RESEARCH ARTICLE OPEN ACCESS

Seismic Assessment of Phil Health Regional Office III Building in the City of San Fernando, Pampanga, Philippines Using Fragility Curves

Aaron D. Balingit[1], Nicole A. Almario[1], Bryan Jolo C. Antonio[1],Jestine L. Bon[1],Jenelyn L. Cada[1], Timothy Joseph D. Soriano[1],John Robert D. Gabriel[2], John Vincent G. Tongol[2]
[1]Student, Department of Civil Engineering, Don Honorio Ventura State University, Pampanga,Philippines
Email:balingitaaron10@gmail.com
[2] Instructors, Department of Civil Engineering, Don Honorio Ventura State University, Pampanga, Philippines

--************************----------------------------------

Abstract:

Earthquakes have the ability to disturb and cause damage to a structure. Due to this, seismic assessment is conducted in order to test the capability of the structure to handle earthquake loads. This study is focused in examining the seismic vulnerability of the PhilHealth Regional Office III Building by constructing fragility curves. In conducting this, the researchers conducted rebound hammer testing on the structure. They collected 20 earthquake data from SAGE, with PGA ranging from 0.1g to 3.0g. After that they used AutoCAD and SAP 2000 in modeling the structure and conducting two other analyses like Push Over Analysis and Capacity Spectrum Method. Based on the results of the study, the largest Probability of Exceedance (Pr) collected was 5.21% under complete damage "As" while there there was no value under the category complete damage that exceeded 10%. The structure was able to meet the minimum requirement of the NSCP Building Code specification, with a peak ground acceleration (PGA) of 0.4g and a 10% probability of exceedance.

Keywords ***—Seismic Assessment, Fragility Curves, SAP 2000, PGA, Rebound Hammer Test.***

--************************----------------------------------

I. INTRODUCTION

Earthquakes are inevitable and pose a significant threat, demanding comprehensive measures and precautions to mitigate property and human losses. Factors such as poor design, low reinforcement, use of substandard materials; bad construction practices and lack of maintenance may lead to buildings collapsing during an earthquake which makes it necessary for us to comprehend and respond to multiple issues. It is important to consider how infrastructure and buildings will react during an earthquake to ensure their ability to cater safety and stability.

Failure to assess an earthquake's structural implications can result in significant loss of life and financial devastation. This underscores the importance of conducting seismic assessments aimed at minimizing or preventing potential damage. Structures designed before the implementation of current seismic codes, those lacking seismic resistance or exhibiting signs of deterioration, are recommended for evaluation. The assessment results play a crucial role in determining whether a structure requires demolition, retrofitting for enhanced integrity, or modification to decrease vulnerability to seismic activity.

The researchers performed a seismic evaluation on a former commercial building, specifically the PhilHealth Regional Office III in City of San Fernando Pampanga. The fragility curves were employed during the assessment to ascertain the seismic resilience of the building and identify the magnitude of an earthquake it could endure. The fragility curve represents the likelihood of a structure, element, or component failing under specific seismic intensity conditions [1]. In order to create this curves the researchers gathered ten local and international ground motion data from SAGE, also performed rebound hammer testing on the critical columns to apply in the structural model from SAP 2000. Push Over Analysis and Capacity Spectrum Method was also utilized in order to identify the potential hazard to the structure.

TABLE I
TEN GLOBAL GROUNDMOTION DATA

Description	Date	Magnitude	Depth
Off W Coast Of Northern Sumatra	12/26/2004	9	26 km
Near East Coast Of Honshu, Japan	3/11/2011	9.1	19.7 km
Near Coast Of Peru	8/15/2007	8	41.2 km
Southern Sumatra, Indonesia	6/4/2000	7.9	52.7 km
Sichuan, China	5/12/2008	7.9	7.6 km
Flores Region, Indonesia	12/12/1992	7.4	27.7 km
Nepal	4/25/2015	7.9	13.4 km
Near Coast Of Ecuador	4/16/2016	7.8	20.59 km
Pakistan	9/24/2013	7.8	15.5 km
Turkey	8/17/1999	7.6	17.0 km

