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Impacts of a Moderate-Sized Earthquake: The 2023 Magnitude (M_w) 4.7 Leyte, Leyte Earthquake, Philippines

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Abstract: On 15 January 2023, a shallow, moderate earthquake with a magnitude (M_w) of 4.7 and a depth of one kilometer struck the northern part of Leyte Island in the central Philippines. Originating along the northern Leyte segment of the Philippine Fault, a well-established creeping fault, the earthquake caused significant geologic, structural, and socio-economic impacts despite its low magnitude. Probable surface rupture and landslides were reported, leading to a comprehensive field investigation. Our investigation revealed an ~8 km discontinuous surface rupture along the northern Leyte segment of the Philippine Fault, with a maximum left-lateral displacement of 2 cm—the first documented occurrence of such a phenomenon associated with an earthquake of magnitude less than 6, particularly along a creeping fault segment. The maximum ground shaking felt was reported at PHIVOLCS Earthquake Intensity Scale (PEIS) VI (very strong), equivalent to Modified Mercalli Intensity (MMI) VI along the fault strike. However, strong motion accelerographs recorded a peak ground acceleration (PGA) of 0.407 g, equivalent to PEIS VIII (very destructive), attributed to local site amplification influenced by subsurface geology. In the area where the local site amplification occurred, limited liquefaction was observed on marshlands with recent and alluvial deposits. Two landslides were observed in the mountainous area west of the fault. Structural damages were noted in areas with PEIS VI intensity and areas transected by the surface rupture. Despite the earthquake's low magnitude, the event documented significant impacts, including surface ruptures, liquefaction, landslides, and severe structural damage. The peculiarities of this event are attributed to the shallowness of the earthquake source, and local site conditions, including geology, geomorphology, and soil properties, contributing to the severity of the impacts. Moderate in size, this earthquake emphasizes the need and importance of documenting moderate-sized earthquakes as a tool and guide for medium and long-term earthquake risk assessment and resiliency.

Keywords: Philippine Fault – Leyte segment; PHIVOLCS Earthquake Intensity Scale (PEIS); surface rupture; liquefaction, landslide, site amplification; disaster risk reduction

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1. Introduction

Being along a complex tectonic boundary, the Philippines is one of the most seismically active countries in the world. For the past decade, at least 10 damaging earthquakes with magnitude >6 have affected the country and were documented. These earthquakes include the 2012 magnitude (M_w) 6.7 Negros Earthquake [1], the 2013 M_w 7.2 Bohol Earthquake [2], the 2017 M_w 6.5 Surigao Earthquake [3], the 2017 M_w 6.5 Leyte Earthquake [4], the 2019 M_w 6.1 Central Luzon Earthquake [5], the 2019 Cotabato-Davao del Sur

Earthquake Sequence with five (5) M_w >6 earthquakes in three months (October to December 2019) [6] and the 2020 M_w 6.6 Masbate Earthquake [7].

In 2022, a major earthquake with M_w 7.0, impacted the northern part of the Philippines with maximum ground shaking of PHIVOLCS Earthquake Intensity Scale (PEIS) VII (destructive) equivalent to Modified Mercalli Intensity (MMI) VII. The 2022 M_w 7.0 Northwestern Luzon Earthquake, despite its significant magnitude, exhibited no identifiable surface rupture. Nevertheless, the earthquake resulted in widespread landslides, liquefaction, and sea level disturbances [8]. It affected more than 574,000 persons, with eight (8) deaths and more than 600 injuries, and about 2.6 billion Philippine pesos (46 million US dollars) estimated cost of damages to structures [8].

Most of the past large magnitude and damaging earthquakes in the Philippines were documented and assessed by the Department of Science and Technology – Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS), a government institute, the academe and disaster risk reduction and management (DRRM) offices [1-8]. The reports for these events have been widely used by different stakeholders for relief operations, the assessment of future seismic hazards, and policy recommendations. Very seldom that moderate-size earthquakes in the past were documented, assessed, and studied by any institutions in the country.

The 2023 M_w 4.7 Leyte, Leyte Earthquake was a moderate-sized earthquake (Figure 1A) and we expected that no significant geologic impact and structural damage resulted from this event. However, preliminary information gathered from broadcast (print, television, and radio) and social media (Facebook, Twitter, Instagram, etc.) revealed that several structures in the municipality of Leyte (population approximately 41,000), province of Leyte were damaged and landslides and probable surface rupture were reported. Based on the Philippine National Disaster Risk Reduction and Management Council (NDRRMC) Progress Report No. 3, the estimated cost of damage to structures is about 27.6 million Philippine pesos or 502 thousand US dollars and affected more than 430 families or 1,775 persons with 18 injuries [9].

