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Earthquake Performance of Structures in Bohol: A Post-event Assessment of the M7.2 October 2013 Bohol Philippines Earthquake

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ABSTRACT: A M7.2 inland earthquake occurred in Bohol, Philippines on 15 October 2013, leaving behind widespread damage to its built environment. The strong ground shaking is linked to the movement of a newly-discovered thrust fault called the North Bohol Fault. To account for the observed structural damage in Bohol, a comprehensive exposure database that characterizes over 18,000 buildings in urban and rural settings was assembled. This involved a statistical building survey covering both damaged and undamaged structures exposed to various levels of earthquake intensity. The existing building typology developed by local engineers has been considered in classifying the structures based on structural materials, building height and era of construction. The majority of the buildings are residential, with walls made of wood, concrete hollow blocks or confined masonry. The impact on structures is expressed in four damage states. This study primarily aims to validate and constrain the fragility curves for selected building types. In the context of seismic risk assessment, this can potentially lead to better impact forecasts and higher priorities on building regulations and construction practices, which will help establish a more seismically resilient community.

1 INTRODUCTION

The mitigation of risks due to natural hazards is highlighted in the Millennium Development Goals (IPU/UNISDR, 2010). Disaster Risk Reduction (DRR) is an integral component of this key development priority and is of particular significance for countries like the Philippines where the risk of impacts from natural hazards like earthquakes is very high.

The Philippines is squeezed between two tectonic plates and surrounded by subduction zones, making it a hotbed of earthquake activity. As a seismically active region, several high magnitude earthquakes have visited the country causing widespread destruction to civil infrastructure.

The devastating potential of earthquake impact was witnessed in the province of Bohol when a M7.2 earthquake occurred in the morning of October 15, 2013. More than 70,000 houses were affected, most of which sustained partial damage (EMI, 2014). Other buildings whose structural integrity was tested during this event include schools, government halls, commercial establishments, tourist facilities and the prominent collapse of historic churches built during the Spanish period.

It is hoped that empirical results furnished in this research will provide valuable insights to disaster managers and disaster relief experts in coming up with credible impact assessments and recovery tools necessary to mitigate future disasters. It may also pave the way for engineers and policy makers in improving seismic design procedures and earthquake-resilient building standards.

2 THE M7.2 BOHOL EARTHQUAKE

The inland quake that hit the island of Bohol, in the central Philippines, is a result of the movement along the northeast-southwest trending reverse fault named the North Bohol Fault (NBF). A surface manifestation of rupture on the northern extent of NBF was observed in the municipality of Inabanga. It is approximately 6km in length with vertical offsets ranging from 0.1m to 5m. In the southwest, particularly in Maribojoc, coastal uplift has been observed which shifted the shoreline about 50m seawards. This is deemed the NBF's southern end (PPDO, 2013).

The locations of the epicentre as calculated by the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and the United States Geological Survey (USGS) are depicted in Figure 1. PHIVOLCS, the national agency in the Philippines mandated to monitor hazards such as earthquakes and volcanic eruptions, has estimated the event's focal depth at 12km with a magnitude of 7.2 (PHIVOLCS, 2013). The intensity map from USGS is used in this study.