TABLE II
TEN LOCAL GROUNDMOTION DATA

Description	Date	Magnitude	Depth
Luzon, Philippines	12/11/1999	7.3	69.6 km
Mindanao, Philippines	2/10/2017	6.5	15.0 km
Mindoro, Philippines	11/14/1994	7	31.5 km
Negros, Philippines	2/6/2012	6.7	17.5 km
Mindanao, Philippines	10/15/2013	7.1	23.2 km
Philippine Islands Region	8/31/2012	7.6	44.4 km
Mindanao, Philippines	2/8/1990	6.7	0.8 km
Luzon, Philippines	7/27/2022	7	46.0 km
Negros, Philippines	2/6/2012	6.7	17.5 km
Mindanao, Philippines	10/29/2019	6.6	14.95 km

II. METHODOLOGY

This research about "Seismic Assessment of PhilHealth Regional Office III Building in the City of San Fernando, Pampanga Using Fragility Curves" used a quantitative approach. A quantitative study dealt with numerical data generated through statistical techniques [2]. Presented in Figure 1 is the conceptual framework of the study in order to further understand the process in conducting a seismic assessment.

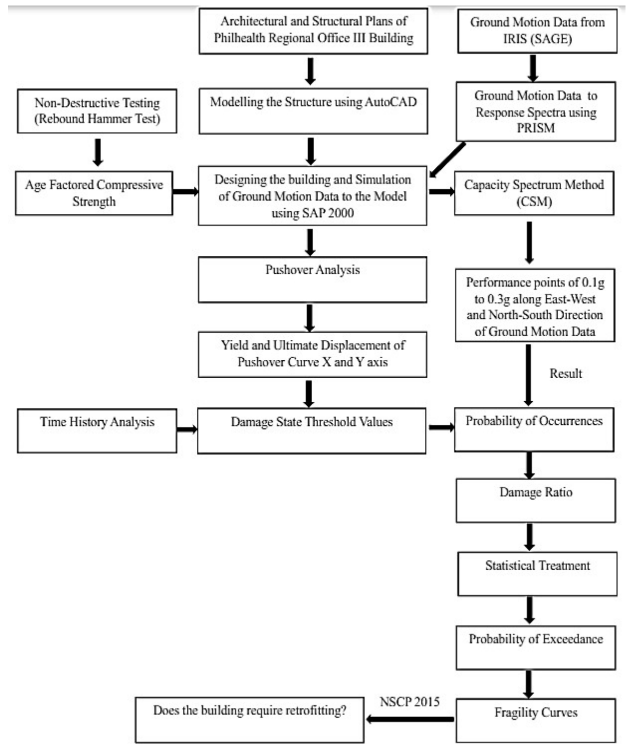

Fig. 1 Conceptual Framework of the Study

A. Data Collection

In the initial phase of the study, the researchers acquired the structural and architectural plans for the PhilHealth Office Regional III Building. After that the researchers gathered ground motion data from SAGE both local and international. Additionally, Rebound Hammer Testing was conducted on columns exhibiting evident cracks to accumulate their current compressive strength, which was subsequently utilized in modelling the structure.

B. Modelling the Structure

Under phase 2, the researchers modelled the structure in AutoCAD then imported it to SAP 2000 and from where it enables them to apply analytical techniques.

C. Push Over Analysis

Utilizing a nonlinear approach, pushover analysis shows how structural capacity responds to increasing horizontal stresses (static), ultimately leading to collapse.The structure's capacity is said to be directly proportional from where as base shear increases the displacement also increases to a specific threshold. This relationship is graphically represented by a pushover curve, also known as the capacity curve [3].

D. Capacity Spectrum Method

Capacity Spectrum Method (CSM) is a linear-dynamic statistical method used to evaluate a predominantly elastic structure's probable maximum seismic response. This assessment takes into account the contribution of each natural mode of vibration [4].

E. Time History Analysis

Time-history analysis provides the linear or nonlinear assessment of the dynamic structural response under loading, which may vary based on the specified time function [5].

F. Fragility Curves

The followingarestepstheresearchersfollowedinordertogeneratefragility:

1. Computethedamagestatethresholdrefertothe tablebelowin determining the spectral displacement of each damage state.

TABLE IIII
DAMAGE STATE THRESHOLD VALUES [6]

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

2. Get damage state for all displacements on performance points gathered.
3. Identify the number of occurrences of each damage state at various PGA level.
4. Acquire probability of occurrences.
5. Peakgroundaccelerationobtainedfromdifferentpastearthquakeslocaland international will be used to obtain the cumulative log normal probability
6. Plottingthefragilitycurvesbyutilizingthecumulativelognormal probability and peak ground acceleration.

