The October 15, 2013 Bohol Island, Philippines earthquake and its damaging effects: An investigative report

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Key Facts
- Hazard Type: Earthquake
- Date of the disaster: October 15, 2013
- Location of the survey: Bohol Island, Philippines
- Date of the field survey: October 26 and 27, November 4 and 5, 2013
- Survey tools:digital cameras and measuring tapes
- Key findings
  1) The epicenter of the earthquake was approximately 6 km S24W of Sagbayan, Bohol with a focal depth of 12 km. The 7.2 magnitude earthquake was of tectonic in origin that was generated from a reverse thrust movement of a previously uncharted faul line. This new fault line is now named as the North Bohol Fault Line.
  2) Damage from this earthquake was significant and widespread that included roads and bridges, schools and hospitals, government and private buildings, houses, seaports and airports
  3) Landslides, liquefaction, sinkholes and lateral ground fissures where observed in many places.
  4) The strong lateral movement also damaged the nation's cultural heritage structures such as centuries old churches and watchtowers

Key Words : *earthquake, liquefaction,cultural heritage structures, damage to infrastructures*

1. INTRODUCTION

Bohol is an island located south of Manila, Philippines. On October 15, 2013 at approximately 08:12 (PST), an earthquake with a magnitude of 7.2 vigorously shook this island and its neighboring islands e.g., Cebu, Negros and Surigao (see **Fig. 1**). According to the Philippine Institute of Volcanology and Seismology (PHILVOLCS) the epicenter (9.86^{o}N, 124.07^{o}E) of the earthquake was approximately 6 km S24^{o}W of Sagbayan, Bohol with a focal depth of about 12 km[1)].

The earthquake was caused by a reverse thrust movement of a previously unidentified fault (see white dashed line in **Fig. 2**) and geologists are at present mapping the entire fault trace. The solid blue line in this figure is the trace of the East Bohol

Fig. 1. Bohol Island, Philippines.

fault line. This earthquake registered a PEIS (Philippine Earthquake Instensity Scale) of VIII that is characteristic of a very destructive earthquake with the presence of liquefaction, lateral spreading and considerably damaged buildings and bridges.

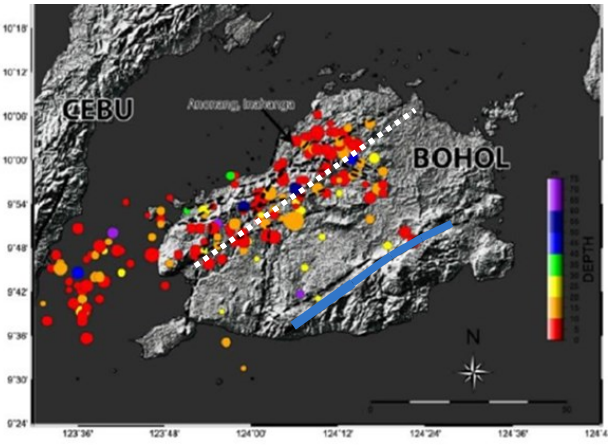

Fig. 2. Epicenter and aftershocks (source: PHILVOLCS)

According to a report by the National Disaster Risk Reduction and Management Council (NDRRMC), the number of fatalities reached 222 (as of November 3, 2013). Furthermore the number of persons reported to have sustained substantial injuries is more than three times this number. In fact, out of the approximately 1.2 million residents of Bohol island, 74,907 familes representing more than 30% of the population were displaced by this earthquake.

This report presents the findings gathered by the authors during a four-day survey augmented by reports from different sources.

The paper is divided into five chapters starting with the introduction with **Chapter 2** briefly explaining the geologic and tectonic setting of Bohol Island. **Chapter 3** expounds on the damage caused by the earthquake and **Chapter 4** summarizes the findings.

2. GEOLOGICAL AND TECTONIC SETTING

(1) Geological and tectonic setting

Bohol Island is the 10th largest island in the Philippine archipelago and is located in the Central Visayas Region. This island has an approximate land area of 4,117.26 km^2 and houses a population of around 260 persons per square kilometer in 47 municipalities[2)].

