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RESEARCH ARTICLE OPEN ACCESS

Seismic Evaluation and Damage Classification for a Preparedness Mapping Plan: Examining Potential Seismic Hazards of Buildings in Don Honorio Ventura State University, Bacolor, Pampanga

Nathaniel H. Navarro[1], Angelica Faye B. Lapuz[2],Frenz Eries P. Galang[3], Aira Mae P. Meneses[4], Sheena Mae R. Pitpitan[5], Princess Paula S. Punzalan[6], Engr. Aaron S. Malonzo[7], Engr. Ma. Luz Q. Manuntag[8]

[1](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: nathanielnavarro1109101@gmail.com)

[2](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: lapuzangelicafaye@gmail.com)

[3](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: frenzgalang007@gmail.com)

[4](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: airamaepinedameneses10@gmail.com)

[5](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: sheenamaepitpitan114@gmail.com)

[6](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: punzalanprincesspaula@gmail.com)

[7](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: asmalonzo@dhvsu.edu.ph)

[8](*Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines*
Email: mlqmanuntag@dhvsu.edu.ph)

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Abstract:

Earthquakes pose significant threats to communities and infrastructure, making it crucial to assess the seismic vulnerability of buildings, especially schools. Rapid Visual Screening (RVS) is a cost-effective method for identifying buildings with seismic susceptibility, using factors like soil composition and architectural characteristics. This research focuses on Don Honorio Ventura State University (DHVSU) in Pampanga, Philippines, due to its vulnerability to earthquakes following the 1991 eruption of Mt.

Pinatubo. The study uses GIS-based mapping to delineate buildings based on seismic parameters, enhancing the university's awareness and preparedness to mitigate casualties in the event of an earthquake. The assessment not only illuminates structural vulnerabilities but also provides critical insights for implementing mitigation measures and ensuring occupant safety. The preparedness mapping system helps visualize differentials among buildings, aiding comprehension and decision-making processes aimed at enhancing overall seismic resilience. The study highlights the importance of seismic resilience in ensuring public safety and mitigating potential damages.

Keywords **—RVS, school buildings, seismic resilience, damage, mapping plan**

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I. INTRODUCTION

Earthquakes, as unexpected natural occurrences, result in significant damage affecting communities and their surroundings. In the Philippines Islands, the relative plate motions range between 5 to 40 mm per year, leading to compression between micro-plates at the boundaries of the Eurasian and Philippines Sea plates [1]. This geological activity gives rise to two main seismotectonic regimes: crustal faults inland and major subduction zones offshore encircling the islands.

Assessing the seismic vulnerability of buildings, especially critical facilities like schools, is crucial as earthquakes pose dangers to both individuals and structures. The number of fatalities and injuries from earthquakes correlates with building vulnerability [2]. Evaluating seismic vulnerability aids in identifying weaknesses at the local level and assessing a building's capacity to withstand future seismic events through various available approaches. [3]

The Valley Fault System in the Philippines comprises the East Valley Fault (10 km) and the West Valley Fault (100 km) [4]. PHIVOLCS predicts a 7.2 magnitude earthquake, known as "The Big One," for Metro Manila due to the extensive length of the West Valley Fault, classified as "Very Destructive."

Earthquakes disrupt social stability, especially endangering children. Schools, essential for normalcy for children and parents, often suffer severe physical damage and reduced functionality during earthquakes [5]. Despite hosting 1.2 billion students globally, with 875 million in earthquake-prone areas, schools frequently lack disaster-resilient construction and maintenance, posing risks to children's lives. [6]

Rapid Visual Screening (RVS) is a cost-effective method identifying buildings necessitating simplified vulnerability assessments by using a scoring system based on factors such as soil type and architectural characteristics. This method aids in identifying critical structures requiring detailed assessments, influencing seismic performance outcomes. [7] By informing stakeholders like disaster management authorities and urban planners, RVS assists in implementing safer countermeasures against seismic risks globally.

II. CONCEPTUAL FRAMEWORK

The main objective of the study is to evaluate potential structural flaws and vulnerabilities that may cause danger to the staff, instructors, and students in the event of an earthquake by performing rapid visual assessments. The study emphasizes the importance of addressing vulnerable structures to minimize casualties and recommends detailed assessments for buildings with a low RVS score.