To assess and document the impacts of this earthquake, the DOST-PHIVOLCS deployed a Quick Response Team (QRT) from 27 January to 01 February 2023 in the affected areas. Our fieldwork includes the identification and documentation of geologic impacts using handheld GPS and remotely piloted aircraft (RPA) and photo documentation. We conducted an earthquake intensity survey and eyewitness interview to verify and assess the severity of ground shaking near and around the epicentral area. The results of this intensity survey are presented as an isoseismal map in Figure 2 and Table 1.

For this paper, we present the results of our field investigation which include detailed assessment and documentation of the geologic and socio-economic impacts of the moderate-sized earthquake. We discuss the severity of the impacts and possible explanations. We recommend actions that should be taken to lessen the impacts of future earthquakes. We also emphasize the importance of documenting earthquake impacts as a tool for medium to long-term earthquake risk assessment, especially in populated areas.

2. Tectonic Setting

Leyte Island, located in the central part of the Philippines, is transected by the Philippine Fault, a north-northwest trending, 1,500 km-long, sinistral strike-slip fault that traverses the entire Philippine archipelago from Luzon Island on the north to eastern Mindanao on the south (Figure 1A) [10, 11]. This fault resulted from the slip partitioning from the oblique convergence of the Philippine Sea Plate (PSP) and Sunda Plate (SP) [12] (Figure 1B). The Philippine Fault stands as a prominent active fault on a global scale, having produced over 20 surface-rupturing earthquakes in the last 400 years. It is accountable for more than half of the significant and destructive historical earthquakes in the country [13].

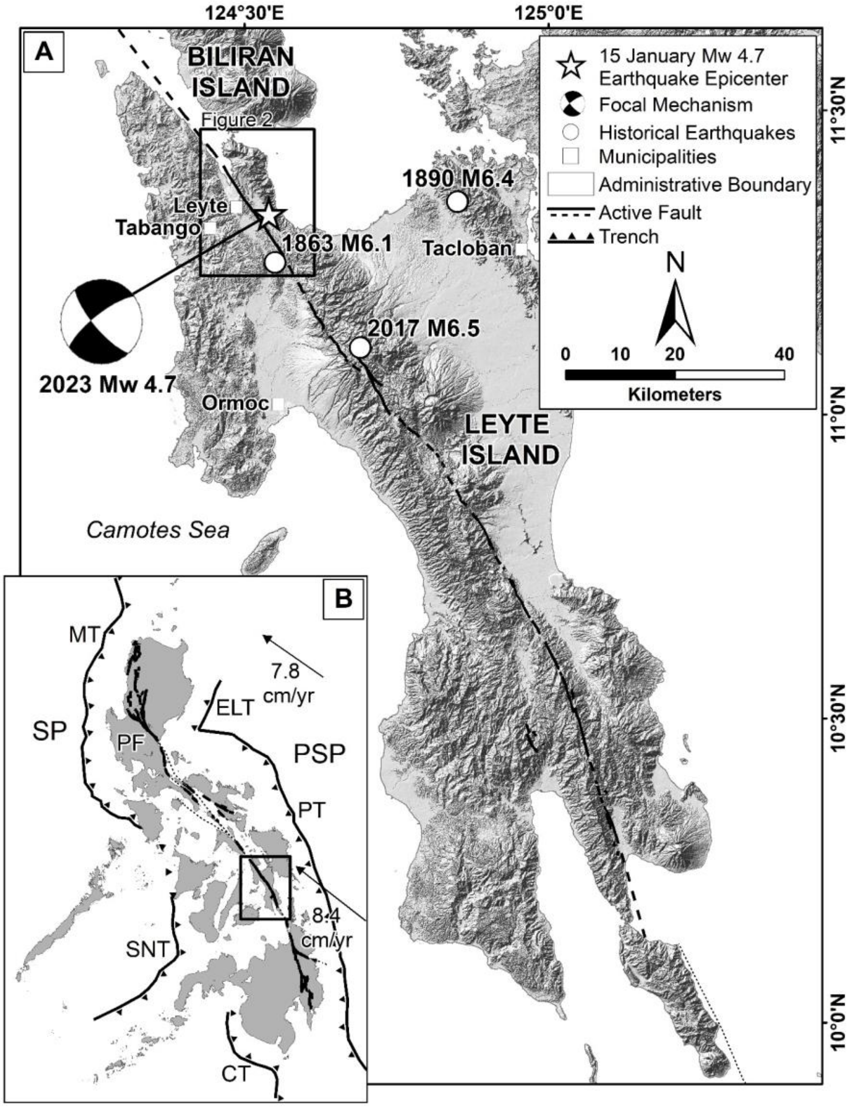

Figure 1. The seismotectonic setting of the 2023 M_w 4.7 Leyte, Leyte Earthquake. (A) The Philippine Fault – Leyte segment and historical earthquakes. The Philippine Fault (PF) trace is from Tsutsumi and Perez [11] while historical earthquakes are from Bautista and Oike [13]. (B) The geodynamic setting of the Philippines. The Philippines is on a complex boundary between the PSP and the SP. Arrows indicate the relative motion of the PSP. ELT – East Luzon Trough, PT – Philippine Trench, MT – Manila Trench, SNT – Sulu-Negros Trench, CT – Cotabato Trench. The base map is IFSAR-DEM from the Philippine National Mapping Resources and Information Authority (NAMRIA). The rectangle in (A) shows the location of Figure 2.

