intensity had to be addressed. For every location in the Philippines, the potential ground shaking intensity could be conveniently obtained from HazardHunterPH [41]. The potential ground shaking intensity given by HazardHunterPH in the PHIVOLCS Earthquake Intensity Scale (PEIS) needed to be converted into peak ground acceleration (PGA) so that the generated fragility curves could be used. Since there was no direct conversion from PEIS to PGA, PEIS was first converted to Modified Mercalli Intensity (MMI) through the equation used in the establishment of the earthquake intensity meter network in the Philippines [42]. The ground-motion-to-intensity conversion equation by Wald et al. [43] was adopted to convert MMI to PGA. Table 4 lists the corresponding PGA in g for each PEIS, as used in this study.

Table 4. PEIS to PGA (g)

PEIS	PGA (g)
V	0.07
VI	0.15
VII	0.32
VIII	0.74

2.6. Calculation of Probability of Collapse

In this study, the probability of collapse was defined as the probability that a building will suffer partial or complete collapse as per FEMA P-154 [5]. Using the definition of conditional probability, the probability of collapse was computed by multiplying the probability that a structure would have complete damage obtained from the fragility curve by the conditional probability of collapse given complete damage. The conditional probability of collapse given complete damage, referred to as the collapse factor, was defined in FEMA P-155 [40]. Due to a lack of studies on the collapse factors for Philippine structures, values from FEMA P-155 were adopted. Table 5 lists the collapse factors for each combination considered in this study. However, it is important to acknowledge that these values were derived from international fragility models developed for construction practices in the United States. While they provide a useful reference, they may not fully capture the specific characteristics of Philippine construction, including differences in material quality, construction techniques, and workmanship. Further studies are needed to validate and refine these collapse factors based on structures found in the Philippines.

Table 5. Collapse Factors

Combination	Collapse Factor [40]
CHB-1	0.60
CHB-2	0.60
CHB-3	0.50
CHB-4	0.50
CHB-5	0.15
CHB-6	0.15

CHB-7	0.13
CHB-8	0.13
C1-1	0.50
C1-2	0.50
C1-3	0.50
C1-4	0.50
C1-5	0.13
C1-6	0.13
C1-7	0.13
C1-8	0.13

For CHB-1, CHB-2, CHB-5, and CHB-6, which are low-code building combinations, the collapse factor for unreinforced masonry was adopted due to a presumed similar condition of lack or insufficiency of reinforcements. For CHB-3, CHB-4, CHB-7, and CHB-8, which are high-code building combinations following the reinforcement requirements set by the National Structural Code of the Philippines for masonry structures, the collapse factor for reinforced masonry was adopted.

2.7. Calculation of Risk Score for Every Computational Model

The Risk Score of a building type quantified the seismic risk of the building as proportional to the probable loss. In developing this score, the domain of the FEMA P-154 Score was considered for easier conversion and comparison.

The worst value of the FEMA P-154 Score is 0.2 [5], which corresponds to a probability of collapse of 63%. The best value of the FEMA P-154 Score was 11.1, which corresponds to a much smaller probability of collapse of 7.9×10^{-10} %. Considering the type of occupancy, the probable loss was calculated as discussed earlier in Section 2.5. Thus the worst case of probable loss was equal to 0.63, which corresponded to a FEMA P-154 Score of 0.2 and an essential type of occupancy. The best case of probable loss was equal to 2.4×10^{-12}, which corresponded to a FEMA P-154 Score of 11.1 and a standard type of occupancy.

For the Risk Score to be more intuitive for novice screeners, it was formulated in this study such that the user would get a higher Risk Score for buildings with a higher Probable Loss. Moreover, to be more convenient, the Risk Score was rescaled such that the precision of the score was limited to whole numbers.

2.8. Calculation of SCREEN Score for Risk to Property by Rapid Tool

To be easily implementable without resorting to a computational model anymore, the calculation of the SCREEN Score during rapid screening was simplified using Score Modifiers corresponding to the values of parameters. To derive the Score Modifiers used in the SCREEN Score, we fitted a linear regression model to the Risk Scores of the 128 computation-model buildings, with six input parameters as independent variables: potential ground shaking intensity, occupancy, shape, vintage, structural type, and unsupported wall width, along with their pairwise interaction terms.

A stepwise selection process was applied to reduce the number of predictor terms to only those with statistically significant contributions to the Risk Score. Initially, the model contained all six main effects and all 15 possible two-way interactions, totaling 21 predictor terms. A backward elimination approach was used, successively removing two-way interaction terms with high p-values ($p > 0.05$).

The SCREEN Score was calculated by subtracting Score Modifiers from the starting value of 100. Thus, the SCREEN Score is a simplified quantitative measure designed to estimate the seismic risk of buildings in a manner that is easily implementable by novice screeners.

In determining a practical application threshold, a tolerance level was introduced to guide the identification of buildings that could be prioritized for further engineering assessment. This threshold was defined as the SCREEN Score above which buildings would be recommended for engineering assessment. The threshold was set such that approximately 60% of buildings are recommended for engineering assessment. This proportion strikes a balance between the need to err on the side of caution in identifying relatively high-risk buildings and the practical limitations of engineering manpower, time, and financial resources.

2.9. Sensitivity and Specificity Analysis

The SCREEN Score was used to indicate either "Yes, the building needs engineering assessment" or "No, the building does not need an engineering assessment at this time."Sensitivity was defined to be the ability of the SCREEN Score to correctly identify buildings that require engineering assessment according to a benchmark tool. It was computed using Eq. 2. TP, or "True Positives", was the number of buildings that have been previously identified to require engineering assessment according to a benchmark tool and also by SCREEN Score. FN, or "False Negatives", was the number of buildings that have been identified by a benchmark tool as requiring engineering assessment but have not been identified so by SCREEN Score.