III. RESULTS AND DISCUSSIONS

G. Rebound Hammer Test

TABLE IV
REBOUND HAMMER TEST RESULTS

	Column	Average f'c (Mpa)	Corrected Average f'c (Mpa)
Ground Floor	D5	41.162	23.504
	D10	34.388	19.636
Second Floor	D5	37.973	21.684
	E9	72.412	41.348
Third Floor	E9	62.725	35.818
	5A-F1	25.373	14.493
Fourth Floor	3A-C1	30.285	17.299
	D5	38.094	21.753

The researchers tested 19 columns but presented in table IV are columns with the highest and lowest compressive strength recorded.

Initially, based on the general notes in the structural plan, the designed compressive strength of the structure is 27.6 MPa.

Large discrepancies in values are shown compared to the rebound number obtained during the rebound hammer test. As observed in a study, the Schmidt hammer provides a 15.32 error for concrete with compressive strength ranging from 48 to 58 MPa while 44.18% for lower and upper regions of the test; this explains the inconsistency of values [7]. In modeling the structure, the researchers used the lowest rebound number available per floor: 19.636 MPa for the ground floor, 21.684 MPa for the second floor, 14.493 MPa for the third floor, and 17.299 MPa for the fourth floor. This represents the current condition of the building and is set as a safety factor for analyses.

H. Structural Model Using AutoCAD

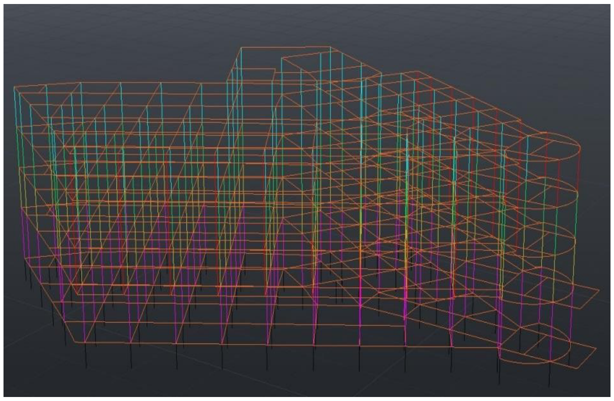

Fig. 2 StructuralModelofthePhilHealthRegionalOfficeIIIBuildingintheCityof San Fernando, Pampanga using AutoCAD

I. Structural Model Using SAP2000

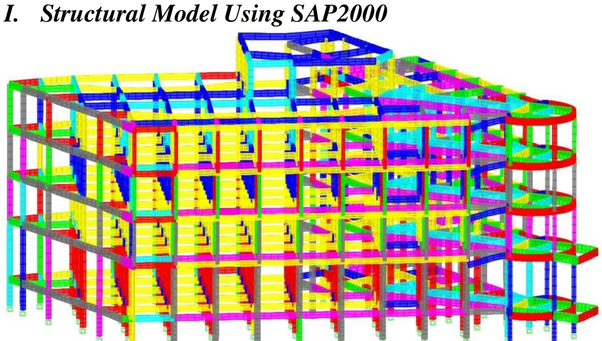

Fig. 3 StructuralModelofthePhilHealthRegionalOfficeIIIBuildingintheCityof San Fernando, Pampanga using SAP2000