Tsutsumi and Perez [11] have mapped in detail and characterized the Leyte segment of the Philippine Fault. This segment traverses the middle part and the backbone range of Leyte Island for about 140 km and is characterized by linear valleys, stream offsets, hillside ridges, and wind gaps (Figure 1A). In the northern section of the Leyte segment, Perez et al. [14] documented the creep of the Philippine Fault in the municipality of Leyte by observing offsets in concrete structures and asphalt roads. Meanwhile, additional studies propose that a significant part of the fault in Leyte exhibits creeping, as indicated by InSAR analysis and field observations conducted by other researchers [15, 16, 17].

Unlike other segments of the Philippine Fault, the Leyte segment exhibits distinct seismicity, with no occurrence of large destructive earthquakes (M > 7) over the past 400 years (Figure 1A) [11, 13]. The most recent damaging earthquake was the 2017 M_w 6.5 Leyte Earthquake that ruptured the 26 km stretch of the Leyte segment with maximum horizontal and vertical displacements of 1.1 and 0.5 m, respectively [4]. An isolated locked patch along the fault generated this earthquake [16, 17], resulting in liquefaction that manifested as lateral spreads, subsidence, sand boils, and extensive landslides [4]. Damages to infrastructures amounted to 220 million Philippine pesos or 4.4 million US dollars, three persons died and 448 injured persons. Other magnitude >6 earthquakes in Leyte include the 1863 (M 6.1) and 1890 (M 6.4) [13] (Figure 1A).

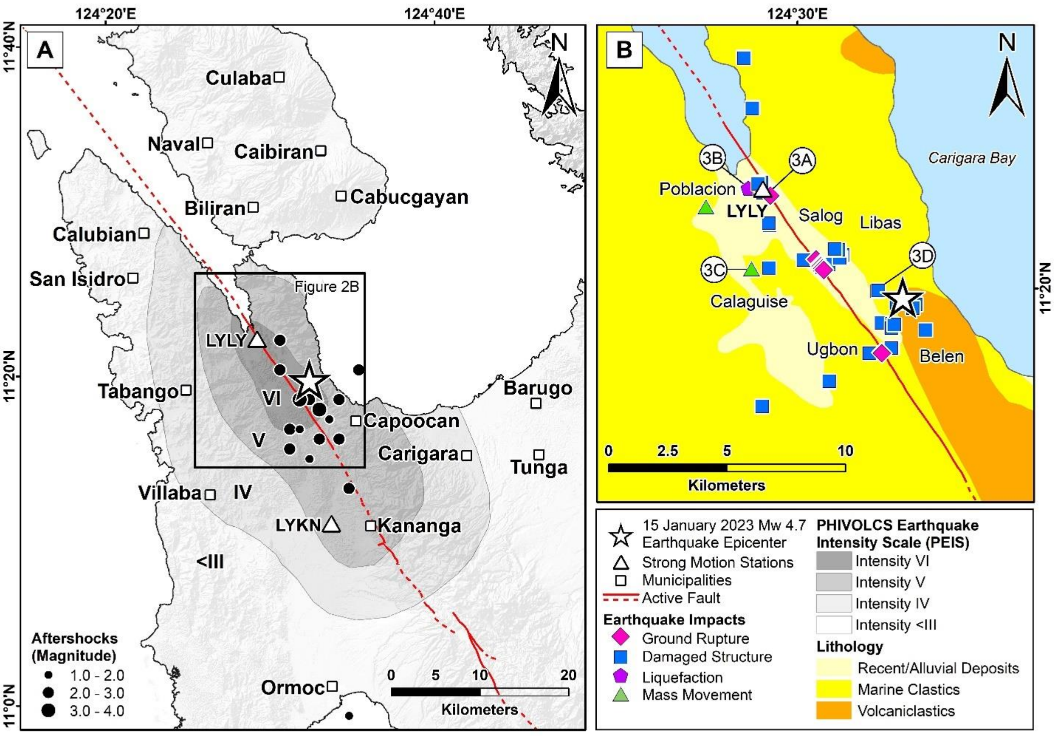

Figure 2. The 2023 M_w 4.7 Leyte, Leyte Earthquake isoseismal, aftershock distribution, and earthquake impact maps. (A) The isoseismal map was based on the latest earthquake information from DOST-PHIVOLCS [18] and the detailed intensity survey and impact assessment conducted in this study. Aftershock distribution (black circle) from 15 to 23 January 2023 was recorded by the Philippine Seismic Network [18]. (B) Spatial distribution of documented damages and geologic impacts (ground rupture, liquefaction, and mass movement). The geologic map was modified from Aurelio and Peña [26]. Circles with letters and numbers show the location of photos in Figure 3. The active fault trace (red line) is from Tsutsumi and Perez [11].