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$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}} \qquad \textbf{Eq. 2}$$

Specificity would be the ability of the SCREEN Score to correctly identify the buildings that do not require engineering assessment according to a benchmark tool. It was computed using Eq. 3. TN, or "True Negatives", was the number of buildings that have been identified as not requiring engineering assessment according to a benchmark tool and also by SCREEN Score. FP, or "False Positives", was the number of buildings that have been identified by a benchmark tool as not requiring engineering assessment but have been identified as requiring engineering assessment by SCREEN Score.

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$$\text{Specificity} = \frac{TN}{TN + FP} \qquad \textbf{Eq. 3}$$

The sensitivity and specificity of the SCREEN Score were computed assuming that the earlier locally developed tools for seismic screening were benchmark tools. Thus, for the CHB structures, How Safe Is My House was considered to be the benchmark tool; for the C1 structures, RCAsT was considered to be the benchmark tool. Six (6) CHB buildings [44] and eleven (11) C1 buildings [19] were used in the sensitivity and specificity analysis.

It is important to acknowledge that the benchmark tools used in this study serve as a basis for comparison rather than definitive gold standards. The findings are limited by the small sample size of 17 buildings, which constrains the generalizability of the results. To enhance the robustness of SCREEN's predictive performance, future studies should validate its results against independent engineering assessments and post-earthquake reconnaissance surveys involving a larger dataset. Such an approach would provide a more comprehensive evaluation of SCREEN Score's reliability in identifying buildings that require further engineering assessment.

III. RESULTS AND DISCUSSIONS

3.1. Classification of Vintage of Structure Based on Year of Construction and Builder of Structure

Table 6. Vintage of Structure Based on Year of Construction and Builder of Structure

Year of Construction	Builder of Structure	Vintage
On or before 1992	Not a Civil Engineer or Architect	Low-Code
On or before 1992	Civil Engineer or Architect	Low-Code
After 1992	Not a Civil Engineer or Architect	Low-Code
After 1992	Civil Engineer or Architect	High-Code

Table 6 shows the vintage of the structure given the year of construction and the builder of the structure. By incorporating both the year of construction and the builder of the structure into the classification process, this study provided a practical method to differentiate among numerous concrete structures with various vintages and ambiguous standards.

3.2. Summary of Fragility Curve Parameters for Concrete-Hollow-Block Structures and Reinforced Concrete Frame Structures

Table 7. Fragility Curve Parameters of Combinations

Combination	Median	Uncertainty
CHB-1	0.060	0.860
CHB-2	0.106	0.860
CHB-3	0.150	0.860
CHB-4	0.265	0.860
CHB-5	0.087	0.860
CHB-6	0.153	0.860
CHB-7	0.218	0.860
CHB-8	0.384	0.860
C1-1	0.144	0.920
C1-2	0.200	0.920
C1-3	0.316	0.920
C1-4	0.439	0.920
C1-5	0.209	0.920
C1-6	0.290	0.920
C1-7	0.458	0.920
C1-8	0.636	0.920

Table 7 shows the summary of the median and uncertainty of the fragility curves for the combinations of vulnerability parameters (as described in Table 1 above). The graphs of the fragility curves are shown in Figure 5 for CHB and Figure 6 for C1.

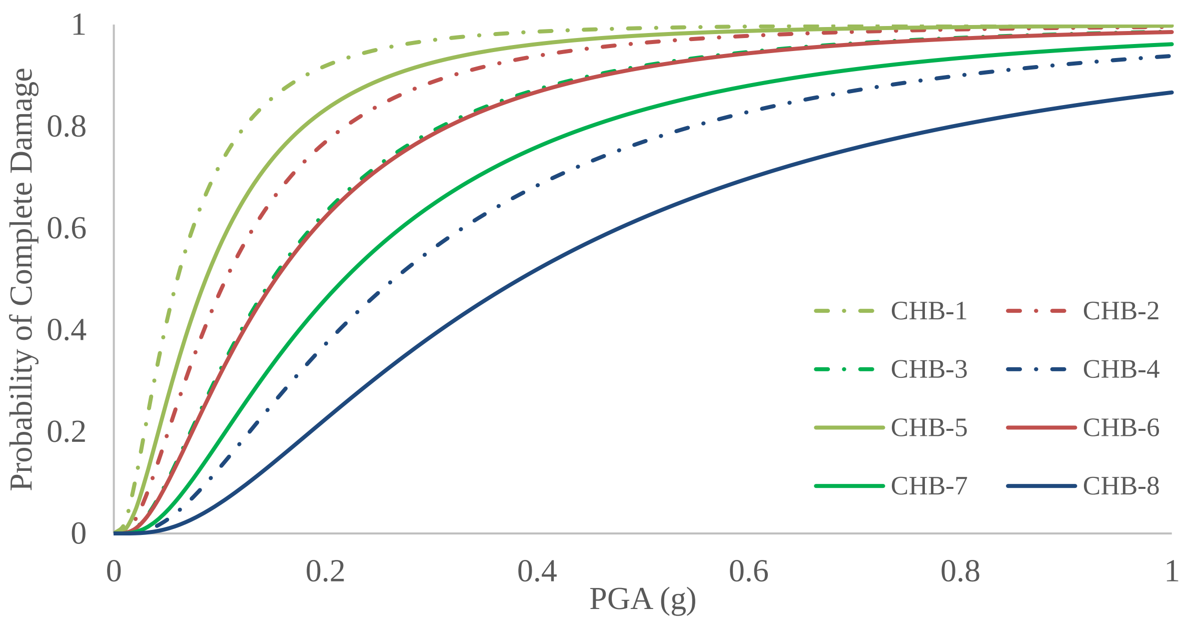

Figure 5. Fragility Curves of CHB Combinations (See Table 1) of Vulnerability Parameters

