

SEISMIC VULNERABILITY ASSESSMENT USING RAPID VISUAL ASSESSMENT AND FRAGILITY CURVE FOR SELECTED BUILDINGS AT SAINT LOUIS COLLEGE OF SOLANO, INC.

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ABSTRACT

Saint Louis College of Solano, Inc. (SLCSI), which is located in Seismic Zone 4 near the active Maddiangat Fault, is exposed to significant seismic risk. Throughout the years, no post-earthquake assessments have been conducted on its major buildings. This study aimed at conducting a thorough seismic risk assessment to ensure building resilience and campus safety. Using UBC 1997 and ASCE 41-17 as a basis for simulations, the selected buildings: Phase 1 & 2 Building, Millennium Building, and Administration Building were subjected to Rapid Visual Assessment (RVA), seismic nonlinear analyses (Incremental Dynamic Analysis), and fragility curves were developed. Based on Solano's peak ground accelerations—0.4g for Design Basis Earthquake (DBE) and 0.5g for Maximum Considered Earthquake (MCE)—site-specific assessments showed a probability of exceedance below 2% for all buildings, indicating low seismic risk. However, building-specific analyses revealed varied performance: the Administration Building had negligible exceedance, the Millennium Building showed slight exceedance, and the Phase 1 & 2 Building exhibited the highest exceedance at 9.65%. Widespread localized weaknesses were identified in both the Millennium and Phase 1 & 2 Buildings, affecting their lateral load-resisting systems. Exterior Shear Walls (ESW) were recommended as a focused retrofitting strategy to strengthen global structural resilience.

Keywords: Seismic vulnerability assessment, performance-based evaluation, incremental dynamic analysis, rapid visual assessment, fragility curve, shear wall retrofitting

INTRODUCTION

Earthquakes rank among the most destructive natural disasters in the Philippines, a nation highly susceptible to seismic hazards due to its location within the Pacific Ring of Fire (Baylon et al., 2021). Earthquakes are cyclical, though relatively infrequent, natural events that can cause significant damage to living environments (Kilic, 2023). According to a survey by Erick Burgueño Salas (2023), the Philippines' disaster risk index (DRI) is 46.86, making it the country with the highest natural disaster risk globally.