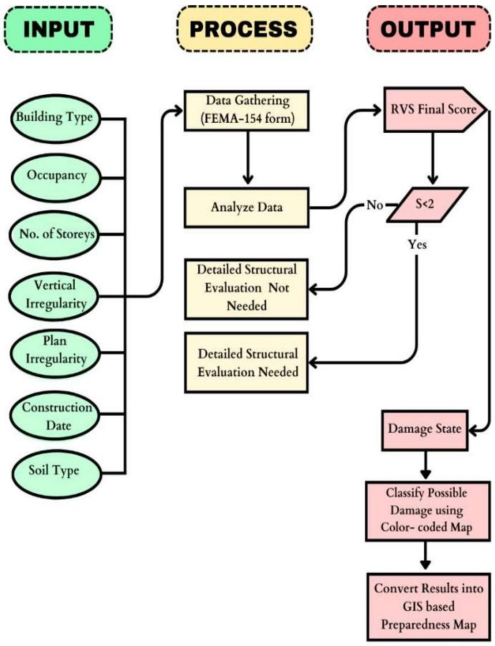


Fig.1. Conceptual Framework

III. METHOD

The methodology employed in this study is a comprehensive three-phase process designed to ensure the effective and systematic collection of data. The first phase involves the planning of the conduction of Rapid Visual Screening, the second phase involves the actual execution of the planned procedures, and lastly, the researchers developed a preparedness map that highlights areas of concern based on the analyzed data.

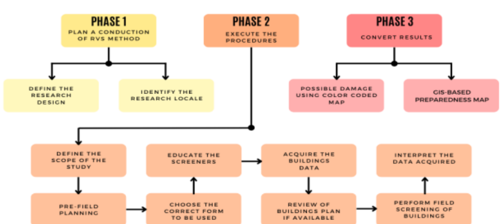


Fig.2. Methodological Framework

A. Research Design

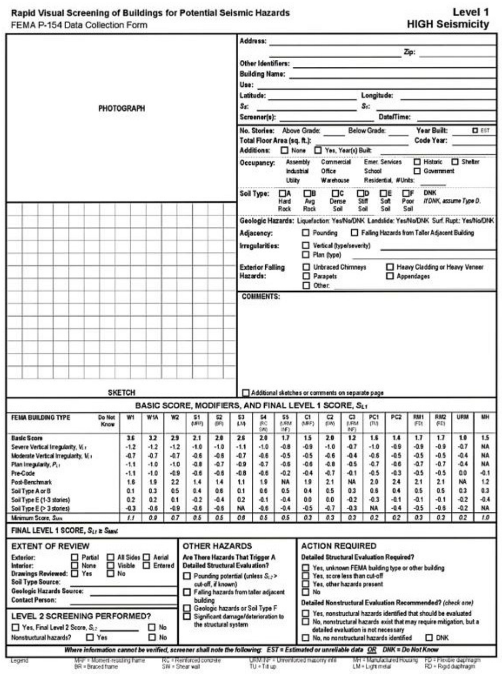
This research examined the seismic resilience of Don Honorio Ventura State University's current school buildings through the application of the RVS method. The utilization of empirical methods in its procedures makes the empirical analysis technique relevant and applicable to this research study. Empirical research relies on real-world observations and measurements to understand phenomena, contrasting with theoretical approaches based on abstract principles. It emphasizes tangible evidence over beliefs, aiming to uncover patterns and insights through systematic data collection. [8]

B. Research Locale

The study focused on Don Honorio Ventura State University (DHVSU) in Bacolor, Pampanga. The campus, set in Bacolor's seismic history, is where the researchers investigate structural vulnerabilities and seismic factors. The insights gained extend beyond the immediate scope of the university campus, contributing to broader discussions on earthquake preparedness and architectural resilience in areas prone to seismic activity. This locale is not only a physical setting but also includes the buildings and structures within the DHVSU campus in Bacolor.

C. Research Instrument

The FEMA P-154 2015 Rapid Visual Screening (RVS) method, a designed to determine the potential seismic risk of the building by using Data Collection Forms. Rapid Visual Screening (RVS) is a qualitative evaluation method developed to identify and screen buildings that are seismically more vulnerable. Typically, this process includes pinpointing the load-bearing system, evaluating the structural materials, considering the seismic zone, and documenting various attributes influencing the building's response to seismic activity.



