Seismic Vulnerability Assessment of College of Engineering and Architecture (CEA) Extension Building in Don Honorio Ventura State University (DHVSU) Main Campus Using Fragility Curves

Mark Jovi D. Gemoya [1], Raxell Roi M. Ordanez [1], Timothy D. Paulino [1], Jobelle M. Razon [1], Abigail N. Santos [1], Jea May F. Songco [1], Michael C. Tongol [1], Juanita Carmelita R. Zoleta [2], John Robert D, Gabriel [2], Michael B. Baylon [3]

[1]*Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines.*

[2]*Instructor, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines.*

[3]*USHER Technologies Incorporated, Philippines.*

Corresponding Author: joshuacabigting1@gmail.com

Abstract: - Due to its location on the Pacific Plate, surrounded by continents prone to movement and earthquakes, the Philippines is susceptible to earthquakes. In the Philippines, earthquakes can cause significant damage and disruption to higher education institutions. This research will be centered on the College of Engineering and Architecture (CEA) Extension Building on the Main Campus of Don Honorio Ventura State University (DHVSU) in Bacolor, Pampanga. Fragility curve's primary objective is to evaluate seismic vulnerability. The CEA Extension Building is more vulnerable to "The Big One," a magnitude 7.2 earthquake located west of the West Valley Fault with a distance of 55.6 kilometers; therefore, the investigation sought to evaluate the CEA Extension Building's seismic vulnerability. As required by the NSCP for Seismic Zone 4 regions, fragility curves were constructed to determine whether the structure could withstand a PGA earthquake of 0.4g with a maximum probability of exceedance of 10%. In order to achieve this goal, a dataset of 15 local and 15 international earthquakes was obtained from Incorporated Research Institutions for Seismology (IRIS). These earthquakes were chosen to represent a spectrum of PGA excitations, from 0.1g to 3.0g in 0.1g increments. A CEA Extension Building structural model was created using the software SAP2000. The CSM was then used to conduct Pushover Analysis using this model. The CEA Extension Building has a 10% Probability of Exceeding a "complete damage" state at 0.592g PGA on its X-axis, which corresponds to Intensity VIII, resulting in significant structural trembling. In addition, the analysis revealed that the "complete damage" condition for the CEA Extension Building had calculated the highest probability of exceedance along the X-axis of 5.27 percent and the Y-axis of zero percent at a PGA of 0.4g. Notably, the results were within the 10% limit, signifying that the DHVSU - Main Campus CEA Extension Building complies with the NSCP seismic requirements for structures in Seismic Zone 4. Consequently, the CEA Extension Building on the DHVSU-Main Campus does not necessitate a suitable retrofitting strategy.

Key Words: — *Factors, Philippines, Pacific Plate, continents, movement, earthquakes, geology, topography, population density, earthquake susceptibility.*

Manuscript revised June 18, 2023; accepted June 19, 2023. Date of publication June 22, 2023.

This paper available online at www.ijprse.com

ISSN (Online): 2582-7898; SJIF: 5.59

I. INTRODUCTION

The Philippines, situated in the Pacific Ring of Fire, is susceptible to various natural disasters due to its geographical location. This region is known for its high seismic and volcanic activity, resulting from the movement of tectonic plates (Orallo, 2011). Therefore, the country encounters a significant number of earthquakes annually, estimated to be around 100 to 150, as reported by PHIVOLCS (Philippine Institute of Volcanology and Seismology). One significant earthquake in the Philippines, known as "The Big One," has been thoroughly investigated (Ong et al., 2021). A magnitude of 7.2 is predicted for this earthquake, making it significant and extremely intense. The fault line linked to "The Big One" runs through a number of cities in Metro Manila and nearby provinces, including Bacolor, Pampanga.

The CEA Extension building is an essential component of DHVSU's main campus and is located in Bacolor, Pampanga. The building underwent renovation, growing from a one-story to a three-story structure in order to accommodate the College of Engineering and Architecture expanding needs. However, this building has not yet undergone a seismic assessment.