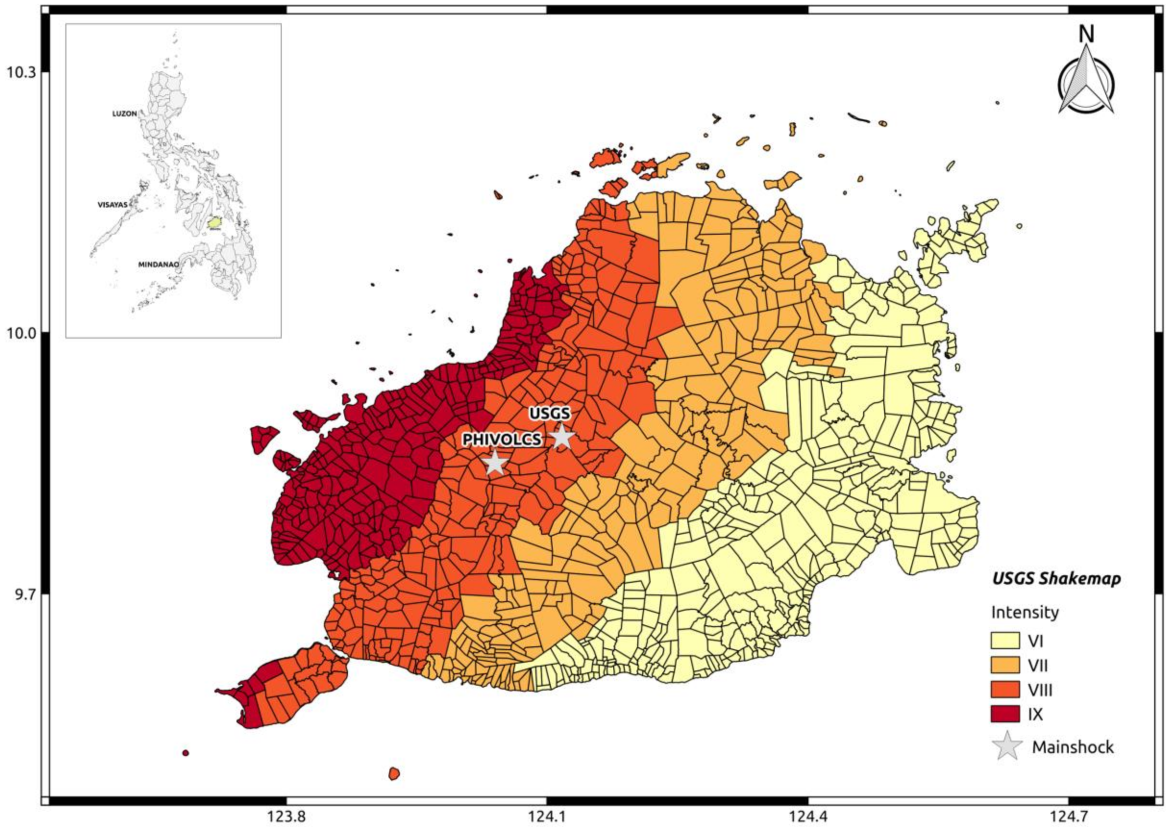

Figure 1.Distribution of intensity from USGS Shakemap and location of epicenters for mainshock as estimated by PHIVOLCS & USGS (with Bohol's location map on the inset)

2.1 Tectonic Framework

The Philippines is subject to high seismic hazard due to its tectonic setting. Shown in Figure 2 is its complex tectonics. The country is surrounded by major tectonic plates such as The Philippine Sea Plate and the Sundaland-Eurasia Plate. In addition, the tectonic structures that play key roles in the considerable seismic activity include the Manila Trench and other minor trenches along its western boundary and the Philippine Trench along with its extension in the East Luzon Trough on the eastern side (Yumul *et al*., 2008).

Prior to the M7.2 Bohol earthquake, a number of high magnitude events within the vicinity of the study area are recorded in Harvard's Global Centroid Moment Tensor (GCMT) catalogue (Dziewonski *et al*., 1981 & Ekstrom, *et al*., 2012) Most of these events displayed a thrust fault type mechanism, consistent with the compressional deformation observed in the region (Rangin, *et al*., 1999) as illustrated in the right panel of Figure 2. Prior to the earthquake, PHIVOLCS had mapped the possible earthquake generators in the area, indicating the East Bohol Fault as the only mapped active fault in Bohol situated along the south eastern portion of the island.

2.2 Structural Damage and Geological Impacts

The intense ground shaking during the Bohol earthquake had a tremendous impact not only on buildings but on other infrastructures as well, such as the bridges, roads and highways. This caused major disruptions in transportation and hampered relief efforts. Areas with unstable rock and soil materials succumbed to landslides. Even the Chocolate Hills, a tourist landmark in Bohol, sustained soil failure. Coastal uplift and subsidence were observed in villages along the northwest side of the island. The hundreds of aftershocks that ensued coupled with prolonged shaking caused further damage and casualties. Other hazards posed by the event include liquefaction and sinkholes, probably owing to Bohol being underlain by limestone. Some of the impacts in Bohol's physical environment and structures are featured in Figure 3.

