Evaluating Cracks and Structural Strength of Essential Educational Buildings Around Porac, Pampanga: Categorizing Retrofitting Requirements Through Color-Coded Mapping

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***Abstract*: The Philippines, located along the Pacific Ring of Fire, is highly prone to seismic activity, with thousands of earthquakes occurring each year, some strong enough to cause significant damage and loss of life. One such event was the 2019 Luzon earthquake, which led to the collapse of the Chuzon Supermarket in Porac, Pampanga, highlighting the need to assess the safety of nearby structures, particularly essential facilities such as schools. This study evaluated the structural condition of three schools located closest to the collapse site—Porac National High School, Porac Model Community High School, and Pulung Santol National High School. Using Rapid Visual Screening (RVS), Pulung Santol National High School was identified as the most critical and selected for comprehensive evaluation. Crack mapping was performed using image-based analysis in MATLAB to obtain data on crack orientation, length, and thickness, while Non-Destructive Testing (NDT), including rebar scanning and rebound hammer testing, was conducted to determine the current compressive strength of cracked elements. A color-coded map was then created to visually present the retrofitting requirements of the assessed buildings. Structural elements with cracks were assigned specific colors based on severity and NDT results, to determine retrofitting required. This ensures that only parts requiring intervention are identified for more practical structural planning. The findings of this study aim to serve as a reference for future assessments and retrofitting prioritization, contributing to safer and more resilient educational environments in seismic-prone areas.**

***Keywords*: RVS, crack mapping, non-destructive testing, MATLAB, cracks, retrofitting.**

1. Introduction

Historically, earthquakes have caused devastation to many parts of the world, including catastrophic events in Haiti (2010) and Japan (2011). The Haitian government estimated that the earthquake had killed more than 300,000 people and destroyed the capital, Port-au-Prince [1]. The 2011 Japan earthquake triggered a massive tsunami and caused the Fukushima nuclear disaster, resulting in severe destruction.

In 2015, the United Nations launched the Sustainable Development Goals (SDGs), which aim to foster global prosperity, peace, and sustainable growth. The seventeen (17) SDGs are interrelated, recognizing that multiple actions are necessary to achieve development and sustainability in a balanced manner [2]. The Sustainable Development Goal 11 meets the study's objectives as it aims to ensure school buildings' safety by identifying and examining various cracks present in the structure, which the SDG 11 supports in building a safe, resilient, and sustainable environment.

The Philippines is an earthquake-prone country due to its location in the Pacific Ring of Fire, where several tectonic plates interact, such as the Philippine Sea Plate, the Eurasian Plate, and the Pacific Plate [3]. The Philippine Trench causes frequent seismic activity in the country due to the major subduction zone of the Philippine Sea Plate, which extends from Eastern Batanes to Southeastern Davao [4].

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) provided detailed information regarding the earthquakes experienced in the country from January 1, 2023 to September 2023. It indicated that 6,065 earthquakes occurred in the past 9 months, recorded 22 seismic events per day with a magnitude of 2.5 and a depth of 30 km. The PHIVOLCS recorded major earthquakes ranging from magnitude 5.8 to 7 in the same year. On January 18, 2023, the strongest earthquake was listed in Balut Island, Davao Occidental, with a 15 km depth [3]. This seismic activity causes serious damage to properties and threatens people's safety.

Along the Western side of Luzon, Philippines, the Bataan Volcanic Arc Complex (BVAC) is a well-known geological feature formed by the subduction of the South China Sea Plate beneath the Philippine Mobile Belt along the Manila Trench (Quebral et al., 1996) [5]. As one of the five distinct segments of the Luzon Volcanic Arc, this volcanic arc features a series of stratovolcanoes, geothermal systems, and volcanic deposits that illustrate the dynamic tectonic and magmatic activities shaping the region. These geological features make the BVAC a critical area of expertise. Furthermore, the arc plays a vital role in sustaining agricultural activities through its fertile soil, and geothermal resources present significant opportunities for sustainable energy development. However, according to the study of Defant et al. (1989), the active nature of some of the volcanoes within the arc poses significant natural hazards, including volcanic eruptions, lahars, and earthquakes, posing a risk to the community that is densely populated [6]. Regular geological monitoring and development of a disaster preparedness plan are important to protect both people and structures located near BVAC.

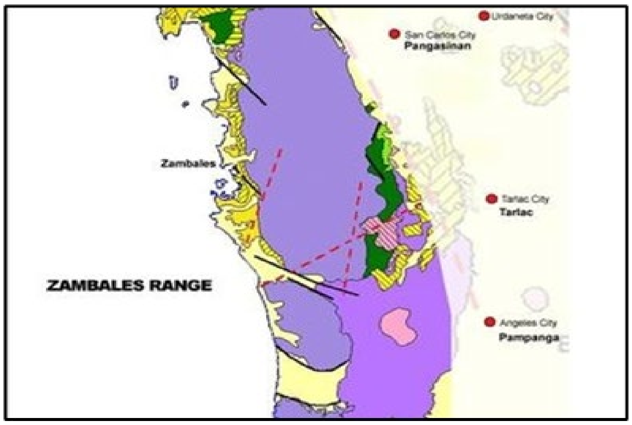


Fig. 1. Bataan volcanic arc complex

Maintaining the structural strength of a building is significant to ensure that a structure can safely support its designed loads without failure. This will help prevent tragic incidents from happening that could result in loss of life and property. However, regular inspections and maintenance are necessary to ensure that a structure is still safe and functional throughout its service life [7].

During earthquakes, both people and infrastructure are at risk. It has been shown in several studies that the number of casualties and injuries following an earthquake is directly connected to the vulnerability of a building [8]. Because of this, assessment of establishments that accommodate large numbers of people, such as schools, is significant. Cracks can compromise the safety of buildings if left unaddressed, as they can progress into more serious structural issues [9]. These can negatively affect a building's strength since they are considered visual imperfections. The cracks present can also identify the current condition of the structure through crack mapping. This method refers to determining, recording, and analyzing cracks present in the structure. The process can be done manually or through advanced and modern techniques [10].

The Matrix Laboratory (MATLAB), a modern technology application, was used for crack mapping in the study. The digital image processing tool is crucial in obtaining the important data, such as the length, orientation, and width, by analyzing the crack images. The Rebound Hammer Test, also known as the Schmidt Hammer Test, was performed to assess and evaluate the current structural strength of the structures. This NDT method was widely used to evaluate the current compressive strength of concrete by measuring the surface hardness using the rebound principle developed by Ernst Schmidt in 1948 [11].

Structures were analyzed and modified to enhance their safety and performance by the updated standards through retrofitting. The specific type of retrofitting method depends on the construction year and current condition of the structure. For instance, seismic retrofitting is designed to improve the structure's ability to withstand earthquakes by enhancing the energy dissipation and ductility of the buildings. It is also interesting to note that seismically active regions have performed well using seismic retrofitting methods such as base isolation, adding bracings, or using dampers in such a way that disastrous failure does not occur even in the case of severe shakes, as indicated by Pampanin and Christopoulos (2016) [12]. Under seismic retrofitting, a shear wall consists of adding walls, increasing the structure's lateral load capacity, an important factor in regions with a lot of wind or earthquakes (Cruz et al., 2018) [13].

2. Methodology

This study follows a systematic methodology that is divided into three main phases: preliminary preparations, investigation and design, and data analysis and interpretation. The process began with the selection of three schools for the study area, followed by the collection of important data such as structural plans and soil profiles, and the calibration and preparation of Non-Destructive Testing equipment necessary for the assessment and investigation.

A. Methodological Framework

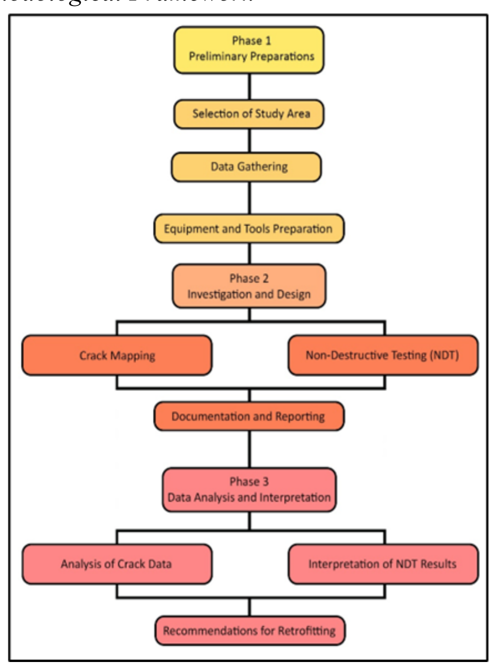


Fig. 2. Methodological Framework

To identify the most critical school for detailed evaluation, a Rapid Visual Screening (RVS) was conducted on each school to quickly identify visible signs of structural vulnerabilities. Based on the result, crack mapping and non-destructive testing were carried out to assess the current structural strength of the buildings. The final phase focused on interpreting the data gathered from crack mapping and NDT. These data are significant to identify the most appropriate retrofitting requirements for each evaluated building. This structured approach ensured that each stage of the study was aligned with the research objectives and contributed to a thorough assessment of structural safety.

B. Phase I: Preliminary Preparations

1) Stage 1: Selection of Study Area

This study was conducted in selected schools within Porac, Pampanga. Three schools were selected based on their proximity to structures heavily damaged by the 2019 Luzon earthquake, specifically the collapsed Chuzon Supermarket and the Santa Catalina de Alejandria Parish Church [14]. The selected schools were Porac National High School, Porac Model Community High School, and Pulung Santol National High School, located approximately within 3–6 kilometers of each other.

Fig. 3. Porac model community high school


Fig. 4. Porac national high school


Fig. 5. Pulung santol high school

The researchers intended to perform RVS on these schools to evaluate the extent of visible damage, with special attention to cracks in critical structural elements. Only three- to four-story buildings, at least five or more years of being built, were selected for inspection, as these are more likely to exhibit signs of wear and potential structural vulnerabilities. The primary objective is to identify buildings displaying a significant number of cracks, which could indicate structural vulnerabilities. To determine whether cracks were serious enough to threaten people's safety during an earthquake, an inspection was carried out. Afterwards, a school with significant damage was selected for a thorough analysis.

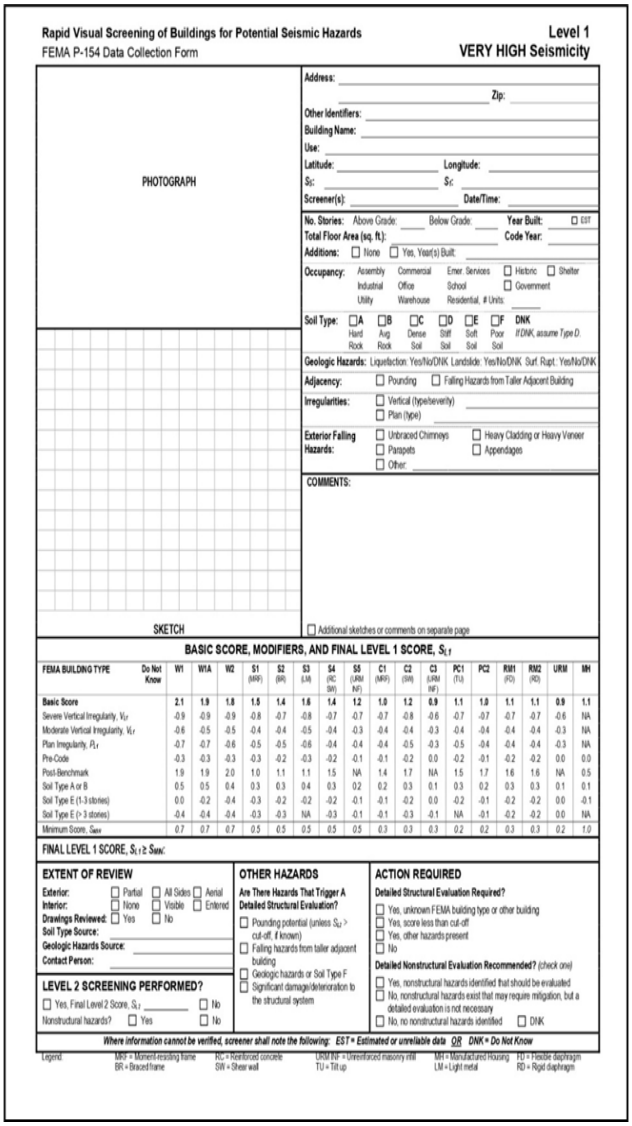
Before proceeding with RVS and inspection, the researchers first asked permission from the principals of Porac Model Community High School (PMCHS), Porac National High School (PNHS), and Pulung Santol National High School (PSNHS). To identify the most structurally vulnerable school within the study area, RVS was employed. Through RVS, the researchers were able to select the most suitable school that require a more detailed analysis.

