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Seismic Assessment and Retrofitting Recommendations for the Main Building at FEU Pampanga using ETABS Software

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Abstract **- This study evaluates the seismic safety of existing reinforced concrete educational buildings in earthquake prone regions of the Philippines. Due to the country location along the Pacific Ring of Fire, many institutional structures constructed prior to updated seismic provisions may exhibit structural deficiencies that affect their performance during strong ground motion. The objective of this research is to assess the seismic performance of selected buildings in FEU Pampanga and to develop appropriate retrofitting recommendations to improve structural resilience. The methodology combines field investigation and advanced structural analysis. Rapid Visual Screening Level 1 was conducted to identify the most vulnerable structure, followed by rebound hammer testing to estimate in situ concrete strength. A three-dimensional structural model was developed in ETABS using calibrated material properties. Nonlinear pushover analysis and nonlinear time history analysis were performed to evaluate structural response in terms of displacement, interstory drift, base shear, and hinge formation under seismic loading. The results were interpreted based on performance levels including immediate occupancy, life safety, and collapse prevention. The study identified critical structural components and potential seismic deficiencies influencing overall performance. The findings provide a performance-based evaluation framework and propose targeted retrofitting strategies to enhance the seismic safety and structural reliability of existing educational buildings.**

Keywords - Nonlinear Time History Analysis, Nonlinear Pushover Analysis, Rebound Hammer Test, ETABS Modeling, Seismic Performance Evaluation

I. INTRODUCTION

Earthquakes are among the most destructive natural hazards, posing serious risks to life, infrastructure, and economic stability. In the Philippines, located along the Pacific Ring of Fire, frequent seismic activity caused by the interaction of the Philippine Sea Plate and Eurasian Plate increases the vulnerability of many structures. Past events, such as the 2019 Davao del Sur earthquakes and the 2025 Davao Oriental earthquakes, revealed significant weaknesses in reinforced concrete (RC) buildings, particularly those constructed before updating seismic design provisions.

In Central Luzon, including Pampanga, seismic risk remains a concern due to nearby fault systems and soil conditions, as demonstrated by the 2019 Luzon earthquake. This highlights the need to evaluate the seismic performance of existing educational buildings to ensure public safety.

This study adopts a performance-based seismic assessment approach integrating field investigation and advanced analysis. Rapid Visual Screening (FEMA P-154) is first conducted to identify vulnerable structures, followed by Rebound Hammer Testing (ASTM C805) to estimate in-situ concrete strength. A detailed 3D model is then developed in ETABS using actual building data.

Nonlinear Time History Analysis is used to simulate structural response under earthquake loading, while Nonlinear Static (Pushover) Analysis evaluates structural capacity and performance levels such as Immediate Occupancy, Life Safety, and Collapse Prevention. These analyses help identify structural deficiencies and guide appropriate retrofit strategies.

II. OBJECTIVES

The objectives of this study are:

1. To conduct Rapid Visual Screening (RVS) Level 1 of the three main FEU Pampanga buildings using FEMA P-154, to identify the most seismically vulnerable building for detailed evaluation.
2. To assess the in-situ concrete quality and material integrity of the selected building using Rebound Hammer testing, providing realistic input parameters for structural modeling.
3. To develop a three-dimensional structural model in ETABS Software
4. To perform nonlinear pushover analysis and nonlinear time history analysis on the selected building to evaluate its seismic performance.

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5. To evaluate the seismic performance of the building based on the results of the nonlinear pushover analysis and nonlinear time history analysis results to formulate retrofit recommendations to enhance seismic resilience and code compliance.