The researchers employed two seismic assessment methodologies: "Pushover Analysis" and "the Capacity Spectrum Method" to analyze the seismic behavior of the CEA Extension building and mitigate the risks and damages caused by an earthquake. These methods were used to generate fragility curves specifically for the CEA Extension building. The Incorporated Research Institutions for Seismology (IRIS) was used to compile a dataset of 30 earthquakes, including 15 local and 15 international earthquakes.

Table.1. Information of Fifteen (15) Local Ground Motion Data

Location	Magnitude	Depth (km)	Date
Philippines Island Region	7.6	44.4	August 31, 2012
Mindanao, Philippines	7.5	33.0	March 05, 2002
Mindanao, Philippines	7.5	33.0	January 01, 2001
Bohol, Philippines	7.1	23.2	October 15, 2015
Panay, Philippines	7.0	18.1	June 14, 1990
Mindanao, Philippines	6.8	18.0	December 15, 2019
Negros, Philippines	6.7	17.5	February 06, 2012
Samar, Philippines	6.6	10.0	August 18, 2020
Luzon, Philippines	6.5	29.7	July 17, 1990
Mindanao, Philippines	6.5	15.0	February 10, 2017
Mindanao, Philippines	6.5	10.0	October 31, 2019
Leyte, Philippines	6.5	6.96	July 06, 2017
Luzon, Philippines	6.4	13.6	October 25, 2022
Samar, Philippines	6.2	3.0	February 15, 2003
Luzon, Philippines	6.1	20.0	April 22, 2019

Table.2. Information of Fifteen (15) International Ground Motion Data

Location	Magnitude	Depth (km)	Date
Tohoku, Japan	9.1	19.7	March 11, 2011
Southern Sumatra, Indonesia	8.5	35.5	September 12, 2007
Near Coast of Peru	8.4	2.2	June 23, 2001
Near Coast of Northern Chile	8.1	17.1	April 01, 2014
Nepal	7.9	13.4	April 25, 2015
Alaska Peninsula	7.8	28.0	July 22, 2020
South of Alaska	7.6	31.1	October 19, 2020
Western Iran	7.3	18.5	June 20, 1990
Qinghai, China	7.3	10.0	May 21, 2021
Northern Sumatra, Indonesia	7.2	31.0	November 02, 2002
Haiti Region	7.0	15.0	January 12, 2010
Kyushu, Japan	7.0	10.0	April 15, 2016
Taiwan	6.9	10.0	September 18, 2022
Hawaii	6.9	2.06	May 04, 2018
Kobe, Japan	6.8	19.0	January 16, 1995

This study aimed to assess seismic activity at the CEA extension building on the Don Honorio Ventura State University Main Campus. The study encompassed specific objectives such as modeling the as-built plan of the CEA ext building, determining the yield displacement and ultimate displacement from pushover curves, obtaining performance points from the intersection of the capacity curve and response spectrum, creating seismic fragility curves that assess the 10% likelihood of exceeding in different damage states, such as slight, moderate, extensive, and collapse, and evaluating the research's findings.

II. METHODOLOGY

The study's goal was to determine how vulnerable the Don Honorio Ventura State University's (DHVSU) - Main Campus CEA Extension Building if there were to be a significant earthquake in the future. Novel parameters were created using analytical methods including the Capacity CSM and Pushover Analysis in order to produce the fragility curves. Design of the study is also shown in Figure 1, along with the methods used to produce fragility curves.