The island of Bohol and most of the Philippines is contained in the Philippine Mobile Belt (PMB) which is a zone of deformation and active seismicity that accommodates by large the stresses caused by the northwestward movement of the Philippine Sea Plate. This zone is bounded in the west by east-dipping subduction zones in the Manila, Sulu, Negros and Cotobato trenches and in the east by west-dipping subduction zones mainly following the outline of the Philippine trench. In addition, within the PMB lies the left-lateral Philippine fault that is roughly 1400 km in length and spans almost the whole of the country. Lastly, southwest of the PMB located is the aseismic Palawan-Mindoro block[3)] (see **Fig. 3**).

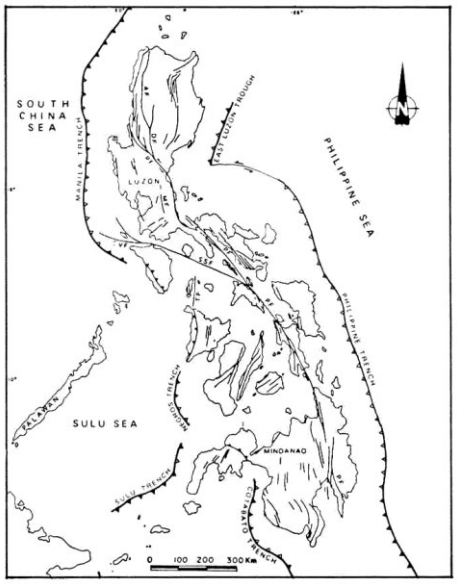

Fig. 3. Overview of the Philippine fault system

(2) Fault setting

The earthquake in Bohol was tectonic in origin and exhibited a reverse thrust movement as observed during the field observations. The earthquake was generated by a new fault that now bears the name North Bohol fault[1)].

According to an interview with the PHIVOLCS through a local news media, the government agency found it hard to recognize the formation of the new fault despite possible signs that emerged in the earthquake back in 1996 due to the prevailing limestone structure of the island that easily wears-off the feign structures / features that might have suggested the materialization of the new fault[4)].

(3) Main shock and aftershocks

As of November 3, 2013 more than 3198 aftershocks have been recorded by PHILVOLCS with 94 of these felt by the general population[2)].

3. DAMAGE TO STRUCTURES

This recent earthquake was one of the strongest in Philippine history. The damage was widespread it affected houses, bridges, schools, roads, highways, public and private building, flood control structures, seaports, airports and hospitals.

According to NDRRMC site report, as many as 222 persons lost their lives, 976 were injured and 8 persons are still unaccounted. What was heart-breaking also was the the damage to our country's heritage structures such as Spanish-era churches and watchtowers. Landslides, sink holes, ground fissures and liquefaction were also reported in many areas.

The following sub-chapters are the damage observed during the site inspection and assessment.

(1) Damage to houses

Damage to houses was enormous and affected dwellings made of timber, reinforced concrete as well as houses made of indigenous materials. According to NDRRMC more that 73,000 homes were damaged not only in Bohol but also in neighboring islands.

Residents whose houses were badly damaged were force to evacuate to town centers or evacuation areas. Home owners whose houses sustained moderate damage moved out of their houses and pitched camp adjacent to their homes for fear of further damage to their homes due to the aftershocks.

F**igure 4** exhibits a soft-storey failure where the ground floor columns failed and the ground floor was crushed by the second floor. In **fig. 5**, the columns of the houses on the left and right failed causing it to lean on the house found in the middle of the photo. Other observed failures of houses are the following: (a) beam to column connection failure (b) corroded reinforcements (c) under reinforced columns (d) no lateral supports of walls and (e) inadequate anchorage.

Fig. 4. Soft-storey column failure of a two-storey house.

Fig. 5. tilting of two residential houses due to column failure

(2) Damage to bridges

A total of 41 bridges were also reported damaged. The two spans of Abatan bridge which connects the Municipalities of Cortes and Tagbilaran (**Fig. 6**) fell to the river. The abutment tilted towards the embankment causing the spans to fall off. Damaged to reinforced concrete piles were also observed.

In Catigbian a bailey bridge with wooden deck swayed to one side while the other end fell into the river (**Fig. 7**).

Fig.6 Unseated superstructure of Abatan bridge.

Fig.7 Failure of a Bailey bridge in Catigbian.

(3) Damage to hospitals

Hospitals also sustained structural as well as non-structural damage. The Catigbian District Hospital (see **Fig. 8**) sustained minor to moderate damage. The damage were mostly confined to non-structural damage such as falling ceiling panels, dislocation of medical equipment, broken glasses etc.

