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ENHANCEMENT OF PROBABILISTIC SEISMIC GROUND MOTION HAZARD MAPS FOR THE ENTIRE PHILIPPINES

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Abstract

The Philippines is located in one of the most seismically hazardous regions of the world and is situated in the vicinity of three (3) major earthquake generators namely; the Philippine Trench, formed by the subduction of the western edge of the Philippine Sea Plate under the Eurasian Plate, the Philippine Fault Zone (PFZ) and the Manila Trench.

Many destructive earthquakes have occurred in various parts of the country, of which the most notable and destructive ones were the M_w 7.6 Casiguran Aurora Earthquake in August 8, 1968, the M_w 8.2 Moro Gulf Earthquake in August 17, 1976, the M_w 6.5 Ilocos Norte Earthquake in August 17, 1983, the M_w 7.7 North Luzon Earthquake in July 16, 1990, the M_w 6.2 Masbate Earthquake in February 15, 2003, the M_w 6.9 Negros Oriental Earthquake in February 6, 2012, the M_w 7.2 Bohol Earthquake in October 15, 2013, the M_w 6.7 Surigao Earthquake in February 10, 2017, the M_w 6.5 Leyte Earthquake in July 6, 2017, and recently the series of earthquakes (different epicenters) in Cotabato, Mindanao with M_w 6.3 October 16, 2019, M_w 6.6 October 29, 2019 and M_w 6.5 October 31, 2019 and M_w 6.9 December 15, 2019 Davao del Sur.

One of the key aspects of the proper seismic-resistant design and construction of buildings is the proper estimation and documentation of the seismic hazard available to the architect, structural engineers and even to the public. This information should be consistent with the latest developments in seismology and earthquake engineering. The main objective of the project carried out is to enhance the Probabilistic Seismic Ground Motion Hazard Maps for the entire Philippines particularly in highly-urbanized regions.

Keywords: seismic hazard maps, spectral acceleration maps, peak ground acceleration, ground motion hazard

1. Introduction

The Philippines is in one of the most seismically hazardous regions of the world and is situated in the vicinity of three (3) major earthquake generators namely; the Philippine Trench, formed by the subduction of the western edge of the Philippine Sea Plate under the Eurasian Plate, the Philippine Fault Zone (PFZ) and the Manila Trench. Many destructive earthquakes have occurred in various parts of the country, of which the most notable and destructive events were the M_w 7.6 Casiguran Aurora Earthquake in August 8, 1968, the M_w 8.2 Moro Gulf Earthquake in August 17, 1976, the M_w 6.5 Ilocos Norte Earthquake in August 17, 1983, the M_w 7.7 North Luzon Earthquake in July 16, 1990, the M_w 6.2 Masbate Earthquake in February 15, 2003, the M_w 6.9 Negros Oriental Earthquake in February 6, 2012, the M_w 7.2 Bohol Earthquake in October 15, 2013, the M_w 6.7 Surigao Earthquake in February 10, 2017, the Mw6.5 Leyte Earthquake in July 6, 2017, the Mw6.1 Central Luzon Earthquake in April 22, 2019, the Mw5.5 Surigao del Sur Earthquake in July 13, 2019, the recent series of earthquake events of different epicenters in Cotabato, Mindanao with M_w 6.3 October 16, 2019, M_w 6.6 October 29, 2019 and M_w 6.5 October 31, 2019, and the M_w 6.9 December 15, 2019 Davao del Sur. Fig. 1 shows the charted traces of faults in Southern Mindanao which were the generators of the series of earthquakes in Cotabato in October 2019.

The notably damaging earthquake of July 16, 1990 in North Luzon brought down a landmark hotel building in Baguio City (see Fig. 2) while the April 22, 2019 Central Luzon earthquake flattened a supermarket building that killed a number of shoppers inside the facility (see Fig. 3).