J. Pushover Analysis

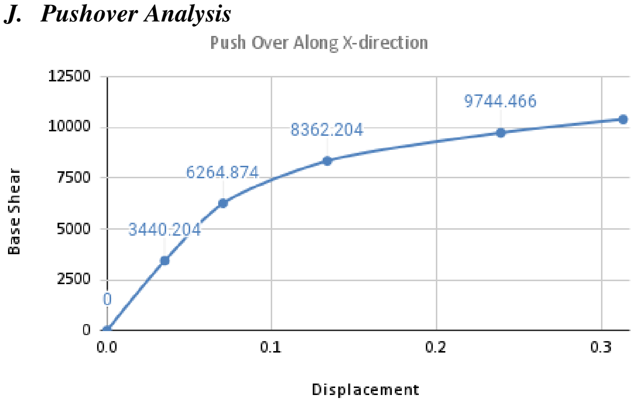

Fig. 4 PushOver CurveAlong X-Direction

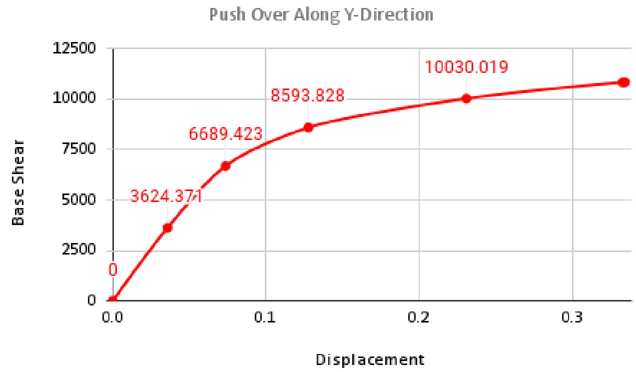

Fig. 5 PushOver CurveAlong Y-Direction

Among the values accumulated along X- the direction, the lowest base shear value is 3440.204 kN and a displacement of 0.035022m, which makes it a yielding displacement, as for the ultimate displacement, the researchers were able to get 0.313418 m and a base shear of 10406.559 kN as shown in Figure 4.On the other direction, which is the Y-axis, the yielding displacement is equal to 0.035764 and a base shear of 3624.371 kN; as for its ultimate displacement, it has an approximate value of 0.334614 and a base shear value of 10843.019 kN as depicted in Figure 5.The yielding and ultimate displacement were differentiated so that the yielding displacement is considered the limit value in terms of elasticity in a structure. In contrast, the ultimate displacement was defined as the maximum point in a capacity or pushover curve that can resist maximum lateral loads [8].

Comparing the two axes, as shown in both Figures 4 and 5, it is obvious that the base shear along the Y- direction is larger than the other. This only means that the PhilHealth Regional Office III Building in the City of San Fernando, Pampanga, can resist more base shear in the Y-axis, making it the strongest axis.

Along with this the researchers were able to come up with the damage thresholdin both X and Y axis using the damage state threshold.

TABLE V

Summaryof theCalculation ofThreshold Valuesin X-Axis		
DS	**SOLUTION**	**THRESHOLDVALUES(mm)**
D	0<dpp≤35.022	0<dpp≤35.022
C	0.7(35.022)<dpp≤35.022	24.52<dpp≤35.022
B	35.022<dpp≤[35.022+0.25(313.418-35.022)]	35.022<dpp≤104.62
A	[35.022+0.25(313.418-35.022)]<dpp≤313.418	104.62<dpp≤313.418
As	dpp>313.418	dpp>313.418

DAMAGE STATE LIMITS ALONG X-AXIS

TABLE VI
DAMAGE STATE LIMITS ALONG Y-AXIS

Summaryof theCalculation ofThreshold Valuesin Y-Axis		
DS	**SOLUTION**	**THRESHOLDVALUES (mm)**
D	0<dpp≤35.764	0<dpp≤35.764
C	0.7(35.764)<dpp≤35.764	25.035<dpp≤35.764
B	35.764<dpp≤[35.764+0.25(334.164-35.764)]	35.764<dpp≤110.364
A	[35.764+0.25(313.418-35.764)]<dpp≤334.164	110.364<dpp≤334.164
As	dpp>334.164	dpp>334.164

The following values were used in order toget the damage state of the structurewith respect to the subjected peak ground acceleration.

K. Seismic Fragility Curve

TABLE VII
SUMMARY OF PEAK GROUND ACCELERATION AT 10% PROBABILITY OF EXCEEDANCE

		Damage Rank				
Push Over	Direction	D	C	B	A	As
X	EW	0.02g	0.027g	0.081g	0.454g	0.583g
X	NS	0.020g	0.026g	0.089g	0.470g	0.581g
Y	EW	0.022g	0.024g	0.098g	0.494g	0.584g
Y	NS	0.021g	0.027g	0.089g	0.482g	0.585g

The seismic fragility curves presented depict the vulnerability of the PhilHealth Regional Office III Building, allowing for comparisons between different damage ranks. It is notable that, as highlighted in the studies of Baylon& Marcos (2018) and Castillo et al. (2020), the "No Damage" category is typically excluded from fragility analyses for practical reasons.