2) Stage 2: Data Gathering

To support the objectives of this study, the researchers gathered three key types of information. The first step involved requesting structural plans and related documents from the Department of Public Works and Highways (DPWH). These included as-built drawings, soil test reports, and any available inspection history reports. These documents were necessary in carrying out methods such as Rapid Visual Screening (RVS), Crack Mapping, and Non-Destructive Testing (NDT).

RVS was used as a primary step to rapidly evaluate the vulnerability of the school buildings during an earthquake. This technique assisted in identifying possible structural issues and determining which school buildings are qualified for more detailed inspection.

It relies on a scoring system rather than structural calculations to identify potential weaknesses that could affect the seismic performance of buildings, which served as a valuable tool in this research study. Afterwards, only one school was selected for further assessment.



Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
VERY HIGH Seismicity

PHOTOGRAPH

Address: Zip:
Other Identifiers:
Building Name:
Use:
Latitude: Longitude:
S_S: S_1:
Screener(s): Date/Time:

No. Stories: Above Grade: Below Grade: Year Built: ☐ EST
Total Floor Area (sq. ft): Code Year:
Additions: ☐ None ☐ Yes, Year(s) Built:
Occupancy: Assembly, Commercial, Emer. Services, ☐ Historic, ☐ Shelter, Industrial, Office, School, ☐ Government, Utility, Warehouse, Residential, # Units:
Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil DNK If DNK, assume Type D.
Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK
Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building
Irregularities: ☐ Vertical (type/severity) ☐ Plan (type)
Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer ☐ Parapets ☐ Appendages ☐ Other:

COMMENTS:

SKETCH

☐ Additional sketches or comments on separate page

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	Do Not Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score		2.1	1.9	1.8	1.5	1.4	1.6	1.4	1.2	1.0	1.2	0.9	1.1	1.0	1.1	1.1	0.9	1.1
Severe Vertical Irregularity, V_{L1}		-0.9	-0.9	-0.9	-0.8	-0.7	-0.8	-0.7	-0.7	-0.7	-0.8	-0.6	-0.7	-0.7	-0.7	-0.7	-0.6	NA
Moderate Vertical Irregularity, V_{L1}		-0.6	-0.5	-0.5	-0.4	-0.4	-0.5	-0.4	-0.3	-0.4	-0.4	-0.3	-0.4	-0.4	-0.4	-0.4	-0.3	NA
Plan Irregularity, P_{L1}		-0.7	-0.7	-0.6	-0.5	-0.5	-0.6	-0.4	-0.4	-0.4	-0.5	-0.3	-0.5	-0.4	-0.4	-0.4	-0.3	NA
Pre-Code		-0.3	-0.3	-0.3	-0.3	-0.2	-0.3	-0.2	-0.1	-0.1	-0.2	0.0	-0.2	-0.1	-0.2	-0.2	0.0	0.0
Post-Benchmark		1.9	1.9	2.0	1.0	1.1	1.1	1.5	NA	1.4	1.7	NA	1.5	1.7	1.6	1.6	NA	0.5
Soil Type A or B		0.5	0.5	0.4	0.3	0.3	0.4	0.3	0.2	0.2	0.3	0.1	0.3	0.2	0.3	0.3	0.1	0.1
Soil Type E (1-3 stories)		0.0	-0.2	-0.4	-0.3	-0.2	-0.2	-0.2	-0.1	-0.1	-0.2	0.0	-0.2	-0.1	-0.2	-0.2	0.0	-0.1
Soil Type E (> 3 stories)		-0.4	-0.4	-0.4	-0.3	-0.3	NA	-0.3	-0.1	-0.1	-0.3	-0.1	NA	-0.1	-0.2	-0.2	0.0	NA
Minimum Score, S_{MIN}		0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2	1.0

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$:

EXTENT OF REVIEW
Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source:
Geologic Hazards Source:
Contact Person:

LEVEL 2 SCREENING PERFORMED?
☐ Yes, Final Level 2 Score, S_{L2} ☐ No
Nonstructural hazards? ☐ Yes ☐ No

OTHER HAZARDS
Are There Hazards That Trigger A Detailed Structural Evaluation?
☐ Pounding potential (unless S_{L2} > cut-off, if known)
☐ Falling hazards from taller adjacent building
☐ Geologic hazards or Soil Type F
☐ Significant damage/deterioration to the structural system

ACTION REQUIRED
Detailed Structural Evaluation Required?
☐ Yes, unknown FEMA building type or other building
☐ Yes, score less than cut-off
☐ Yes, other hazards present
☐ No
Detailed Nonstructural Evaluation Recommended? *(check one)*
☐ Yes, nonstructural hazards identified that should be evaluated
☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data OR DNK = Do Not Know

Legend: MRF = Moment-resisting frame, BR = Braced frame, RC = Reinforced concrete, SW = Shear wall, URM INF = Unreinforced masonry infill, TU = Tilt up, MH = Manufactured Housing, LM = Light metal, FD = Flexible diaphragm, RD = Rigid diaphragm

Fig. 6. RVS High seismicity level 1 data collection form

The required data were obtained during a site visit, including the site address, construction year, number of stories, total floor area, building occupancy and use, soil type, irregularities, and other relevant information about the building.

1. *Building Identification Information and Building Characteristics:* The primary section of the Federal Emergency Management Agency (FEMA) P-154 data collection form referred to general information, encompassing important details such as address, location, screener identification, number of stories, total floor area, usage, construction year, and buildings with additions, supported by images and sketches of the observed building. Afterwards, the second portion involved assigning equivalent scores to equivalent parameters based on the type of building.
2. *Photographing the Building and Sketching Elevation Views and Plans:* Providing photographs of the building, sketches of the structure's floor plan, and optionally an elevation drawing were necessary to emphasize key features and convey essential details of the structure. These elements helped the individual checking the information examine all aspects of the structure, including irregularities. Additionally, the floor plan sketch included the building's specific location on the site and its distance from neighboring structures, offering a clear visualization of its layout and context.

   - *SketchUp Pro:* SketchUp, a 3D modeling software utilized across various drawing applications, including landscape architecture, architecture, interior design, mechanical and civil engineering, film, and design, provides a range of tools for creating detailed 3D models. These tools facilitated tasks such as spatial planning and design visualization [15]. In this study, SketchUp Pro 2024 was used to create color-coded maps to visualize the severity of cracks present in each building.

3. *Building Occupancy:* The building occupancy refers to its use. Even though it did not typically bear immediately on the structural hazard, building occupancy was crucial when identifying priorities for mitigation. The form included nine general occupancy categories: Assembly, Industrial, Commercial, Office, Emergency Services (Emer. Services), Residential, Historic, Government, and School Buildings. The occupancy classifications remained consistent with those used in the previous edition of FEMA P-154, making them easily identifiable from the street, covering a wide range of building uses in the United States (US), and resembling the categories found in the Uniform Building Code [16].
4. *Site Soil Type:* Scoring adjustments depended on the soil type, as the data collection forms only included modifiers for soil types A, B, and E, while the baseline score was calculated based on the average properties of soil types C and D. However, there is no scoring adjustment applied for Soil Type F since the RVS process could not effectively assess buildings on this type of soil. For buildings situated on Soil Type F, they were categorized as a "Geologic hazard," requiring a more comprehensive structural assessment.
5. *Determining Potential Exterior Falling Hazards:* Certain elements, like unbraced chimneys, cornices, veneers, parapets, heavy cladding, and overhangs, pose safety risks if they are not securely attached to the building. However, even if such hazards existed, the

building's primary lateral load-bearing system might still have been well-designed, meaning additional evaluation was not necessarily required.

6. *Documenting the Basic Structural Score:* The data collection form recorded the Basic Structural Scores, which were located in the top row of the structural scoring matrix at the bottom section of the form. In regions with moderate to high seismic activity, these scores pertained to buildings constructed after the initial implementation and enforcement of seismic codes but before the latest substantial code upgrades, specifically prior to the benchmark year. In areas with low seismic activity, these scores are applied to all buildings, excluding those designed and built after the benchmark year.
   Score modifiers included in the collection form allowed adjustments to the Basic Structural Hazard Score based on the building's design and construction period.
7. *Classification of Buildings:* Building classification systems provide standardized terminology and definitions commonly used within the construction industry [17]. These systems enabled consistent communication and facilitated the organization of existing knowledge in a clear, structured manner. The proposed classification scheme is shown in Table 1.
8. *Type of Irregularities:* Buildings were often irregular due to functional, economic, or architectural reasons. Building irregularities were typically grouped into two categories: plan irregularities and vertical irregularities.
   - *Vertical Irregularities:* In Level 1 RVS procedure, vertical irregularities were further separated into severe vertical irregularities, which had a significant adverse effect on building performance, and moderate vertical irregularities, which had a fewer significant adverse effect. The RVS score accounted for irregularities by including negative Score Modifiers, which depended on the type and severity of the structure's irregularities.
   - *Plan Irregularities:* According to FEMA P-154, five different plan irregularities were identified. When one or more plan irregularities were observed, a corresponding modifier was chosen in the assessment.

Table 1
Building types

FEMA Building Type	
W1:W1A	Light wood frame
W2	Wood frame, commercial, and industrial
S1	Steel moment-resisting frames
S2	Braced steel frame
S3	Light metal frame
S4	Steel frame with concrete shear walls
S5	Steel frame with infill unreinforced masonry walls
C1	Concrete moment-resisting frame
C2	Concrete shear wall
C3	Concrete frame with infill, unreinforced masonry walls
PC1	Tilt-up construction
PC2	Precast concrete frame
RM1	Reinforced masonry with flexible floor and roof
RM2	Reinforced masonry with rigid floor and roof
URM	Unreinforced masonry bearing wall
MH	Manufactured housing
DNK	Building type cannot be definitely identified, or if the engineer is uncertain about the building type.

- *Pre-Code:* This score modifier was appropriate if the building being screened had been designed and built prior to the primary enforcement of seismic codes. In regions with low seismic activity, this modifier was not applied, as it had already been incorporated into the basic score itself.
- *Post-Benchmark:* If the building being screened had been designed and constructed after significantly improved seismic codes were adopted and enforced by the local jurisdiction, this score modifier was applied. Determining the years when seismic codes were initially implemented and when they were enhanced (benchmark year) in the region was essential for properly utilizing both pre-code and post-benchmark modifiers.
  In his analysis titled "Structural Design Practices in the Philippines: Looking Back and Looking Beyond," Sy, J.A. outlined distinct eras in the country's structural design history. Before 1972, known as the Pre-Code years, no formal structural design code was in place. This changed with the introduction of the National Structural Code for Buildings (NSCB) 1972. The post-benchmark period began around 1992, marked by the publication of the National Structural Code of the Philippines (NSCP) 1992, 4th Edition.[18] This era saw a significant increase in construction activity, driven by improvements in structural design standards.