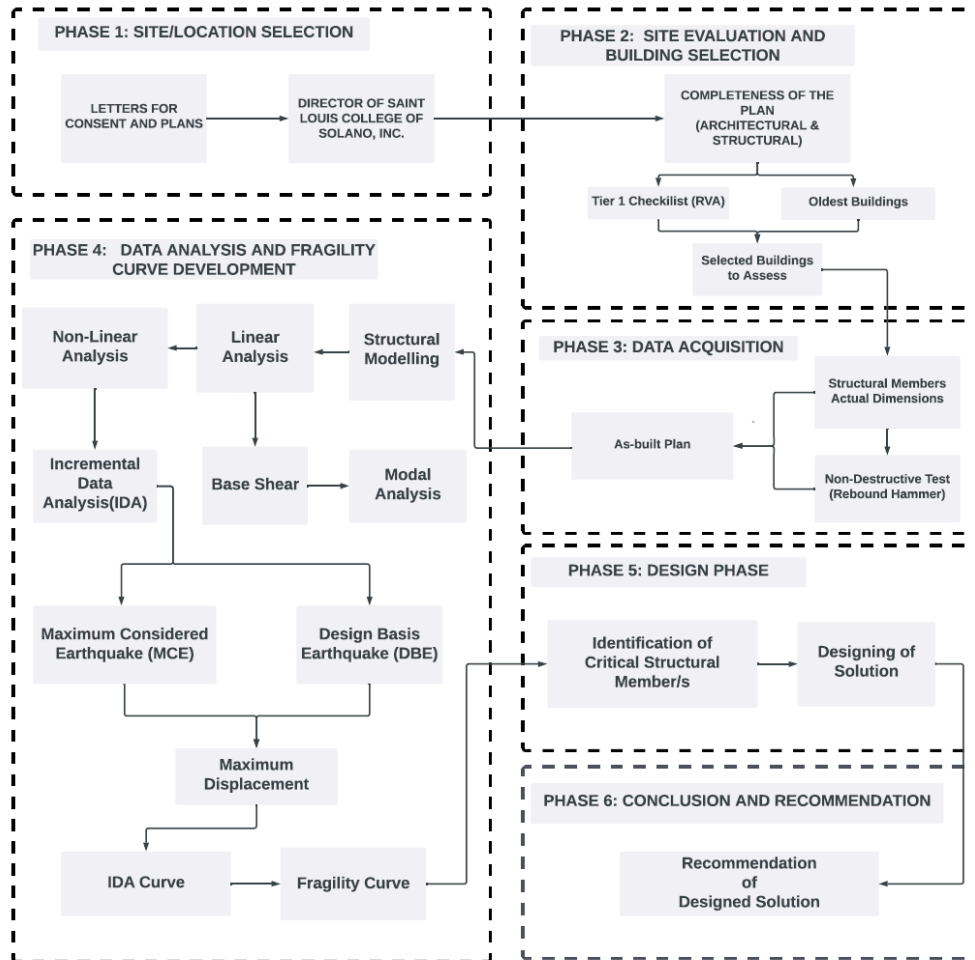
Saint Louis College of Solano Inc. (SLCSI), formerly known as Saint Louis School of Solano Inc. (SLSI), is a longstanding institution of basic education in Nueva Vizcaya, established in 1935. Currently, SLCSI serves a community of 1,876 students and employs 92 staff members. According to Baylon (2018), the age of buildings significantly contributes to their vulnerability to seismic hazards. On the Saint Louis College of Solano, Inc. (SLCSI) campus, four key structures—Phase I, Phase II, Millennium Building, and the Administration Building—meet the criteria for seismic analysis based on their age, functionality, and occupancy.

The need for a seismic assessment is further underscored by increasing seismic activity in the region. Notably, the 7.0 magnitude earthquake that struck Abra, Philippines in July 27, 2022, heavily affected Northern Luzon, including the Province of Nueva Vizcaya. SLCSI also faces heightened vulnerability due to its location within Seismic Zone 4—the highest seismic risk category in the country—where structures are required to withstand significant earthquake forces.

METHODOLOGY

A. Research Design

Figure 1
Conceptual Framework



Shown on Figure 1 is the Conceptual Framework for the data gathering procedure of the study.

Phase 1

The first phase of the data-gathering process involved identifying the most critical buildings within the Saint Louis College Inc. (SLCSI) campus for seismic vulnerability assessment. The selection focused on structures with the highest relevance in terms of age, daily occupancy, and essential function within the institution.

Phase 2

Phase 2 focused on selecting buildings for evaluation based on three criteria: the building must be at least ten years old, functional, and in active use, and it should hold significance for its users and the broader community.

- a) The requirement that buildings be at least ten years old is because older structures, in general, are the most susceptible to damage during seismic activities. The dynamic interaction between structures and external forces leads to a gradual loss of capacity over time, which is a process known as structural deterioration. This deterioration

results from both progressive damaging events (e.g., corrosion, fatigue) and sudden incidents (e.g., earthquakes) (Sánchez-Silva et al., 2013).

- b) The emphasis on functionality and active use underscores the critical importance of evaluating buildings that consistently fulfill their intended purposes. This focus not only reflects their ongoing relevance to their users but also provides valuable insights into their structural integrity and adaptability to user needs.
- c) Structures that hold significant value according to their occupancy category based on NSCP 2015 underscore the critical need for a comprehensive seismic vulnerability assessment. Since the school is open for evacuation during calamities, it can be considered an essential facility.

