PHILIPPINE HISTORICAL EARTHQUAKES AND LESSONS LEARNED

Maria Leonila P. Bautista and Bartolome C. Bautista

ABSTRACT: A realistic seismic hazard assessment requires a robust earthquake catalog. The longer the coverage of the catalog and the better determined the parameters are, the better are the results of the assessment. Usually, the earthquake catalog of a given country consists only of the instrumental catalog, the period when seismic instruments started to be operated. The first earthquake report for the Philippines was in 1589 while the first instrumentally derived earthquake parameter for the country was for an earthquake in 1892 determined using global seismic stations. This paper discusses how the magnitudes and epicenters of Philippine historical earthquakes from 1589 to 1896 were estimated with the aim of extending the earthquake catalog of the country. The results are compared with earthquake parameters covering the instrumental period that covers the period 1897 to present. The results show that although some historical earthquakes lie along known tectonic structures, some are found in areas with unknown earthquake source zones and/or where no known large magnitude event had occurred during the last centuries. This suggests that by only considering instrumental catalog, the seismicity of a given area could not be fully understood and therefore, there is a need to extend the catalog to understand an area's seismicity. Finally, the paper identifies the lessons learned from these earthquakes. The two more important lessons learned from the review of historical earthquakes are that damages were due to poor construction practices and to effects of site response. It is important that we keep the lessons learned from these historical earthquakes in order that we can avoid them in the future.

Keywords: historical earthquakes; seismic hazard assessment; earthquake catalog; site response

1. INTRODUCTION

The main aim of conducting scientific studies is to use the results to make our society a better place to live in. Seismologists doing seismic hazard assessment studies aim to make realistic assessments that can reflect a specific area's vulnerability to earthquake hazards. One of the primary inputs to making realistic seismic hazard assessment studies is a longer earthquake catalog. The complete earthquake catalog of a given country may be defined as the time when instrumental monitoring started and the time when only earthquake accounts existed. By combining the two types of information, one can we have a complete earthquake catalog. The instrumental catalog for the Philippines started for the year 1897. Prior to this, earthquake consisted only of accounts by priests, government officials, historians and newspapers. For these older earthquakes to be useful to other researchers, they have to be parameterized or be given, at the very least, magnitudes and epicenter estimates. This paper summarizes, based on a previous paper by Bautista and Oike (2000), how the magnitudes and epicenters of Philippine historical earthquakes from 1589 to 1896 were systematically estimated with the aim of extending the earthquake catalog of the country. The results will also be compared with earthquake parameters covering the instrumental period that covers the period 1897 to present. Finally, the paper identifies the lessons learned from these earthquakes.

2. DATA AND METHODOLOGY

Previous attempts to estimate unknown earthquake magnitudes especially for historical earthquakes were made by devising equations that relate magnitudes with intensities at epicenter (Io) or to maximum intensities (Imax). These kinds of relationships may be affected by site response. More recent attempts to estimate magnitude were done by relating magnitudes and felt areas. Bollinger et al (1993) found out that earthquakes with magnitudes from 4.5 to 7.5 occurring in the eastern United States are felt five times bigger than those occurring in the western United States. Similar studies by other workers have shown that equations relating magnitudes and felt areas are site dependent and areas with different tectonic and geologic setting could be characterized by different empirical relationships. In this study, 86 well-documented, recent earthquakes from 1911 to 1995 were selected for establishing the magnitude-felt area relations for the Philippines. After determining these equations for various intensity levels, the equations were then used to determine magnitudes of historical earthquakes. To do this, historical accounts from more than 3,000 accounts consisting of 6,679 intensity reports from the period 1589 to 1895 were reviewed. In reviewing historical earthquakes, it is important to know the stage of development of the existing masonry structures in order to assess the intensities accurately. In order to understand the seriousness of the damages alluded to in the historical accounts, it was also important to trace the development of the various towns in terms of the dates and types of construction of various masonry structures. Before the Spaniards came, the native inhabitants lived in houses made of nipa. It was only when the Spanish colonizers arrived that large, masonry structures started to be built. Most of these were the churches which were used as an important colonizing tool by the colonizers. Hence, these churches were built to be impressive and elegant. Early churches, however, were made of local materials such as wood. Later on and as time went by, these churches were slowly built from contributions and donations. Most of these early masonry structures, however, lacked reinforcing materials.