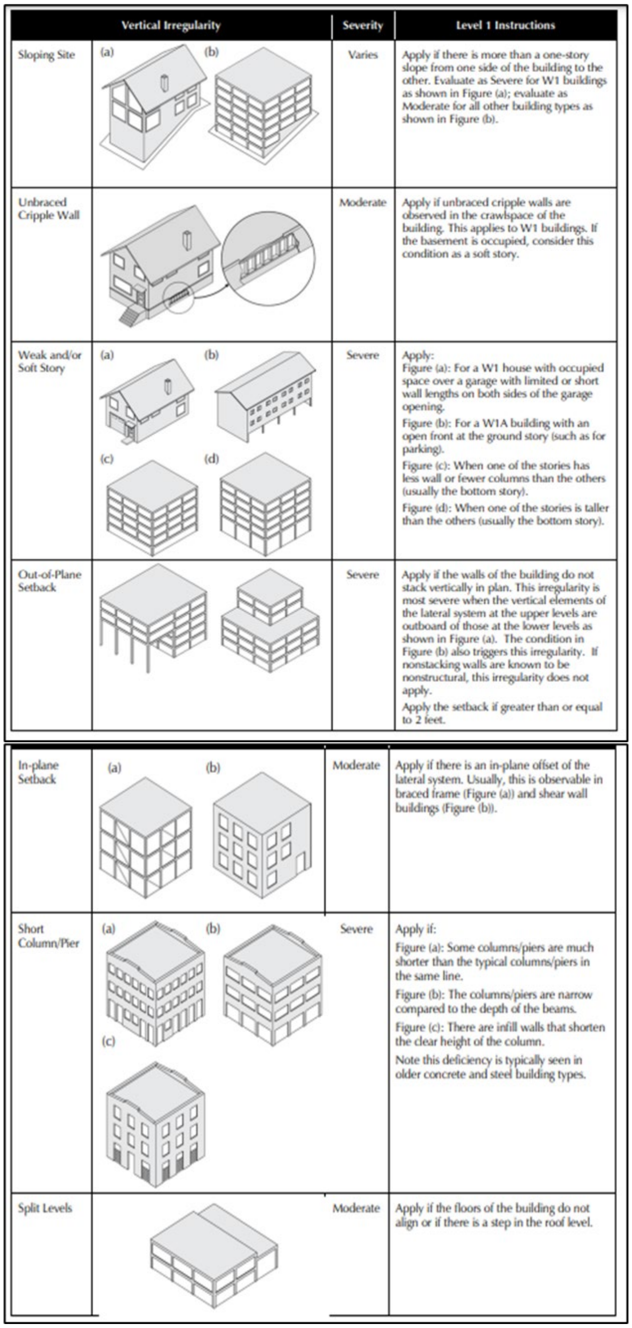


Fig. 7. Vertical irregularities

- *Minimum Score:* In some cases, a building's final score could be zero or even negative, indicating damage beyond 100%. To address this, FEMA P-154 provided a minimum score that could be assigned on the data collection form. If a building's calculated final score fell below the minimum, the pre-determined minimum score was used as the final value. This minimum was derived by considering the worst possible combination of all score modifiers simultaneously.

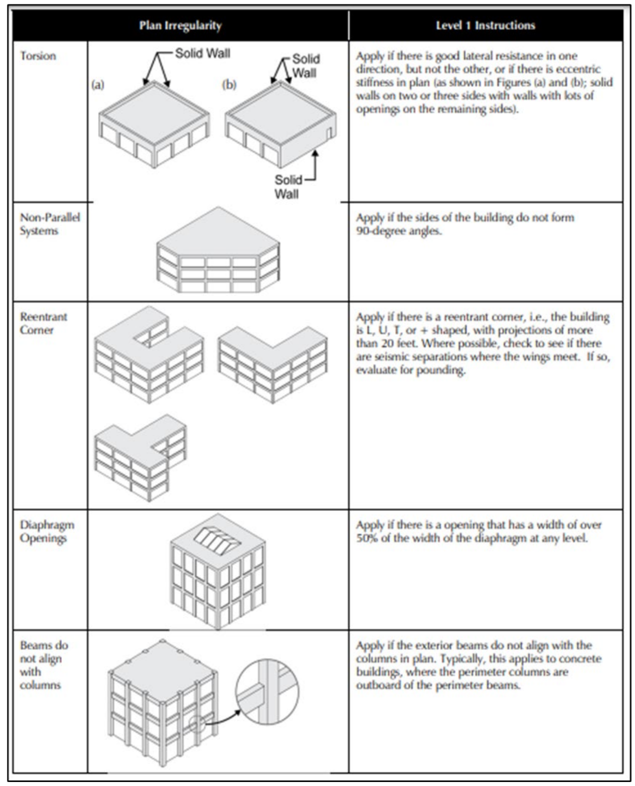


Fig. 8. Plan Irregularities

- *RVS Score:* Once the RVS process was completed, the building's Final Structural Score (S) was determined and the potential damage, as shown in Table 2. This score was calculated based on the Basic Structural Hazard Score and the associated Score Modifiers. For RVS authorities, understanding what the S score represented was crucial. Essentially, it estimated the probability that the building would collapse if subjected to ground motions equal to or greater than the Maximum Considered Earthquake (MCE) ground motions, as outlined in FEMA for detailed seismic evaluations. However, these probabilities were approximations, as they relied on limited observational and analytical data.

9. *Damage Classification:* The RVS method thus holds great importance for preliminary risk assessment of buildings and infrastructure. Cost and efficiency are among the greater advantages that it offers; ongoing research and innovative advances, however, are needed to overcome some limitations of this method and to improve its reliability.

EMS-98 is the most applied tool to quantify earthquake intensity by considering the effects due to earthquakes on people, buildings, and the environment. The European Seismological Commission came up with this version after several updates from previous scales, specifically MSK-64, and raised its standards through the well-defined classification system and more detailed building vulnerability assessments as well as structural response criteria [19]. It is divided into twelve classes starting from the point where the movements are not detected up to fully destruction, extensively applied in all types of analyses concerning seismic hazards, disaster mitigation and preparedness, and paleoearthquakes [20]. Compared with the other such scales, it has been emphasized that EMS-98 is generally more systematic or standardized than for example Modified Mercalli Intensity (MMI) or Japan Meteorological Agency (JMA) scale of intensity, to avoid subjective assignments in intensity classes [21]. Modern seismic research basically needs the scale, which can be integrated with advanced technologies such as remote sensing and artificial intelligence, to enhance earthquake impact analysis [22].

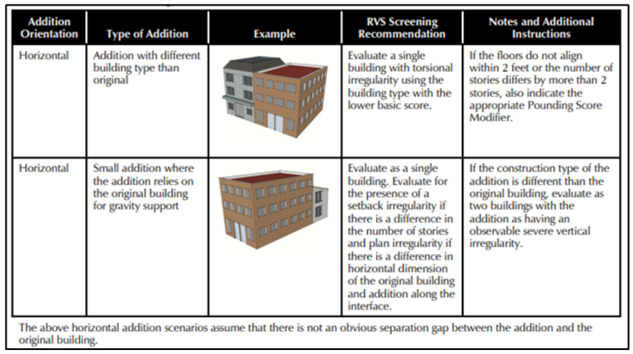
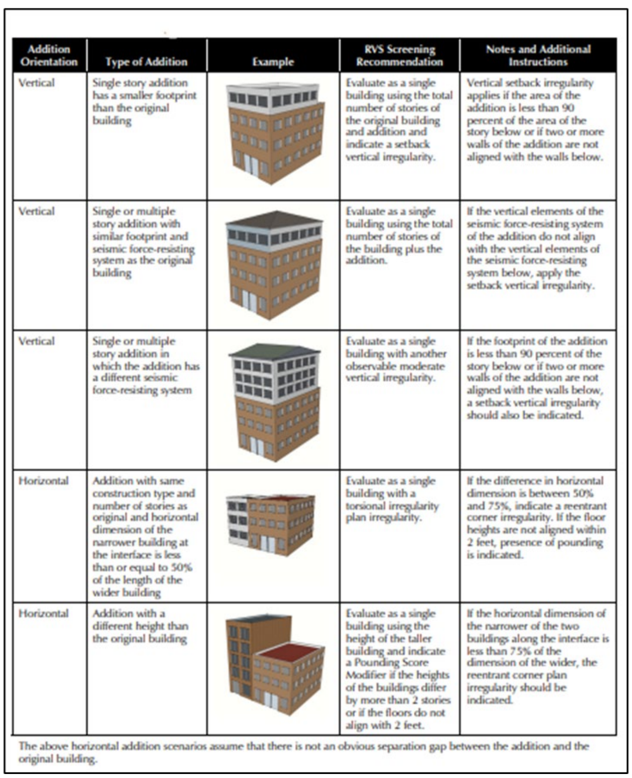


Fig. 9. Building addition references guide

Table 2
Interpretation of RVS Score

RVS Score	Potential Damage
S < 0.3	High probability of Grade 5 damage; very high probability of Grade 4 damage
0.3 < S < 0.7	High probability of Grade 4 damage; very high probability of Grade 3 damage
0.7 < S < 2.0	High probability of Grade 3 damage; very high probability of Grade 2 damage
2.0 < S < 3.0	High probability of Grade 2 damage; very high probability of Grade 1 damage
S > 3.0	Probability of Grade 1 damage



10. *Hazard Hunter:* GeoRisk PH developed the Hazard Hunter application to assess the hazards at a specific location in the Philippines, such as earthquakes, wind, and floods. The application is supported by the Department of Science and Technology (DOST) and the Philippine Institute of Volcanology and Seismology (PHIVOLCS), providing information to the general public. The application provides information on the hazard assessment of a certain location to prevent catastrophes and prepare people to avoid the effects of these hazards. The data collected is used to create plans for buildings that may need further evaluation, retrofitting, redesign, or reconstruction to ensure their resilience against natural hazards [23].

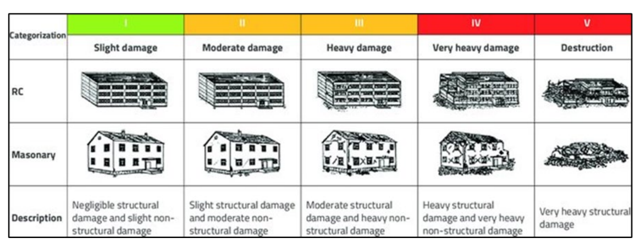


Fig. 10. Classification of damage grade for masonry and reinforced concrete

An assessment of 105 buildings in Sorsogon, Philippines, was conducted to evaluate their hazard safety and sustainability. The study highlighted the vulnerability of each building to various natural hazards. An application like Hazard Hunter were used to collect data regarding the safety of these buildings from the hazards in the area. The study evaluated the hazard prone buildings and assessed those buildings that need further evaluation, retrofitting, redesign and reconstruction. The findings determined the vulnerability of each type of building to extreme hazards and the identified actions that can be used to reduce the risks [24].

In 2024, a study in evaluation and classification of seismic preparedness mapping plan conducted at Don Honorio Ventura State University (DHVSU) in Bacolor, Pampanga, assessed the buildings vulnerability through Hazard Hunter. The tool provides data regarding the geological hazards presents that can impact buildings in the campus. The assessment prepared the school to mitigate and plan the safest routes during unforeseen events. The use of Hazard Hunter highlights the effectiveness of supporting preparedness and safety planning in educational institutions [25].

3) Stage 3: Equipment and Tools Preparation

To gather accurate data on crack orientation, length, and thickness, the researchers employed essential equipment like a drone camera, rebar scanner, and rebound hammer. To guarantee reliable results, it is crucial to appropriately prepare each tool. The researchers were assisted by a Department of Public Works and Highways (DPWH) engineer who provided the necessary tools, including the rebar scanner and rebound hammer. Additionally, technological advice and knowledge were exchanged to increase the precision and effectiveness of data collecting. A accurate assessment of the buildings' structural state has been achieved as a result of this coordination and careful tool preparation.

Fig. 11. Rebound hammer

The rebound hammer was used to check the surface hardness of concrete. Its actual appearance can be seen in Figure 11. This tool provides an indirect estimate of the concrete's current compressive strength by measuring the distance traveled by a spring-loaded plunger after hitting the concrete surface. This method assisted in identifying the consistency of the concrete, determining areas that are weak, and evaluating the quality of concrete without inflicting damage on the structure. Calibration of the rebound hammer was done in advance, by strictly following the manufacturer's guidelines to guarantee that the results are reliable.

Shown in Figure 12 is another non-destructive tool called rebar scanner was used to locate and measure the depth and diameter of reinforcement within concrete structures. Before using it, the device settings were adjusted according to the manufacturer's instructions. The scanner was placed on the concrete surface and the movement across the area being inspected must be steady to ensure the accuracy of the test. This tool provided necessary information such as the rebar location, spacing, and estimated size which were displayed on the screen. The detected positions were marked on the concrete surface using pencil or chalk to guarantee that the reinforcement bars would not interfere with the rebound hammer test results.

Fig. 12. Rebars scanner

Fig. 13. Drone camera

Some cracks in the structures were found in areas that were difficult to reach, that is why the researchers made use of drone cameras to provide high-resolution image and videos. Figure 11 shows the drone camera, which allowed the researchers to inspect large areas of buildings with the presence of cracks, without needing any scaffolding or physical access.

C. *Phase II: Investigation and Design*

1) *Stage 4: Crack Mapping of Buildings*

Based on the RVS results, Pulung Santol National High School (PSNHS) was selected as the school that required a detailed analysis, as it contains irregularity and more visible cracks, as compared to other schools assessed. Crack mapping was conducted to analyze both patterns and severity of the detected visible cracks. Since relying on manual measurements is prone to error, the researchers adopted a more efficient and precise method. Using MATLAB, high-resolution images of cracks were used and processed. This method helped categorize cracks accurately according to their geometric features such as orientation, length, and thickness.