Phase 3

Phase 3 focused on assessing the physical properties of the structural components within the selected buildings. The building configurations of the Millennium and Administration buildings were obtained from the institution's as-built architectural and structural plans. For Phase 1 and Phase 2 buildings with no available as-built plans, a detailed building plan was produced using code-based approaches. Due to the limited scope of non-destructive testing and measures, the number of bars, bar diameters, and their corresponding yield strengths (f_y) were determined by computation, in accordance with the standards in effect at the time the buildings were constructed.

ASCE 41-17 Procedures were carried out to further assess the subject buildings. ASCE 41-17 outlines the procedures for assessing the seismic safety of existing buildings. It provides detailed guidelines for evaluating a building's performance during an earthquake. It offers a systematic approach for determining whether the building complies with current seismic safety standards. This study employed Tier 1, Tier 2, and Tier 3 evaluation methods, including field measurements with a tape measure, non-destructive testing of concrete compressive strength (f'_c) using a Rebound Hammer, linear and nonlinear structural analyses, and the development of retrofitting recommendations.

The objective of these activities was to verify accuracy and validate the structural and architectural characteristics as they currently exist, highlighting any discrepancies. This method helps in developing precise, comprehensive as-built plans, which are crucial for modeling efforts. In the Tier 3 phase, detailed nonlinear analyses were conducted using the refined as-built models to simulate the building's response under seismic loading more accurately. This phase enabled a more rigorous evaluation of structural performance and potential failure mechanisms, ultimately informing the development of targeted, effective retrofitting strategies to enhance seismic resilience.

Phase 4

Phase 4 focused on the structural modeling and analysis of data acquired from the previous phase. Building models were developed in ETABS, using both linear and nonlinear analyses. In the linear analysis, static and dynamic methods were applied to determine key parameters, including base shear, modal mass participation ratios, and the building's response to external forces.

For nonlinear modeling, ASCE 41-17 highlighted the importance of plastic hinge length in simulating inelastic behavior in structural members. This nonlinear approach is essential in defining seismic performance levels, including immediate occupancy, life safety, and collapse prevention, by quantifying inelastic rotations and deformations. By applying the Takeda Hysteresis Model, the non-linear analysis was simplified, effectively capturing the behavior of reinforced concrete elements under repeated earthquake loading. This model was particularly valuable for simulating inelastic behavior in building structures, enhancing the accuracy and reliability of the seismic performance assessment.

For the nonlinear dynamic analysis, also known as Time History Analysis, the seismic hazard data provided by the Philippine Institute of Volcanology and Seismology (PHIVOLCS)—specifically the Peak Ground Acceleration (PGA) maps and the Spectral Acceleration Map of the Philippines (SAM PH)—served as the basis for determining the parameters of both the Design Basis Earthquake (DBE) and the Maximum Considered Earthquake (MCE). These parameters were used to develop the response spectra applied to the building models for each scenario.

The DBE, which has a 10% probability of exceedance in 50 years (corresponding to a return period of 475 years), establishes the minimum seismic resistance required to maintain functionality and limit damage during moderate earthquakes, prioritizing life safety and operational continuity. The MCE, with a 2% probability of exceedance in 50 years (return period of 2,475 years), represents the maximum expected ground motion. While structures must withstand the MCE without collapsing, they may experience significant damage during these extreme events.

The Design Basis Earthquake (DBE) response spectra were developed in accordance with the provisions of the National Structural Code of the Philippines (NSCP 2015), while the Maximum Considered Earthquake (MCE) spectra were established in accordance with the guidelines of ASCE 7. These spectra were used as target functions for spectral matching of ground motion records, a critical step in developing fragility curves. Such curves are essential for performance-based seismic assessment, as they visually quantify the structure's probabilistic vulnerability across a range of seismic intensities.

Phase 5

Phase 5, which is the design phase consisted of two key stages: Identification of critical structural members and designing solutions.