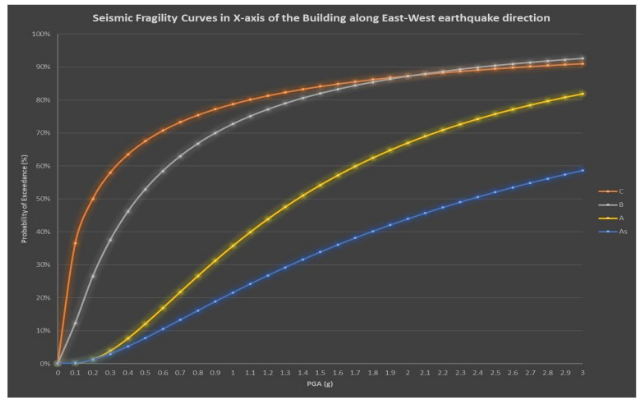

Fig. 6Seismic Fragility Curve of East-West Direction Along X-Axis

The chart illustrated above (Fig 6) is the seismic fragility curve of the PhilHealth Regional Office III Building along X-axis of the building in the EW-direction. The PhilHealth Regional Office III Building is projected to experience the following damage levels with a 10% probability of occurrence with corresponding specific peak ground accelerations (PGAs): slight damage is expected at 0.027g, moderate damage at 0.081g, extensive damage at 0.454g, and complete collapse at 0.583g.

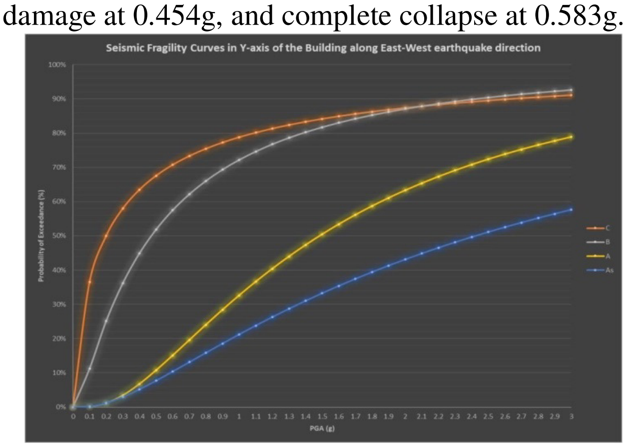

Fig. 7Seismic Fragility Curve of East-West Direction Along Y-Axis

According to the data presented in Figure 7, the

PhilHealth Regional Office III Building is projected to experience the following damage levels with a 10% probabilityof occurrence with corresponding specific peak ground accelerations (PGAs): slight damage is expected at 0.024g, moderate damage at 0.098g, extensive damage at 0.494g, and complete collapse at 0.584g.

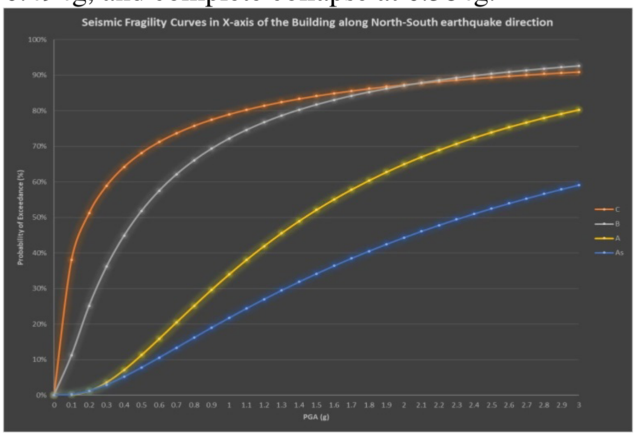

Fig. 8Seismic Fragility Curve of North-South Direction Along X-Axis

Figure 8, the PhilHealth Regional Office III Building is projected to experience the following damage levels with a 10% probability ofoccurrencewith correspondingspecificpeak groundaccelerations(PGAs): slight damage is expected at 0.026g, moderate damage at 0.089g, extensive damage at 0.470g, and complete collapse at 0.581g.