The high-resolution images were processed and analyzed using MATLAB's Image Processing and Statistics with Machine Learning Toolboxes. The crack centerline was derived to define its path and direction by isolating the cracks from background elements. The measurements of crack length and thickness were performed using pixel-to-metric conversion. Afterwards, the histogram of crack thickness and the Cumulative Distribution Function (CDF) were generated to assess the distribution patterns of cracks and identify the governing thickness.

Fitting with the classification method adopted in the study by A.S. Zanke (2020), the researchers classified crack width as thin, medium, or wide according to the thickness primarily governing it, as determined from histogram analysis.

Fig. 14. Thin crack (less than 1mm)

Fig. 15. Medium crack (between 1-2 mm)

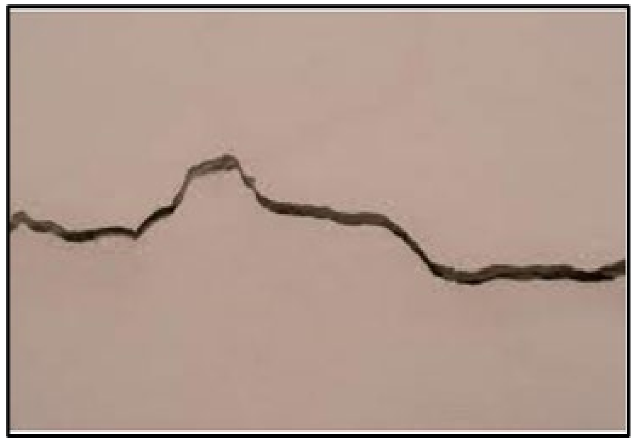


Fig. 16. Wide crack (more than 2 mm)

In addition, these cracks were recorded based on each exact location, whether they are located at wall-beam connections or areas near windows and doors. Their corresponding floor level was also noted, including their orientation like horizontal, vertical, diagonal, or curved. Such observations enhanced the understanding of the researchers in the crack patterns for the subsequent stages.

2) *Stage 5: Non-Destructive Testing (NDT)*

In this stage, different NDT methods were used to detect internal defects and evaluate the durability and strength of the affected educational facilities. The researchers utilized techniques such as Rebar Scanning and Rebound Hammer Testing, with assistance of an expert from the Department of Public Works and Highways (DPWH) to ensure proper tool usage and accurate results.

The steps for Rebar Scanning and Rebound Hammer Testing are as follows:

1. Rebar Scanning
    1. *Preparation of the Site.* Before scanning, the concrete surface was cleared of grease, dirt, debris, coatings, or anything else that could interfere with the Ground Penetration Radar (GPR) signal. A grid spaced by 10 cm by 10 cm was marked using chalk or pencil to guide the scan consistently. The area was then examined for any obstructions, such as electrical conduits or pipe, which were noted for future use as references throughout the research [26].
    2. *Equipment Setup.* The frequency of the GPR system was adjusted to match the anticipated depth of the rebars (lower frequency for deeper scanning, for example). To guarantee accurate findings, calibration was also carried out in accordance with the manufacturer's instructions. After that, a test scan was performed on a known rebar area to ensure that the device functioned as intended. [25]
    3. *Scanning Procedure.* To obtain reliable and accurate data when scanning rebar, it was essential to set the GPR antenna flat on the

concrete surface. The scanning procedure started from the indicated grid's starting point and required moving the device slowly and steadily to cover the area systematically. The researchers and operators indicated the location of detected rebar directly on the concrete surface while keeping an eye on the data shown on the device's screen in real time. Further scans were carried out at various angles, such as perpendicular or diagonal to the original scan, to guarantee accuracy. [26]

4. *Data Collection*. The raw data from the scan was recorded to determine the position, depth, and spacing of the rebars. Surface defects that could have affected the results, including visible rebar or fissures, were recorded. For documentation purposes, test area photos and videos of the scanning procedure were taken.

2. Rebound Hammer Testing

According to ASTM C805-18 the step-by-step procedure of Rebound Hammer Testing are as follows:

1. *Prepare Test Surface.* The testing area had a diameter of at least 150 mm to guarantee consistency in measurements. The testing surface is smooth, free from textured or loose mortar, and moisture or water on the concrete surface was removed prior to testing, as excess moisture could have affected the result. It was also crucial not to test frozen concrete, as it could have resulted in high rebound numbers due to the presence of ice. Additionally, testing surfaces with steel reinforcement were avoided in order to prevent unreliable results. A rebar scanner was used to locate the steel placement and ensure accurate testing.
2. *Rebound Hammer Direction.* When performing the rebound hammer test, it was crucial to ensure the proper orientation of the instrument, which is shown in Figure 15 to obtain accurate and consistent results. The testing began by holding the rebound hammer securely, this ensures that the rebound hammer was pointing right at the testing surface. This ensured that the impact was applied correctly and the rebound readings were reliable. Additionally, the orientation of the instrument was taken into consideration. The position of the instrument was recorded according to its orientation, whether it is placed horizontally, vertically upward and downward or in any angles. Properly documenting the angle of the test was essential for interpreting the results, as the rebound number could vary depending on the direction of the test.

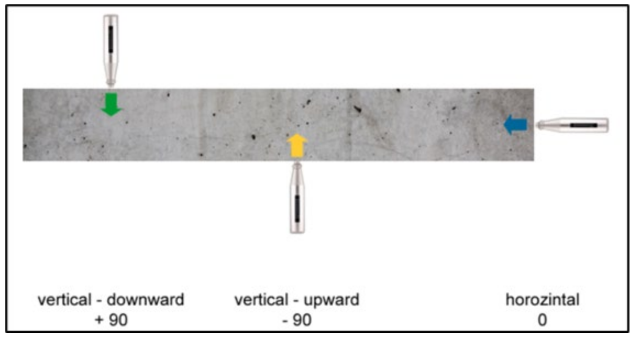


Fig. 17. Rebound hammer direction

3. *Taking Measurements.* When taking measurements with the rebound hammer, the device was properly aligned, and the angle was recorded accurately. Once in position, the instrument was pushed onto the testing surface. Following the impact, constant pressure was applied to the rebound hammer, and the plunger was locked in by pressing the side button. Lastly, the rebound number, displayed on the instrument, was recorded and rounded off to the whole number. Ten readings were obtained from each testing location, which has at least 25 mm distance from every point, and a distance of 50 mm from the concrete edge in order to ensure accurate results which is shown in Figure 18.

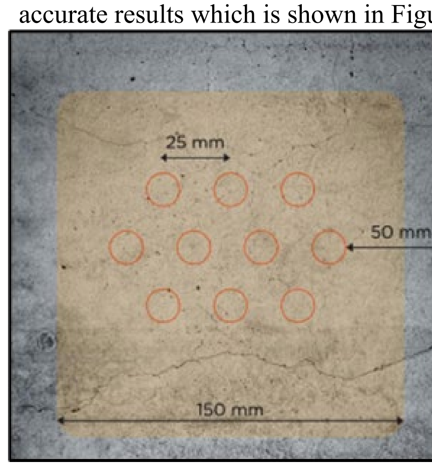


Fig. 18. Taking measures

4. *Calculating Rebound Number.* To calculate the rebound number, multiple rebound readings were first collected from the test surface, typically 10 readings from a single test location. Each reading's average was then calculated and rounded off to the whole number.
5. *Determining the Compressive Strength Based on the Conversion Chart in the Rebound Hammer Instrument*. After calculating the final rebound number, the corresponding compressive strength of the concrete was determined using the conversion chart located on the body of the

rebound hammer. This chart, which varies depending on the hammer model, provided a direct relationship between the rebound number and estimated compressive strength (typically in MPa or N/mm²). By aligning the final rebound number with the appropriate curve, the strength value was read directly from the chart.

3) Stage 6: Documentation and Reporting

This stage focused on the organized documentation and organization of data gathered from previous stages, ensuring that all findings were presented in a clear, structured, and technically sound manner. The results from RVS, Crack Mapping, and NDT were systematically organized into detailed tables, figures, and charts to ensure that a comprehensive overview of the structural condition of the evaluated school buildings is provided.

All tabulated data encompassed important parameters such as crack location, orientation, length, thickness range, and classification. Also, the rebound hammer values and their corresponding actual concrete strength were shown. The interpretation of rebound hammer test results was carried out in accordance with the guidelines outlined in the CPWD Handbook (2002), which categorizes concrete quality based on average rebound values as shown in Table 3.

A formal report was prepared to compile and present all research findings, which served as the basis for interpretation and recommendation in the following stages. This documentation ensured that engineers, school officials, and other relevant stakeholders could readily engage with the data, making them well-informed with regards to the structural safety and retrofitting needs of the structures.

Table 3
Quality of concrete corresponding to different rebound numbers

Average Rebound Number	Quality of Concrete
> 40	Very good hard layer
30 – 40	Good layer
20 – 30	Fair
< 20	Poor
0	Delaminated

D. Phase III: Data Analysis and Interpretation

1) Stage 7: Analysis of Crack Data

Using Conventional Image Processing Toolbox, Statistics and Machine Learning Toolbox from MATLAB, the researchers analyzed the characteristics of cracks such as thickness, length, and orientation, at this stage. Crack mapping techniques, including detection, measurement, and classification based on geometric features, were employed in alignment with the established methodologies [27].

The study demonstrates the accuracy and consistency of computational techniques with the code developed by Preetham M. Using the code, important crack characteristics such as length and thickness were extracted [28]. The procedure began with capturing high-resolution images of visible cracks. After that, each image was processed by isolating the image and converting it into bitmap format to prepare it for analysis. Once converted, the image was processed in MATLAB which allowed the researchers to generate charts including Cumulative Distribution Function (CDF) and histogram that illustrated the distribution of crack thickness. In determining the crack length, the same procedure was followed: crack identification, photographic capture, image isolation, and bitmap conversion. After that, the area covered by the image was calculated and processed in MATLAB to obtain precise crack length measurement.

Charts (Cumulative Distribution Function (CDF) of the Crack Thickness and Histogram of the Crack Thickness)

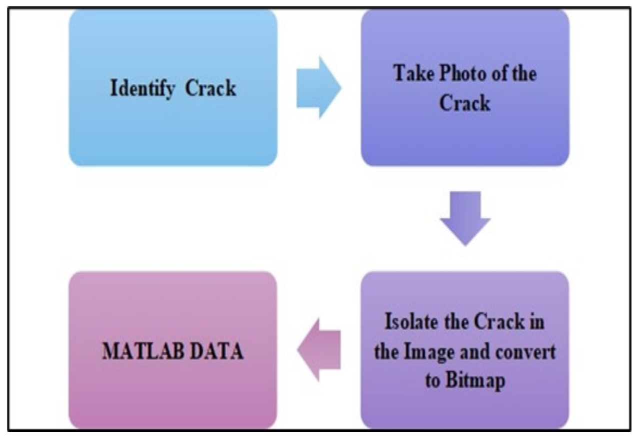


Fig. 19. Code 1 for obtaining charts

Crack Length

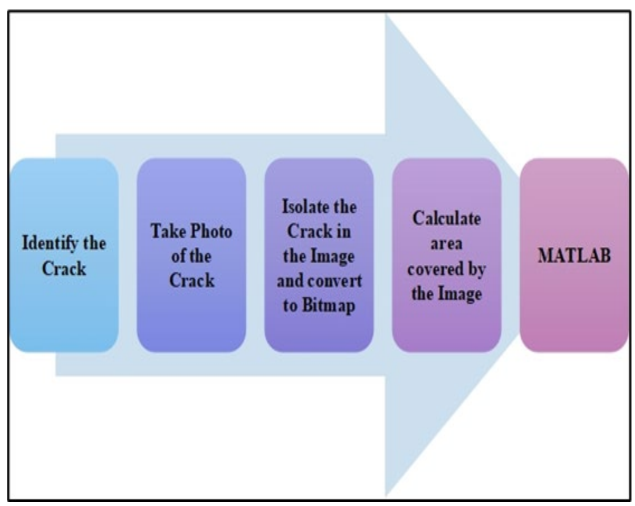


Fig. 20. Code 2 for obtaining crack lengths

After processing the CDF, histogram, and length data using MATLAB, the researchers evaluated the cracks at Pulung Santol National High School in Porac, Pampanga. The cracks were analyzed based on their orientation, total linear length, and thickness classification, using the criteria established in Stage 4. Afterwards, cracks were categorized as thin, thin–medium, medium, thin–wide, and wide based on the histogram analysis of their governing thickness.