The disaster analysis conducted by the Center for Disaster Management and Risk Reduction Technology (CEDIM) days after the quake presents the building count of damaged and destroyed houses. Thousands of houses in at least 15 municipalities in Bohol were severely damaged or destroyed. A considerable number of houses were also reported to have incurred damage in Cebu City on the neighbouring island to Bohol. Not much information though, is given regarding the structure types, heights or any other attributes that may characterize the structures' vulnerability (CEDIM, 2013).

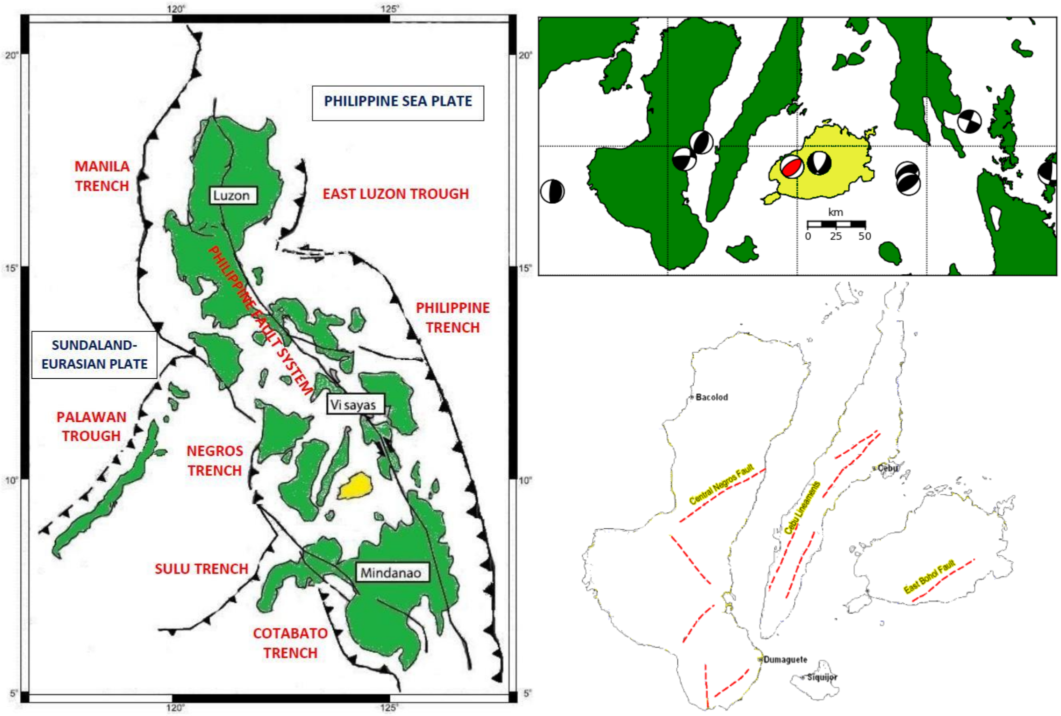

Figure 2. Left: Primary tectonic features of the Philippines; Right: On top, epicentral plot of earthquakes based on GCMT solutions & below, mapped traces of active faults (modified from PHIVOLCS)

Figure 3.Structural damage & geologic impacts of Bohol Earthquake

Bohol has a total of 259,520 housing units based on the 2010 Census of Population and Housing conducted by the National Statistics Office (now known as the Philippine Statistical Authority). Of the occupied housing units, 34% have outer walls made of concrete, brick or stone, 26% have bamboo, cogon or nipa while 22% employ a combination of both materials. The percentage unaccounted for is not reported but it may have comprised makeshift houses. Out of the total number of housing units, 57,405 incurred partial damage and 14,480 were rendered completely damaged. Municipalities with the highest number of damaged houses include Calape, Carmen, Catigbian, Loon and Tubigon (EMI, 2014).

3 THE EXPOSURE DATABASE

Bohol is the 10th largest island in the Philippines, consisting of 47 municipalities and one capital city. The major resources available in the island are upland forestry, lowland agriculture, coastal/marine and water resources which drive its economic sector towards agriculture, fisheries, forestry, trade, industry and tourism (PPDO, 2010). Covering a total land area of 4117 square kilometres with over 1.25M population (NSO, 2010), 67% of Bohol's land is utilized for agricultural purposes and 25% for forestland (PPDO, 2010).

In building an exposure database, the core elements at risk considered in this study are the buildings and the people. The database is primarily an inventory of the location and characteristics describing these elements.