In the first stage, identification of critical structural members, the researchers used the simulation results from ETABS obtained in the previous phase. These simulations, conducted as part of the Incremental Dynamic Analysis (IDA), provided detailed insights into the structure's behavior under seismic loads corresponding to both the Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) conditions. The performance levels of Immediate Occupancy (IO) and Life Safety (LS) were set for DBE and MCE, respectively. By carefully analyzing and interpreting the results, specific structural components—such as beams, columns, or connections—prone to failure were identified. Furthermore, the types of failures were identified based on the formation and performance levels of plastic hinges—such as flexural yielding, shear-related failure, or instability. These hinge behaviors, categorized by Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP), were used to assess their impact on the overall structural performance.

In the second stage, designing solutions, ETABS was used as our primary design tool, and the researchers adhered to the provisions outlined in ASCE 41-17 to ensure compliance with established seismic retrofit guidelines. During this stage, retrofitting strategies were developed to address the critical deficiencies identified in the first stage. The solutions were designed to mitigate the specific type of failure observed, thereby enhancing the strength, stiffness, and ductility of the critical structural members. This stage involved planning and designing possible retrofitting techniques such as jacketing, FRP wrapping, the addition of bracing systems, the integration of shear walls, or the implementation of base isolation and damping systems. Each solution was evaluated for feasibility, cost-effectiveness, and contribution to improving the structure's seismic performance.

Phase 6

The conclusion provides a comprehensive interpretation of the results obtained from the seismic analyses and a compilation of identified critical structural members that exhibit vulnerabilities or deficiencies under seismic loads. These components were highlighted based on their significance in maintaining structural integrity and their susceptibility to damage or failure. The findings were summarized to provide a clear understanding of the structure’s overall seismic performance and areas requiring urgent attention.

B. Research Locale

The study was conducted exclusively within the premises of Saint Louis College of Solano, Inc. Specifically, the seismic risk evaluation focused on the four buildings of the campus: Phase 1, Phase 2, the Millennium, and the Administration Building.

The investigation was centered on specific buildings at Saint Louis College of Solano, Inc. that urgently required seismic hazard assessments. Phase 1, completed in 1992, is the oldest structure on campus and a key candidate for seismic evaluation. It was followed by Phase 2, completed in 1998. Both buildings are three-story structures, interconnected in a seamless architectural layout. The Millennium Building, a three-story structure completed in 2000, is used to cater to their college programs, with a library on the third level that promotes learning. Furthermore, the Administration Building is a three-story structure completed in 2014 that houses offices and other administrative services.

Figure 2
Saint Louis College of Solano Inc.

- LEGEND:**
- PHASE 1 BUILDING
 - PHASE 2 BUILDING
 - MILLENIUM BUILDING
 - ADMINISTRATION BUILDING



Source: Google Maps

C. Research Instrument and Tools

The research utilized a range of instruments and software tools at different phases of the study as follows:

1. Rebound Hammer

- A portable tool that measures the rebound of a spring-loaded hammer hitting the concrete surface to determine the compressive strength of the material.

2. Tape Measure

- A flexible measuring device with indicated gradations; the tape measure is used to measure an object's length or measurements, usually in carpentry and building. It was used to confirm measurements of the structural elements (distances, dimensions, and sizes).

3. AutoCAD

- A popular computer-aided design (CAD) software is extensively used for producing accurate two-dimensional and three-dimensional drawings and models. In the preliminary stage, it served as a tool for creating the as-built plans.

4. Microsoft Excel

- It is a flexible and commonly available data organization and analysis application, particularly for data analysis, that is more complex and sophisticated. In addition to being used for fragility curve development, it was used to store data from building surveys.

5. ETABS

- Extended Three-dimensional Analysis of Building Systems (ETABS) is a software application widely used by civil engineers for structural analysis and design. It features a comprehensive user interface for modeling, analysis, design, and reporting.

RESULTS AND DISCUSSION

Results

A total of three buildings were analyzed for seismic performance: the combined Phase I and Phase II Building, the Millennium Building, and the Administration Building. These structures were prioritized due to their long-standing use and critical roles in supporting both educational and administrative operations. Given their high daily occupancy, assessing their seismic safety was essential. Phases I and II were considered a single building in the analysis, as they were constructed continuously and are physically connected.