This structure gave an insight into the crack patterns and supported making informed maintenance decisions that could help extend the lifespan of the structures, ensure continued safety, and adequately suggest cost-effective retrofitting interventions. The crack analysis results are presented through pie graphs and line charts to visualize and better interpret the conditions of each building.

2) Stage 8: Interpretation of NDT Results

In this phase of the study, detailed analysis and interpretation were made regarding results from NDT procedures carried out in the previous stage. This included rebar scanning to ascertain both condition and position of reinforcement bars for the different concrete elements. Interpretation started with evaluating the rebound hammer test results, which provided an estimation of compressive strength of the concrete elements, compared with the design compressive strength, further defined as pre-service strength, as per the structural plans and records. This comparison allowed the researchers to evaluate the degree of strength reduction of structural elements over time.

Using bar graphs, the researchers presented an organized interpretation of the rebound hammer test results. Pie charts were also used to categorize and depict the overall concrete quality of the buildings depending on rebound numbers.

These charts provided a more efficient visual identification for evaluating variations in concrete quality among walls, beams, and columns, based on the standard classifications outlined in the rebound hammer testing guidelines. This correlation showed the amount of strength reduction, emphasizing areas with the most reduced structural strength that may require action. By comparing the rebound values with original strength standards, the researchers were able to identify areas of weakness and the discrepancies within the concrete structure.

The combination of NDT findings with crack mapping data enabled a more comprehensive evaluation of each building's durability. This combined analysis supported the development of a color-coded map that categorized the retrofitting requirements for each evaluated building. This approach directly supported the study's objective of improving safety in educational facilities located within seismic zones.

3) Stage 9: Recommendations for Retrofitting

Based on the comprehensive analysis of crack severity and measured compressive strength, the researchers proposed specific retrofitting recommendations for each structural element on all three school buildings. These recommendations were based on the combined results from Crack Mapping and NDT, particularly using the data gathered from the rebound hammer test and rebar scanning. The retrofitting classifications were organized to reflect the level of urgency and extent of intervention needed and are defined as follows:

1. Seismic Retrofitting Required
    - *Criteria*: Structural elements with severe structural cracks, significantly reduced concrete strength as identified through NDT, or both, indicating a high likelihood of failure during seismic events
    - *Examples*: Reinforced concrete shear walls, post-tensioning, base isolation systems, and steel bracing.
2. Minor Retrofitting Required (Orange)
    - *Criteria*: Structural elements with moderate cracks with little to noticeable reductions in compressive strength, especially in structural load-bearing elements, that may affect long-term durability and structural performance.
    - *Examples*: Epoxy injection, polyurethane (PU) grouting, and carbon fiber reinforcing.
3. Aesthetic Retrofitting Only (Yellow)
    - *Criteria*: Structural elements with mostly superficial or hairline cracks that do not compromise structural safety but may require repairs for preventive maintenance or surface restoration.
    - *Examples*: Low viscosity epoxy resins, concrete resurfacing, surface patching, flexible coatings, and tile or veneer cladding.

To ensure that structural issues were addressed accordingly, the classification served as a clear and practical guide for identifying the necessary interventions. The responsibility for determining and implementing specific retrofitting techniques was assigned to the Department of Public Works and Highways (DPWH) or other relevant agencies. By outlining these recommendations, the study aimed to help prioritize appropriate actions and make sure that limited sources were used efficiently by focusing on the most critical structural concerns.

In addition, to help teachers, students, and other school staff better understand the findings and avoid possible confusion, the researchers created an infographic brochure. This brochure clearly explains what each color in the retrofitting means using simple words and illustrations. Its primary purpose is to make sure that everyone, even ordinary people, can interpret the results correctly. By presenting the information in an easy-to-understand format, the brochure supports awareness and preparedness, while also helping to prevent misinterpretation or panic about the condition of the school buildings.

4) Stage 10: Development of a Color-Coded Map

In the final stage of the study, a color-coded map was created employing SketchUp Pro 2024 to present a clear visualization of the retrofitting needs of the evaluated structural elements in each building based on the results of both Crack Mapping and Non-Destructive Testing (NDT). The map served as a simplified but meaningful representation of the overall structural condition of each element. Specific colors were used to represent specific retrofitting categories, which makes it easier to spot which beams, columns and walls need urgent attention. The retrofitting categories were defined as follows:

1. Green (Safe). No retrofitting required. The element shows no significant cracks and maintains adequate compressive strength.
2. Yellow (Aesthetic Retrofitting). Cracks present are mostly superficial in nature with no to very minimal strength reduction based on NDT, requiring only cosmetic repairs.
3. Orange (Minor Retrofitting). Structural elements show signs of moderate damage, such as wider cracks in key load-bearing members or slightly reduced compressive strength. These conditions necessitate minor reinforcement or localized structural repairs.
4. Red (Seismic Retrofitting Required). Severe damage is present, particularly in critical load-bearing elements, and low strength values, indicating a high likelihood of structural failure without immediate intervention.

The application of this classification supported the visualization of structural priorities across the school site and provided a clear framework for identifying the extent of retrofitting needed for each structural element.

E. Ethical Considerations

This research involved acquiring structural plans of high school buildings in Porac, Pampanga, from the Department of Public Works and Highways (DPWH), as well as their assistance in conducting non-invasive testing methods, such as the Rebound Hammer Test and Rebar Scanning. The primary ethical considerations focused on data privacy, duty-bound data handling, and ensuring that the research was conducted with minimal disruption to the school community.

Structural plans, soil profile data and all other information obtained from the DPWH, were used strictly in accordance with institutional and legal guidelines, ensuring that no confidential or sensitive data were disclosed or misused. All data were for the purpose of this study, and all measures were taken to respect the privacy of all the schools involved in the study.

The researchers interacted with DPWH personnel and school administrators to ensure that all NDT procedures were performed accurately and transparently. Tests and experiments were carried out with the full knowledge and consent of the pertinent authorities to minimize potential hazards and avoid unneeded disruption to school activities.

The researchers complied with globally accepted ethical standards throughout the span of the study to ensure the safety of all stakeholders, the protection of institutional data and the responsible presentation of research findings. All stages of the study were carefully done with transparency, respect, confidentiality and integrity.

3. Results and Discussion

A. Rapid Visual Screening (RVS)

1) Type of Form Used

This study focused on assessing the safety of structures using Rapid Visual Screening (RVS). The researchers used the FEMA P-154 Data Collection Form, which is designed for high-risk areas. Necessary information, such as the age, number of stories, and the type of construction of each building, was obtained as they are needed in accomplishing the RVS Form. Some factors that affect the response of buildings to earthquakes include soil conditions and near active faults. The results identify the building condition that may require repairs, retrofitting, or strengthening to ensure the building's safety.

Given that Porac, Pampanga, is classified as a region with very high seismic activity according to the Spectral Acceleration Maps of the Philippines 2021 issued by DOST-PHIVOLCS, the researchers have chosen to utilize the "Very High Seismicity" Data Collection Form from FEMA P-154. This form is specifically designed to collect detailed information on buildings located in areas prone to intense seismic activity.

2) Building Identification Information

Table 4 summarizes the essential details of the evaluated school buildings in Porac, Pampanga, including their name, year of construction, number of stories, and primary function. Understanding these factors is crucial in assessing structural strength, as older buildings may not adhere to current seismic design standards. Since this study aims to evaluate cracks and categorize retrofitting requirements, identifying these characteristics establishes a foundation for assessing the buildings' vulnerability to structural failure.

3) Year Built

Assessment through RVS is pivotal for gathering key information about the buildings. It illustrates characteristics such as the construction year and design of the assessed buildings, with FEMA explaining the influence of building age. Understanding these characteristics facilitates the assessment of the current condition and potential risks in the future. Figure 18 illustrates the categorization of the buildings into Post-Benchmark or Pre-Code. It shows that all the buildings in Porac National High School (PNHS), Porac Model Community High School (PMCHS), and Pulung Santol National High School (PSNHS) are post-benchmark, as they were built after 1992.

4) Number of Stories

The number of stories in a building significantly influences its vulnerability to earthquake damage. Taller buildings are ground motion and higher loads. The study initially focused on assessing buildings in Porac, Pampanga, which are three to four stories and were built from 2019 and below. However, due to the unavailability of three-story buildings, only four-story buildings were considered. Figure 20 indicates that the buildings have four floors, making them more exposed to earthquake forces compared to lower-rise structures. Therefore, regular inspections and safety measures are recommended to

Table 4
Building identification information of porac national high school, porac model community high school, and pulung santol national high school

Name of Building	Construction Date	No. Of Stories	Building Use
Porac National High School – High School Building	2015	4	Classroom
Porac Model Community High School – Junior High School Building	2015	4	Classroom
Porac Model Community High School – Senior High School Building	2019	4	Classroom/Laboratory
Pulung Santol National High School – Building A	2018	4	Classroom
Pulung Santol National High School – Building B	2017	4	Classroom
Pulung Santol National High School – Building C	2019	4	Classroom/Laboratory

ensure the building's safety.
highly susceptible to earthquake damage due to factors such as

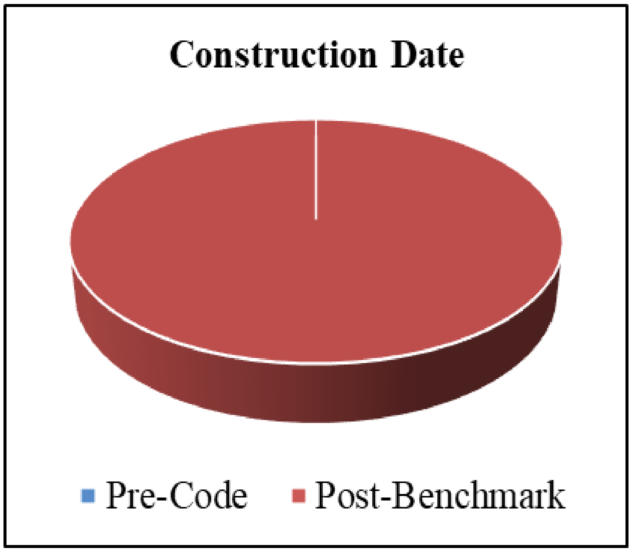


Fig. 21. Year built

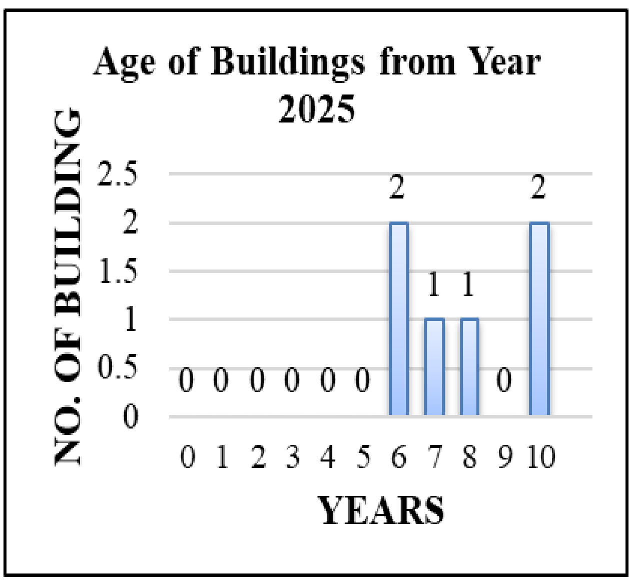


Fig. 22. Age of buildings from year 2025

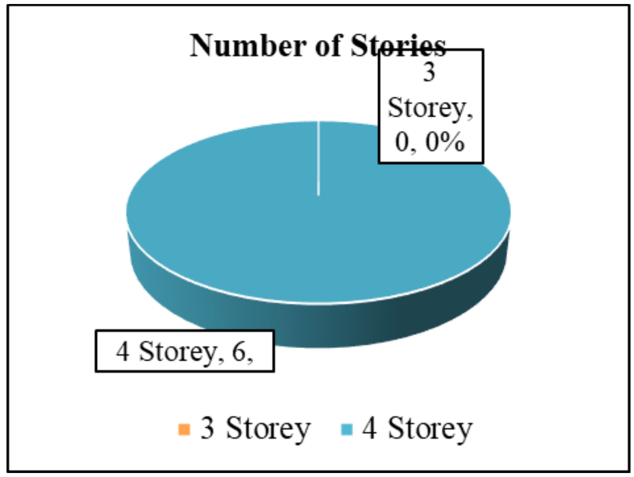


Fig. 23. Number of stories

5) Type of Soil

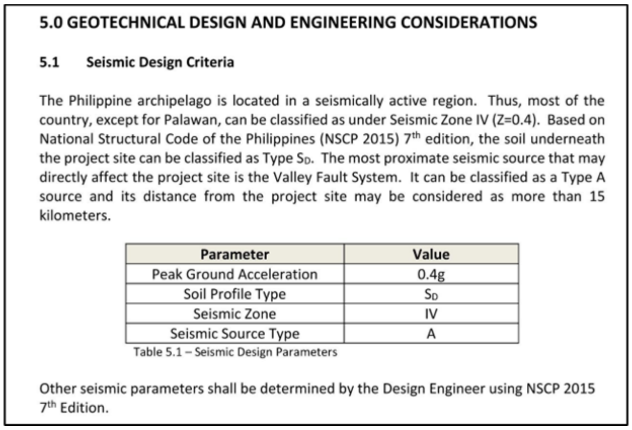
To determine the soil type at PNHS, PMCHS, and PSNHS for RVS, the researchers coordinated with the Department of Public Works and Highways (DPWH) - Pampanga 2nd District Engineering (DEO), San Antonio, Guagua, Pampanga, to obtain relevant soil data. The DPWH provided official documents detailing the soil profile of the area, including information on its seismic zone and seismic source type. Based on the analysis of these records, the soil at PNHS, PMCHS, and PSNHS is classified as Soil Type D, as shown in Figure 21. This classification is essential for RVS, as soil conditions significantly influence a building's seismic performance, facilitating the identification of potential vulnerabilities and prioritizing structural evaluations and retrofitting measures.