III. LITERATURE REVIEW

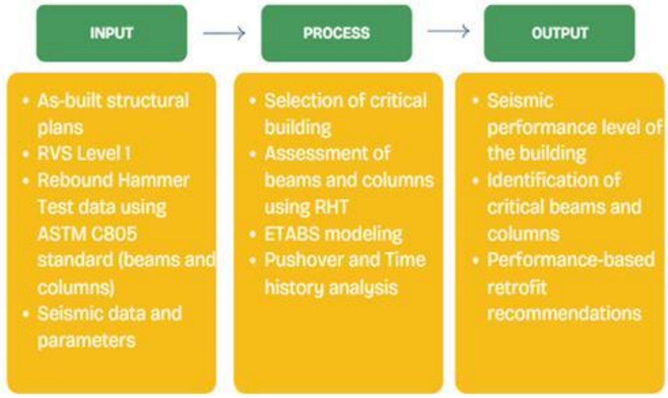
Rapid Visual Screening, as defined in FEMA P-154, is a widely used preliminary method for identifying buildings susceptible to seismic hazards based on observable characteristics such as structural system, irregularities, and construction quality. Developed through studies associated with ATC-21 and FEMA, it provides a cost-effective approach for assessing large building inventories and prioritizing structures for detailed evaluation. Studies by Schnabel et al. (2003) and Calvi (2004) confirm its effectiveness in identifying vulnerable buildings, while local applications such as Pacheco et al. (2016) demonstrate its relevance in assessing reinforced concrete school buildings in the Philippines, particularly those constructed before modern seismic provisions.

The ASTM C805 standard defines the Rebound Hammer Test, a non-destructive method used to estimate the compressive strength and uniformity of hardened concrete. The method is widely recognized in structural engineering for its practicality in assessing existing structures without causing damage. Research by Malhotra and Carino (2004) and Bungey et al. (2006) confirms its reliability in detecting variations in concrete quality, while studies in the Philippines by Dizon et al. (2015) highlight its effectiveness in identifying strength deficiencies due to aging and environmental exposure. These findings support its use in calibrating material properties for structural modeling.

Seismic evaluation and retrofit design are guided by established standards such as NSCP 2015, ASCE 41-17, ASCE 7-10, and UBC 1997. NSCP 2015 provides local seismic design requirements, while ASCE 41-17 introduces a performance-based framework for evaluating existing buildings. ASCE 7-10 outlines procedures for determining seismic loads and response spectra, and UBC 1997 offers foundational provisions for base shear calculation and drift limits. These standards are widely applied in both international and local studies, including those by Diaz et al. (2020) and Villanueva et al. (2019), demonstrating their effectiveness in structural assessment and retrofitting.

FEMA 440 enhances nonlinear static analysis procedures by improving the accuracy of pushover analysis in predicting structural response under seismic loading. It incorporates considerations for inelastic behavior, ductility, and energy dissipation, making it a valuable tool for evaluating structural performance and designing retrofit strategies. Complementing this, ETABS serves as a comprehensive software platform for modeling and analyzing building structures, enabling engineers to simulate seismic behavior and assess critical response parameters. Nonlinear Pushover Analysis provides insight into structural capacity and failure mechanisms, while Nonlinear Time History Analysis captures the dynamic response of structures under realistic earthquake records. Studies by Chopra (2017) and Vamvatsikos et al. (2006), along with local research, confirm the effectiveness of these methods in identifying vulnerabilities and guiding retrofitting decisions.

IV. CONCEPTUAL FRAMEWORK



V. METHODOLOGY

The methodological framework of this study was developed to provide a systematic and performance-based approach for evaluating the seismic vulnerability of existing reinforced concrete buildings in FEU Pampanga and for formulating technically sound retrofit recommendations.