3.1 Post-Event Survey

The principal objective of the survey is to characterize the existing structures prior to the occurrence of the earthquake. Each structure is described based on selected attributes such as building use, number of storeys, occupancy, era of construction, type of wall, roof and flooring, damage incurred during the event and site characteristics where the structure is constructed. Through actual interviews, these data are extracted primarily from health workers or officials who conduct monthly visits in each housing unit for health care administration and related services.

A simple form is utilized during the interview as shown in Figure 4. The survey form has drop down menus from which the interviewees can select the best suitable description of the structure being defined. Most of these attributes can be described with ease except the era of construction. In this case, the interviewees are encouraged to give the best possible information they have. During the interview, spot maps aid in accounting for all structures in a *barangay* – the Filipino term for village. These spot maps are available in all barangays and are updated in an annual basis.

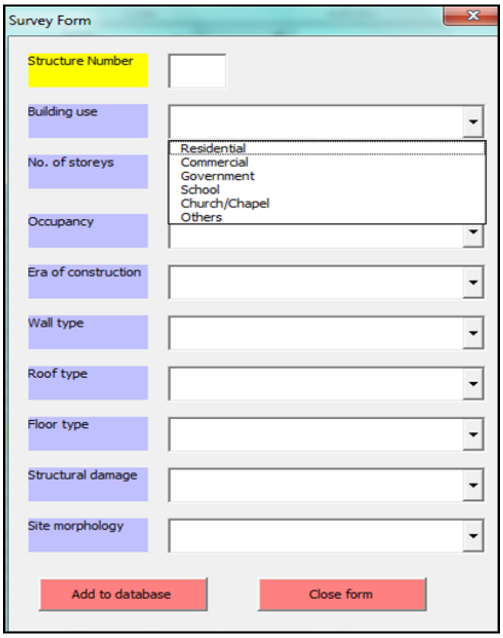

Figure 4.Survey form used in interviews and the corresponding attributes describing the structures

The survey involves 20 municipalities with at least three barangays per municipality. In total, 61 barangays participated in the interview, covering a total of 18,028 structures. Factors considered in site selection include the earthquake intensity levels, urban and rural areas, population and existing damage reports and surveys.

After the field reconnaissance, the Australian National University (ANU) carried out pilot interviews in three barangays to test the coherency of the methodology and the survey form as well. In order to speed up the data gathering, local universities assisted the ANU in the conduct of interviews. Groups of students from the University of Bohol (UB) and the Holy Name University (HNU) participated in the process. The map in Figure 5 shows the distribution of selected sites, with barangays classified as rural or urban and the corresponding university that conducted the interviews.