Meanwhile. historical epicenters were estimated to be located at the area of highest intensity, area of the next highest intensity or even a hundred kilometer away from the highest intensity. Controlling factors would be location of existing towns or settlements when a particular earthquake occurred, effects of local geology, status of local construction and the level of development. The resulting earthquake parameters were also classified as A, B or C. An A classification would mean 10 reports or more, B would be 5-10 reports and C would be less than 5 reports. This classification would further guide future users on deciding how to use the parameters in the catalog.

3. DISCUSSION OF RESULTS

Out of these more than 3,000 historical accounts, the parameters of 487 historical earthquakes were estimated. To verify how near the location of these historical epicenters are as compared with recent events, the seismicity maps for both time periods were plotted. Then, by assuming that the plot of recent events is more complete, one can observe the areas where earthquakes are still lacking in the historical catalog. The seeming lack may be due to poor reporting or lack of data for some earthquakes. Figure 1 shows the seismicity during the recent instrumental period from 1897 to 1995 based on the data of the United States Geological Survey – National Earthquake Information Center (USGS-NEIC).

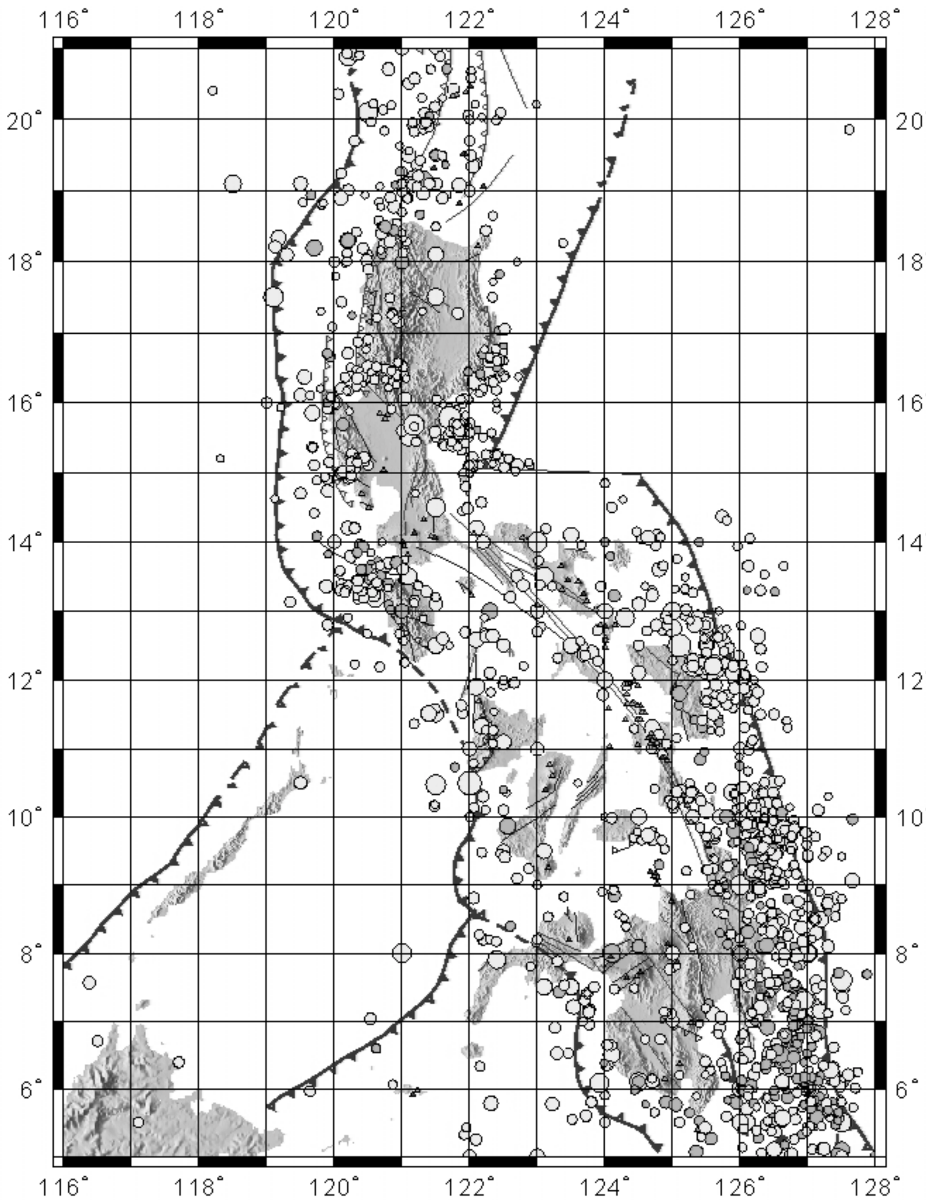

Figure 1. Instrumental seismicity of the Philippines showing earthquakes with magnitudes 5 and above. Data from the United States Geological Survey – National Earthquake Information Center (USGS-NEIC).