3. Earthquake parameters, focal mechanism, and aftershocks

The hypocenter for the 2023 M_w 4.7 Leyte, Leyte Earthquake was located at 11.33°N and 124.54°E or 7 km S55°E of Leyte, Leyte at a very shallow depth of 1 km [18] (Figure 1A). The earthquake's focal mechanism was derived from the Philippine Seismic Network (PSN) by waveform inversion in the frequency domain of body waves. This method adopted the Source parameter determination based on the Waveform Inversion of Fourier Transformed seismogram (SWIFT) that determines the centroid moment tensor (SWIFT-CMT) of the earthquake [19, 20, 21]. The calculated SWIFT-CMT solution for this earthquake (Figure 1A) indicates that the preferred nodal plane is trending northwest with a strike, dip, and rake of 140°, 83°, and -4° respectively, indicating a left-lateral motion following the trend of the Philippine Fault – Leyte Segment. A seismic moment of (Mo) of 1.22×10^6 N.m. and M_w 4.7 was obtained from the inversion.

The PSN recorded 26 aftershocks from 15-23 January 2023, of which 15 were plotted and 12 were felt (Figure 2A) [18]. The magnitudes of recorded aftershocks range from 1.7 to 3.9 (Fig. 2) and the highest magnitude was felt at PEIS III (weak), equivalent to MMI III, in Leyte, Leyte. The recorded aftershocks were relatively few with abrupt decay from 16 on the 1st day, five (5) on the 2nd day, and less than three (3) to zero from the 3rd to 9th day [18]. The distribution of the aftershocks also indicates that the earthquake generator for this earthquake is the Philippine Fault – Leyte Segment.

4. Geologic impacts

4.1 Ground shaking and intensity distribution

Based on the earthquake information from DOST-PHIVOLCS, the maximum reported earthquake intensity was PEIS VI (very strong), equivalent to MMI VI, and was widely felt in the municipalities of Leyte and Tabango, province of Leyte. Ground shaking was felt as far as 100 km away from the epicenter [18]. Areas that reported PEIS VI (very strong) suffered significant damage to poorly built structures on sloping ground, most of which were schools, and concrete hollow block (CHB) houses made from substandard materials. Many people in these areas were frightened, many ran outdoors and some went out of their houses.

Earthquake Intensity	Province	City/Municipality
VI (very strong)	Leyte	Along the strike of the Philippine Fault-Leyte segment in Leyte and the easternmost part of Tabango
V (strong)	Leyte	The rest of Tabango and Leyte; Capoocan and Kananga
IV (moderately strong)	Leyte	Calubian, Carigara and San Isidro
III (weak)	Biliran	Biliran, Cabucgayan, Caibiran, Culaba and Naval
	Leyte	Alangalang, Babatngon, Barugo, Jaro, San Miguel, Tunga, Villaba, Ormoc City and City of Tacloban
II (slightly felt)	Biliran	Almeria
	Leyte	Albuera, Matag-ob, Santa Fe, Pastrana, Merida, Palompon, Palo and Isabel
I (scarcely perceptible)	Cebu	City of Bogo
	Eastern Samar	City of Borongan

Table 1: Summary of reported intensities in PHIVOLCS Earthquake Intensity Scale (PEIS) of the 2023 M_w 4.7 Leyte, Leyte Earthquake based on DOST-PHIVOLCS Earthquake Information and intensity surveys and impact assessment conducted in this study (refer to Figure 2 for the isoseismal map).

To verify the limited reported intensities, we have conducted a detailed intensity survey and damage assessment in the affected area. Table 1 shows the result of our survey and is illustrated as an isoseismal map in Figure 2A, while Figure 2B summarizes the location of the geologic and structural impacts.