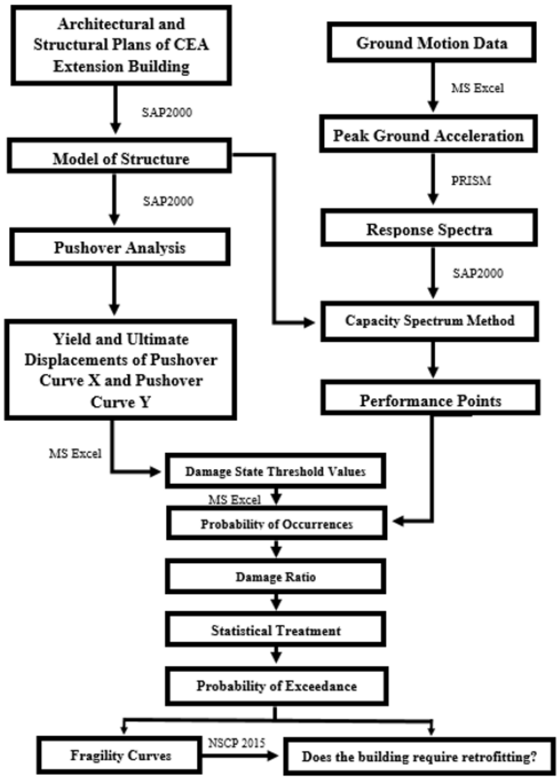

Fig.1. Research Design

2.1 Capacity Spectrum Method

The CSM is a method used in structural engineering to assess how well a structure performs under various loading scenarios. By comparing the capacity and demand of the structure, the CSM can be used to calculate a building's inelastic response during an earthquake. The equivalent linearization approach, which made use of the ATC-40, served as the foundation for the development of the CSM (Applied Technology Council, 1996). Consequently, the capacity spectrum comprises two distinct curves: the demand curve and the capacity curve. The point at which these two curves intersect signifies the critical performance point in the seismic analysis of the structure. Specific methods, such as the following, were used to apply CSM:

- Choose the GMD option from IRIS.
- Using Prism convert into Response Spectra the Normalized PGA.
- Define Response Spectrum functions.
- Create a new capacity spectrum method (CSM) load case.
- Set the necessary load cases to be used in running the Capacity Spectrum Method.

2.2 Developing of Seismic Fragility Curves

The ultimate and yield displacement obtained from the Nonlinear Static Analysis, along with the performance points provided the seismic fragility curves for the DHVSU CEA Extension Building. The analytical method used by Shinozuka (2000) to develop these fragility curves was followed in detail step by step as follows:

- Calculate the threshold for the damage state by referring to Table 2.1, which provides the spectral displacement range for each damage state.

Table.3. Damage State Threshold Values (Vasavada & Petel in Baylon et al., 2021)

Damage State	Description	Threshold Values
D	No Damage	$0 < d_{pp} \leq 0.7d_y$
C	Slight Damage	$0.7d_y < d_{pp} \leq d_y$
B	Moderate Damage	$d_y < d_{pp} \leq [d_y + 0.25(d_u - d_y)]$
A	Extensive Damage	$[d_y + 0.25(d_u - d_y)] < d_{pp} < d_u$
As	Complete Damage	$d_{pp} > d_u$

Where:

d_{pp} = displacement of the performance points;

d_y = yield displacement;

d_u = ultimate displacement.

- For each displacement value at the performance points of the Capacity Curve and Response Spectra determine the damage state.
- Calculate the frequency of events at each excitation level of PGA.
- By dividing the total count of instances for each damage state by the number of occurrences of each damage state at various levels of PGA excitation, the probability of occurrence is determined.

- Determine the damage ratio.

- The damage ratio's seismic curves can be seen and verified clearly by using the natural logarithmic (ln) of PGA. To compute the mean and standard deviation for each damage state, equations (2) and (3) were utilized

Where:

$$\lambda = \frac{\Sigma \quad x}{N} \tag{2}$$

$$\xi = \frac{\sqrt{\Sigma \quad (x-\lambda)^2}}{N-1} \tag{3}$$

Where:

x = individual ground motion data obtained

N = sample size of ground motion data obtained;

λ = mean ground motion data obtained from Equation

- Utilizing Shinozuka's Equation (4) from Baylon et al. (2021), determine the probability of exceedance (Pr).

$$Pr = \Phi\left[\frac{\{ln\,(X) - \lambda\}}{\xi}\right] \tag{4}$$

Where:

Φ = standard normal distribution;

X = peak ground acceleration;

λ = mean of the ground motion data;

ξ = standard deviation.

- Create seismic fragility curves for the both directions of earthquakes in the DHVSU CEA Extension Building by plotting the probability of exceedance on the y-axis and the PGA excitation levels (ranging from 0.1g to 3.0g) on the x-axis.