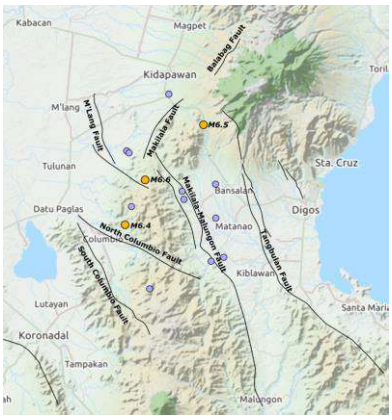

Fig. 1 - Map of the M ≥ 5.0 earthquakes from the October 2019 sequence, highlighting the three largest events. (Source: 2019 Cotabato EQs+faults - 2019 Cotabato earthquakes - Wikipedia)

Fig. 2 - Hyatt Terraces Hotel in Baguio City that was knocked down in the July 16, 1990 North Luzon earthquake aftermath

Fig. 3 - Chozun Supermarket building in Pampanga that was flattened after the April 22, 2019 Central Luzon earthquake

There have been several major earthquakes in the world in recent years, resulting in over 15,000 casualties in just the past decades. For the destructive events as listed, Table 1 is the matrix of casualties and damages to property:

Table 1 - Major earthquake events in the past 60 years in the Philippines

Earthquake events	Casualties[1]	Damage Effect[2]
M_w 7.6 Casiguran Aurora Earthquake in August 8, 1968	207–271 dead, 261 injured	Collapse of six-storey Ruby Tower
M_w 8.2 Moro Gulf Earthquake in August 17, 1976	5,000–8,000 killed	With tsunami
M_w 6.5 Ilocos Norte Earthquake in August 17, 1983	16 killed 47 injured	Collapse of four-storey building, 300-year statue of Saint Monica
M_w 7.7 North Luzon Earthquake in July 16, 1990	1,621 dead	Collapse of prominent buildings such Hyatt Terraces, hotels, schools, etc. and damaged lifelines structures including roads and bridges
M_w 6.2 Masbate Earthquake in February 15, 2003	No available data	Damaged vertical and horizontal infrastructures
M_w 6.9 Negros Oriental Earthquake in February 6, 2012	51 dead 112 injured 62 missing	Damaged roads and bridges due to liquefaction
M_w 7.2 Bohol Earthquake in October 15, 2013	222 dead; 8 missing; 976 injured	Damage / collapse of some historical churches and lifeline structures in Cebu and Bohol
M_w 6.7 Surigao Earthquake in February 10, 2017	8 dead 202 injured	Cost of damage to property and infrastructure is at least PHP 665 million
M_w 6.5 Leyte Earthquake in July 6, 2017	4 dead, 100+ injured	at least PHP 271 million of damage
M_w 6.1 Central Luzon Earthquake in April 22, 2019	18 dead; 3 missing; 256 injured	PHP 539 million of damage
M_w 5.5 Surigao del Sur Earthquake in July 13, 2019	52 injured	Several homes, churches and other buildings damaged
M_w 6.3, M_w 6.6 and M_w 6.5 Cotabato Earthquakes in October 16, 29 and 31, 2019, respectively	October 16: 7 dead, 215 injured October 29 and 31: 24 dead, 11 missing, 563 injured	October 16: Malls in Davao City and General Santos City were damaged. October 29: A major fire broke out in General Santos City. Some residential and commercial buildings in Davao City and SOCCSKSARGEN[3] collapsed. October 31: A hotel building in Kidapawan City collapsed.
December 15, 2019	13 people had been killed, one remained missing and a total of 210 people were reported injured	5,973 houses were destroyed in Davao del Sur, with 31,832 suffering some damage and a further 32 in North Cotabato; 397 schools and 62 health facilities were damaged in Davao del Sur, Sarangani and North Cotabato.

The cities in the Philippines may be highly vulnerable to catastrophic risk to life and property due to the combined effects of high seismic vulnerability, many non-engineered and old buildings and structures that do not conform to the advances in earthquake engineering and design. Proper design and construction of buildings can have a major impact on the actual loss of life and property from a particular earthquake that has become evident from the difference in the casualties of the earthquakes in Haiti, Chile, China, Italy, New Zealand, Japan and Taiwan, to name a few countries that are also of high seismic hazard and risk.

[1] Source: https://en.wikipedia.org/
[2] Source: https://en.wikipedia.org/
[3] SOCCSKSARGEN stands for a region composed of **So**uth **C**otabato, **C**otabato, **S**ultan **K**udarat, **Sar**angani and **Gen**eral Santos City

2. Definition of Terms

The following terms and acronyms are defined to provide clear understanding and information regarding the organizations, institutions and activities involved in the undertaking of the objectives of this paper.

ASEP. Association of Structural Engineers of the Philippines. The professional organization of the practicing structural engineers of the Philippines which is established in 1961.

NSCP Volume I. National Structural Code of the Philippines, Volume I. The referral code of the National Building Code (P.D. 1096) for the design and construction of buildings, towers and other vertical structures.