6) Hazard Assessment

To evaluate the seismic risks affecting school buildings, Hazard Hunter PH was utilized to examine factors such as ground shaking, liquefaction potential, and proximity to active faults. Since Porac lies within a seismically active region, these hazards have a direct impact on structural stability. By identifying high-risk areas, the study contributes to categorizing retrofitting requirements, ensuring that seismically vulnerable schools are prioritized for appropriate safety interventions.

1. Distance from nearest active fault and their corresponding coordinates

Table 5 presents the geographic coordinates and proximity of selected school buildings to the nearest active fault, specifically the Iba Fault. The listed institutions include PNHS, PMCHS (both Junior and Senior High), and PSNHS (Buildings A, B, and C). These findings highlight that all the identified schools are within a similar range from the fault. Identifying the geographic coordinates of these school buildings is important in understanding their potential earthquake risk.



5.0 GEOTECHNICAL DESIGN AND ENGINEERING CONSIDERATIONS

5.1 Seismic Design Criteria

The Philippine archipelago is located in a seismically active region. Thus, most of the country, except for Palawan, can be classified as under Seismic Zone IV (Z=0.4). Based on National Structural Code of the Philippines (NSCP 2015) 7th edition, the soil underneath the project site can be classified as Type S_D. The most proximate seismic source that may directly affect the project site is the Valley Fault System. It can be classified as a Type A source and its distance from the project site may be considered as more than 15 kilometers.

Parameter	Value
Peak Ground Acceleration	0.4g
Soil Profile Type	S_D
Seismic Zone	IV
Seismic Source Type	A

Table 5.1 – Seismic Design Parameters

Other seismic parameters shall be determined by the Design Engineer using NSCP 2015 7th Edition.

Fig. 24. Geotechnical design and engineering considerations

2. Geologic Hazards

7) *Building Type and Irregularity*

All the evaluated buildings at the three specified schools have been categorized as Concrete Moment Resisting Frame (C1) structures since they display characteristics of C1 structures. This includes the use of reinforced concrete for all frames that are exposed and the proper connection of beams and columns according to FEMA guidelines. This classification signifies that the buildings are constructed to effectively resist lateral forces such as those influenced by earthquakes.

When the layout diverges from a regular, symmetrical shape, plan irregularities in structures occur, which can influence how seismic forces are distributed within the structure. These irregularities can arise due to asymmetrical floor layouts, large openings, or projections in the building plan, making certain areas more susceptible to stress concentrations during an earthquake. Table 7 provides detailed information on whether the assessed buildings exhibit any plan irregularities.

Out of the six four-story school buildings assessed at the schools mentioned, only two were found to have a plan irregularity. This irregularity falls under the category of horizontal irregularities and is specifically identified as a re-entrant corner irregularity. The identified irregularities are directly associated with specific scoring criteria applicable to C1 structures.

Table 5
Distance from nearest active fault and its corresponding coordinates

Name of Building	Coordinates		Distance from Nearest Active Fault
	Latitude	Longitude	
Porac National High School – High School Building	15.07115°N	120.53967° E	Approximately 36.5km east of the Iba Fault
Porac Mode Community High School – Junior High School Building	15.04278° N	120.52889° E	Approximately 36.7km southeast of the Iba Fault
Porac Model Community High School – Senior High School Building	15.04278° N	120.52944° E	Approximately 36.7km southeast of the Iba Fault
Pulung Santol National High School – Building A	15.04764° N	120.55715° E	Approximately 39.3 km southeast of the Iba Fault
Pulung Santol National High School – Building B	15.04784° N	120.55722° E	Approximately 39.3 km southeast of the Iba Fault
Pulung Santol National High School – Building C	15.04801° N	120.55739° E	Approximately 39.3 km southeast of the Iba Fault

Table 6
Geologic hazards

Name of Building	Liquefaction	Earthquake-InducedLandslide	Ground Rupture
Porac National High School – High School Building	Safe	Safe	Safe
Porac Model Community High School – Junior High School Building	Safe	Safe	Safe
Porac Model Community High School – Senior High School Building	Safe	Safe	Safe
Pulung Santol National High School – Building A	Safe	Safe	Safe
Pulung Santol National High School – Building B	Safe	Safe	Safe
Pulung Santol National High School – Building C	Safe	Safe	Safe

8) Interpretation of RVS Score

The RVS scores provide an initial assessment of each building's structural performance under seismic loads.

Table 7
Building type and irregularity

Name of Building	Legend	Building Type	Plan Irregularity	Vertical Irregularity
Porac National High School – High School Building	S1	C1	N/A	N/A
Porac Model Community High School – Junior High School Building	S2	C1	Re-Entrant Corner	N/A
Porac Model Community High School – Senior High School Building	S3	C1	N/A	N/A
Pulung Santol National High School – Building A	S4	C1	N/A	N/A
Pulung Santol National High School – Building B	S5	C1	N/A	N/A
Pulung Santol National High School – Building C	S6	C1	Re-Entrant Corner	N/A

Table 8
RVS Score and damage grade of school buildings

Name of Building	RVS Level 1 Scores (SL1)	Damage Grade
Porac National High School – High School Building	2.7	Grade 1- Grade 2
Porac Model Community High School – Junior High School Building	2.3	Grade 1 - Grade 2
Porac Model Community High School – Senior High School Building	2.7	Grade 1 - Grade 2
Pulung Santol National High School – Building A	2.7	Grade 1 - Grade 2
Pulung Santol National High School – Building B	2.7	Grade 1 - Grade 2
Pulung Santol National High School – Building C	2.3	Grade 1 - Grade 2

Structures with scores 2.0 or higher indicate moderate resilience, while those below 2.0 require further evaluation and potential retrofitting. Since this study seeks to categorize buildings based on retrofitting needs using a color-coded mapping system, interpreting these scores helps prioritize which schools require immediate intervention to prevent structural failure.

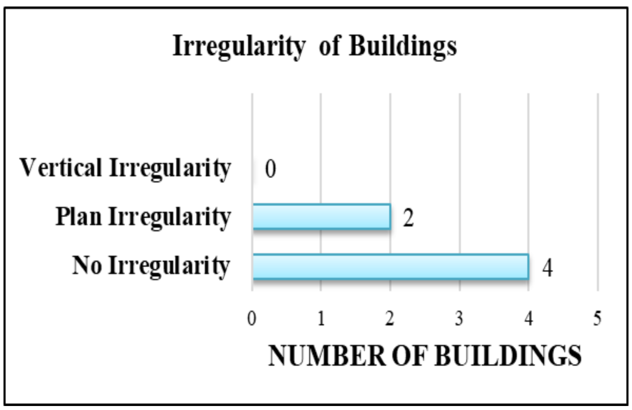


Fig. 25. Irregularity of Buildings

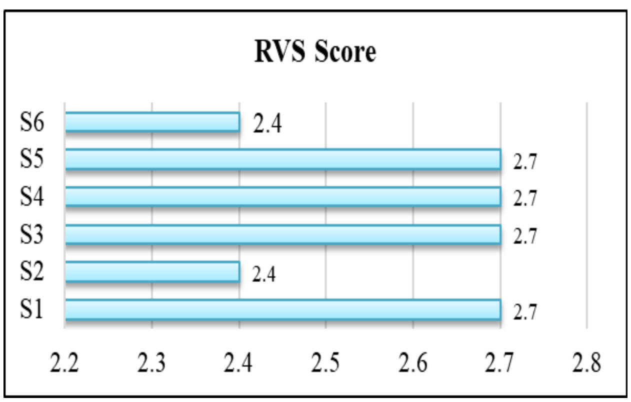


Fig. 26. RVS Scores

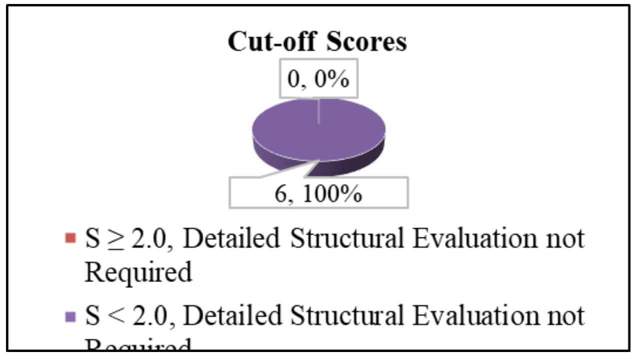


Fig. 27. Cut-off scores

9) Damage Grade of School Buildings

Each building's final RVS score is translated into a damage grade, ranging from Grade 1 (minor damage) to Grade 5 (structural collapse). These classifications help visualize the extent of damage that may occur during seismic events. By incorporating color-coded mapping, the study effectively categorizes buildings based on their retrofitting urgency. This approach aligns with the objective of developing a systematic framework for identifying, prioritizing, and addressing structural weaknesses in Porac's educational buildings.

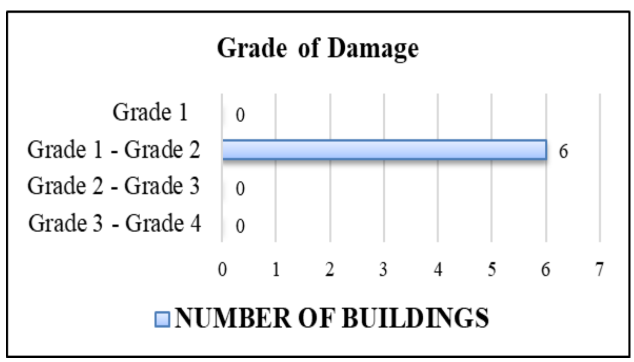


Fig. 28. Grade of damage

10) Results of Rapid Visual Screening (RVS)

After conducting RVS, both PMCHS and PSNHS were found to have a re-entrant corner irregularity, which is a significant plan irregularity that could impact the building's structural stability. However, the researchers chose PSNHS as the research site because of the notable differences in the conditions of the buildings. While both schools have the same irregularity, only PSNHS displayed more cracks, especially around the structural elements of the building. These cracks suggested potential weaknesses in the structure, which made this school a more critical site for further investigation and analysis of cracks based on this study's objectives.

Analyzing the school with more cracks is important because these visible signs of distress are often the first indicators of structural failure. Cracks can worsen and spread, which may lead to larger and more dangerous structural issues if not addressed properly. Since PSNHS contains a notable presence of cracks, there is a greater chance of further damage and degradation, specifically in the event of an earthquake.

Additional signs or indicators of structural distress in PSNHS show a higher risk of damage. By focusing on this particular school, the researchers aim to have a clearer understanding of how different cracks affect the safety of the building and learn more about how these cracks could influence the long-term performance of the building.

B. Analysis of Crack Data from Crack Mapping

To assess and evaluate each crack present on each evaluated building, MATLAB was utilized. This digital image processing tool allows the researchers to obtain necessary crack characteristics such as orientation, lengths, and thickness [27].