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

Level 1
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, Industrial, Utility, Commercial, Office, Warehouse, Emer. Services, School, Residential, #Units: ☐ Historic ☐ Shelter ☐ Government
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		3.6	3.2	2.9	2.1	2.0	2.6	2.0	1.7	1.5	2.0	1.2	1.6	1.4	1.7	1.7	1.0	1.5
Severe Vertical Irregularity, V_{L1}		-1.2	-1.2	-1.2	-1.0	-1.0	-1.1	-1.0	-0.8	-0.9	-1.0	-0.7	-1.0	-0.9	-0.9	-0.9	-0.7	NA
Moderate Vertical Irregularity, V_{L1}		-0.7	-0.7	-0.7	-0.6	-0.6	-0.7	-0.6	-0.5	-0.5	-0.6	-0.4	-0.6	-0.5	-0.5	-0.5	-0.4	NA
Plan Irregularity, P_{L1}		-1.1	-1.0	-1.0	-0.8	-0.7	-0.9	-0.7	-0.6	-0.6	-0.8	-0.5	-0.7	-0.6	-0.7	-0.7	-0.4	NA
Pre-Code		-1.1	-1.0	-0.9	-0.6	-0.6	-0.8	-0.6	-0.2	-0.4	-0.7	-0.1	-0.5	-0.3	-0.5	-0.5	0.0	-0.1
Post-Benchmark		1.6	1.9	2.2	1.4	1.4	1.1	1.9	NA	1.9	2.1	NA	2.0	2.4	2.1	2.1	NA	1.2
Soil Type A or B		0.1	0.3	0.5	0.4	0.6	0.1	0.6	0.5	0.4	0.5	0.3	0.6	0.4	0.5	0.5	0.3	0.3
Soil Type E (1-3 stories)		0.2	0.2	0.1	-0.2	-0.4	0.2	-0.1	-0.4	0.0	0.0	-0.2	-0.3	-0.1	-0.1	-0.1	-0.2	-0.4
Soil Type E (> 3 stories)		-0.3	-0.6	-0.9	-0.6	-0.6	NA	-0.6	-0.4	-0.5	-0.7	-0.3	NA	-0.4	-0.5	-0.6	-0.2	NA
Minimum Score, S_{MIN}		1.1	0.9	0.7	0.5	0.5	0.6	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 3. FEMA P-154 Data Collection Form

D. Conversion of Results

The Geographic Information System (GIS) model is used to create a preparedness map in the school in case of a seismic event. The researcher began with the process by determining spatial data, determining the school location, surrounding infrastructure, road networks, and seismic hazards. This GIS-based approach involves pinpointing the precise coordinates of the school, allowing for accurate mapping of its possible damage. This includes the identification of key infrastructure elements in the vicinity, such as buildings, utilities, and emergency exits. Understanding the spatial relationships between these components is vital for formulating an effective emergency response strategy.

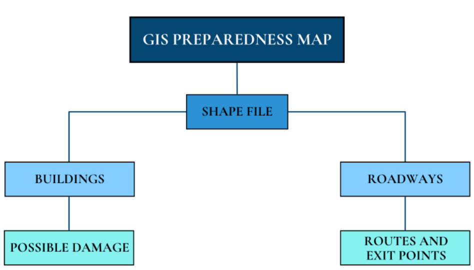


Fig 4.GIS Preparedness Map Flowchart

IV. RESULTS AND DISCUSSION

Researchers employed the RVS methodology to assess the structural integrity of each building. The screening process evaluated various parameters, including building type, year of construction, identification of irregularities, and potential hazards. Each building received a score corresponding to a specific damage classification.

E. Type of Form Used

Considering the categorization of Bacolor, Pampanga, as a region characterized by high seismic activity, as per the "Spectral Acceleration Maps of the Philippines 2021" issued by DOST-PHIVOLCS, the researchers have opted to employ the corresponding "High Seismicity" Data Collection Form sourced from FEMA P-154.