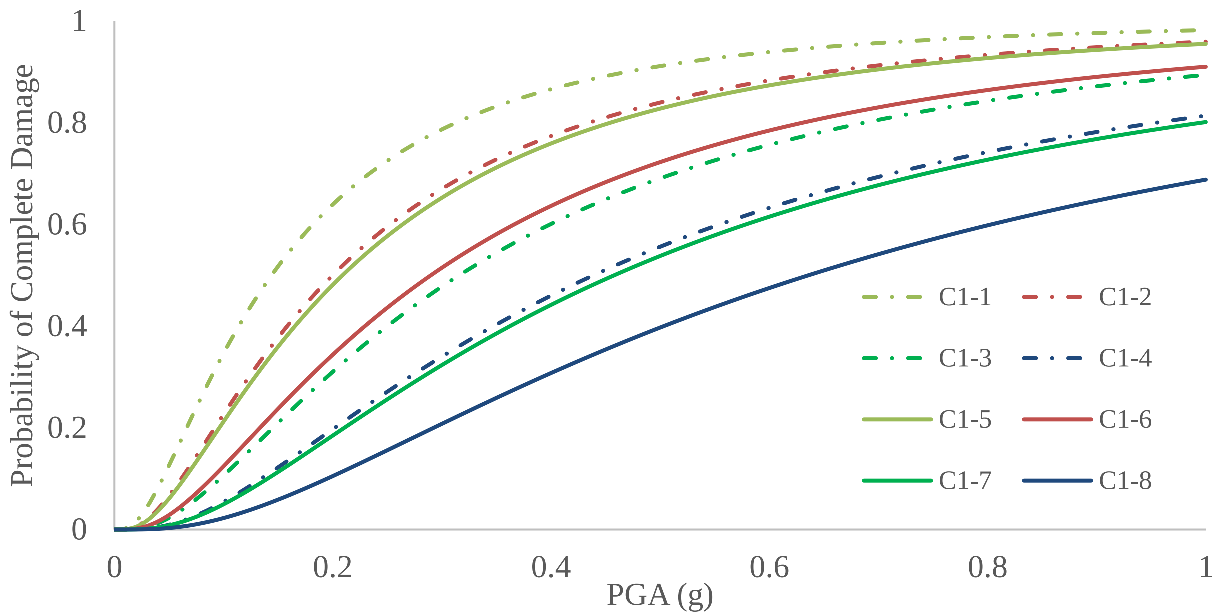

Figure 6. Fragility Curves of C1 Combinations (See Table 1) of Vulnerability Parameters

3.3. *Probability of Collapse for Concrete-Hollow-Block Buildings and Reinforced Concrete Frame Buildings*

The probability of complete damage at the PGAs corresponding to each PEIS given in Hazard Hunter PH was obtained from the fragility curves (as shown in Figure 5 for CHB and Figure 6 for C1). The probability of complete damage for each of the 16 combinations of vulnerability parameters, at each PEIS intensity from V to VIII, is listed in Table 8. The probability of collapse for each of the combinations of vulnerability parameters is listed in Table 9.

Table 8. Probability of Complete Damage at Specified Intensity

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	0.57	0.86	0.97	1.00	C1-1	0.23	0.53	0.81	0.96
CHB-2	0.34	0.68	0.91	0.99	C1-2	0.13	0.38	0.69	0.92
CHB-3	0.19	0.50	0.81	0.97	C1-3	0.05	0.21	0.50	0.82
CHB-4	0.06	0.26	0.60	0.89	C1-4	0.02	0.12	0.37	0.71
CHB-5	0.39	0.72	0.93	0.99	C1-5	0.12	0.36	0.68	0.91
CHB-6	0.19	0.50	0.81	0.97	C1-6	0.06	0.24	0.54	0.84
CHB-7	0.09	0.33	0.67	0.92	C1-7	0.02	0.11	0.35	0.70
CHB-8	0.02	0.14	0.42	0.78	C1-8	0.01	0.06	0.23	0.56

Table 9. Probability of Collapse at Specified Intensity

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	0.34	0.51	0.58	0.60	C1-1	0.11	0.26	0.41	0.48
CHB-2	0.20	0.41	0.55	0.59	C1-2	0.06	0.19	0.35	0.46
CHB-3	0.09	0.25	0.41	0.48	C1-3	0.02	0.10	0.25	0.41
CHB-4	0.03	0.13	0.30	0.44	C1-4	0.01	0.06	0.18	0.36
CHB-5	0.06	0.11	0.14	0.15	C1-5	0.02	0.05	0.09	0.12
CHB-6	0.03	0.08	0.12	0.15	C1-6	0.01	0.03	0.07	0.11
CHB-7	0.01	0.04	0.09	0.12	C1-7	0.00	0.01	0.05	0.09
CHB-8	0.00	0.02	0.05	0.10	C1-8	0.00	0.01	0.03	0.07

The reduction factors used for nonregular structures were derived from FEMA P-155 and serve as a preliminary reference but require further validation and refinement through progressive collapse and reliability analyses study to reflect Philippine construction practices more accurately. Moreover, the effect of different types of observable nonregularities should be further explored in future studies.

3.4. Probable Loss with Consideration of Type of Occupancy

The probable loss — as a fraction between 0 and 1 — for each of the combinations of vulnerability parameters, assuming standard occupancy, is listed in Table 10. The probable loss for combinations of vulnerability parameters assuming essential occupancy is listed in Table 11; the unit-cost ratio between standard-occupancy structure and counterpart essential-occupancy structure had been assumed as 0.3 (see also Section 2.2).