PHIVOLCS. Philippine Institute of Volcanology and Seismology. The national government agency which is a service institute of the Department of Science and Technology (DOST) that is principally mandated to mitigate disasters that may arise from volcanic eruptions, earthquakes, tsunami, and other related geotectonic phenomena.

ProjectSAM. SAM stands for Spectral Acceleration Mapping, a project being initiated by ASEP in collaboration with DOST-PHIVOLCS in its objective to update the NSCP following the latest developments in seismic design, disaster mitigation, preparedness and response, and disaster risk reduction and management.

SAM PH. Spectral Acceleration Maps of the Philippines is the expected deliverable of the Project SAM that represents the spectral response acceleration parameters S_s and S_1 (short and 1-s periods, respectively) on rock site for 2% probability of exceedance in 50 years (2475-year mean recurrence interval) at 5% damping.

PEM. Philippine Earthquake Model is an atlas that aims to help engineers in designing earthquake-resistant buildings and other structures and to enhance the existing National Structural Code of the Philippines.

3. The Issue

One of the key aspects of the proper earthquake-resistant design and construction of buildings is the proper estimation and documentation of the seismic hazard available to the architect, structural engineers and even to the public. This information should be consistent with the latest technological developments in seismology and earthquake engineering.

The structural design of the buildings in the Philippines is governed by the National Structural Code of the Philippines (NSCP). The NSCP is written and published by the Association of Structural Engineers of the Philippines (ASEP). The most recent version of the code was published in April 2015 following its edition approval by the National Building Official on February 15, 2017. The National Building Official as mandated in the National Building Code of the Philippines (under Presidential Decree No. 1096[4]) is the Secretary of the Department of Public Works and Highways (DPWH). However, some important provisions of the code, especially those related to seismic design and safety may need to be aligned with the international standards such as the International Building Code (IBC) and the ASCE 7 Standards. This definitely requires a more detailed seismicity study and mapping.

The latest international codes such as the IBC, ASCE 7, ACI 318, AISC, etc. where the most provisions of the NSCP are referenced have advanced extensively in terms of seismic design of structures. The most recent versions of the International Building Code (IBC) or even previous editions cannot be used or adopted in the current NSCP edition because of non-availability of approapriate seismic hazard maps.

[4] https://www.dpwh.gov.ph/DPWH/references/laws_codes_orders/national_law

3. Seismic Hazard Mapping

The main objective of the work carried out under this project is to enhance the Probabilistic Seismic Ground Motion Hazard Maps for the entire Philippines particularly in highly-urbanized regions such as the National Capital Region (NCR), Region III (Central Luzon), Regions IV-A (CALABARZON [5]) and IV-B (MIMAROPA[6]), Davao Region, Central Visayas and other regions of the country, using the procedures developed for the latest USGS Seismic Hazard Maps and the Global Seismic Hazard Map. This contrasts with earlier hazard maps developed and available for the Philippines that were used in the NSCP 2001, 2010 and 2015 editions in which fault maps were utilized. The current maps were developed based on the combination of several new scientific techniques and methodologies developed in recent years. In ProjectSAM, the new models account for the possibility that future large, damaging earthquakes may occur near previous small- and moderate-size earthquakes.

3.1 Scope of Seismic Hazard Mapping

The newer techniques quantify the hazard at a site from all possible earthquakes and magnitudes, at 300-km radius from the site of interest, as a probability by taking into account their frequency of occurrence. The past observed seismicity in and around the target map area are compiled in an earthquake catalog, gathered from many different sources, both international and local database including data from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) seismograph network.

The data of active faults in and around the considered area are reassessed based on literature reviews, including the effects of long-term slip rates and estimates of earthquake size from various studies. The ground motion parameters, such as Peak Ground Acceleration (PGA) and Spectral Accelerations (S_a), at a given area are estimated from the earthquake magnitude, source-to-site distance, and local site condition by ground motion prediction equations deemed appropriate for the Philippines. PHIVOLCS had started the seismic hazard analysis in terms of PGA but not the spectral response accelerations yet in early 2010 for 5% of critical damping. The agency had developed the rapid earthquake damage assessment system (REDAS) software in which the seismic hazard module was deterministic, not probabilistic due to lack of data. This limitation does not hamper the undertaking as PHIVOLCS following its mandate to mitigate disasters that may arise from volcanic eruptions, earthquakes, tsunami, and other related geophysical phenomena (*Peñarubia et al. 2020*).