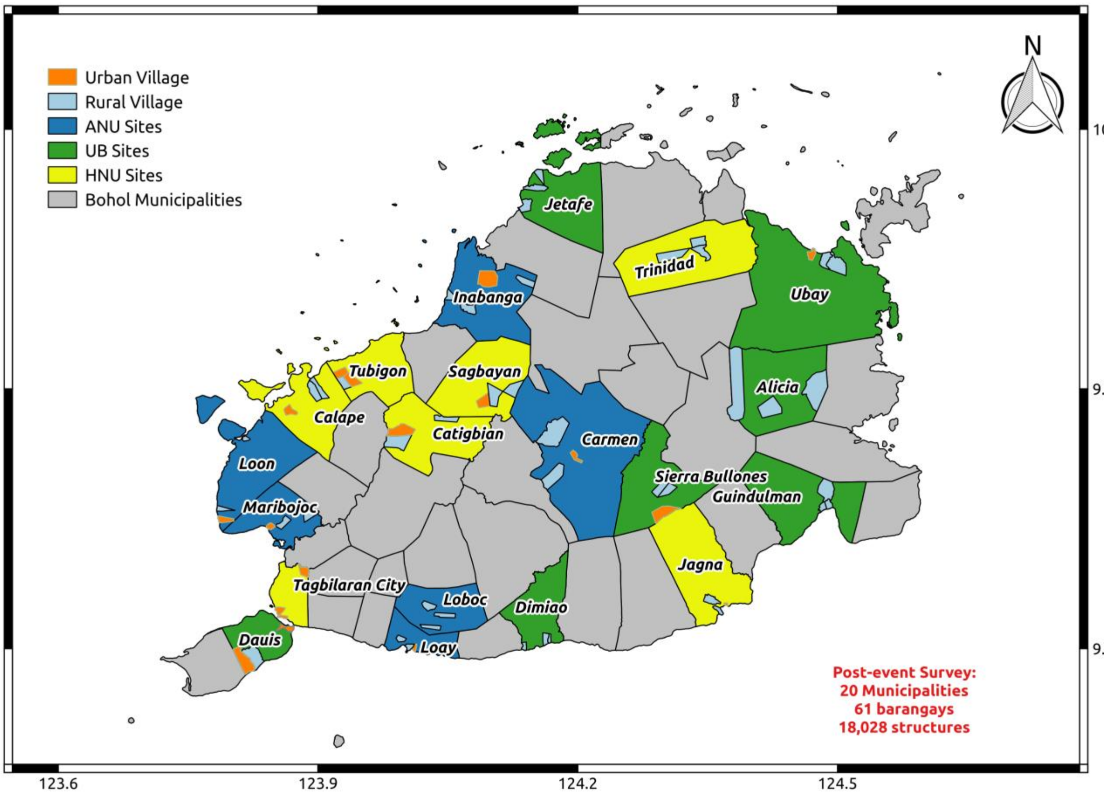

Figure 5.Selected sites for post-event survey in Bohol

3.2 **Building Typology**

A summary of the building survey that has been conducted to come up with a comprehensive exposure database is shown in Figure 6. The majority of the buildings are of residential type, with one or two storeys, housing one to seven people and built in flat terrain. As for the structural materials, a large proportion of buildings use wood, concrete hollow blocks (CHB) or combination thereof for the walls, light materials for the roofing and concrete slab for the flooring.

The severity of damage is expressed in four damage states including No Damage, Minor Cracks, Repairable and Collapse. No Damage covers minor tilting for wooden structures and no visible cracks for concrete buildings. Minor Cracks denote slight cracks in structures but repair is not necessary. If the structure is still standing but has suffered extensive damage and reparation is required, this corresponds to the Repairable damage state. Collapse is linked to structures which are rendered uneconomic to repair and require total reconstruction.