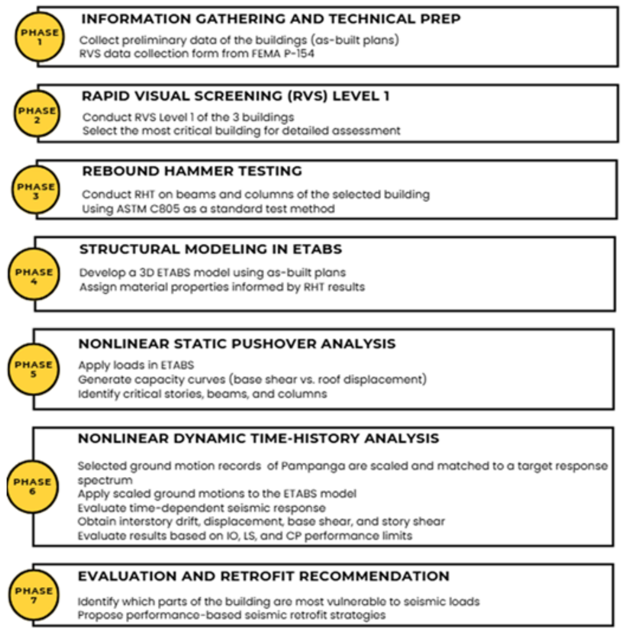


Fig 2. Methodological Framework of the Study

A. Information Gathering and Technical Preparation

Information Gathering and Technical Preparation, where key structural data for SHSB, RPB, and Main Building is collected. This includes obtaining as-built plans and structural drawings, as well as preparing a Rapid Visual Screening data form based on FEMA P-154 to document building type, configuration, and any visible irregularities or deterioration.

B. Rapid Visual Screening Level 1

Rapid Visual Screening Level 1 was conducted following FEMA guidelines to preliminarily assess the seismic vulnerability of selected buildings within FEU Pampanga.

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The evaluation considered parameters such as structural system type, number of stories, plan irregularities, construction quality, and visible signs of deterioration. Based on the computed screening scores, the building with the highest vulnerability was selected for detailed assessment.

C. Rebound Hammer Testing

Rebound hammer testing was performed in accordance with standard procedures to estimate the in situ compressive strength of concrete. Representative beams and columns from different floors were selected to capture variability in material properties. Multiple readings were obtained at each test location and averaged to improve reliability. The results were used to evaluate material condition and to define realistic input parameters for structural modeling.

D. Structural Modeling in ETABS

A three-dimensional model of the selected building was developed using ETABS software based on available asbuilt plans and field data. Structural elements such as beams and columns were modeled to accurately represent the geometry and load resistance system. Material properties were calibrated using the results from rebound hammer testing to ensure that the analytical model reflects the actual condition of the structure.

E. Nonlinear Pushover Analysis

Nonlinear static pushover analysis was conducted to evaluate the lateral load capacity and inelastic behavior of the structure. Incremental lateral loads were applied to the model until a target displacement was reached. The resulting capacity curve was used to assess structural performance, identify plastic hinge formation, and determine potential failure mechanisms. Performance levels were evaluated in terms of immediate occupancy, life safety, and collapse prevention.

F. Time History Analysis

Nonlinear time history analysis was performed to simulate the dynamic response of the structure under earthquake loading. Selected ground motion records were scaled to match the target response spectrum based on local seismic conditions. The analysis provided time dependent responses including displacement, interstory drift, and base shear. These results were used to evaluate the structural performance under realistic seismic excitation.

G. Evaluation and Retrofit Recommendation

The results from pushover and time history analyses were interpreted based on established seismic performance criteria. Critical structural components and potential deficiencies were identified based on response parameters and hinge behavior. The findings served as the basis for developing appropriate retrofitting strategies aimed at improving structural strength, stiffness, and overall seismic resilience.

VI. RESULTS AND DISCUSSION

A. Rapid Visual Screening Level 1 Results

The Rapid Visual Screening Level 1 results indicated that all evaluated buildings belong to the concrete moment resisting frame system and are situated on soil conditions susceptible to seismic amplification. Among the three assessed structures, the Main Building obtained the lowest screening score, indicating higher seismic vulnerability. This is primarily attributed to the presence of plan irregularity and its relatively older construction compared to the other buildings. The irregular geometry introduces potential torsional effects that may lead to uneven distribution of seismic forces during earthquake events. Based on these findings, the building was selected for detailed structural assessment.