3.2 Earthquake Models

The motivation of the development of probabilistic seismic hazard analysis model for the Philippines was brought about by the fact that the Philippine archipelago is tectonically complex and seismically hazardous. Considering the present high-risk seismicity of the Philippines, few seismic hazard assessments that have covered the entire nation. In the latest NSCP 2015 edition, seismic coefficients are determined to indicate the expected force of earthquake ground motion and are used to calculate the seismic design base shear of the structure that ranges from ***0.15g*** to ***0.65g*** depending on the soil profile type, source-to-site distance, and type of seismic source. PHIVOLCS published the faultfinder[7] and hazardhunter[8] apps for use by the structural engineers and designers as a reference to the NSCP 2015 seismic load provisions.

However, recent destructive events in the Philippines such as the 6 February 2012 M_S 6.9 Negros Oriental Earthquake, the 15 October 2013 M_S 7.2 Bohol Earthquake, and the 10 February 2017 M_S 6.7 offshore Surigao Earthquake significantly exceeded the prescribed seismic coefficients set by the NSCP (*Peñarubia, 2017*).

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[5] CALABARZON stands for a region composed of **Ca**vite, **La**guna, **Ba**tangas, **R**izal and Que**zon**
[6] MIMAROPA stands for a region composed of **Mi**ndoro, **Ma**rinduque, **Ro**mblon and **Pa**lawan
[7] https://faultfinder.phivolcs.dost.gov.ph/
[8] https://hazardhunter.georisk.gov.ph/map

The following procedures were employed to process the development of the probabilistic seismic ground motion hazard analysis:

- Compile, purge and complete assessment of available earthquake catalogs. The earthquake catalog used to produce and test the Philippines hazard source model is a merged version of the ISC-GEM extended catalog (*Weatherill et al., 2016*) and the PHIVOLCS catalog. The catalogs were merged by stacking the two catalogs and then purging duplicate events. The ISC-GEM event information is used in cases of duplicates. The resulting catalog has close to 37,000 earthquakes, about 160 of which are contributed by the PHIVOLCS catalog, and ranges from 1619 to 2015, including 15 earthquakes with $M_w > 7.0$ that predate the 1905 start of the ISC-GEM catalog. While the PHIVOLCS contribution includes both historical and instrumental earthquakes, the ISC-GEM catalog is exclusively instrumental, including some earthquakes as small as M_w 2.8, but the completeness magnitude varies with time. Here, earthquakes with $M_w > 5.0$ are used to help define source geometry, but not to compute seismicity rates. (*Peñarubia et al. 2020*).
- Delineate and assess the seismicity of source zones. The characterization of seismicity and construction of the source model for the Philippines is described. The source model includes shallow crustal and subduction zone (i.e., interface and Intraslab) seismicity and consists of a single logic tree branch, in which each described source is given full weight. The source geometries are modeled by points, faults with both simple and complex geometry, and predefined ruptures. Rates are derived from a combination of observed earthquake occurrence rates and tectonics. (*Peñarubia et al. 2020*).

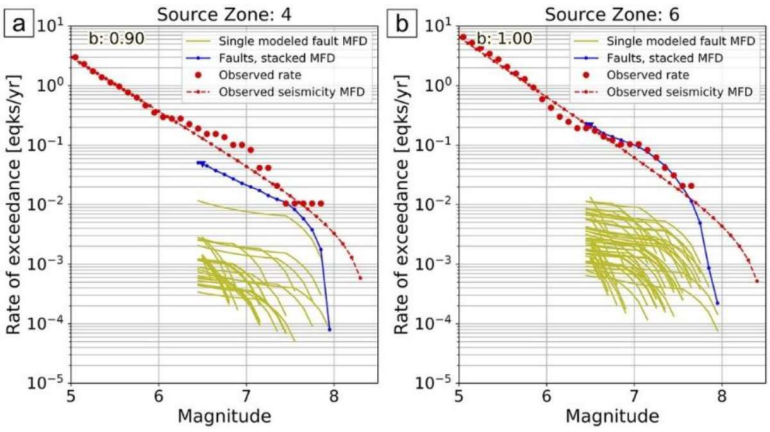

Fig. 4 – Example MFDs for (a) source zone 4 and (b) source zone 6 - both contain faults - showing the degree to which the modeled faults capture the observed seismicity. Each yellow line is the cumulative MFD for a single modeled fault source, and the blue line is the sum of these. The red line and points show the MFD and observed cumulative seismicity rates. (Source: *Peñarubia et al. 2020*)

Subduction interface. The subduction interface seismicity is modeled as a set of finite ruptures occurring on a fault surface, where each interface segment corresponds to one fault, and ruptures are floated across the surface and scaled by a magnitude–area scaling relationship. (*Peñarubia et al. 2020*).