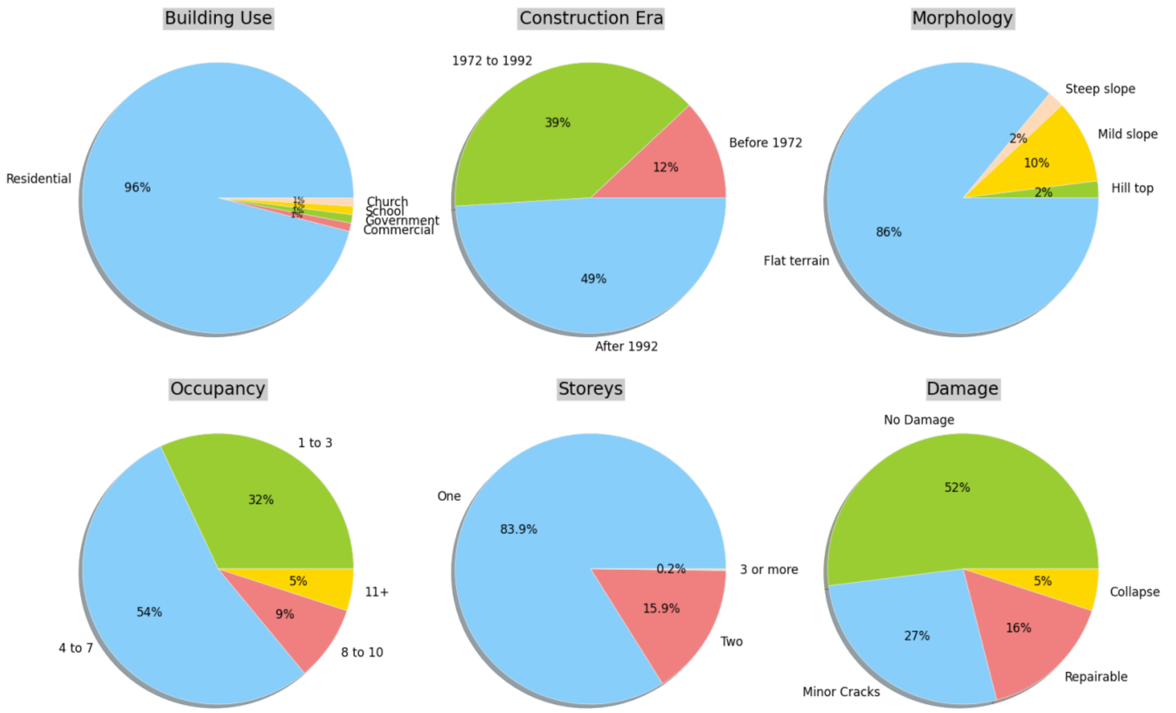

Figure 6.Summary of the exposure database

The engineers from the University of the Philippines Diliman (UPD) developed a list of building typology for the Philippines as part of an effort to develop fragility curves for key building types (UPD-ICE, 2013). In this study, this list is considered to categorize the predominant types in the building stock in Bohol. The building height is also used in the classification for one and two-storey (L) structures. Further, the era of construction represents three vintages based on the amendments in the National Structural Code of the Philippines (ASEP, 2001). These are the same vintages presented in UPD's assessment. Table 1 lists the generalized building types evaluated in this study, aligned to fit in the existing building typology.

Table 1.Building types adapted in this study

Building Type		**Description**
Wood, Light Frame	W1-L	Buildings with walls made of plywood, gypsum board, bamboo and other wooden materials. Materials for roofing may include wood, nipa, bamboo, galvanized iron (GI) metal sheets or other light materials. Flooring uses wood, bamboo, earth or concrete.
Confined Masonry	CM-L	Structures with reinforced concrete frames confining the concrete hollow blocks. The floors consist of wood, earth or concrete while the roofs are GI sheets or light materials.
Concrete Hollow Blocks with Wood or Light Metal	MWS-L	Structures with layers of concrete hollow block masonry in the lower wall and wooden or light materials in the upper wall, with no reinforced concrete frame. Floor construction may include wood sheathing, earth or concrete. Roofing is made of GI sheets or other light materials.
Concrete Hollow Blocks	CHB-L	Low rise structures with concrete hollow blocks wall and no reinforced concrete frame. The flooring has board sheathing, earth or concrete. The roofs are GI sheets or light materials.

4 PRELIMINARY ASSESSMENT

Each building type is well represented in the surveyed municipalities. CHB has a much smaller sample size compared with other building categories. In Figure 7, the comparison between W1 and CHB is shown taking into account the earthquake intensity levels and construction era. Highlighted in W1 is the large structure count placed under the No Damage state and fewer collapsed structures especially when exposed to severe conditions like higher intensity and the construction period falls before 1972. For CHB, all damage states are noticeable even at lower intensity levels. Results may have not established a clear trend, especially at intensity IX where more new buildings collapsed but this can be attributed to the number of structures representing each age category.

For all building types, the database showcases a general trend wherein all damage states become prevalent in the exposed population as structures incur more damage with increasing earthquake intensity. Also, buildings constructed after 1992 appear to perform much better than older buildings. Not surprisingly, preliminary findings suggest that wooden structures are able to endure earthquake forces quite well when compared to other building types. On the other hand, at least 50% of structures classified under MWS and CM were able to resist the seismic loads, although a considerable percentage needs repair and suffered minor cracks.