A) Rapid Visual Assessment (RVA)

As part of the initial seismic evaluation, a Rapid Visual Assessment (RVA) was conducted using the ASCE 41-17 Tier 1 Checklist, which screens for visible seismic vulnerabilities and determines whether further analysis is necessary. Key information, including each building's performance level, seismic hazard classification, and seismic activity exposure, was identified as essential during the analysis.

Under NSCP 2015, SLCSI's buildings are classified as Occupancy Category III due to their high occupant load. However, since they serve as evacuation centers during disasters, they may also be classified as Category I essential facilities. Given the daily occupancy of the Administration, Millennium, and Phase 1 & 2 buildings, their failure would pose a significant risk to life, consistent with ASCE 7's Category III.

During the Tier 1 evaluation, the lack of structural plans for the Administration and Phase I & II buildings limited seismic assessment, requiring escalation to Tier 2 and Tier 3 under

ASCE 41-17. Only the Millennium Building had complete data for a full Tier 1 review. To ensure consistency, all buildings underwent nonlinear analysis. They were evaluated using Design Basis Earthquake (DBE) criteria, with required performance levels set at life safety or immediate occupancy.

B) Data Acquisition

By retrieving the as-built plans of the selected buildings. It was found that the school archives contained only the architectural plan of the Administration Building. On the other hand, the Millennium Building had complete records of both architectural and structural plans. Since the as-built plan for Phase I & II Building was unavailable, it was recreated by measuring the actual dimensions of its structural members using a tape measure. The structural design of the Admin Building was evaluated in accordance with NSCP 2010, while the Phase I & II Building was assessed in accordance with ACI 318-99. Discrepancies of 30 mm to 50 mm were found on the sizes of the structural members of the subject buildings, but no major changes were found except for the Millennium Building, which has a newly constructed library on the third floor.

To obtain the actual compressive strengths of the structural members of the buildings, the researchers conducted a rebound hammer test with ten (10) trials per member. For efficiency, the testing of the structural members of the buildings was batched into two (2) columns and two (2) beams per floor. The results were then factored for more accurate measurements. Based on the rebound hammer test results, the Millennium Building exhibited the highest in-situ concrete compressive strength among the three structures evaluated, while the Admin Building had the lowest.

C) Data Analysis and Fragility Curve Development

Base shear reactions were assessed along the global X and Y axes, with the X-axis defined as the principal direction and the Y-axis as the minor direction. To determine the seismic weight, a load combination was applied using load factors of 1.0 for Dead Load (DL) and 0.25 for Live Load (LL) as per NSCP 2015.

Table 1

Base Shear of the Building

BASE SHEAR	BUILDING		
	PHASE 1 & 2	MILLENNIUM	ADMIN
Fy Global	3417.3861 kN	3275.2725 kN	2483.2143 kN
Fx Global	3417.3869 kN	3275.2725 kN	2483.2143 kN

The linear dynamic analysis focused on evaluating the buildings' modal responses. In accordance with the National Structural Code of the Philippines (NSCP), the analysis aimed to achieve at least 90% mass participation in both the principal (X) and minor (Y) directions. For Phase 1 & 2 Building, the required mass participation was achieved by the fifth mode, with 93.81% in the X-direction (UX) and 94.54% in the Y-direction (UY). Similarly, the Millennium Building reached 91.63% (UX) and 91.99% (UY) by the fifth mode. In contrast, the Administration Building required up to the 18th mode to surpass the 90% threshold, achieving 92.98% in UX and 92.53% in UY.