The statistical approach solves for Guttenberg-Richter (GR) ***a*** and ***b*** values (a negative exponential) from the declustered sub-catalogs filtered for completeness. (*Weichert 1980*).

Intraslab. Intraslab sources are implemented as a set of ruptures dipping at 45 and 135 within the slab volume of 60 km thickness (the same volume used for tectonic classification). The slab segmentation model (Fig. 5) allows spatial variability in the observed seismicity to be accounted for in the seismic source model while still using non-parametric ruptures. Each slab segment is

assigned a single GR MFD (*regressed using Weichert 1980*) from the declustered sub-catalogs filtered for completeness (refer to **Error! Reference source not found.**) assuming spatially uniform rates throughout each segment. The MFDs are applied to ruptures of M_w 6.5 to $\boldsymbol{M_{max}}$, where $\boldsymbol{M_{max}} = \boldsymbol{M_{max,obs}} + 0.5$, using the intraslab magnitude scaling relationship of Strasser (*2010*).

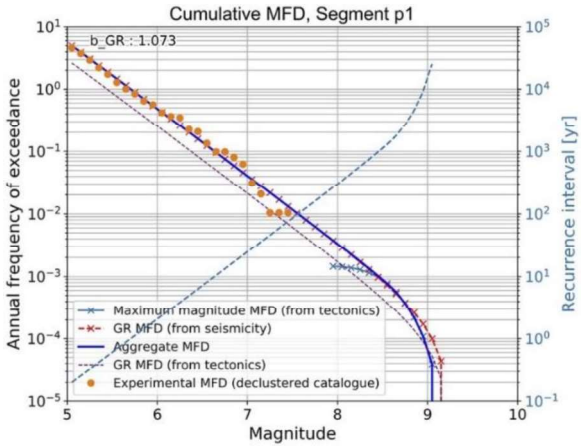

Fig. 5 – Hybrid MFD for the Philippine trench section 1. The characteristic component only barely deflects the MFD from the Gutenberg–Richter component, as is the case for all interfaces in the PEM. (Source: *Peñarubia et al. 2020*)

- Select appropriate attenuation models for peak ground acceleration (PGA) and spectral acceleration ($\boldsymbol{S_a}$).

  Ground motion characterization. The development of ground motion prediction equations (GMPEs) specific for the Philippines has been limited because of the relatively few strong-motion data available to develop such models. In recent years, considerable effort has been made to increase the number of strong-motion stations within the Philippines in order to record data of sufficient quality and quantity. In the meantime, GMPEs derived for regions with similar tectonic settings as the Philippines must be applied for national-scale hazard assessments. (*Peñarubia et al. 2020*).

  The ground motion characterization for the Philippines hazard model is divided into three tectonic regions: active shallow crust, subduction interface, and subduction intraslab, each using a weighted set of GMPEs. Sufficient strong-motion recordings are available for active shallow crustal earthquakes to perform a residual analysis to the GMPEs for some magnitude and distance ranges, while the subduction GMPEs are selected from various global models to account for the full range of possibilities. (*Peñarubia et al. 2020*).

  Attenuation models. In this probabilistic seismic hazard analysis, an evaluation of published GMPEs to crustal earthquakes in the Philippines was originally part of the 2014 PHIVOLCS-Geoscience Australia Risk Analysis for the Philippines project, a hazard and risk analysis for the Greater Metro Manila Area (RAP; Allen et al., 2014). For active shallow crustal earthquakes, the group of GMPEs used are: Zhao et al. (2006), Boore and Atkinson (2008), Chiou and Youngs (2008), Abrahamson et al. (2014), Boore et al. (2014; low-Q), Campbell and Bolognian (2014; low-Q), Chiou and Youngs (2014), and Bindi et al. (2017).

  For intraslab earthquakes, the logic tree was selected from trellis plots for the distance range 50 km to 300 km ($\mathbf{R_{rup}}$) and M_w 6.5 to 8.5, equally weighting (0.33) Zhao et al. (2006), Atkinson and Boore (2003) with the Cascadia term, and Youngs et al. (1997).

  For interface earthquakes, the attenuation patterns of the candidate GMPEs compare differently for different magnitudes, leading to the selection of four equally weighted (0.25) GMPEs: Youngs

et al. (1997), Atkinson and Boore (2003), Zhao et al. (2006) with the Cascadia term (e.g., Atkinson and Adams, 2013), and Abrahamson et al. (2016).