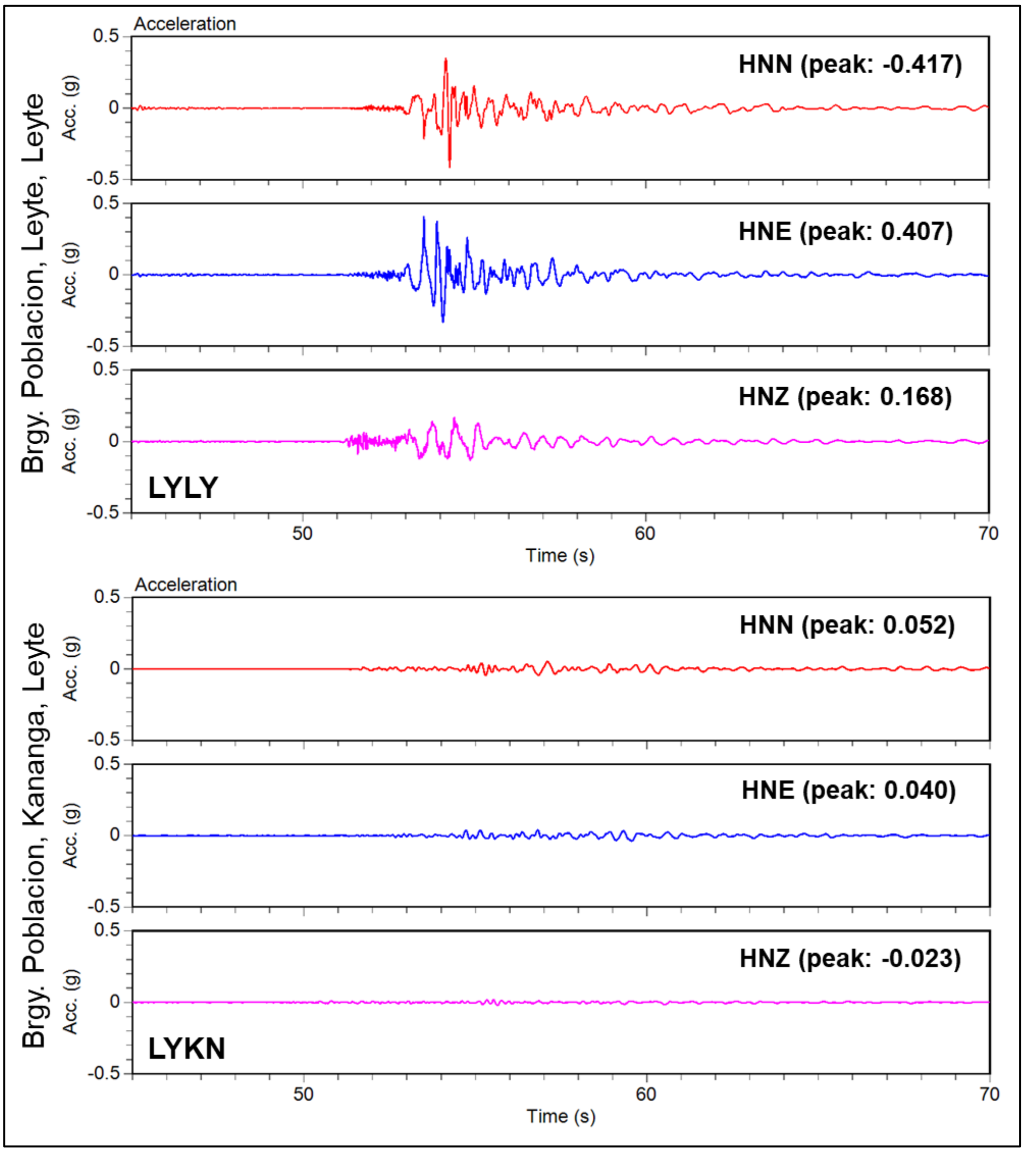

Figure 3. Peak ground acceleration (PGA) record from the Philippine Strong Motion Network (PSMNet) stations in Brgy. Poblacion, Leyte (Station code: LYLY) and Brgy. Poblacion, Kananga (Station code: LYKN). PGA value for the two sites corresponds to the expected ground shaking felt in the area and is influenced by the soft sediment subsurface as manifested by the geology and geomorphology of the area. Refer to Figure 2 for the location of the two (2) accelerographs.

The strongest ground shaking (PEIS VI) was felt in areas or barangays (smallest political unit in the country; abbreviated as Brgy.), in the municipality of Leyte, along the strike of the Philippine Fault and the easternmost part of the municipality of Tabango (Figure 2 and Table 1). These barangays where the strongest ground shaking was felt were also the locations where the surface ruptures along the trace of the fault were also documented. This is manifested by the elongation of the isoseismal lines in the isoseismal map along the strike of the fault (Figure 2). The intense ground shaking in this area damaged several structures and induced geologic impacts such as liquefaction and mass movement.

For a more detailed assessment of the ground motion, data from two (2) accelerographs positioned near the epicenter were examined, both belonging to the Philippine Strong Motion Network (PSMNet) (refer to Figures 2 and 3). The first accelerograph (station code: LYLY) is located in Brgy. Poblacion, Leyte, and ~7 km NW of the epicenter recorded a peak ground acceleration (PGA) of 0.407 g equivalent to PEIS VIII (very destructive) [22] while the second accelerograph (station code: LYKN) located in Brgy.

Poblacion, Kananga and ~16 km southeast of the epicenter has recorded a much smaller PGA, 0.052 g, equivalent to PEIS V (strong) [22].