Using the Pacific Earthquake Engineering Research (PEER) Center and the carefully identified parameters, three (3) earthquakes, presented in Table 2, were matched per building

based on the Abra earthquake. These earthquakes were used to simulate the seismic force of Philippine earthquakes on the subject buildings. These selected seismic events were then analyzed by matching their response spectra to both the Design Basis Earthquake (DBE) and the Maximum Considered Earthquake (MCE). This process was conducted to generate time-history data that accurately represents the characteristics of earthquakes occurring in the Philippines. It was also found that under stiff soil conditions, the province of Nueva Vizcaya exhibits a PGA of 0.4g for a 500-year return period, indicating a significant seismic hazard that warrants attention in structural design. For a 2500-year return period, the PGA increases to 0.5g, reflecting a more severe seismic scenario with greater potential impacts on infrastructure.

In accordance with ASCE 41-17 guidelines, a comprehensive performance evaluation was conducted for three buildings using two key limit states: Immediate occupancy and life safety. The immediate occupancy limit state, defined by a 0.10% Interstory Drift Ratio, emphasizes maintaining structural integrity and functionality to allow continued use of the building after a moderate seismic event. In contrast, the life safety limit state, with a higher threshold of 0.75%, focuses on minimizing the risk of structural collapse and ensuring occupant safety during more severe earthquakes. These criteria serve as critical benchmarks in assessing the seismic resilience of structures.

Table 2
Matched Earthquakes

Buildings	Matched Earthquakes
Phase 1 & Phase 2 Buildings	Montenegro, Yugo., 4/15/1979, Ulcinj - Hotel Olympic
	Loma Prieta, California, 10/17/1989, Capitola
	Whittier Narrows-01, California, 10/01/1997, Hacienda Heights - Colima
Millennium Building	Montenegro, Yugo., 4/15/1979, Ulcinj - Hotel Olympic
	Coalinga-01, California, 05/02/1983, Pleasant Valley - P.P. bldg.
	Northridge - 01, California, 01/17/1994, Beverly Hills - 14145 Mulhol
Administration Building	Montenegro, Yugoslavia, 4/15/1979, Ulcinj - Hotel Olympic
	Iwate, Japan, 6/14/2008, IWT011
	Niigata, Japan, 10/11/2004, NIG020

Discussion

Incremental Dynamic Analysis

For the Phase 1 & 2 Building (DBE), the UX and UY response curves for the Montenegro and Whittier Narrows earthquakes showed little to no difference, suggesting that the building exhibits similar stiffness in both orthogonal directions. In contrast, a slight but not critical difference between UX and UY was observed for the Loma Prieta earthquake, with the UX

direction generally experiencing higher drift demands. At MCE, the Interstory Drift Ratio (ISDR) responses in both the UX and UY directions showed minimal variation across Montenegro, Loma Prieta, and Whittier Narrows earthquake records.

For the Millennium Building (DBE), under the Montenegro earthquake, the building reached an inter-story drift ratio (ISDR) of 2.07% at 2g PGA, slightly exceeding the 2% life safety threshold. There's a likelihood of minimal non-structural and structural damage, as well as possible permanent deformation. However, for the Coalinga and Northridge earthquakes, the ISDR remained at approximately 1.5% and below at 2g PGA, suggesting acceptable performance within safe drift limits. At MCE, at a PGA of 2.0g, ISDR values ranged from approximately 1.3% to 1.5% in the X-direction and 1.5% to 2.1% in the Y-direction. Of the three records, Montenegro resulted in the highest drift, with Y-direction ISDR slightly exceeding the 2% life safety (LS) threshold.

For the Administration Building (DBE), there were noticeable differences in Interstory Drift Ratios between directions UX and UY in all earthquakes. At 2.0g, the difference in ISDR in directions UX and UY of the Iwate earthquake was 0.15%. In contrast, Niigata and Montenegro earthquakes required similar ISDRs at 0.23% and 0.24%, respectively. However, there was an incremental difference, but not a critical ISDR, in both UX and UY directions, noticeable on the graph at a PGA of 0.5g, peaking at 2.0g, where a higher drift demand was observed in the UX direction. At MCE, there were differences in ISDR in directions UX and UY across all earthquakes, but they were not critical. At 2.0g, the difference in ISDR between UX and UY is 0.19% in the Iwate earthquake and 0.25% in the Niigata earthquake. The Montenegro earthquake required the highest ISDR at 0.34%, but it was still not considered critical.