Fig. 6 shows the Trellis plots for medium rock site PGA of the GMPEs for three tectonic regions.

- Prepare the probability modeling of hazard (Poisson model, characteristic earthquake model). The OpenQuake engine (*Pagani et al., 2014*) was used to compute hazard curves at ~3400 sites (~10 km spacing) with reference soil conditions equivalent to $\mathbf{V_{S30}}$ of 760 - 800 m/s for the intensity measures PGA and $\mathbf{S_a}$ at periods of 0.2 s and 1.0 s. The discussion is limited to PGA for rock sites ($\mathbf{V_{S30}}$ ~760 m/s) for 475- and 2475-year return periods, equivalent to a 10% and 2% probability of exceedance (PoE) in 50 years, respectively (Fig. 7) for brevity, and because this intensity measure was referenced to determine the seismic coefficient used to calculate the design base shear (Sections 208.5.1 and 208.5.2) of the latest NSCP 2015. However, the NSCP covers all vertical and horizontal structures nationwide, and so in the upcoming revision, ASEP will incorporate the full uniform hazard response spectra; for this update, seismic design will be based on IBC 2018 (International Code Council (ICC), 2018) and ASCE 7-05 Standard (American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI), 2005).

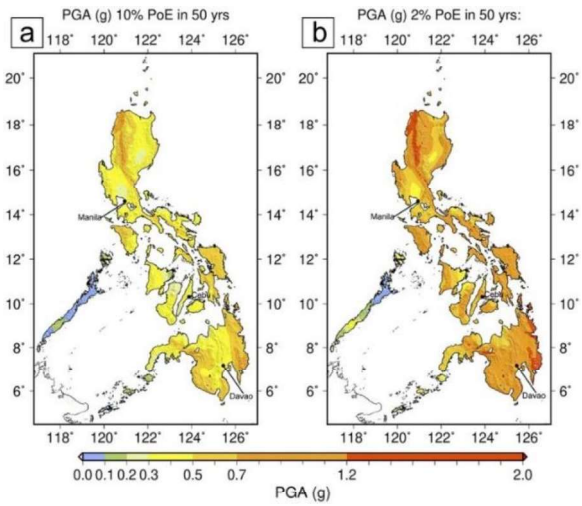

Fig. 6 – Mean PGA with (a) 10% and (b) 2% PoE in 50 years overlain on the hill shaded SRTM topography (Farr et al., 2007). The same color scale is used for both PoEs. The plotted cities are metropolitan areas evaluated by disaggregation. (Source: *Peñarubia et al. 2020*)

3.3 Earthquake Models Launched

The fruition of the efforts of PHIVOLCS in collaboration with the Global Earthquake Model (GEM) Foundation and Geoscience Australia and in consultation with ASEP has been realized at the start of the year 2018.

In January 17, 2018, the Department of Science and Technology – Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS) launched the Philippine Earthquake Model (PEM) Atlas and the probabilistic seismic hazard assessment maps in Metro Manila. PEM Atlas contains the Peak Ground Acceleration Maps and Spectral Acceleration Maps for 500-year return period on stiff soil. These maps were generated from the PSHA through the collaborative efforts and expertise of seismologists, geologists, engineers, and researchers of the Institute in a series of technical consultations with ASEP, PICE, DPWH, NHA, HLURB, MMDA, MM LGUs, the academe, NGOs, and other government and private institutions. That model was intended as a reference in the seismic design of structures in the Philippines. However, some technical experts have been cautious to accept the significant changes and design impact through this

development, hence prompting the need for validation and international collaboration (*Peñarubia et al. 2020*). The technical collaboration was forged between DOST-PHIVOLCS and the GEM Foundation.

In July 4, 2018, PHIVOLCS launched the Metro Cebu Earthquake Model (MCEM) Atlas which is a probabilistic seismic ground motion hazard assessment tool specific for Metro Cebu. On October 29. 2019, DOST-PHIVOLCS launched the Metro Cebu Site Response Atlas that includes: (1) Active Faults Map of Cebu Province from the Philippine Institute of Volcanology and Seismology, (2) Geologic Map of Metro Cebu from Mines and Geoscience Bureau[9], (3) Peak Ground Acceleration Map of Metro Cebu based on deterministic seismic hazard assessment (DSHA), (4) $\mathbf{V_{s30}}$ Model Map of Metro Cebu, (5) Short Period Microzonation Map of Metro Cebu, and (6) Long Period Microzonation Map of Metro Cebu. These maps provide information to understand the ground motion characteristics of underlying rock and sediment deposits and ground motion response that may occur in Metro Cebu in the event of an earthquake.