1) Crack Orientation

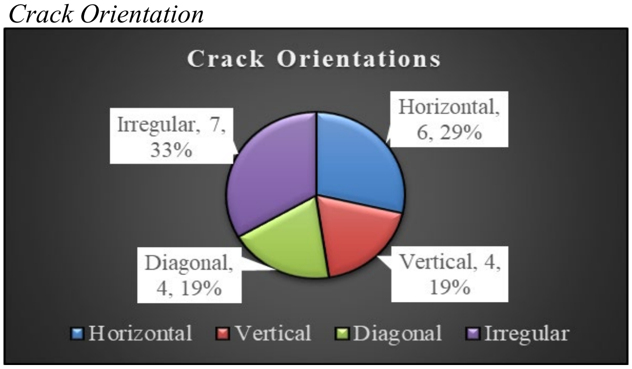


Fig. 29. Crack orientation in building A

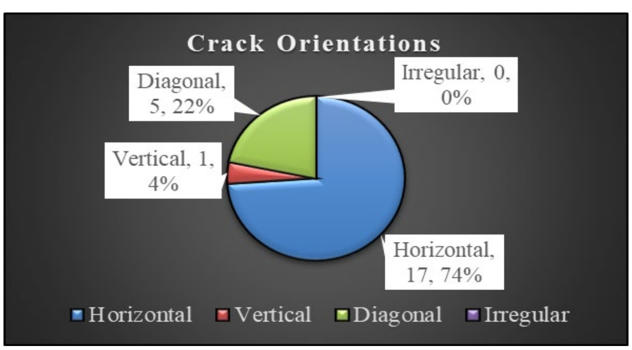


Fig. 30. Crack orientation in building B

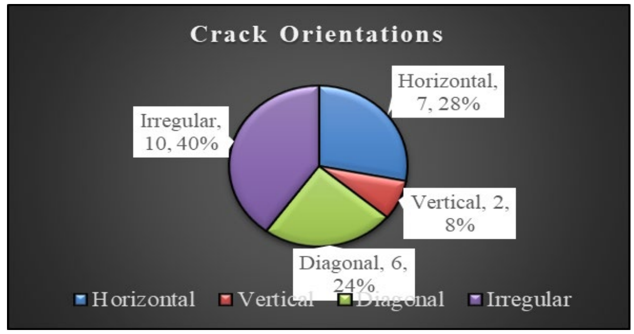


Fig. 31. Crack orientation in building C

The orientation of each crack was determined using MATLAB's crack centerline visualization feature, which allowed the researchers to trace the path of each crack and identify its direction [29]. Cracks were categorized as horizontal, vertical, diagonal, or irregular. Figures 26 to 28 shows the distribution of crack orientations for Buildings A, B, and C.

The graphs show that most cracks in Building A were horizontal, suggesting possible lateral or expansion-related stress. Building B had a mix of all types, while Building C had more irregular cracks. These findings are significant because study conducted by Futhalla et al. crack states that crack orientation helps show where structural weakening may begin, especially in walls and beams that carry loads.

2) Crack Length

Using MATLAB, the total length of each crack was measured to help determine the extent of surface damage. Although crack length alone does not determine severity, it is essential for understanding the spread and affected area. Figure 29, 30, and 31 shows the comparison of the shortest and longest crack lengths identified in Buildings A, B, and C.

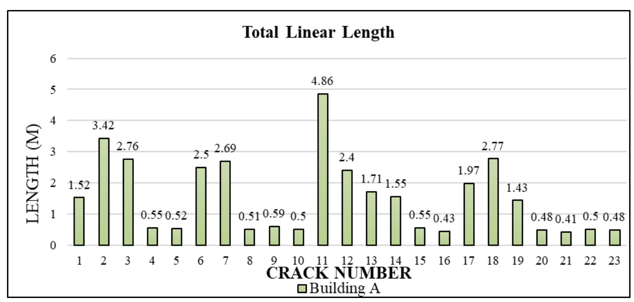


Fig. 32. Crack length at building A

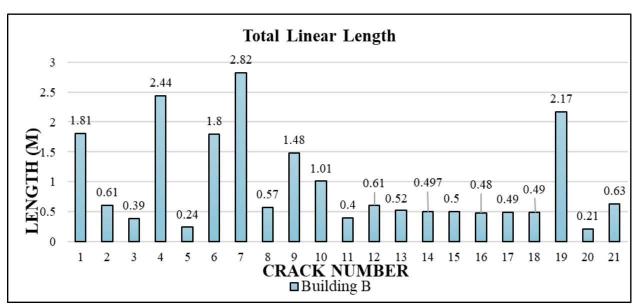


Fig. 33. Crack length at building B

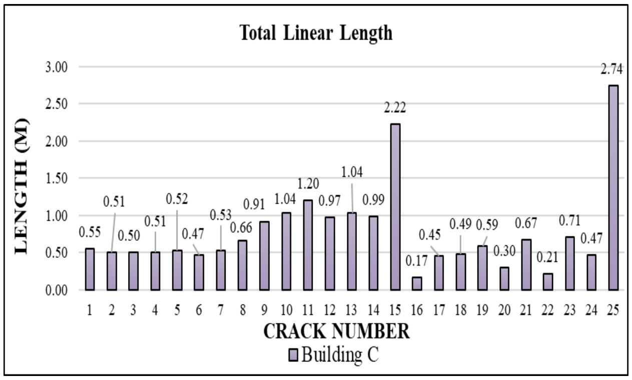


Fig. 34. Crack length at building C

The analysis showed that Building A had the longest crack, measuring 4.86 meters, with most of its cracks ranging between 0.41 and 4.86 meters. Building B had cracks from 0.21 to 2.82 meters, while Building C ranged from 0.17 to 2.74 meters. Across all three buildings, many cracks were measured around 1 meter in length. These findings are crucial since the studies conducted by Liao Jing and Shendkar et al. states that longer cracks, especially those greater than two meters, may indicate more serious structural concern and require stronger retrofitting measures depending on their location.

3) Crack Classification According to Thickness

To determine each crack classification, the researchers used the histogram of crack thickness to determine the governing range per crack. The Cumulative Distribution Function (CDF) was also used to analyze thickness variation along the length of each crack. Cracks were then categorized as thin, thin-medium, medium, wide, or thin-wide. Shown in figures 32 to 34 are the thickness classification distribution of cracks found in each building.

Building A had no wide or thin-wide cracks, but most of its cracks were thin to medium. Building B showed a small percentage of thin-wide cracks, while Building C had a slightly more varied distribution, including one wide crack. These classifications helped determine which elements required retrofitting, as studies by Miura et al. and Alomari et al. confirmed that as crack thickness increases, the compressive strength of concrete tends to decrease.

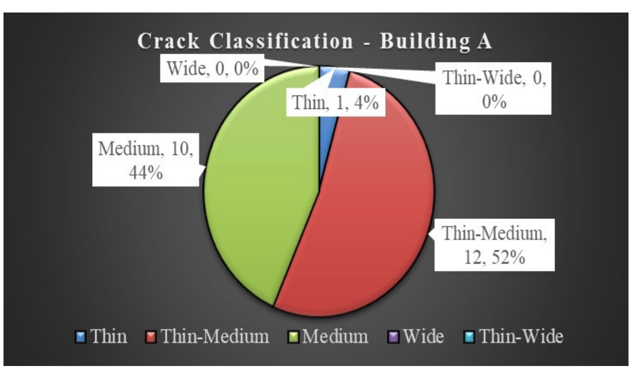


Fig. 35. Classification of cracks in building A

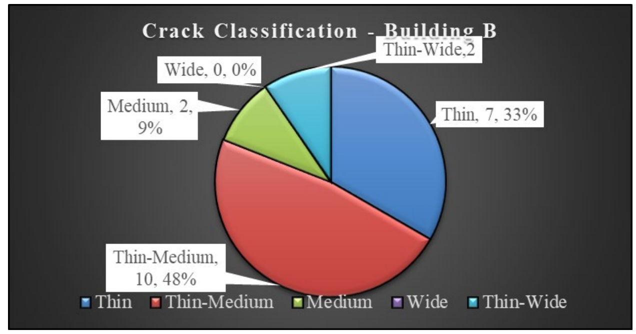


Fig. 36. Classification of cracks in building B

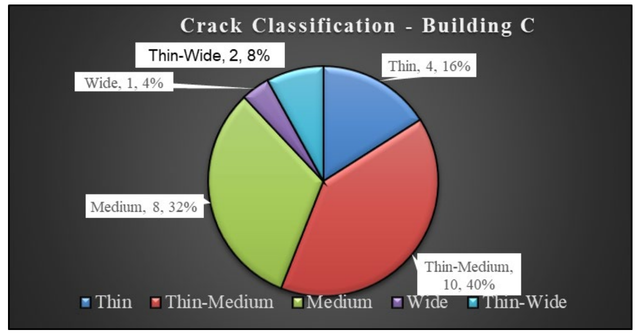


Fig. 37. Classification of cracks in building C

4) Summary of Crack Mapping Results

The crack mapping across the three buildings at PSNHS reveals variations in crack patterns regarding location, orientation, length, and thickness. While many cracks are thin to medium, the presence of wider cracks, especially in Building C, and cracks in structural elements, raises concerns about potential structural weaknesses. The consistent presence of horizontal cracking may suggest common factors like settlement or shrinkage, as noted by A.S. Zanke (2020).

Crack mapping provides a crucial visual assessment, but to fully evaluate the buildings' structural strength and develop reliable retrofitting recommendations, Non-Destructive Testing (NDT) is necessary. Specifically, the Rebound Hammer Test, which quantifies the concrete's compressive strength, complementing the crack mapping data for a more complete understanding of the buildings' structural condition.

C. Non-Destructive Testing Results

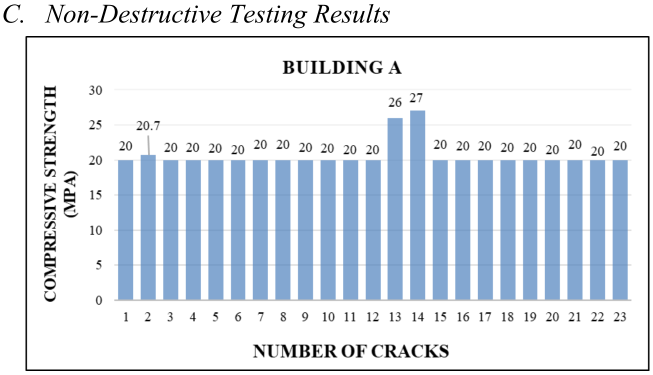


Fig. 38. Actual compressive strength at building A

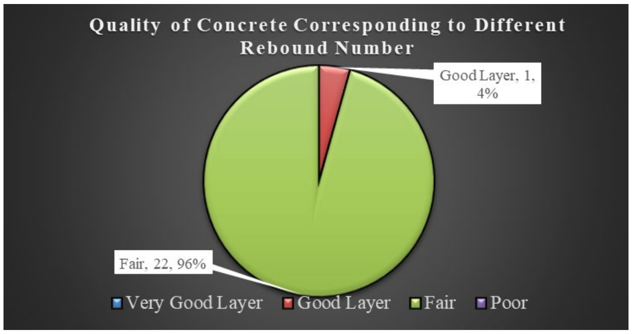


Fig. 39. Quality of concrete based on rebound number at building A

Figure 38 summarizes the actual compressive strength of each element with cracks at Building A. Rebound hammer test results revealed a variation in concrete compressive strength related to the presence and severity of cracks. Additionally, results indicated that wall elements with cracks generally exhibited compressive strength values at or slightly below the designed strength of 20.7 MPa. Notably, walls under medium to wide cracks classification showed a slight reduction in strength, highlighting the impact of cracks on concrete's performance and durability. While beams and columns, designed for a compressive strength of 27.6 MPa, presented values ranging from 24 MPa to 28 MPa, those results falling below the design criteria suggest a significant loss of strength attributed to cracking. These findings emphasize that wider cracks in walls, beams, and columns are associated with the most significant reduction in compressive strength, highlighting the need for applicable retrofitting techniques to mitigate potential structural weaknesses, especially considering the seismic history of the region.

The concrete quality of Building A based on the average rebound values is shown in Figure 36. According to the Test Book of Rebound Hammer Test, the rebound numbers for wall elements suggested a concrete quality of "fair". On the other hand, beams and columns showed a "good" concrete quality.