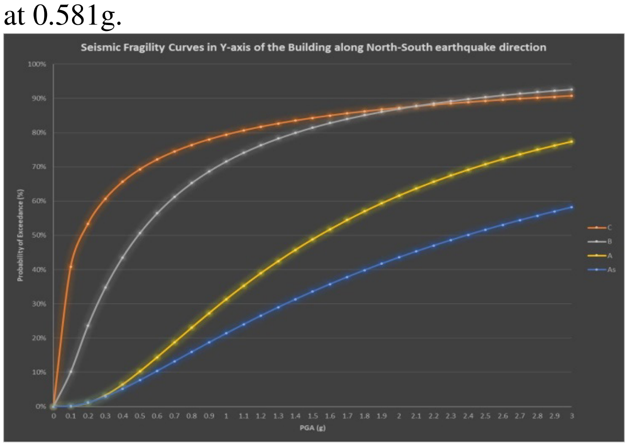

Fig. 9Seismic Fragility Curve of North-South Direction Along Y-Axis

Figure 9 is the seismic fragility curve of the PhilHealth Regional Office III Building along Y-axis of the building in the NS-direction. The PhilHealth Regional Office III Building is projected to experience the following damage levels with a 10% probability ofoccurrencewith correspondingspecificpeak groundaccelerations(PGAs): slight damage is expected at 0.027g, moderate damage at 0.089g, extensive damage at 0.482g, and complete collapse at 0.585g.

Apeak ground acceleration(PGA)of0.4gequate aseismicforcesubjected onthe PhilHealth Regional Office III situated on Lazatin Boulevard in San Fernando, Pampanga. In accordance with national standards, the building must adhere to specific seismic design and construction codes just like the rest of the nation.However, it is notablethatexceptionsexistforcertainregionsofthecountry,namelyPalawan (excludingBusuanga),Sulu,andTawi-Tawiduetotheiruniquegeologicalcharacteristics and seismic activity patterns.

The research examined the Probability of Exceedance (Pr) of the "collapse damage (As)" state for the x and y axes of the PhilHealth Regional Office III when subjected to an earthquake with a peak ground acceleration (PGA) of 0.4g and this is in accordance with the National Structural Code of the Philippines (NSCP) as well as the standards set by the Structural Engineers Association of California (SEAOC). Additionally, the structure demonstrated its capacity to withstand seismic forces of 0.4g PGA, meeting the NSCP criteria for constructions in Seismic Zone 4. Given that themode of collapse was solelyattributed to base shear force, PhilHealth Regional Office III was evidently structurally sound when subjected with seismic activity.

Axes	East-West Direction (%)				North-South Direction (%)			
	C	B	A	AS	C	B	A	AS
X	63.46	46.1	7.62	5.20	64.22	44.87	7.09	5.19
Y	65.61	43.5	6.42	5.20	63.46	44.89	6.73	5.21

TABLE VIII
SUMMARY OF PROBABILITY OF EXCEEDANCE

IV. CONCLUSIONS

The main objective of this study was to generate seismic fragility curves for the PhilHealth Regional Office III Building to determine if it could still withstand powerful earthquakes. After gathering and analyzing the data as well as the results of this study, the following conclusions were drawn:

a) Based on the results of the rebound hammer test, the researchers utilized the lowest available rebound number per floor, resulting in compressive strength valuesof19.636MPaforthegroundfloor,21.684MPaforthesecondfloor, 14.493 MPa for the third floor, and 17.299 MPa for the fourth floor. These values represent the current condition of the building's concrete structure and serve as a safety factor for subsequent analyses. Moreover, these conservative strength values were incorporated into the modeling of the structure in its initial phase.

b) The result of Pushover Analysis, it was clearly visible that the building's Y-axis can resist larger base shear in comparison to its X-axis. On that account, the stronger axis of the building is the Y-axis.

c) Pushover Analysis and the interpretation of Fragility Curves, it is clear that the PhilHealth Regional Office III Building only sustaineda moderate damage during the analysis with the strongest earthquake which is magnitude 9.1 that was gathered by the researcher in the simulation.

d) The plotted set of fragility curves at Y-axis along North-Southdirectionwhereintheminimum/criticalpeak groundacceleration(PGA)for each damage state at 10% Probability of Exceedance (Pr) was established, the PhilHealth Regional Office III Building was expected to attain "slight damage (C)"atPGA=0.027gearthquake.Ontheotherhand, "moderatedamage(B)" would be sustained if the building was subjected to a PGA=0.089g earthquake. Concurrently, the building would attain "Extensive damage (A)" at PGA 0.482g and "Complete Damage (As)" if subjected to a PGA of 0.585g.

e) Subsequently, given that the PhilHealth Regional Office III Building is designed to endure seismic activity with a minimum PGA of 0.585g to reach a state of "Completedamage(As)" it is thereforedeemedsafefor occupancyas it surpassed the NSCP's minimum requirement of 0.4g, Additionally, at PGA=0.585g, the damage level corresponds to Intensity VIII (very destructive).

f) Furthermore, based on the results obtained from the plotted fragility curves, the structure evidently meets the minimum requirement of the NSCP Building Code specification, with a peak ground acceleration (PGA) of 0.4g together with the 10% probability of exceedance noted at Appendix D. The greatest Probability of Exceedance (Pr) under the condition of "complete damage (As)" was 5.21% and there was no value under the category complete damage that exceeded the 10% which indicates that the building can withstand the minimum requirement of 0.4g PGA.