Subsequently, DOST-PHIVOLCS also launched the Metro Davao Site Response Atlas that includes: (1) Active Faults Map of Davao Region from the Philippine Institute of Volcanology and Seismology, (2) Geologic Map of Metro Davao from the Mines and Geosciences Bureau[10], (3) Peak Ground Acceleration Map of Metro Davao, (4) $\mathbf{V_{s30}}$ Model Map of Metro Davao, (5) Short Period Microzonation Map of Metro Davao, and (6) Long Period Microzonation Map of Metro Davao. These maps provide information to understand the ground motion characteristics of underlying rock and sediment deposits and ground motion response that may occur in Metro Davao in the event of an earthquake. In September 4, 2019, the Metro Davao Earthquake Model (MDEM) was launched. The MDEM Atlas includes: (1) Spectral Acceleration Maps for short and 1-s periods on rock site for 500-year, 2500-year return periods, and (2) PGA Maps for short and 1-s periods on rock site for 500-year, 2500-year return periods and (3) Soil Classification Map.

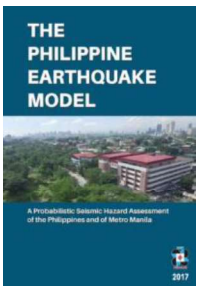

Fig. 7 - PEM Atlas

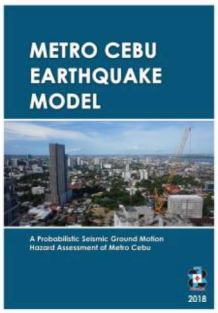

Fig. 8 - MCEM Atlas

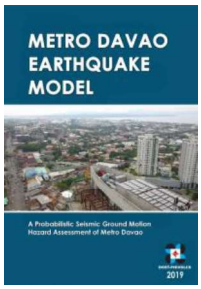

Fig. 9 - MDEM Atlas

The MCEM and MDEM were improved versions specifically for Metro Cebu and Metro Davao of the Philippine Earthquake Model that PHIVOLCS had started in 2017. The earthquake models were developed for use as seismic design reference in most structures either regular or essential and critical structures in Metro Cebu and Metro Davao considering 475-year mean recurrence interval and 2475-year mean recurrence interval spectral response acceleration parameters. Figures Fig. 10 through 12 are the cover pages of the PEM, MCEM and MDEM, respectively, published by PHIVOLCS in 2018 and 2019.

3.4 Objectives of Seismic Hazard Mapping

As previously stated, the main intent of the seismic hazard mapping is to enhance the probabilistic seismic ground motion hazard which is tagged as Project Spectral Acceleration Mapping (or ProjectSAM) for use by the civil/structural engineers, building officials and government engineers, the academe in the civil engineering

[9] Mines and Geosciences Bureau (MGB) is a government agency of the Philippines under the Department of Environment and Natural Resources (DENR). MGB is responsible for the conservation, management, development and use of the country's mineral resources, including those in reservations and public lands.
[10] Mines and Geosciences Bureau (MGB) is a government agency of the Philippines under the Department of Environment and Natural Resources (DENR).

education, and even foreign engineers doing projects in the Philippines. The main deliverable of this undertaking is the Spectral Acceleration Maps of the Philippines or SAM PH. The SAM PH atlas will serve as a useful tool for the seismic design of structures to include regular low- to medium- to high- rise structures or other civil engineering structures under occupancy categories of essential, critical, and hazardous facilities.

SAM PH provides the detailed identification and mapping of the seismic hazard in a particular target area. This greatly enhances availability of information for disaster fragility, disaster risk reduction and management to include preparedness and mitigation. For the structural engineers and designers, the seismic hazard mapping provides information for use and application of state-of-the-art and internationally-consistent analysis procedures for the design of seismic-resistant buildings and other structures. This eventually leads to the overall enhancement of buildings and other structures to provide greater life safety of the public and stakeholders and minimal loss of property.