III. Results And Discussion

3.1 Modelling using SAP2000

This study utilized SAP2000 to model the structural plan of the CEA building of Don Honorio Ventura State University that was obtained from the physical facilities office on campus. SAP2000 was also used to do the Nonlinear Static Analysis (Pushover Analysis) and the Capacity Spectrum method in order to extract the fragility function parameters.

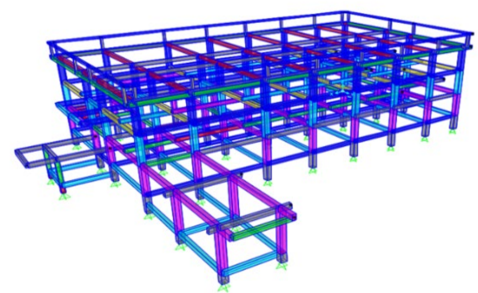

Fig.2. Structural Model of CEA Extension Building in Don Honorio Ventura State University Main Campus

3.2 Pushover Analysis

The pushover analysis results along axes of X and Y of the CEA Extension Building at Don Honorio Ventura State University are depicted in Figures 3 and 4. The diagram show demonstrates that base shear is correlated with displacement, demonstrating that the building's displacement increases in tandem with the building's base shear force until it reaches the peak maximum yield.

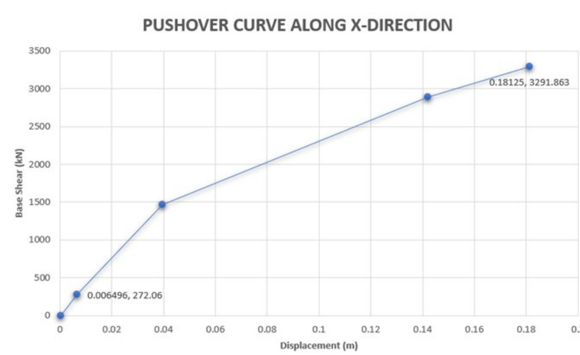

Fig.3. Pushover Curve along X-direction of the CEA Extension Building in Don Honorio Ventura State University Main Campus

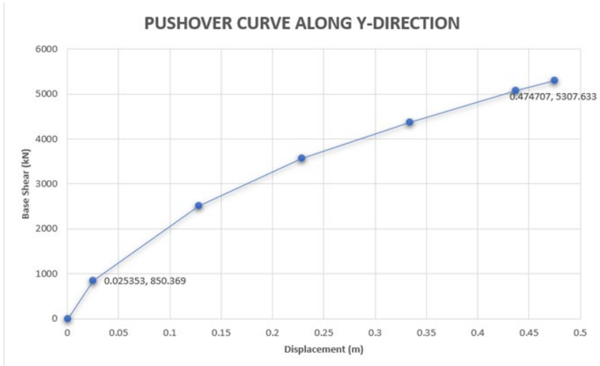

Fig.4. Pushover Curve along Y-direction of the CEA Extension Building in Don Honorio Ventura State University Main Campus

Structures' capacity to sustain a maximum number of lateral loads is measured at the maximum point of the pushover curve, while the structure's elastic limit is measured at the yield point (Pierre & Hidayat, 2020, cited in Atendido & Baylon, et al., 2022).

Atendido & Baylon et al., 2022 used the Damage State Threshold (Vasavada, 2016) to assess the damage state of each building based on data of ground motion. The damage state constraints of the structure are shown along the axis of X and Y by the tabulated data in Tables 3 and 4.

Table.3. Damage State Limits of College of Engineering and Architecture (CEA) Extension Building in Don Honorio Ventura State University (DHVSU) Main Campus in X-Axis

Damage State	Spectral Displacement	Lower Limit (mm)	Upper Limit (mm)
Slight	0.7Dy	0	4.5472
Moderate	Dy	4.5472	6.496
Extensive	Dy + 0.25(Du−Dy)	6.496	50.1845
Complete	Du	50.1845	181.25

Table.4. Damage State Limits of College of Engineering and Architecture (CEA) Extension Building in Don Honorio Ventura State University (DHVSU) Main Campus in Y-Axis