The Natalio P. Castillo Sr. Mermorial Hospital however (**Fig. 9**) suffered major structural damage. This hospital was almost ready for occupancy but unfortunately was badly damaged during the earthquake. The building housing the emergency room located across this structure was also damaged and is now subject to detailed structural investigation.

Fig.8 Non-structural damage to Catigbian District Hospital.

Fig.9 Structural damage to Natalio P. Castillo Sr. Memorial hospital.

(4) Damage to roads and highways

Roads and highways also sustained damage due to the intense ground shaking. Large cracks in the concrete pavement (**Fig. 10**) were observed in many areas as well as failure of concrete guide rails.

Damage to a road section along Baclayon - Alburquerque – Loay highway was also observed probably to ground liquefaction was also seen.

Fig.10 Large crack in concrete pavement.

(5) Damage to cultural heritage structures

National cultural treasures such as spanish-era churches and watch towers were not spared during this earthquake. The following modes of failure were observed during the site inspection[6].

a. arch collapse – the loss of compression in the arch caused the failure of this structural element. This type of failure was predominantly found in the Our Lady of the Assumption Church in Dauis (**Fig. 11**).

b. wall collapse - walls which did not have enough resistance to large shear and moment forces toppled quickly (**Fig. 12**). This failure was observed in many churches such as the Sto. Niño Parish Church in Cortes.

c. facade walls with no horizontal supports nor diaphragms also collapsed due to the strong lateral movement (**Fig. 13**). This failure was observed in many churches such at the Our Lady of the Immaculate Conception in Baclayon.

d. total collapse – the St. Vincent Ferrer Church in Maribojoc (**Fig. 14**) and the Our Lady of Light Church in Loon were totally damaged (**Fig. 15**)

Fig. 11. Arch failure at Dauis Church

Fig. 12. Observed wall failure

Fig. 13. Façade wall failure at the Our Lady of the Immaculate Conception in Baclayon

Fig. 14. St. Vincent Ferrer Church in Maribojoc, before and after the earthquake

Fig. 15. Our Lady of Light Church in Loon, before and after the earthquake

A summary[7] of the damaged cultural heritage properties in Bohol and Cebu are summarized in Tables 1 and 2.

Table 1. Heritage structures in Bohol that sustained damage during the earthquake.

Church Name	Declared properties	Damage
Alburquerque	ICP	minimal damage
Baclayon	NCT, NHL	facade and belfy fell
Carmen	ICP	nave with celing mutals collapsed
Clarin	HH	church collapsed
Cortes	ICP	facade collapsed
Dauis	NCT, NHL	facade collapsed
Dimiao	NHL	Minimal damage
Inabanga	ICP	facade left standing
Loay	NHL	facade collapsed
Loboc	NCT, NHL	facade collapsed
Loon	NCT, NHL	totally destroyed
Maribojoc	ICP	totally destroyed
Tubigon	ICP	facade collapsed
Punta Cruz Tower	NCT	roof fell in
Panglao Tower	NCT	roof totally de-stroyed
Balilihan Tower	NCT	totally destroyed

NCT – National Cultural Treasure
NHL – National Historical Landmark
ICP – Important Cultural Property
HH – Heritage House
Note: the churches in bold font were personally inspected by the first author

Table 2. Heritage structures in Cebu that sustained damage during the earthquake.

Church Name	Declared properties	Damage
Argao	NHL	minor damage baluster of belfry gave way
Basilica Minore del Sto. Nino	ICP	belfy collapsed
Carcar	ICP	facade and belfry fell
Cebu Cathedral	ICP	minor damage
Dalaguete	NHL	Heavy damage to belfry and pediment
Sibonga	ICP	some cracks

4. SUMMARY

A strong earthquake occurred inland in Bohol on October 15, 2013. The strong ground motion was caused by a reverse thrust movement of a newly discovered fault now named as the North Bohol fault. This upwardmovement caused widespread damage to lives and properties especially on the westside of the fault line.
This paper reports the results of the inspection and investigation of the damage in Bohol Island after the

event. It was observed that damage to structures was significant and widespread that included houses, bridges, schools, roads, highways, public and private building, flood control structures, seaports, airports and hospitals. Damage to cultural heritage structures was also observed.

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