3.5 Results of Seismic Hazard Mapping

The deliverables of the ProjectSAM will pave the way for the migration of the earthquake loads provisions of the NSCP from the Uniform Building Code 1997 seismic loads to the seismic provisions of the ASCE 7-05. Though the current edition of the latter is ASCE 7-16, the migration is led to ASCE 7-05 as the response spectral acceleration parameters produced by this undertaking is at the maximum considered earthquake (**MCE**) level. However, the work of this project will continue to generate the different levels of risks and eventually produce the risk-targeted response spectral acceleration parameters for 2% probability of exceedance in 50-years or 2475-year mean recurrence interval $\mathbf{MCE_R}$. Aside from this risk level, ProjectSAM will generate the service-level earthquake (**SLE**) and long-period spectral response ($\mathbf{T_L}$). Sensitivity analysis for at least 1000 sites is being generated to determine the response spectrum curves with different probabilities of exceedance. Similarly, as the ASEP is set to update the NSCP and publish the eighth edition in 2022, relevant coefficients that will be used in the seismic design procedures prescribed in ASCE 7-05 will be deliberated jointly by ProjectSAM and the subcommittee of NSCP on minimum design loads in which the earthquake loads provisions are included.

SAM PH Atlas was officially launched on March 23, 2021 by the DOST-PHIVOLCS virtually through Zoom webinar application with the DOST Secretary Fortunato Dela Peña as the main keynote speaker and guest of honor. DOST-PHIVOLCS' Probabilistic Seismic Hazard and Risk Assessment (PSHRA) project proponents and technical working group members spearheaded the development of the probabilistic seismic hazard analysis model for the entire Philippines in technical collaboration with GEM Foundation and Geoscience Australia, and in close consultation with ASEP ProjectSAM Committee members, SAM PH provides the maximum considered earthquake (**MCE**) in which the site condition is on rock site. It is expected that these **MCE** maps will be adopted in the revision of the earthquake loads provisions of the National Structural Code of the Philippines – Volume I, 8th Edition in 2022. The maps can be used for the seismic design of the structures as (1) regular structures i.e., low- to medium-rise buildings, houses and structures under Occupancy Categories III, IV and V, (2) essential and hazardous facilities under Occupancy Category I i.e., hospitals, evacuation centers, pre-determined emergency and resource facilities, (3) critical lifeline structures i.e., water and power plants, communication towers, power grids, dam, bridges, etc., and high-risk facilities under Occupancy Category II i.e., hazardous and biochemical plants, etc. Figures Fig. 13 through 15 show the PGA (PEM 2017) and spectral acceleration maps of the Philippines (SAM PH) developed for integration in the NSCP next edition:

Fig. 10 – PGA map at 2475-year MRI on rock site (Source: PHIVOLCS PEM 2017)

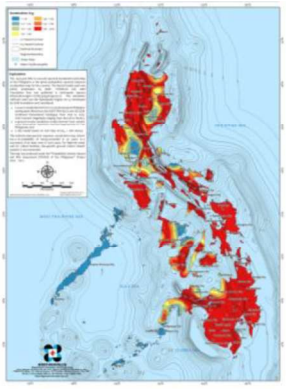

Fig. 11 – Spectral map S_s (0.2 s) at 2475-year MRI on rock site (Source: PHIVOLCS SAM PH 2021)

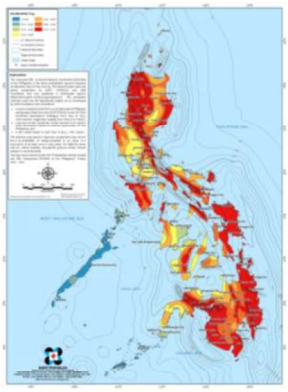

Fig. 12 – Spectral map S_1 (1.0 s) at 2475-year MRI on rock site (Source: PHIVOLCS SAM PH 2021)

4. Conclusions

Since 1992 after the devastating North Luzon earthquake in July 16, 1990 and other very destructive earthquakes that have hit the Philippines, the national structural code on seismic provisions has been patterned from the Uniform Building Code editions (in particular UBC 1997) from the fifth edition (2001), sixth edition (2010) and the seventh edition (2015). Seismic load provisions of other international codes as IBC, ASCE, Eurocode, Japan, etc. have evolved significantly ensuring that structures are designed to be earthquake-resistant, if not earthquake-resilient.

The atlas maps generated by DOST-PHIVOLCS would mark the starting point of the works of the ASEP NSCP committee to update the current NSCP edition to the next edition in which one of the main highlights is the migration of the seismic provisions from UBC 1997 to ASCE 7-05; that is, from seismic zoning to seismic hazard mapping.

5. Acknowledgements

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6. Copyrights

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