	SHS Building	Rosalina Pagcu Building	Main Building
Year Built	2019	2015	2011
Total Floor Area (m^2)	2240	2240	2,974
Plan Configuration	Rectangular	Rectangular	Slight Semicircle (Front)
FEMA Building Type	C1	C1	C1
Basic Score (Table 1.5)	1.5	1.5	1.5
Post-Benchmark Score (PT)	1.9	1.9	1.9
Soil Type	D	D	D
Liquefaction Hazard	Yes	Yes	Yes
Plan Irregularity	None	None	Present (Moderate)
Estimated Final Level 1 Score (S)	3.4	3.4	2.8

Table I. *RVS Scores*

B. Rebound Hammer Test Results

Rebound hammer testing was conducted on representative columns and beams across multiple floor levels. For each test location, ten readings were obtained and outliers beyond acceptable deviation were discarded to ensure data reliability.

The estimated compressive strength of concrete for columns ranged from approximately 32.2 MPa to 46.7 MPa, while beam elements exhibited values ranging from approximately 32.2 MPa to 52.8 MPa. Ground floor columns generally showed consistent strength values, while upper floors exhibited slight

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variability, which may be attributed to differences in curing conditions and long-term material exposure.

Beam elements demonstrated relatively higher variation compared to columns, indicating possible inconsistencies in material quality or construction practices. Despite this variability, the overall strength range is within acceptable limits for reinforced concrete structures. These results were used to calibrate the material properties of the structural model in ETABS, ensuring a more realistic representation of the existing condition of the building.

C. Nonlinear Pushover Analysis Results

The pushover analysis produced a capacity curve that represents the relationship between base shear and roof displacement. The initial portion of the curve shows linear elastic behavior, followed by a nonlinear region indicating stiffness degradation and plastic hinge formation. The analysis identified that plastic hinges predominantly formed at beam ends and selected column regions, which is consistent with expected structural behavior under increasing lateral loads.

Evaluation of hinge states indicated that most structural elements remained within the immediate occupancy and life safety performance levels under moderate displacement demands. However, certain elements approached the collapse prevention level at higher displacement values, suggesting potential vulnerability under strong seismic events. The results highlight the presence of critical members that may require strengthening to improve overall structural performance.

Parameter	X Direction	Y Direction
Performance Displacement (mm)	204.5	226.1
Base Shear at Performance Point (kN)	8281.9	8163.6
Ductility Ratio	3.85	3.33
Effective Period (s)	1.77	1.73
Effective Damping (%)	19.30	17.60

Table II. Performance Point Parameters

Table II. shows the performance displacement represents the roof displacement at which the seismic demand is satisfied. The higher displacement in the Y-direction (226.1 mm) indicates lower lateral stiffness along that axis. The base shear at the performance point is near the structure's maximum capacity, showing strong lateral resistance before reaching deformation limits. Ductility ratios of 3.85 (X) and 3.33 (Y) suggest the structure can undergo significant inelastic deformation, which is adequate for reinforced concrete moment-resisting frames. The elevated effective damping ratios indicate increased energy dissipation due to nonlinear behavior and plastic hinge formation.

D. Nonlinear Time History Analysis Results

The nonlinear time history analysis provided detailed insight into the dynamic response of the structure under simulated earthquake loading. The results showed that maximum story displacements and interstory drift ratios varied depending on the characteristics of the input ground motions. In general, the structure exhibited stable response behavior, with most drift values remaining within acceptable performance limits.

However, peak responses indicated that certain stories experienced higher drift concentrations, which may be associated with stiffness irregularities or mass distribution along the height of the building. Base shear responses were found to be within the expected range, confirming that the structure possesses sufficient lateral strength under the considered loading conditions.

E. Structural Performance Evaluation

The combined results of pushover and time history analyses indicate that the structure exhibits acceptable performance under moderate seismic loading but shows limitations under higher intensity ground motions. The presence of plastic hinge concentration and localized drift increase suggests potential weaknesses in stiffness distribution and energy dissipation capacity.