Fragility Curves

Table 3

Summary of Probability of Exceedance of the Buildings in DBE

Buildings	Site-Specific		Building-Specific	
	X	Y	X	Y
Phase 1 & 2	0.27%	0.24%	2.64%	2.65%
Millennium	0.02%	0.23%	0.34%	2.70%
Admin	0.00%	0.00%	0.00%	0.00%

Table 4

Summary of Probability of Exceedance of the Buildings in MCE

Buildings	Site-Specific		Building-Specific	
	X	Y	X	Y
Phase 1 & 2	1.77%	1.11%	9.65%	5.95%
Millennium	0.25%	0.97%	1.10%	4.07%
Admin	0.00%	0.00%	0.00%	0.00%

For the Phase 1 & 2 Building (DBE), for immediate occupancy, there is a rapid increase in exceedance probability from 0% to 100% between 0.05g and 0.20g in the X-direction, and between 0.05g and 0.25g in the Y-direction. At life safety, at a ground shaking level of 0.4g—illustrated by the PGA of Solano, Nueva Vizcaya—the probability of exceeding the LS limit is relatively low: 0.27% in the X-direction and 0.24% in the Y-direction. For MCE, at the IO level, the exceedance probabilities became significant at 0.20g in the X-direction and 0.25g in the Y-direction. At the LS performance level, at a ground shaking level of 0.50g—representative of the Peak Ground Acceleration (PGA) for Solano, Nueva Vizcaya—the probability of exceeding the LS limit remains low, at 1.77% in the X-direction and 1.11% in the Y-direction.

For the Millennium Building, (DBE), at IO level, the probability of exceedance reached significant values at peak ground accelerations (PGA) of approximately 0.25g in the X-direction and 0.20g in the Y-direction. The probability of exceeding the LS threshold is relatively low, measured at 0.02% in the X-direction and 0.23% in the Y-direction. At MCE, the IO curves rise sharply, with exceedance probabilities approaching 100% at approximately 0.20g. However, the probability of exceeding the LS threshold is relatively low, measured at 0.25% in the X-direction and 0.97% in the Y-direction.

For the Administration Building (DBE), at the immediate occupancy (IO) performance level spanning 0.05g to 0.15g, there is a rapid increase in the probability of exceedance before reaching the 100% upper limit at 0.2g. The same is true when considering the UY direction. There is a rapid increase between 0.05g and 0.2g, then it reaches 100% at 0.25g. Conversely, at the life safety level, the probability of exceedance at directions UX and UY is basically negligible at 0.00%. At MCE, in both directions, there is a rapid increase in the probability of exceedance at the immediate occupancy (IO) performance level, from 0.05g to 0.2g, reaching 100% at 0.25g. At LS level, the curve indicates a low probability of exceedance at 0.00% in both principal directions.

Building Specific Analysis

For the Phase 1 & 2 Building, it was determined that the structure's fundamental period, based on 100% modal participation, is 0.0460 seconds. This corresponds to spectral accelerations of 0.66g for the DBE and 0.73g for the MCE. The fragility analysis reveals that, under the Design Basis Earthquake (DBE), the probability of the building exceeding the Life Safety (LS) performance limit is 2.64% in the X-direction and 2.65% in the Y-direction. Under the more severe Maximum Considered Earthquake (MCE), these probabilities rise to 9.65% and 5.95%, respectively.

For the Millennium Building, based on its dynamic properties, the building's fundamental period where it exhibits 100% modal mass participation was identified as 0.0250 seconds, corresponding to spectral accelerations of 0.56g (DBE) and 0.60g (MCE) from its response spectrum. At LS threshold, under DBE, the likelihood of surpassing LS is 0.34% in the X-direction and 2.70% in the Y-direction. These rise to 1.10% and 4.07% under MCE.