Table 10. Probable Loss for Standard Occupancy Structures at Specified PEIS Intensity

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	0.10	0.15	0.18	0.18	C1-1	0.03	0.08	0.12	0.14
CHB-2	0.06	0.12	0.16	0.18	C1-2	0.02	0.06	0.10	0.14
CHB-3	0.03	0.08	0.12	0.15	C1-3	0.01	0.03	0.08	0.12
CHB-4	0.01	0.04	0.09	0.13	C1-4	0.00	0.02	0.05	0.11
CHB-5	0.02	0.03	0.04	0.04	C1-5	0.00	0.01	0.03	0.04
CHB-6	0.01	0.02	0.04	0.04	C1-6	0.00	0.01	0.02	0.03
CHB-7	0.00	0.01	0.03	0.04	C1-7	0.00	0.00	0.01	0.03
CHB-8	0.00	0.01	0.02	0.03	C1-8	0.00	0.00	0.01	0.02

Table 11. Probable Loss for Essential Occupancy Structures at Specified PEIS Intensity

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	0.34	0.51	0.58	0.60	C1-1	0.11	0.26	0.41	0.48
CHB-2	0.20	0.41	0.55	0.59	C1-2	0.06	0.19	0.35	0.46
CHB-3	0.09	0.25	0.41	0.48	C1-3	0.02	0.10	0.25	0.41
CHB-4	0.03	0.13	0.30	0.44	C1-4	0.01	0.06	0.18	0.36
CHB-5	0.06	0.11	0.14	0.15	C1-5	0.02	0.05	0.09	0.12
CHB-6	0.03	0.08	0.12	0.15	C1-6	0.01	0.03	0.07	0.11
CHB-7	0.01	0.04	0.09	0.12	C1-7	0.00	0.01	0.05	0.09
CHB-8	0.00	0.02	0.05	0.10	C1-8	0.00	0.01	0.03	0.07

3.5. Risk Score

A form of the equation to calculate the Risk Score for SCREEN shown in Eq. 4 was considered. The constant a would be equal to the maximum value of the SCREEN Score, and since the probable loss, as a fraction of the total cost or value of the building, would always be less than 1, then the second term in Eq. 4 would always be negative. It was decided in this study to equate the maximum possible score to 100.

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$$\text{Risk Score} = a + b\,log(\text{Probable Loss}) \qquad \textbf{Eq. 4}$$

The coefficient b was computed such that the SCREEN Score in the best case of probable loss would not be negative but would be a small positive number, and the SCREEN Score equivalent to the FEMA P-154 Cutoff Score would be a multiple of 5. Thus, when b was set equal to 8, the SCREEN Score in the best case of probable loss was equal to 7, and the SCREEN Score that is equivalent to the FEMA P-154 Cutoff Score was 80. The resulting formula as calibrated is Eq. 5.

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$$\text{Risk Score} = 100 + 8\,log(\text{Probable Loss}) \qquad \textbf{Eq. 5}$$

Table 12. Risk Scores for Standard Occupancy Structures

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	92	94	94	94	C1-1	88	91	93	93
CHB-2	90	93	94	94	C1-2	86	90	92	93
CHB-3	88	91	93	93	C1-3	83	88	91	93
CHB-4	84	89	92	93	C1-4	80	86	90	92
CHB-5	86	88	89	89	C1-5	81	85	87	88
CHB-6	83	87	88	89	C1-6	79	84	87	88
CHB-7	80	85	87	88	C1-7	75	81	85	87
CHB-8	76	82	86	88	C1-8	72	79	84	87

Table 13. Risk Scores for Essential Occupancy Structures

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	96	98	98	98	C1-1	92	95	97	97
CHB-2	94	97	98	98	C1-2	90	94	96	97
CHB-3	92	95	97	97	C1-3	87	92	95	97
CHB-4	88	93	96	97	C1-4	85	90	94	96
CHB-5	90	92	93	93	C1-5	85	89	92	93
CHB-6	88	91	93	93	C1-6	83	88	91	92
CHB-7	85	89	92	93	C1-7	79	85	89	92
CHB-8	80	86	90	92	C1-8	76	83	88	91

Using the calculated probable loss for each combination of vulnerability parameters from Table 10, the Risk Scores assuming standard occupancy were calculated using Eq. 5 as listed in Table 12. Similarly, the SCREEN Scores for combinations of vulnerability parameters, assuming essential occupancy, were calculated using the probable loss from Table 11 as listed in Table 13.

3.6. SCREEN Score

The SCREEN Score Modifiers, shown in Table 14, provide a simplified way to estimate the seismic risk of buildings by subtracting them from 100 to determine the SCREEN Score. From Tables 12 and 13, it can be observed that the maximum Risk Score is 98, which corresponds to the worst scenario—CHB-1 subjected to a potential ground shaking intensity of VIII. Since CHB-1 at an intensity level higher than VIII would logically have a SCREEN Score greater than 98, we assume that the SCREEN Score Modifier for ground shaking intensities greater than VIII is zero.

After performing a stepwise selection process, only the two-way interaction terms between potential ground shaking intensity and shape of structure, vintage of structure, type of structure, and width of unsupported walls were retained in the final linear model at a significance level of $p < 0.05$. Interaction terms not involving potential ground shaking intensity—such as those between occupancy, shape, vintage, type, and wall width—were excluded due to lack of statistical significance ($p > 0.05$). Thus, modifiers were developed separately for each level of potential ground shaking intensity. The coefficients obtained from the final linear model served as the quantitative basis for developing the modifier table used in the SCREEN Score. These coefficients were interpreted and discretized into Score Modifiers shown in Table 14, allowing risk estimation to be performed using simple look-up tables rather than computation-heavy formulas. This step was essential to ensure the usability of the SCREEN Score. Tables 15 and 16 list the 128 SCREEN Scores which correspondes to the Risk Scores listed in Tables 12 and 13.