4.2 Surface rupture

Surface rupture is commonly observed for shallow inland earthquakes (0-10 km) with magnitude ≥6 [19, 20]. The last surface rupturing event on Leyte Island before this event occurred during the 2017 M_w 6.5 Leyte Earthquake [4].

Figure 4. Geologic and structural impacts of the 2023 M_w 4.7 Leyte, Leyte Earthquake. (A) Observed road cracks (red line) along the national highway in Brgy. Poblacion, Leyte coinciding along the trace of the Philippine Fault – Leyte segment [11]. Inset: 2 cm left-lateral displacement measured along the offset road paint. (B) Lateral spreads (cracks) formed on the earth dikes beside fishponds in Palaypalay District, Brgy. Poblacion, Leyte. (C) A shallow landslide consisting of soil rock and debris partly covered a road in Brgy. Calaguise, Leyte. (D) Damaged house (concrete hollow block) in Brgy. Belen, Leyte. Refer to Figure 2B for the location of photos.

It is uncommon for a magnitude <6 earthquake to have surface rupture [23, 24]. However, our field investigation revealed an 8-km-long northwest-trending discontinuous rupture associated with the 2023 M_w 4.7 Leyte, Leyte Earthquake that occurred along the previously mapped Philippine Fault – Leyte segment [11, 14, 15]. Detailed ground and drone surveys conducted during the investigation showed that the surface rupture affected at least three barangays (Brgys. Poblacion, Salog, and Ugbon) in Leyte (Figures 2B and 4A). The surface rupture was manifested as a continuous crack with discernable left-lateral displacement or parallel *en-echelon* visible cracks identified as Riedel shear structures. Measured displacements range from 1.5 to 2 cm. Figure 4A shows a portion of the surface rupture manifested as hairline cracks along a road with 2 cm horizontal displacement coinciding with the previously mapped active fault. Eyewitness accounts verified that the hairline cracks were caused by the earthquake. It also affected residential houses traversed by the active fault. These residential houses were also previously identified to be damaged by fault creeping in the past studies [14, 15]. A detailed discussion of this rare surface rupture is presented in Llamas et al. [25].

4.3 Liquefaction

The lowlands of the municipality of Leyte are characterized by recent sediments along the broad valley plain traversed by the Palaypay River and its tributaries [26]. This river drains to the northwest towards Leyte Bay, with marshlands lining the mouth of the river. Some of these marshes are still covered with mangroves and nipa, while other portions have houses built on top or modified to be fishponds.

Documented liquefaction occurrences were limited to the marshlands with recent and alluvial deposits in the Palaypay District, Brgy. Poblacion, Leyte (Figure 2B) [26] and was near the epicentral area. In these sites, lateral spreads were observed along the earth dikes of a fishpond (Figure 4B). These dikes were made up of soil dug up from the adjacent fishponds. Ground cracks measuring up to 20 m in length and 4 cm of horizontal gaps were documented. These cracks are all nearly parallel to the length of the earth dikes and spread towards the fishponds. A house beside the fishpond was also damaged. Portions of the house sank in soil by 3 cm. According to the house owner, the house was built on top of the sandy fill dug out from the nearby fishpond. In other areas of the Palaypay District, ground failures also caused damage to some built-up structures. In two houses, the flooring of the houses is made up of concrete, sustained cracks, sank, and tilted towards the nearby marsh. In another two houses, the comfort rooms made of CHB also sank and tilted.

In the absence of sediment and water venting (or sand boils), it is difficult to attribute the lateral spreads and structural damages solely to liquefaction. The lateral spreads of the earth dikes may be gravity-driven, and the tilted CHB structures and damaged concrete floorings may just be poorly built. To determine if liquefaction could have caused these impacts, soil samples up to 3.5 m deep from the marshlands in Palaypay District were collected using a hand auger for grain size analysis.