Shown in Figure 37 is the summary of the actual compressive strength of each element with cracks at Building B. The Rebound Hammer Test results indicate a correlation between crack severity and concrete compressive strength. Similar to Building A, rebound hammer tests showed that structural elements with cracks yielded compressive strength values at or below the designed strength. Elements with medium to wide cracks show slightly reduced strength, further supporting the observation that cracking negatively influences concrete performance. In beams and columns, where the designed compressive strength is 27.6 MPa, the obtained values ranged from 24 MPa to 28 MPa, with values below this range suggesting strength reduction due to cracking. The data suggests that medium to wide cracks are linked to the minimization in compressive strength, highlighting the necessity for structural assessment to enhance the building's strength against seismic activity and ensure occupant safety. Furthermore, the concrete quality in Building B, as shown in Figure 39, showed "fair" quality for all wall elements. While beams and columns, in particular, revealed signs of "good" quality.

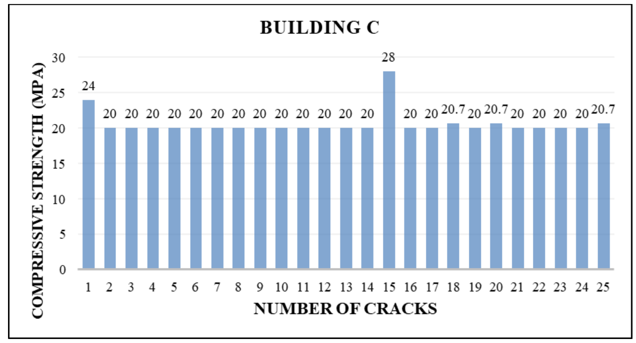


Fig. 40. Actual compressive strength at building C

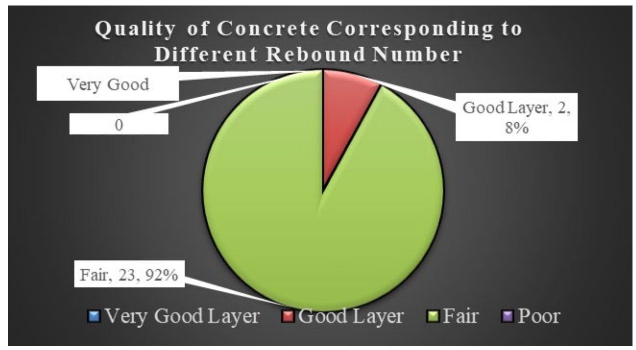


Fig. 41. Quality of concrete based on rebound number at building C

The NDT result for Building C, detailed in Figures 39 and 40, reveals the impact of cracking on the structural strength of concrete elements. Rebound hammer indicated that structural elements with cracks exhibited compressive strength values at or slightly below the designed strength. Specifically, elements with medium to wide cracks showed slightly reduced compressive strength values, again confirming the negative effect of cracking on concrete performance. For beams and columns, designed for a compressive strength of 27.6 MPa, the measured values ranged from 24 MPa to 28 MPa, with lower values indicating strength loss due to cracking. The findings highlight that those elements with medium to wide cracks experienced the most significant loss in compressive strength, which compromises the building's structural safety against future seismic activity.

Figure 4 provides an overview of the concrete quality in Building C based on average rebound values. The rebound average for the wall elements indicated a "fair" concrete quality, while the beams and columns are classified as "good" quality.

1) Summary of Non-Destructive Testing Results

The Non-Destructive Testing of Buildings A, B, and C revealed a correlation between concrete compressive strength and the presence and severity of cracks. In general, structural elements with cracks exhibited compressive strength values at or slightly below the designed strength. Notably, elements classified with medium to wide cracks showed a greater reduction in strength, indicating the negative influence of cracking on concrete performance. While beams and columns showed compressive strength values ranging from 24 MPa to 28 MPa for Buildings A, B, and C, most results fell below the designed strength, suggesting strength loss due to cracking. In terms of concrete quality, rebound hammer test results indicated "fair" quality for wall elements across the buildings, while beams and columns generally showed "good" quality.

D. Color-Coded Map

1) Building A

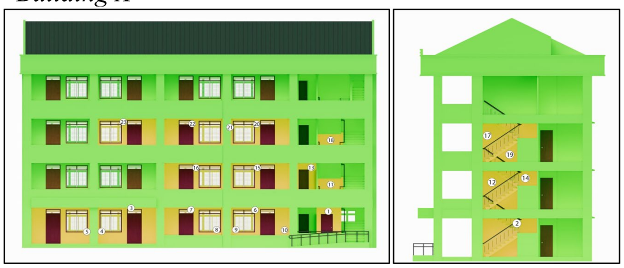


Fig. 42. Color-Coded map showing retrofitting requirements at building A

2) Building B

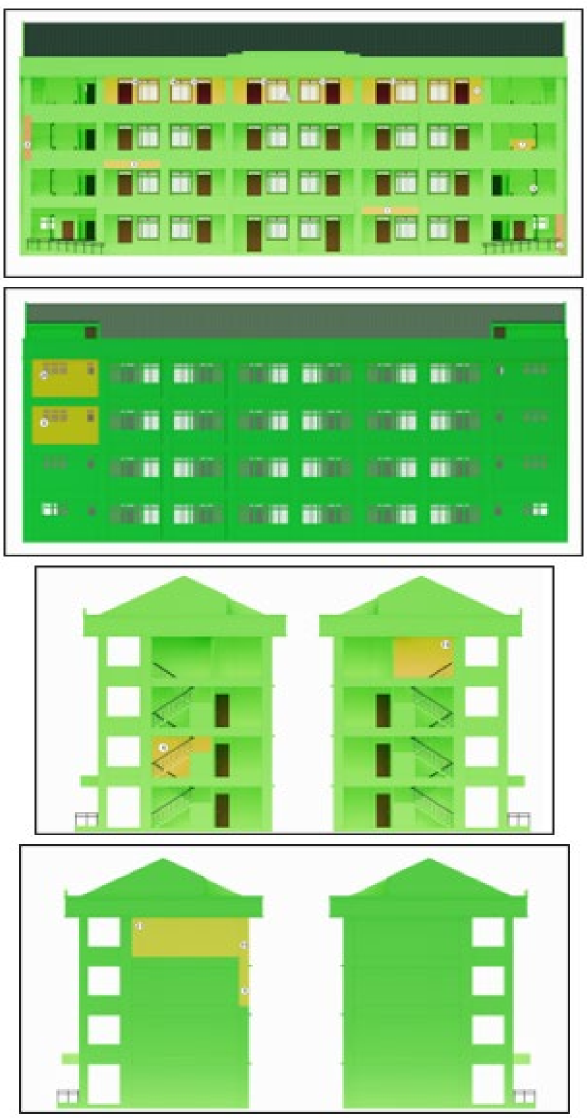


Fig. 43. Color-Coded map showing retrofitting requirements at building B

3) Building C

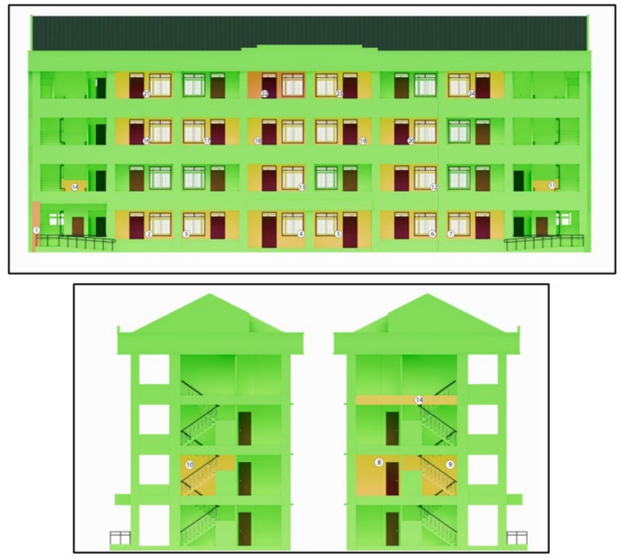


Fig. 44. Color-Coded map showing retrofitting requirements at building C

Structural elements with cracks were assigned specific colors depending on their observed condition, while elements without any cracks were marked green, indicating that no retrofitting is required. Generally, cracks that ranged from thin to medium were marked yellow, signifying the need for aesthetic retrofitting. Meanwhile, elements with wide cracks were marked orange, indicating the need for minor retrofitting, especially when cracks were found near or within critical structural components such as beams or columns.

4. Summary, Conclusions and Recommendations

A. Summary

The researchers employed Rapid Visual Screening (RVS) to assess the seismic vulnerability of selected public schools in Porac, Pampanga, including their structural conditions. Porac Model Community High School (PMCHS), Porac National High School (PNHS), and Pulung Santol National High School (PSNHS) were chosen, as they are close to the structures that collapsed during the 2019 earthquake. This evaluation aimed to determine the overall condition of the building, as well as to identify which of these schools needs detailed analysis. Based on the results of RVS, PSNHS was chosen as the school to be investigated due to the large number of cracks present in its structural elements as compared to the other schools assessed. Since Porac, Pampanga, has a high level of seismic activity, the researchers used the FEMA P-154 “Very High Seismicity” Data Collection Form that is suitable for high-risk seismic areas. This form considers critical parameters such as soil type, distance from the Iba fault, and geological hazards, all of which were found safe. The RVS scoring indicated that all buildings achieved scores above the 2.0 cutoff score, indicating a Grade 1-2 damage level, which suggests moderate to minimal expected damage during seismic events.

The study further focused on PSNHS due to the observed existence of cracks, specifically in structural elements. Crack mapping was conducted using MATLAB, where the crack variations were identified, including orientation, length, thickness, and location across Buildings A, B, and C, with cracks categorized as thin to wide. The presence of medium to wide cracks raised structural concerns. Prior to the rebound hammer test, scanning of rebars was utilized to ensure that the steel rebars present in the structural elements did not affect the results of the rebound hammer test. Consequently, the rebound hammer test revealed that elements with wider cracks exhibited reduced compressive strength, with walls generally falling under “fair” quality while beams and columns were rated as “good”. These findings highlight the relationship between crack severity of ongoing assessment and targeted retrofitting techniques to maintain the safety and resilience of school buildings located in seismically active regions. The color-coded map of PSNHS showed that several parts of the buildings fall under yellow and orange levels, indicating that minor and aesthetic retrofitting are needed, respectively. This visual classification aligns with the results of the conducted tests and highlights the importance of timely retrofitting measures to ensure the safety of school buildings.

B. Conclusion

The findings of this study revealed that several essential educational buildings in Porac, Pampanga, vary in structural performance, particularly concerning visible cracks and internal strength. By employing RVS, Crack Mapping through MATLAB, and NDT methods, the researchers conducted a comprehensive assessment of each structure. The results indicate that while certain buildings maintain acceptable resilience and strength, others present clear signs of structural weakening and reduced surface hardness, highlighting their potential vulnerability to seismic threats. The researchers created a color-coded map that served as a practical tool for identifying retrofitting needs, from minimal repairs to urgent reinforcement, and helped prioritize repairs accordingly. This study places great emphasis on the importance of regular structural assessments and maintenance, especially in seismically active areas, as school buildings also function as temporary emergency shelters. Ensuring their safety through early detection of issues, appropriate retrofitting, and the integration of preparedness tools such as structural condition maps and evacuation routes is vital in protecting students, faculty, and staff during disasters.

C. Recommendations

The researchers suggested the following recommendations, based on the study's findings and conclusion, to serve as guidelines for future application in improving school safety and assessment methods during seismic events.

1. *Evacuation Planning*: It is recommended that schools develop and implement clearly defined evacuation plans. These should be complemented by visible, easy-to-understand signage indicating emergency exit routes in all buildings, to ensure orderly and safe evacuation during seismic events.
2. *Training and Education*: Regular earthquake drills and preparedness programs should be conducted for both students and school personnel. These initiatives will enhance and improve awareness and readiness of everyone during unforeseen earthquakes.
3. *Conduct of Regular Structural Monitoring*: Periodic evaluations using crack mapping and NDT should be scheduled to detect early signs of structural degradation, ensuring timely intervention.
4. *Expansion of Structural Assessments to Other Buildings*: This study focused only on multi-story buildings with 3 or more floors. Future researchers are encouraged to include single or two-story structures, which may also develop cracks due to age, material quality, environmental stressors and earthquakes.
5. *Propose and Simulate Specific Retrofitting Methods*: While this study categorized buildings based on the need for retrofitting, future researchers may take a step further by recommending and simulating specific retrofitting methods—such as Fiber Reinforced Polymer (FRP), or base isolation—using software tools like ETABS, SAP2000, or ANSYS. Simulating various methods would help compare effectiveness, cost-efficiency, and applicability to similar school buildings.

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