Table 14. Score Modifiers

		Potential Ground Shaking Intensity				
		>VIII	VIII	VII	VI	V
Type of Occupancy	Essential	0	2	3	3	3
	Standard	4	6	7	7	7
Shape of Structure	Nonregular	0	0	0	0	0
	Regular	4	5	5	6	7
Vintage of Structure And Builder of Structure	≤ 1992	0	0	0	0	0
	>1992 and Not Built by an Architect or CE	0	0	0	0	0
	>1992 and Built by an Architect or CE	0	0	1	3	5
Type of Structure	CHB	0	0	0	0	0
	C1	0	0	1	3	4
Width of Unsupported Walls	> 3 m	0	0	0	0	0
	≤ 3 m	0	0	0	1	2

Tolerance was defined in this study as the highest SCREEN Score that would still not require the building to undergo engineering assessment. The SCREEN tolerance adopted in this study is 88, which corresponds to the same probability of collapse of a standard-occupancy structure at the FEMA P-154 cutoff score. A SCREEN Score that is greater than 88 would indicate, "Yes, the building needs engineering assessment". Otherwise, it would indicate, "No, the building does not need an engineering assessment at this time." However, a greater deviation from the threshold implies a higher seismic risk. While all buildings exceeding 88 should undergo assessment, prioritization may be given to those with significantly higher scores.

Table 15. SCREEN Scores for Standard Occupancy Structures

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	93	93	93	94	C1-1	89	90	92	94
CHB-2	91	92	93	94	C1-2	87	89	92	94
CHB-3	88	90	92	94	C1-3	84	87	91	94
CHB-4	86	89	92	94	C1-4	82	86	91	94
CHB-5	86	87	88	89	C1-5	82	84	87	89
CHB-6	84	86	88	89	C1-6	80	83	87	89
CHB-7	81	84	87	89	C1-7	77	81	86	89
CHB-8	79	83	87	89	C1-8	75	80	86	89

Table 16. SCREEN Scores for Essential Occupancy Structures

	V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)		V (0.07g)	VI (0.15g)	VII (0.32g)	VIII (0.74g)
CHB-1	97	97	97	98	C1-1	93	94	96	98
CHB-2	95	96	97	98	C1-2	91	93	96	98
CHB-3	92	94	96	98	C1-3	88	91	95	98
CHB-4	90	93	96	98	C1-4	86	90	95	98
CHB-5	90	91	92	93	C1-5	86	88	91	93
CHB-6	88	90	92	93	C1-6	84	87	91	93
CHB-7	85	88	91	93	C1-7	81	85	90	93
CHB-8	83	87	91	93	C1-8	79	84	90	93

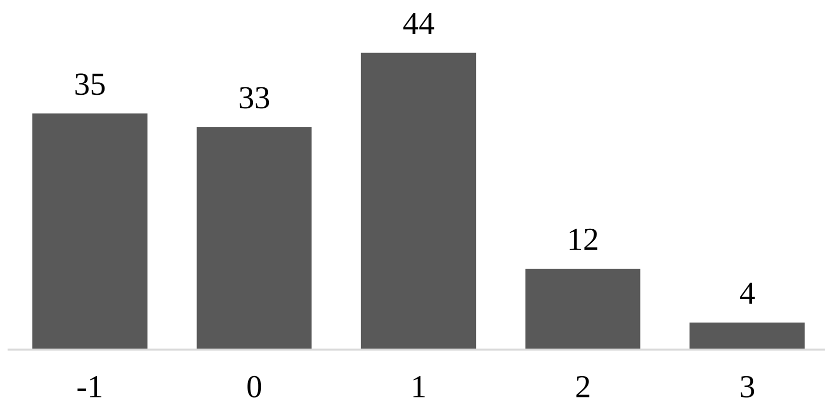

Figure 6. Histogram of Errors (SCREEN Score – Risk Score)

The distribution of errors between the SCREEN Score and the Risk Score indicates that the SCREEN Score performs reasonably well as an approximation tool. Only 16 cases showed an overestimation by more than one point. Notably, no case exhibited an underestimation greater than 1 point. This suggests that the SCREEN Score is slightly more conservative bias than the Risk Score. The close alignment in proportion affirms the utility of SCREEN Score as a screening tool that enables rapid decision-making.

The histograms of Risk Scores and SCREEN Scores are shown in Figure 7. Both distributions follow a similar pattern, though the SCREEN Score tends to shift slightly more buildings toward the mid-to-upper range, consistent with its observed slight conservatism. Based on the Risk Score distribution, a tolerance score of 88 results in 76 out of 128 buildings (59%) being flagged. Applying the same threshold to the SCREEN Score yields 82 out of 128 buildings (approximately 64%), which is acceptably close to the target of 60%. While the SCREEN Score flags slightly more buildings for engineering assessment, this is considered desirable for a simplified tool. It helps reduce the risk of overlooking buildings with high seismic risk while maintaining a manageable number of buildings prioritized for engineering assessment.

These results are based on the assumption that all 128 cases are equally likely to be observed. However, in practice, the distribution of building parameters may not be uniform. Therefore, it is recommended that field surveys be conducted to determine the actual prevalence of such cases in the target population. The data obtained from these surveys can then be used to calibrate the SCREEN Score, ensuring that it remains both accurate and representative across different contexts.