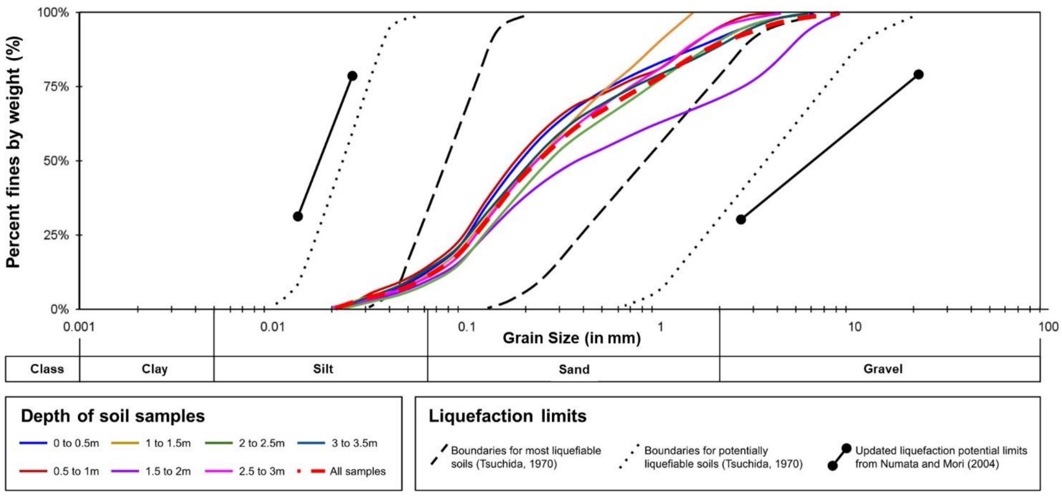

Figure 5. Grain size analysis of soil samples taken on the earth dikes that liquefied in Palaypay District, Brgy. Poblacion, Leyte with liquefaction limits set by [27 and 28].

Figure 5 shows the summary of the grain size analysis of soil samples we have collected and compares it to liquefaction limits on grain sizes suggested by Tsuchida [27] and Numata and Mori [28]. The majority of the collected soil samples have grain sizes ranging from very fine to very coarse sand (0.0625 to 2.0 mm) and are within the boundaries of most liquefiable soils (Figure 5) [27, 28, 29]. While the soil sample collected from 1.5 to 2 m depth has 30% of its grains that are granule-pebble sized (2.0 to 8.0 mm), this is still within the boundary for potentially liquefiable soils. With these soil properties and geomorphology coupled with the measured PGA of 0.407 g (recorded by LYLY, 500m from Palaypay

District) (Figure 2A and 3), and as evidenced by subsidence and tilting of some buildings and lateral spreads on some earth dikes, we are therefore more certain that liquefaction occurred in these soils.

4.4 Landslide

The municipality of Leyte is flanked by mountains on its eastern and western perimeters. Only two instances of landslides were observed, as illustrated in Figure 2B. A rockfall was recorded along a densely vegetated hill in Brgy. Palid Uno in Leyte, while a shallow landslide occurred in Brgy. Calaguise, Leyte (Figures 2B and 4C). The shallow landslide, composed of earth debris and rocks, partially covered sections of the Calaguise-Calubian Road. The landslide took place on the steeply sloping road cut of a highly jointed sedimentary bedrock. Fortunately, no casualties or damages were reported due to mass wasting.

5. Structural and socio-economic impacts

Based on the Rapid Damage Assessment and Needs Analysis report done by the municipality of Leyte, there were about 434 residential houses and 26 public infrastructures including schools and government buildings were affected by the earthquake [25]. The DOST-PHIVOLCS QRT documented damaged structures which are summarized in Figure 2B. Our assessment revealed that most of the damages were located near the epicentral area and can be attributed to poor quality or substandard construction materials such as CHB and reinforcing bars (Figure 4D). Notably, most of the damaged structures were located in alluvial and recent deposits (Figure 2B).

This earthquake affected about 437 families or 1,775 persons in 15 barangays. There was a total of 18 injuries and no reports of death. The estimated cost of damage to structures is about 27.6 million Philippine pesos or 502 thousand US dollars [9].

6. Discussion

The documentation and analysis of the 2023 M_w 4.7 Leyte, Leyte Earthquake impacts are limited to the affected area and visited by the DOST-PHIVOLCS QRT. Moderate in size, we have documented significant geologic, structural, and socio-economic impacts. Geologic impacts include surface rupture, the first documented occurrence along the creeping segment of the Philippine Fault, liquefaction in marshland with recent and alluvial deposits, and two landslides in the mountainous area west of the fault. Severe structural damages were documented in areas with PEIS VI (very strong) equivalent to MMI VI.

Rare that an earthquake with a magnitude <6 will have a surface rupture [19]. We have documented an 8-km-long discontinuous rupture, which is the first documented surface rupture along the Philippine Fault and is unusual from other surface rupturing earthquakes in the world [23, 24]. Moreover, it is established that this part of the Leyte segment is creeping [11, 14 to 17], and has not ruptured during the 2017 M_w 6.5 Leyte Earthquake [4]. Hence, analyzing and documenting this phenomenon may widen our knowledge regarding creeping faults and surface rupture during moderate earthquakes. Quick but detailed investigation for moderate-sized earthquakes along creeping faults may help us characterize these types of faults.