Critical structural components, particularly beams and selected columns, were identified as priority elements for retrofitting. Strengthening measures are necessary to enhance structural ductility, reduce drift demand, and improve overall seismic resilience.

Overall, the findings demonstrate that while the building maintains adequate baseline strength, targeted retrofitting interventions are required to achieve improved performance levels and ensure compliance with modern seismic design standards.

VII. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The seismic performance of the Main Building was evaluated using nonlinear static pushover analysis and nonlinear time history analysis implemented in ETABS. The assessment aimed to determine the structure's capacity to resist seismic forces and its overall behavior under earthquake loading.

Rapid Visual Screening based on FEMA P-154 identified a slightly reduced performance score relative to comparable structures, primarily due to plan irregularity associated with the semicircular frontage. This irregularity introduces potential torsional effects and non-uniform seismic force distribution. Additionally, the site is classified as Soil Type D with potential liquefaction susceptibility, which may adversely influence seismic response.

Pushover analysis results indicate that the structure possesses adequate lateral strength and deformation capacity to meet expected seismic demands. The derived capacity curve demonstrates stable behavior under increasing lateral loads,

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confirming sufficient energy dissipation capacity. Plastic hinge formation was predominantly concentrated in beam elements, while columns largely remained elastic, consistent with a strong-column weak-beam mechanism. Most hinges were within Immediate Occupancy (IO) to Life Safety (LS) performance levels, indicating controlled nonlinear behavior. The building satisfies the Life Safety (LS) performance objective, implying that although structural damage may occur during a design-level earthquake, overall stability is maintained, preventing collapse and allowing safe occupant evacuation.

Nonlinear time history analysis using multiple ground motion records provided further insight into dynamic response characteristics. Results show moderate story displacements, interstory drifts, and shear forces, with variability depending on ground motion frequency content and amplitude. Slightly higher response in one principal direction was observed, likely due to stiffness irregularities and plan asymmetry, indicating susceptibility to torsional response.

The structure demonstrates acceptable seismic performance with adequate strength, ductility, and stability under design earthquake conditions. However, plan irregularity, torsional effects, and site soil conditions remain critical factors that may influence performance and should be considered for potential seismic performance enhancement.

B. Recommendations

Although the Main Building demonstrates acceptable seismic performance, targeted retrofit measures are proposed to further enhance its structural resilience under strong earthquake loading. These recommendations are based on observed analytical behavior and established seismic strengthening practices for reinforced concrete (RC) structures.

The addition of reinforced concrete shear walls is recommended to improve lateral stiffness, load resistance, and overall structural stability. Shear walls effectively reduce interstory drift and lateral displacement while mitigating torsional effects associated with plan irregularity. Strategic and symmetric placement of these elements is essential to enhance stiffness distribution and minimize torsional response. Strengthening of beam-column joints is also proposed to ensure reliable performance of critical regions in the momentresisting frame system. Techniques such as fiber-reinforced polymer (FRP) wrapping or reinforced concrete jacketing can enhance joint shear capacity, confinement, and ductility. This intervention supports the preservation of the strong-column weak-beam mechanism observed in the analysis, while preventing brittle joint failure. FRP systems are particularly advantageous for existing and occupied buildings due to their lightweight nature and ease of installation. Additionally, the incorporation of steel bracing systems, including diagonal or X-bracing configurations, is recommended to further improve lateral stiffness and energy dissipation capacity. Steel bracing enhances seismic performance by redistributing lateral forces and reducing demand on existing RC members. This approach is especially effective in directions exhibiting lower stiffness and can be implemented in selected structural bays or perimeter frames to minimize disruption to building operations.

The proposed retrofit strategies provide complementary mechanisms for improving strength, stiffness, ductility, and seismic reliability, thereby enhancing the building's performance under earthquake loading conditions.

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