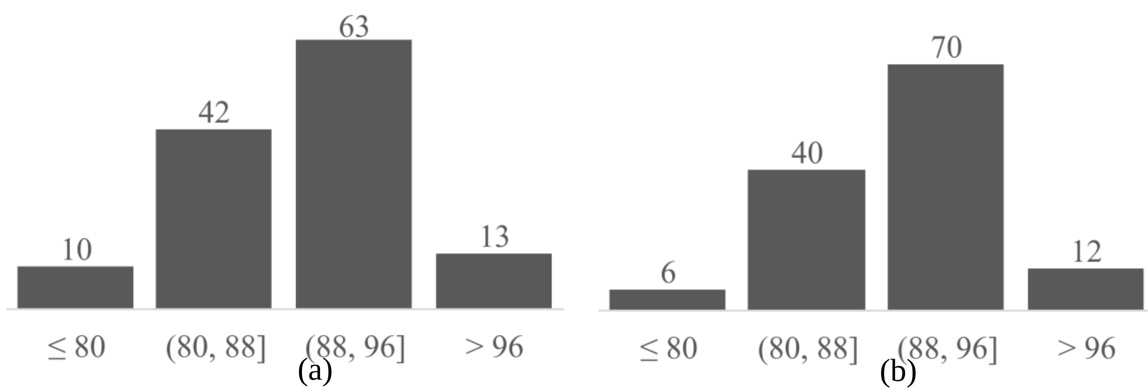

Figure 7. (a) Histogram of Risk Scores, (b) Histogram of SCREEN Scores

The development of the SCREEN Score in this study addresses a significant gap identified in previous screening tools, which did not explicitly account for the exposure of the building to seismic damage. Previous tools, such as FEMA P-154 [5], indirectly considered exposure by adjusting the tolerance score, with the appropriate adjustment left to the discretion of the stakeholders. This study directly incorporates exposure by calibrating the SCREEN Score to account for probable loss, enhancing the practical application of SCREEN.

3.7. Sensitivity and Specificity of SCREEN Score Based on 17 Sample Buildings

For CHB buildings, How Safe is My House was previously tested for 6 sample houses in Bohol in 2013 [44]. The potential ground shaking intensity in Bohol is Intensity VIII, according to HazardHunterPH. For benchmarking, the results of SCREEN were compared with How Safe is My House for the sample buildings in Table 17.

Table 17. Summary of Scores of How Safe Is My House and SCREEN for Sample Houses from Imai et al (2015)

CHB Sample Houses from [44]	How Safe is My House (PHIVOLCS and ASEP, 2014)	SCREEN	
	Engineering Assessment is Required?	SCREEN Score	Engineering Assessment is Required?
Imai-1	Yes	89	Yes
Imai-2	Yes	94	Yes
Imai-3	Yes	89	Yes
Imai-4	Yes	94	Yes
Imai-5	Yes	89	Yes
Imai-6	No	89	Yes

For C1 buildings, RCAsT was previously tested for 11 sample C1 buildings at the University of the Philippines Diliman in 2014 [19]. The potential ground shaking intensity at the University of the Philippines Diliman is Intensity VIII, according to HazardHunterPH. The summary of screening results by RCAsT, FEMA-154, FEMA P-154, and SCREEN is listed in Table 18, together with the conclusion of whether engineering assessment is required. Note that the sample buildings from Hernandez et al. [19] are arguably the worst-situated buildings in terms of four parameters: type of occupancy, number of occupants, number of stories, and vintage of structure. Therefore, it is expected that the tools indicate a requirement for engineering assessment for almost all of these sample buildings. It was noteworthy that the "No" assessment by RCAsT did not agree with the "Yes" assessment by FEMA-154 or FEMA P-154.

Table 18. Summary of Scores by RCAsT (2013), FEMA-154 (2002), FEMA P-154 (2015), and SCREEN for Sample Buildings from Hernandez et al (2014)

Sample Buildings from Hernandez et al (2014)	RCAsT	FEMA-154 (FEMA, 2002)	FEMA P-154 (FEMA, 2015)	SCREEN	
	Engineering Assessment Required?	Engineering Assessment Required?	Engineering Assessment Required?	SCREEN Score	Engineering Assessment Required?
Asian Institute of Tourism	Yes	Yes	Yes	98	Yes
Benton Hall	Yes	Yes	Yes	93	Yes
College of Education	Yes	Yes	Yes	98	Yes
Malcolm Hall	Yes	Yes	Yes	98	Yes
Molave Residence Hall	Yes	Yes	Yes	98	Yes
Marine Science Institute	Yes	Yes	Yes	98	Yes
National Institute of Geological Sciences	Yes	Yes	Yes	98	Yes

Nat'l Ins for Science and Math Educ Dev't	No	Yes	Yes	98	Yes
Natural Sciences Research Institute	Yes	Yes	Yes	98	Yes
Pavilion 4	Yes	Yes	Yes	98	Yes
Palma Hall Annex	No	Yes	Yes	98	Yes

Among the 17 buildings, there were identified 14 true positives (TP), 0 false negatives (FN), 0 true negatives, and 3 false positives (FP) when compared against the assumed benchmark tools. Based on this comparison, SCREEN demonstrated a sensitivity of SCREEN of 100%, indicating that it was comparable with the benchmark tools in detecting the CHB and C1 structures truly requiring engineering assessment. However, its specificity was 0%, meaning that, for this set of buildings, SCREEN overestimated seismic risk compared to the benchmark tools. It is important to note that these sensitivity and specificity values are relative to the selected benchmark tools, which serve as a basis for comparison rather than definitive gold standards. Additionally, the limited sample size of 17 buildings constrains the generalizability of these findings. To improve the robustness of SCREEN's predictive performance, future studies should validate its results against independent engineering assessments and post-earthquake reconnaissance surveys involving a larger set of buildings. This would enable a more accurate calculation of sensitivity and specificity.

Since the specificity of the SCREEN Score was low, some of the building owners or occupants of buildings classified as requiring engineering assessment might experience undue anxiety. However, from a conservative risk management perspective, this can be seen positively, as it encourages owners or occupants to verify whether their building truly has a high seismic risk through further engineering assessment.

In contrast, the high sensitivity of the tool ensures a low likelihood that buildings classified as low-risk are actually high-risk, reducing the risk of false assurances. Weighing between the benefits of higher sensitivity and higher specificity, higher sensitivity was prioritized in this study to minimize the likelihood of overlooking high-risk buildings, even if it means overestimating risk in some cases.