F. Year Built

In the Rapid Visual Assessment process, it is crucial to gather data on a design of building and construction year. This information is vital because the age of a building often correlates with its construction techniques and design features. According to FEMA, the age of a building can influence its classification and subsequent assessment score. Therefore, understanding the relationship between building age and design is essential for accurately assessing its condition and potential risks during emergencies. This modifier also affects the final score assigned to each school building. It shows that all buildings were constructed during the post-benchmark period, which refers to construction occurring after 1992.

G. Number of Stories

The number of stories in a building significantly influences its vulnerability to earthquake damage. Taller buildings are more prone to earthquake damage due to factors like amplified ground motion, resonance, complex structures, higher loads, and design irregularities. Out of the total of 50 school buildings examined, it was observed that 6 of them were single-storey structures, constituting 12% of the total. Meanwhile, a majority of the buildings, comprising 52% of the total, were identified as two-storey constructions, totaling 26 buildings.

Moreover, 18 out of the 50 buildings, representing 36% of the total, were found to have three stories.

H. Types of Soil

Through an informal interview with the OPPF, researchers ascertained that the general soil-bearing capacity at DHVSU is approximately 60 kilopascals (kPa). Additionally, the OPPF provided a Geotechnical Evaluation report for one building in this study, the IRTPC Extension Building, revealing a soil-bearing capacity of 40 kPa and classifying it as Soil Type E. Consulting external resources from Tensar Co., which classifies soils with a bearing capacity below 75 kPa as soft clay, researchers were able to infer the soil type at DHVSU. Based on this combined information, the soil at DHVSU likely falls under the category of soft clay, consistent with Soil Type E.

I. Building Type

Considering the categorization of Bacolor, Pampanga, as a region characterized by high seismic activity, as per the "Spectral Acceleration Maps of the Philippines 2021" issued by DOST-PHIVOLCS, the researchers have opted to employ the corresponding "High Seismicity" Data Collection Form sourced from FEMA P-154.All the buildings assessed at Don Honorio Ventura State University are categorized as Concrete Moment Resisting frame (C1) structures due to their demonstration of C1 characteristics, including the utilization of reinforced concrete for all exposed frames and the incorporation of beams and columns that are joined together according to FEMA guidelines. In the Philippines, the primary structural system for low-rise buildings frequently involves the utilization of reinforced concrete (RC) moment resisting frames, which commonly incorporate concrete hollow block (CHB) walls, typically serving as non- structural elements.[9]

J. Irregularity

Out of the 50 buildings assessed, 11 were identified with vertical irregularities, 21 exhibited plan irregularities, and 24 displayed no irregularities. The prevalent plan irregularities were characterized by re-entrant corners, while vertical irregularities were predominantly manifested as out-of-plane conditions. These identified irregularities are directly associated with specific scoring criteria applicable to Concrete Moment Resisting frame (C1) structures.

K. Interpretation of RVS Performance Scores

The scores range from 1.9 to 3.4. From the data gathered, it is observed that 10% or 5 buildings scored 1.9, falling below the cutoff score of 2.0, while 90% of 45 buildings scored equal to or greater than the cutoff score of 2.0. This data indicates that buildings with scores of 2.0 or higher are in a moderate condition and are not at risk of collapsing. However, buildings scoring less than 2.0 require further structural evaluation.

L. Type of Form Used

The final scores of the screened buildings are associated with specific levels of damage, categorized as follows: a) G1 - Negligible to slight damage, b) G2 - Moderate Damage, c) G3 - Substantial to heavy damage, d) G4 - Very heavy damage, and e) G5 – Destruction. Figure 3.9.1 illustrates the distribution of these damage grades among the buildings. Notably, 24 buildings are categorized as Grade 1, 21 buildings are classified under Grades 1 and 2, and 5 buildings are designated as Grades 2 and 3. These damage grades come with descriptions outlining the structural state of the buildings during an average seismic event.

M. Classification of Damage Using Color-Coded Map

The findings of the study were converted into a color-coded map using SketchUp Pro 2021 as shown in figure 4. This map visually represents the seismic vulnerability assessments conducted on the screened school buildings within the university. Various colors are employed to signify the damage sustained by the buildings in accordance with the research findings. As a result, the risk levels associated with these buildings are effectively communicated and integrated within the map layout.