Damage State	Spectral Displacement	Lower Limit (mm)	Upper Limit (mm)
Slight	0.7Dy	0	17.7471
Moderate	Dy	17.7471	24.353
Extensive	Dy + 0.25(Du−Dy)	24.353	137.6915
Complete	Du	137.6915	474.707

3.3 Seismic Fragility Curves

In an assessment of seismic fragility curves is conducted using PGAs between 0.1g and 3.0g. A graph of Pr or conditional probability for each damage scenario (light, moderate, extensive, and complete damage) can be found in Figures 3.13 to 3.16. It is important to note that the fragility curves should not include the "D" (damage) or "No Damage" conditions. Additionally, the fragility curves for the CEA Extension Building were analyzed in both North-South and East-West earthquake directions, considering the four damage states.

The CEA Extension Building at DHVSU is anticipated to experience the following damage, at a 10% probability of exceeding, based on the chart in figure 5: it is anticipated to experience slight damage at PGA=0.068g and moderate damage at PGA=0.464g. At PGA=0.565g, substantial damage is predicted, followed by full damage at PGA=0.592g.

The CEA Extension Building of DHVSU was anticipated to experience the following damage, at a 10% probability of exceeding, based on the chart in figure 6: it was anticipated to experience slight damage at PGA=0.069g and moderate damage at PGA=0.468g. At PGA=0.575g, it was predicted to become significantly damaged, and at PGA=0.592g, it was predicted to become fully ruined.

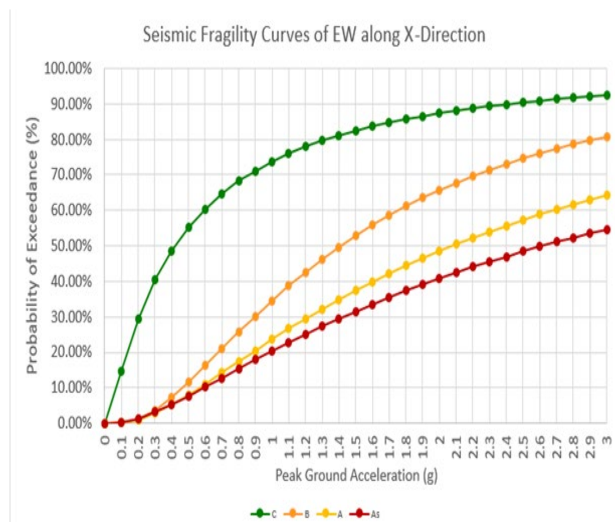

Fig.5. Seismic Fragility Curves in X-Axis of the CEA Extension Building along the East-West Direction of Earthquakes

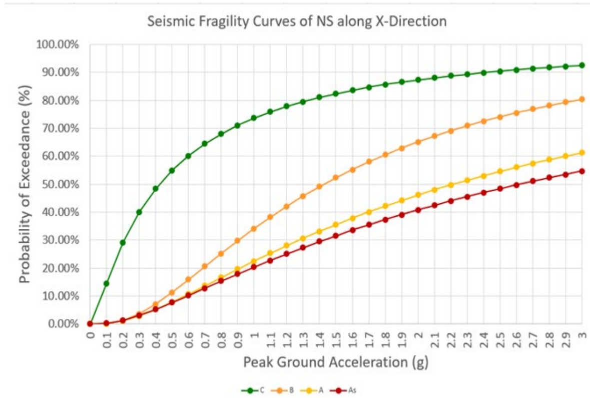

Fig.6. Seismic Fragility Curves in X-Axis of the CEA Extension Building along the North-South Direction of Earthquakes

The CEA Extension Building at Don Honorio Ventura State University was predicted to sustain the following damage, at a 10% probability of exceeding, based on the chart in figure 7: it was predicted to sustain slight damage at PGA=0.404g and moderate damage at PGA=0.555g. While it was not anticipated to reach a completely damaged state, it was anticipated to become severely damaged at PGA=0.584g.