IV. CONCLUSION

This study provided a practical framework and a corresponding rapid screening tool to enhance seismic risk management by empowering novices, thereby making large-scale risk assessment campaigns typically done by local governments and disaster risk reduction offices more feasible. SCREEN framework addresses key challenges observed in previous screening tools. First, SCREEN's scoring system is tailored to buildings found in the Philippines using fragility curves developed for concrete hollow block and reinforced concrete frame buildings in the country. Second, SCREEN incorporates the type of occupancy by classifying buildings as essential- or standard-occupancy. Third, the various vintages and ambiguous standards of structure were considered by classifying whether a building is low-code or high-code. Fourth, for ease of implementation, the calculation of the SCREEN Score has been simplified to arithmetic operations and has been made more intuitive by assigning a higher SCREEN Score to buildings with a higher probable loss.

To enhance large-scale adoption, it is recommended to interface SCREEN with existing platforms such as HazardHunterPH, which could enhance seismic risk assessments and strengthen disaster preparedness efforts. Additionally, its adoption by local government units and disaster risk reduction agencies could help inform policy decisions, strengthen building regulations, and guide resource allocation to mitigate seismic risk. For future improvements, further research is recommended to refine the reduction factors for nonregularities and collapse factors adopted from FEMA P-155, ensuring their applicability to Philippine structures. Moreover, validating SCREEN on a larger set of low-rise concrete buildings with varying levels of true seismic risk through detailed engineering assessment or post-earthquake reconnaissance will strengthen its reliability in terms of both sensitivity and specificity.

References:

[1] UN OCHA Philippines. 2014. Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/ OCHA Philippines Bohol Earthquake Sitrep No6.pdf on 16 June 2021.

[2] ABS-CBN. 2019. Retrieved from https://news.abs-cbn.com/news/04/28/19/infra-damage-from-luzon-quake-hits-p500-million on 16 June 2021.

[3] (PHIVOLCS) Philippine Institute of Volcanology and Seismology. 2019. Retrieved from https://reliefweb.int/report/philippines/october-2019-series-earthquakes-cotabato-and-vicinity on 16 June 2021.

[4] Federal Emergency Management Agency (FEMA). 2002. Rapid visual screening of buildings for potential seismic hazards: A handbook (FEMA-154). 2nd ed. Washington, D.C., USA: Applied Technology Council for the Federal Emergency Management Agency.

[5] Federal Emergency Management Agency (FEMA). 2015. Rapid visual screening of buildings for potential seismic hazards: a handbook (FEMA P-154). 3rd ed. Washington, D.C., USA: Applied Technology Council for the Federal Emergency Management Agency.

[6] Hernandez JJ, Diola N, Zarco MA, Antonio OV, Cariño R, Germar F, Longalong RE, Orozco C, Tan LR, Tan Tian J, Torio L, Victor J. 2013. Rapid condition assessment tool (RCAsT). Institute of Civil Engineering. University of the Philippines Diliman.

[7] Orozco C, Diola N, Hernandez J, Zarco MA, Antonio OV, Germar F, Tan LR, Torio L, Cariño R, Tan Tian J, Victor J, Longalong RE. 2013. Development of a rapid condition assessment tool for reinforced concrete moment-resisting frame buildings in the Philippines: Material component. SB 13 Conference; Manila, Philippines.

[8] Tan LR, Hernandez JJ, Diola N, Zarco MA, Antonio OV, Germar F, Orozco C, Torio L, Cariño R, Tan Tian J, Victor J, Longalong RE. 2013. Development of a rapid condition assessment tool for reinforced concrete moment-resisting frame buildings in the Philippines: Structural component. SB 13 Conference; Manila, Philippines.

[9] Zarco MA, Torio L, Tan Tian J, Diola N, Hernandez JJ, Antonio OV, Germar F, Cariño R, Orozco C, Tan LR, Victor J, Longalong RE. 2013. Development of a rapid condition assessment tool for reinforced concrete moment-resisting frame buildings in the Philippines: Geotechnical component. SB 13 Conference; Manila, Philippines.

[10] (PHIVOLCS) Philippine Institute of Volcanology and Seismology. 2014. Retrieved from https://www.phivolcs.dost.gov.ph/ vault/pdf/Publication_Earthquake Preparedness/Flyer-How-Safe-Is-Your-House.pdf on 3 May 2021.