V. RECOMMENDATIONS

- Future researchers should take note of the existing cracks in the buildings since analyzing cracks during an earthquake evaluation could give valuable information about the areas with low strength and the ones likely to fail first among other members. Moreover, this can help in coming up with ways through which retrofitting can be done at specific points or general strengthening measures taken. However, to minimize confusion and inaccurate visual screening the future investigators should note that buildings can break due to various reasons.
- Future researchers should also consider the importance of soil stability for it has a significant effect on the way in which buildings perform during earthquakes. Weak soils can lead to foundation failure whereas loose saturated soils can cause settlements or even building collapse. Also, loose soils

may result into landslides which could affect adjacent structures and people living around.

- Future researchers should conduct a comparative analysis between the current NSCP 2015 and previous versions, particularly the 2001 and 2010 editions. This analysis aims to determine which NSCP code, when applied to the construction of structures, offers superior resistance to seismic events for safety purposes. By examining the differences between these codes, researchers can identify potential improvements in seismic design standards and enhance structural resilience against earthquakes.
- Future researchers should also pay attention to structures undergoing structural modifications such as renovations, repairs, or retrofitting, as the research locale of this study underwent some modifications. These changes can alter a structure's dynamic behavior and seismic response by affecting material properties, geometry, and load capacity. By factoring in these modifications during fragility analysis, researchers can evaluate their impact on the building's seismic risk profile.

REFERENCES

[1] T. Rossetto, D. D'Ayala, I. Ioannou, and A. Meslem, "Evaluation of Existing Fragility Curves," *Geotechnical, Geological and Earthquake Engineering*, vol. 27, pp. 47–93, 2014, doi: 10.1007/978-94-007-7872-6_3.

[2] "Research Methods," ScienceDirect. https://www.sciencedirect.com/book/9780081022207/research-methods?via=ihub=#book-description (accessed Nov. 28, 2023).

[3] Y. Seo, "How to Perform Pushover Analysis?," *www.midasstructure.com*. https://www.midasstructure.com/blog/pushover_analysis_ (accessed Nov. 27, 2023).

[4] "Generating response-spectrum curves - Technical Knowledge Base - Computers and Structures, Inc. - Technical Knowledge Base," *wiki.csiamerica.com*.https://wiki.csiamerica.com/display/kb/Generating+response-spectrum+curves (accessed Nov. 27, 2023).

[5] "Time-history analysis - Technical Knowledge Base - Computers and Structures, Inc. - Technical Knowledge Base," *wiki.csiamerica.com*. https://wiki.csiamerica.com/display/kb/Time-history+analysis (accessed Nov. 27, 2023).

[6] M. Jovi *et al.*, "Seismic Vulnerability Assessment of College of Engineering and Architecture (CEA) Extension Building in Don Honorio Ventura State University (DHVSU) Main Campus Using Fragility Curves," *INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN SCIENCE AND ENGINEERING*, vol. 4, no. 06, 2023.

[7] J.ReiandM.Co,"AssessmentoftheReliabilityofReboundHammerTesting ontheEstimationofConcreteCompressiveStrength,"Apr.2019. Accessed: Apr. 21, 2024. [Online]. Available: https://www.researchgate.net/publication/338680234_Assessment_of_the_Rel iability_of_Rebound_Hammer_Testing_on_the_Estimation_of_Concrete_Co mpressive_Strength

[8] A. Atendido, G. Atillano, J. Oliveros, and M. Bautista Baylon, "DEVELOPMENT OF SEISMIC FRAGILITY CURVES FOR DPWH BUILDING OF DOÑA ROSARIO ELEMENTARY SCHOOL 1 PUBLICATION 0 CITATIONS SEE PROFILE 1 PUBLICATION 0 CITATIONS SEE PROFILE," 2022, doi: https://doi.org/10.13140/RG.2.2.26956.69760.
.