The CEA Extension Building at Don Honorio Ventura State University was predicted to sustain the following damage, at a 10% probability of exceeding, based on the chart in figure 7: it was predicted to sustain slight damage at PGA=0.412g and moderate damage at PGA=0.561g. While it was not anticipated to reach a completely damaged state, it was anticipated to become severely damaged at PGA=0.586g.

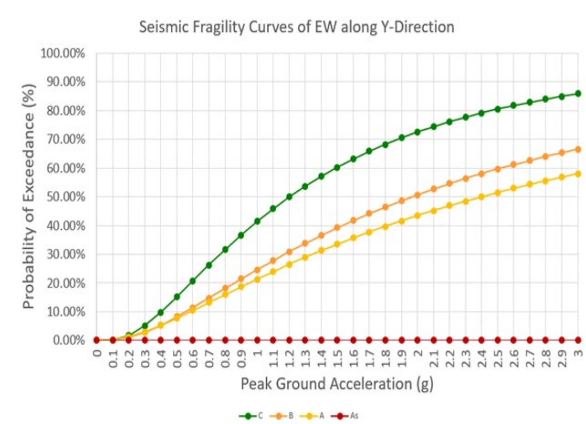

Fig.7. Seismic Fragility Curves in Y-Axis of the CEA Extension Building along the East-West Direction of Earthquakes

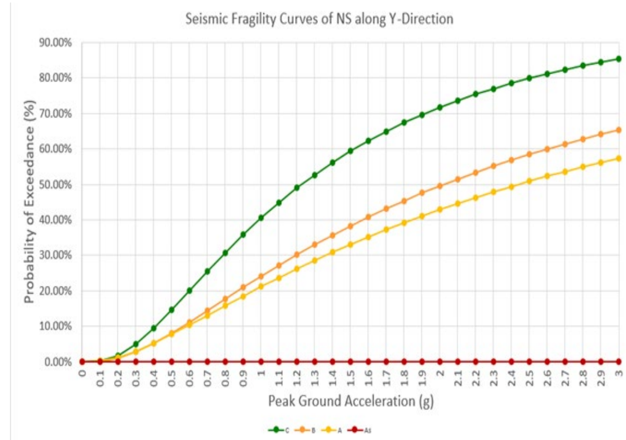

Fig.8. Seismic Fragility Curves in Y-Axis of the CEA Extension Building along the North-South Direction of Earthquakes

With a 0.4g PGA, the College of Engineering and Architecture (CEA) Extension Building of DHVSU Main Campus must meet the same standards as the nation as a whole, Except for Palawan but excludes Busuanga, Sulu, and Tawi-Tawi, which fall under Zone 2, the seismic zone factor specified by the NSCP applies to the rest of the country, which is categorized as Zone 4.

As part of the study, the probability of exceeding the threshold (Pr) for collapse damage (As) of the CEA Extension Building was assessed using the Structural Engineers Association of California (SEAOC) and the National Structural Code of the Philippines (NSCP). As part of the examination, the building's x and y axes were specifically considered.

In addition, the structure has been tested to withstand an earthquake of PGA=0.4g, which meets the standard for constructions within Seismic Zone 4 based from NSCP. As the CEA Extension Building collapsed solely by base shear forces, it was determined that it was safe from the effects of earthquakes.

Table.5. Probability of Exceedance of CEA Extension Building in X and Y Axes along East-West and North-South Direction of 0.4 PGA Earthquake

	East-West (E-W) Direction of Earthquakes				North-South (N-S) Direction of Earthquakes			
	C	B	A	As	C	B	A	As
X-Axis	48.62%	7.27%	5.23%	5.27%	48.35%	7.13%	5.19%	5.27%
Y-Axis	9.80%	5.31%	5.20%	0%	9.38%	5.27%	5.21%	0%

IV. Conclusion And Recommendation

4.1 Conclusion

Based from the plotted fragility curves, the minimum/critical peak ground acceleration (PGA) for each damage state at 10% Probability of Exceedance (Pr) was then determined. The CEA Extension Building was expected to attain "slight damage (C)" at PGA=.068g earthquake. However, a "moderate damage (B)" would be sustained if the building was subjected to a PGA=.464g earthquake. Meanwhile, the building would attain "Extensive damage (A)" if subjected to PGA=.565g earthquake. Finally, the building was expected to reach "Complete damage (As)" if subjected to PGA=.592g earthquake.