[11] Bromme R, Jucks R. 2018. Discourse and expertise: The challenge of mutual understanding between experts and laypeople. In: Schober M, Rapp D, Britt MA (Eds.). New York and Oxon: The Routledge Handbook of Discourse Processes. Taylor and Francis. p. 222–246.
[12] Imai H, Minowa C, Lanuza AG, Penarubia HC, Narag IC, Soridum RU, Okazaki K, Narafu T, Hanazato T, Inoue H. 2015. A full-scale shaking table test on Philippine concrete hollow blocks (CHB) masonry houses. Journal of Disaster Research. 10:113-120.
[13] Pacheco B, Hernandez JJ, Castro PP, Tingatinga EA, Suiza R, Tan LR, Longalong RE, Veron MC, Aquino DH, Macuha R, Mata W, Villalba IB, Pascua MC, Ignacio U, Germar F, Diño, JR, Reyes GP, Tirao JL, Zarco MA. 2013. Development of vulnerability curves of key building types in the Greater Metro Manila Area Philippines. Institute of Civil Engineering. University of the Philippines Diliman.
[14] Baniqued JR, Oringo JM, Pacheco B. 2024. Expert and novice perceptions of influence and convenience of certain parameters in rapid screening of seismic risk of damage in low-rise concrete buildings in the Philippines. [Manuscript submitted for publication]. Institute of Civil Engineering, University of the Philippines Diliman.
[15] Baniqued JR, Pacheco B. 2022. Redeveloping a non-expert visual screening tool for estimating the seismic risk of low-rise concrete buildings in the Philippines. College of Engineering, University of the Philippines Diliman.
[16] Oringo JM, Baniqued JR. 2024. Validating and recalibrating a seismic screening tool for novice screeners. College of Engineering, University of the Philippines Diliman.
[17] United Nations. 2016. Retrieved from https://www.undrr.org/publication/report-open-ended-intergovernmental-expert-working-group-indicators-and-terminology on 20 July 2021.
[18] GMA News. 2018. Retrieved from https://www.gmanetwork.com/news/news/metro/640081/ dpwh-finishes-structural-audit-on-gov-rsquo-t-buildings-in-metro-manila/story/ on 31 May 2021.
[19] Hernandez JJ, Diola N, Zarco MA, Antonio OV, Cariño R, Germar F, Longalong RE, Orozco C, Tan LR, Tan Tian J, Torio L, Victor J. 2014. Phase II RCAsT Report. Institute of Civil Engineering. University of the Philippines Diliman.
[20] Association of Structural Engineers of the Philippines, Inc. (ASEP). 2010. National Structural Code of the Philippines. 6th Edition.
[21] Mukhopadhyay P, Dutta SC. 2017. Rapid visual screening of earthquake-susceptible buildings. Proceedings of the Institution of Civil Engineers: Municipal Engineer. 170:74–81.
[22] Wang Y, Goettel KA. 2007. Enhanced rapid visual screening (E-RVS) method for prioritization of seismic retrofits in Oregon. Oregon Department of Geology and Mineral Industries 31.
[23] Wallace NM, Miller TH. 2008. Seismic screening of public facilities in Oregon's western counties. Practice Periodical on Structural Design and Construction. 13:189-197.
[24] Ishack S, Bhattacharya SP, Maity D. 2021. Rapid visual screening method for vertically irregular buildings based on seismic vulnerability indicator. International Journal of Disaster Risk Reduction. 54:102037.
[25] Cardenas O, Farfan A, Huaco G. 2020. Seismic risk assessment of Peruvian public school buildings using FEMA P-154 rapid visual screening. 2020 Congreso Internacional de Innovacion y Tendencias en Ingenieria. CONIITI 2020. 0-4.
[26] Indian Institute of Technology Bombay. 2004. Retrieved from https://www.civil.iitb.ac.in/~rsinha/ Vulnerability_Assessment.pdf.
[27] SAARC Disaster Management Centre. 2011. Rapid structural and non-structural assessment of school and hospital buildings in SAARC countries. New Delhi.
[28] Marshall JD, Eeri M, Jaiswal K, Eeri M, Gould N, Eeri M, Turner F, Eeri M, Lizundia B. 2013. Post-earthquake building safety inspection: Lessons from the Canterbury, New Zealand, Earthquakes. Earthquake Spectra 29(3):1091-1107.
[29] Ericsson KA. 2015. Acquisition and maintenance of medical expertise: A perspective from the expert-performance approach with deliberate practice. Academic Medicine.
[30] Mieg H. 2001. The social psychology of expertise. Mahwah, NJ: Lawrence Erlbaum Associates.
[31] Ghasemi A, Mahsuli M, Mortazavi SMS. 2018. Perception and communication of seismic risk: Design and implementation of a functional tool. Natural Hazards Review. 19:04017028.
[32] Association of Structural Engineers of the Philippines, Inc. (ASEP). 1992. National Structural Code of the Philippines. 4th ed.
[33] (JICA) Japan International Cooperation Agency. 2004. Retrieved from https://openjicareport.jica.go.jp/pdf/11763752_02.pdf on 18 May 2021,

[34] Gencturk B, Elnashai AS Song J. 2007. Fragility relationships for populations of buildings based on inelastic response. MAE Center Report. p. 7-18.
[35] Krawinkler H. 1996. Pushover analysis: why, how, when, and when not to use it. 65th Annual Convention of the Structural Engineers Association of California. p. 17-36.
[36] DIANA. 2021. DIANA FEA [software].
[37] DIANA. n.d. Retrieved from https://tutorials.dianafea.com/MasonryHouse.pdf on 22 Sept, 2021,
[38] Rossetto T, Gehl P, Minas S, Galasso C, Duffour P, Douglas J. Cook O. 2016. FRACAS: A capacity spectrum approach for seismic fragility assessment including record-to-record variability. Engineering Structures. 125:337-348.
[39] Computers and Structures, Inc. 2008. ETABS v 9.5.0 [software].
[40] Federal Emergency Management Agency (FEMA). 2015. Rapid visual screening of buildings for potential seismic hazards: Supporting documentation (FEMA P-155). 3rd ed. Washington, D.C., USA: Applied Technology Council for the Federal Emergency Management Agency,
[41] (PHIVOLCS) Philippine Institute of Volcanology and Seismology. 2020. Retrieved from https://hazardhunter.georisk.gov.ph
[42] Lasala M, Inoue H, Tiglao R, Fan Z, Bautista B, Narag I. 2015. Establishment of earthquake intensity meter network in the Philippines. Journal of Disaster Research. 10:43-50.
[43] Wald D, Quitoriano V, Heaton T, Kanamori H. 1999. Relationships between peak ground acceleration, peak ground velocity, and modified Mercalli intensity in California. Earthquake Spectra 15:557-564.
[44] Imai H, Akitoshi N, Lanuza AG, Penarubia HC, Ison R, Tamayo M, Narag I, Solidum RU, Inoue H, Sakuma J, Okazaki K. 2015. Development of practical tools for vulnerability and safety evaluation of houses in the Philippines. Journal of Disaster Research. 10:121-128.