For the Administration Building, it was determined that at 100% modal participation, the period of Administration Building is 0.01 seconds, corresponding to a PGA of 0.4921g based on the Design Basis Earthquake (DBE) response spectrum and 0.5126g in the Maximum Considered Earthquake (MCE) response spectrum. In DBE, the probability of exceedance is at 0.00%. Similarly, in the MCE fragility curve of the Administration Building, both UX and UY directions display a 0.00% probability of exceedance.

Critical Members

Critical structural members were identified through nonlinear time history simulations using multiple earthquake ground motions. The assessment focused on the formation and

distribution of failure hinges, which indicate locations where structural components exceeded their deformation capacity.

For the Phase 1 and Phase 2 Buildings, the most critical structural members were identified as the corner ground-floor column and the second-floor beams on the leftmost side of the structure. Simulations of the Millennium Building identified the most critical structural members as the two front-most corner columns along grid A (from the ground to the second floor) and the adjacent beams on grids 1 and 15, located at the stairwells at both ends of the building. Two critical structural members were identified from the seismic analyses conducted on the Administration Building. These two members are columns A-2 and B-2 at the ground floor level only.

Retrofitting Measures

Seismic analyses of the building complex revealed varying levels of vulnerability, with widespread formation of both life safety (LS) and immediate occupancy (IO) plastic hinges observed in the Phase 1 and 2 Buildings as well as the Millennium Building. Although only a few structural members may have been identified as critical through the seismic vulnerability assessment, addressing them with a global retrofitting approach remains the most reliable and forward-looking strategy.

Shear walls were introduced for the Millennium and Phase 1 & 2 buildings as retrofitting measures to enhance their global stiffness and maintain structural performance within the LS level. These walls were strategically placed at corner areas near the stairs, where significant deformation demands and hinge formations were identified during nonlinear simulations. Their placement was aimed at maximizing effectiveness in controlling inter-story drifts and redistributing lateral forces, particularly in structurally vulnerable regions. The area where the proposed shear wall retrofits are to be constructed was also considered. The researchers established that no major changes will be made to the current architectural facade or the buildings' functionality.

Table 5
Conclusion on the Probability of Exceedance of the Buildings in DBE

Buildings	Site-Specific		Building-Specific		LS Threshold (10%)
	X	Y	X	Y	Remarks
Phase 1 & 2	0.27%	0.24%	2.64%	2.65%	Passed
Millennium	0.02%	0.23%	0.34%	2.70%	Passed
Admin	0.00%	0.00%	0.00%	0.00%	Passed

Table 6
Conclusion on the Probability of Exceedance of the Buildings in MCE

Buildings	Site-Specific		Building-Specific		LS Threshold (10%)
	X	Y	X	Y	Remarks
Phase 1 & 2	1.77%	1.11%	9.65%	5.95%	Passed

Millennium	0.25%	0.97%	1.10%	4.07%	Passed
Admin	0.00%	0.00%	0.00%	0.00%	Passed

REFERENCES

- Baylon, M. B., & Cecilia, M. (2018). Seismic vulnerability assessment of adamson university buildings' as-built using fragility curves. *Global Journal of Engineering Research*, 18(1), 29–49. <https://doi.org/10.17406/GJRE/290899>
- Baylon, M. B., Lictaoa, C. S., Castillo, I. J. C., Dungog, C. K. P., & Jerusalem, L. R. (2021). Seismic vulnerability assessment of Sta. Lucia high school in Pasig City, Philippines using rapid visual assessment and fragility curves. *International Research Journal of Science, Technology, Education, and Management*, 1(2), 119–135. <https://doi.org/10.5281/zenodo.5726470>
- Kilic, G. (2023). Assessment of historic buildings after an earthquake using various advanced techniques. *Structures*, 50, 538–560. <https://doi.org/10.1016/j.istruc.2023.02.033>
- M. Sánchez-Silva, & J. Riascos-Ochoa. (2013, December 31). *Seismic risk models for aging and deteriorating buildings and civil infrastructure*. <https://doi.org/10.1533/9780857098986.3.387>