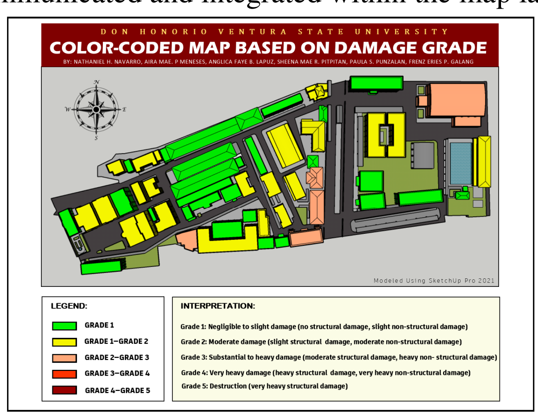


Fig 5.Color-coded Map based on Damage Grade

N. Seismic Preparedness Mapping Plan

Figure 5 was generated employing ArcGIS, a Geographic Information System (GIS) which represents a significant progress in disaster preparedness efforts. This preparedness map serves as a vital tool for raising awareness and promoting readiness among students, workers, and other community members. Offering insights into potential hazards and safe zones during seismic events, the map empowers individuals to plan and navigate the safest routes for evacuation or emergency response.

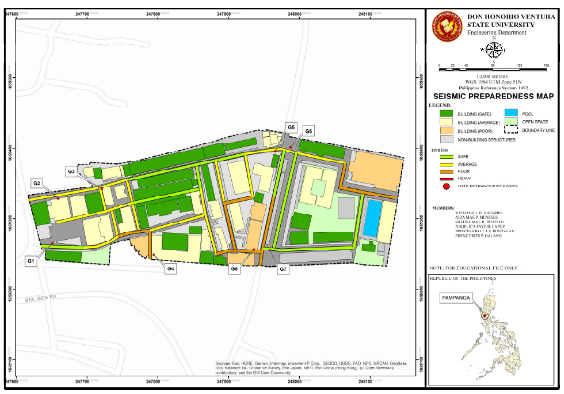


Fig 6.Color-coded Map based on Damage Grade

V. CONCLUSION

The findings of the study indicate that the majority of buildings within the university demonstrate satisfactory seismic performance, suggesting their ability to withstand moderate seismic activity with minimal damage. This resilience highlights the overall preparedness of the infrastructure at the university to endure seismic events, offering a reassuring level of safety for occupants. It underscores the efficacy of existing building codes and construction standards in maintaining structural integrity. In times of calamities like earthquakes, school buildings serve as indispensable infrastructure, functioning as crucial evacuation centers for affected individuals. To sustain this level of seismic resilience over time, continual monitoring and maintenance efforts are essential, particularly given the critical role school buildings play as essential facilities. Creating a preparedness map for the seismic resilience of the university is imperative to ensure the safety and well-being of students, faculty, and staff during seismic events. By identifying vulnerable areas, establishing clear safe routes and assembly points, and marking exit and entrance points, the university can enhance its capacity to respond effectively to seismic events.

Based on the conclusion of the study, the researchers propose recommendations for future research directions on this topic. The following approaches are suggested for future researchers to investigate.

1. The university administration may consider setting up evacuation signs and routes, particularly in zones where most students and staff are situated. Additionally, it may be beneficial for all buildings to have readily accessible copies of preparedness maps indicating routes and safe exit points for easy reference.
2. The university may offer thorough training and educational programs to ensure that all staff and students are well-informed and equipped to respond effectively during seismic events.
3. To gain a deeper understanding and ensure a comprehensive assessment, it is recommended to undertake additional investigation of the soil data and construction plans of buildings. This deeper examination may provide valuable insights and enhance the effectiveness of the rapid visual screening method.
4. When carrying out the Rapid Visual Screening (RVS) process for individual buildings, it is advisable to enlist the assistance of supervising engineer recommended by FEMA. Their expertise enables a comprehensive examination, even when utilizing only the Level 1 assessment form.
5. Perform a seismic assessment using engineering software or by consulting with structural engineers to understand the building's behavior during earthquakes. This method includes analyzing factors such as the building's movement patterns and how it responds to seismic forces.

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