Considering that the CEA Extension Building has the capacity to endure a minimum PGA of 0.592g, which corresponds to "Complete damage (As)" as per the NSCP 2015, and surpasses the minimum demand of PGA=0.4g, it can be deemed safe for occupancy. It is worth noting that a PGA of 0.592g is equivalent to Intensity VIII (very destructive).

Furthermore, the generated fragility curves showed that at 0.4g, the greatest Probability of Exceedance (Pr) under the condition of "complete damage (As)" was 5.27%, no values exceeding 10%. The CEA Extension Building of Don Honorio Ventura State University (DHVSU) - Main Campus complies with the requirements for buildings located under Seismic Zone no. 4. Consequently, there is no need for any further retrofitting measures for the building.

4.2 Recommendation

Using the data and findings obtained from the study, it is highly recommended that future researchers do the following:

- Future researchers should explore other structural analysis and design software, such as ETabs and STAAD, to be applied to the analyses to extract the parameters for the fragility function.

- Future researchers should assess older buildings because newly-built buildings are highly reinforced. Furthermore, it is recommended to assess the vulnerability of buildings built before 1997 and before the implementation of NSCP 2015.

- Future researchers should also assess other types of structure such as residential buildings, industrial buildings, commercial buildings, and bridges as they have different uses.

- Future researchers should also assess steel structures as there are only few existing studies about it.

- Future researchers should consider conducting a cost-benefit analysis to determine the retrofitting cost for the structure after it has sustained damage during a seismic event.

References

[1]. Arayata, M. C., & Agoot, L. (2022, October 26). Magnitude 6.4 quake jolts abra, generates 368 aftershocks. Philippine News Agency.

[2]. Arayata, M. C. (2022, July 22). Magnitude 7 quake jolts Abra. Philippine News Agency.

[3]. Atendido, A. M., Atillano, G. A. L., Mabunga, J. C., & Oliveros, J. E., Baylon, M. B. (2022, May). Development Of Seismic Fragility Curves for Dpwh Building Of Doña Rosario Elementary School. Researchgate.

[4]. Masum, M., & Akbar, M. A. (2019). The Pacific Ring of Fire is working as a home country of geothermal resources in the world. IOP Conference Series: Earth and Environmental Science, 249, 012020.

[5]. Featherston, N. R. (2019). Design for extreme seismic event scenarios for long span bridges in the Ring of Fire. IABSE Congress, New York, New York 2019: The Evolving Metropolis.

[6]. Sarao, Z. (2022, August 11). Abra earthquake damage now over P1.8B; agriculture damage over P56m. INQUIRER.net.

[7]. SAP 2000. ACECOMS. (2022, February 3). Retrieved October 2, 2022.

[8]. Baylon, M., Ang, K., & Valentin, R. C. (2018). seismic vulnerability of FRC Buildings.

[9]. Atendido, A. M., Atillano, G. A. L., Mabunga, J. C., & Oliveros, J. E., Baylon, M. B. (2022, May). Development Of Seismic Fragility Curves for Dpwh Building of Doña Rosario Elementary School. Research gate.

[10]. ATC, S. (n.d.). Evaluation and retrofit of concrete buildings, Rep. ATC-40, Applied Technology Council, Redwood City, California.

[11]. NASA. (n.d.). Seismic Data available from the IRIS. NASA. Retrieved April 25, 2023.

[12]. Data Products at the IRIS DMC: Stepping Stones for research and other ... Research Gate. (n.d.). Retrieved April 24, 2023.

[13]. Jeong, S.-H. (n.d.). about Prism. Prism - program for earthquake response spectra. Retrieved April 25, 2023.

[14]. Introduction to earthquake. Philippine Institute of Volcanology and Seismology. (n.d.).

[15]. The big one part 2. Department of Science and Technology - National Research Council of the Philippines. (n.d.).

[16]. 1976 August 17 Mw8.1 Moro Gulf earthquake. Philippine Institute of Volcanology and Seismology. (n.d.).