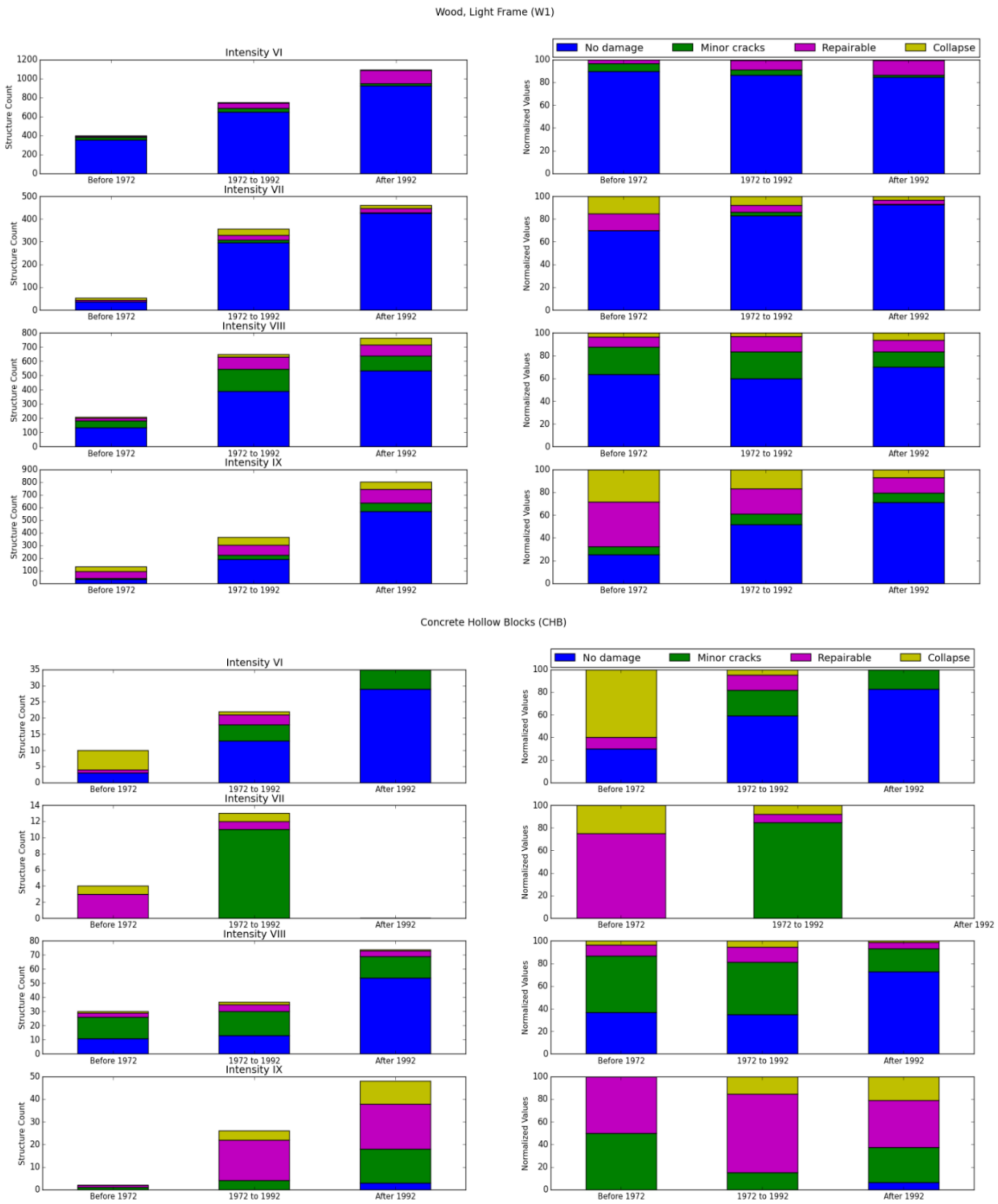

Figure 7. Comparison between W1 & CHB at various intensity levels and era of construction

Looking into how each attribute influences the performance of a structure, morphology is another interesting attribute to explore. It is expected that structures constructed along slopes or hilltops are more prone to damage or collapse, and the database confirms this perception. Buildings on steep slopes are more likely to exhibit torsional response along slope shaking and hilltop structures may experience amplification due to ridge effects. The bulk of structures in the database were constructed on flat terrain where less damage was observed compared to other morphologies.

5 SUMMARY

In this paper, the preliminary stage of the post-event evaluation of damage caused by 2013 Bohol Philippines earthquake is presented. The compilation of a comprehensive exposure database yields a first-hand appreciation of the extent of damage. Various facets of building components and construction contribute to an investigation of the performance of structures. By looking into the current database and possibly gaining more information to represent other building types, a more in-depth analysis of hazard and risk can be realized.

The data indicates four generalized building types prominent in Bohol. Among these types, the wooden structures perform quite well when subjected to earthquake loads. Structures in flat terrain perform better than those built on slopes or hilltops. A general trend is also established as to the performance of structures over time. Most of the old structures behave poorly while new buildings are able to withstand the seismic forces much better. This may signify an improvement in building standards and practices. Using an empirical method, the corresponding fragility curves can be validated. Further, analysis can be extended to associated repair and reconstruction costs.

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