The PGA value recorded in Brgy, Poblacion, Leyte (station code: LYLY) is relatively high (0.407 g) and is equivalent to PEIS VIII (MMI VIII) (Figure 2A and 3) [22]. This value seems to contradict the maximum earthquake intensity, PEIS VI (very strong), felt in areas along the trace of the fault based on reports and intensity surveys (Figure 2A). In some cases, recorded PGA value may be affected by local site amplification of the ground motion which may have been influenced by the subsurface geology of the area. LYLY is located in an area that is mainly overlain by thick sediments which is consistent with the geology (alluvial deposits) and geomorphology (marshland) (Figure 2) [26]. Thus, site amplification is the reason why there was a relatively high PGA value recorded in Brgy. Poblacion, Leyte. A PGA value of 0.052 g was recorded in Brgy. Poblacion, Kananga (station code: LYKN), which is located ~16 km southeast of the epicenter (Figures 2A and 3), is equivalent to PEIS V (strong). This recorded PGA corresponds to the observed earthquake intensity felt in the area based on the intensity survey we have conducted (Table 1 and Figure 2A).

The limited liquefaction occurrence can be attributed to several factors. First, the low magnitude of the earthquake (M_w 4.7) suggests that liquefaction will be constrained to around 13 km from the epicenter as discussed by Castilla and Audemard [29]. The documented liquefaction in Palaypay District (Figures 2 and 4B) is around 8 km from the epicenter, which is within the estimated maximum distance of liquefaction impacts. Another factor is the relatively short duration of ground shaking from the earthquake. According to the locals interviewed, ground shaking lasted for less than 10 seconds which is consistent with the duration inferred by the PSMNet (Figure 3). The low-magnitude earthquake coupled with the short ground shaking duration corresponds to a lesser load on the soil to lose its shear strength and liquefy. This is the same case with the distribution of landslides. Using the magnitude-distance relations of occurrences of earthquake-induced landslides in Greece [30], the maximum distance that landslides can occur from a M_w 4.7 earthquake is around 10 km from the epicenter. The landslides in Brgys. Calaguise and Palid Uno are 6 km and 9 km from the epicenter respectively, both within the expected maximum distance of earthquake-induced landslides [30]. We should take note that the magnitude-distance relations used may be applicable on a regional scale or with specific tectonic and geologic settings, thus the maximum distance of landslide potential may vary. Our information about the occurrence of landslides in a moderate-sized earthquake may add to the global liquefaction database. It is also important to mention that the occurrence of liquefaction and earthquake-induced landslides for this moderate-sized earthquake coincided with the hazard zones reflected in the DOST-PHIVOLCS regional-scale earthquake-related hazard maps [31, 32].

Significant damage to structures was concentrated around the epicentral area and can be attributed to poor construction practices, substandard construction materials, and improper building design. These observations were also identified in past damaging earthquakes [1 to 8] but our investigation also revealed that even for a moderate-size earthquake, structural damages may also be expected. Despite the existence of the National Building Code in the Philippines and the National Structural Code of the Philippines [33], their non-implementation and poor regulation have contributed to the severe impacts after an earthquake. Thus, strict implementation of the building codes should be considered in rehabilitation and future development. Moreover, post-earthquake investigation and assessment can allow us to revisit and analyze the earthquake impacts, validate and improve the seismic building code and seismic hazard assessment, update the existing earthquake contingency and business continuity plans, and educate the different stakeholders in explaining the causes of the earthquake impacts and damages.

Despite the low magnitude of this earthquake, significant impacts, including the occurrence of surface ruptures, liquefaction, mass wasting and severe damage to structures were documented. The peculiarity of this event may be attributed to the shallowness of the earthquake source. Moreover, site conditions, such as the geology, geomorphology, and soil properties, cause local amplification of ground motion that contributes to the severity of the impacts. Documentation and analysis of the impacts of these moderate-size earthquakes should be done in the future such as soil and water content analysis for liquefaction and hazard modelling.

The impacts of the 2023 M_w 4.7 Leyte, Leyte Earthquake reminded us of the importance of earthquake preparedness. It is important to re-examine efforts on earthquake preparedness and contingency planning of the national and local government units as well as the community. While there are assumptions in seismic hazard assessment, efforts must be enhanced to develop resilience to earthquakes.

6. Summary and Conclusion

The 2023 M_w 4.7 Leyte, Leyte Earthquake is considered a moderate-sized earthquake but in terms of its geologic, structural, and socio-economic impact, this earthquake is worthy to be discussed and analyzed in the scientific and disaster risk reduction and management field. This paper emphasizes the importance of documenting earthquake impacts as a tool and guide for medium and long-term earthquake risk assessment and resiliency, even for low-magnitude earthquakes. The significant geologic, structural, and economic impacts were documented for this event. The 8-km-long surface rupture was the first documented surface rupture along the Philippine Fault with a magnitude <6. Liquefaction and mass wasting impacts occurred near the epicentral area, and its distribution coincides with previous studies. Based on the analysis of earthquake and field data, we suggest that the shallow hypocenter and the site conditions explain the significant impacts associated with this moderate-size earthquake. We also reiterate the need for earthquake preparedness, and proper adherence to the National Building Code of the Philippines to lessen earthquake impacts.

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