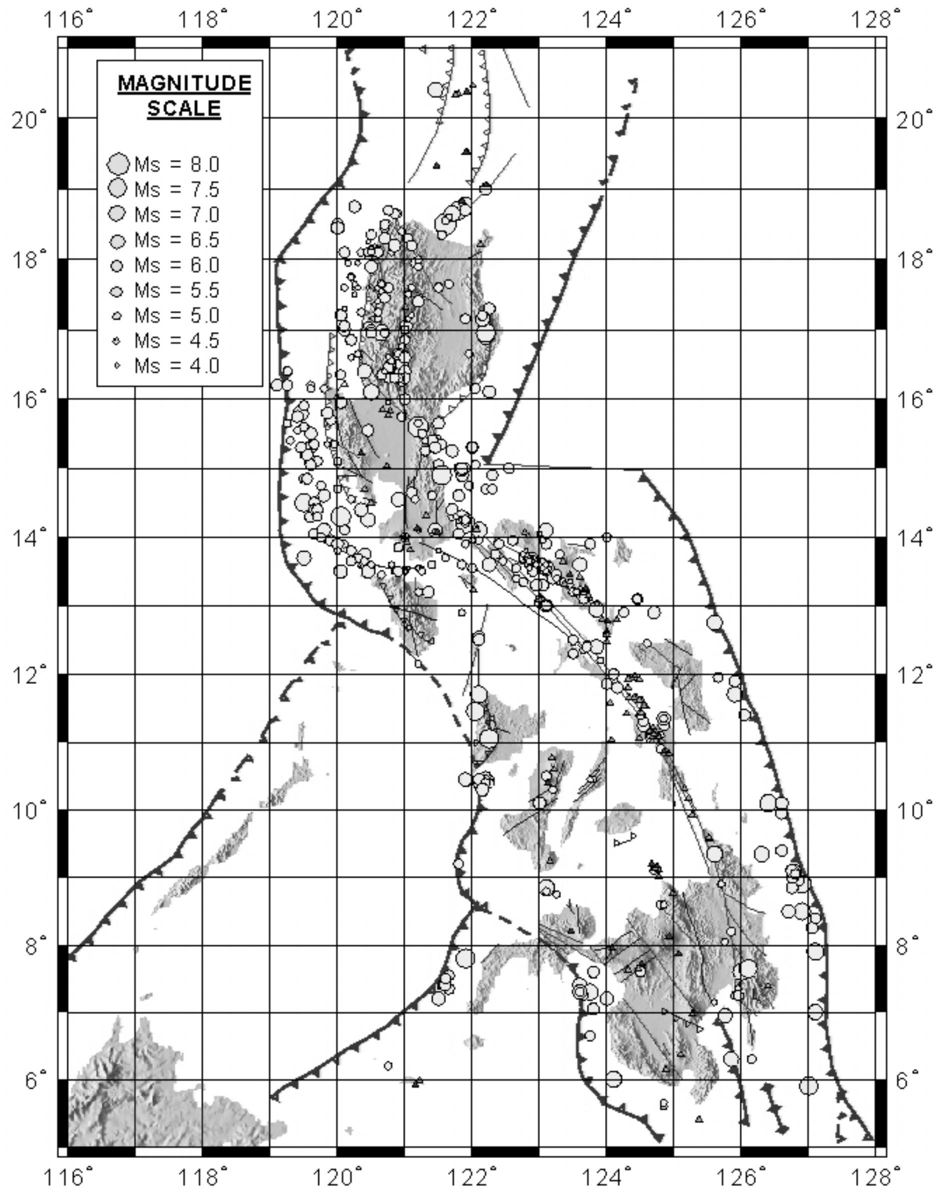

Figure 2. Plot of historical earthquakes of the Philippines determined by Bautista and Oike (2000).

The historical epicenters are found to mostly lie along known tectonic structures. As compared with recent seismicity, however, the eastern Philippine region and Mindanao island showed low seismicity as compared to recent data. This may be a factor of the data source as many of the earthquake accounts came from church records which were under the Christian religion. Most of Mindanao during the Spanish period in the Philippines remained under Muslim religion and there were fewer churches as compared to Luzon and Visayas where Christian colonization was more complete. The study also tried to determine the completeness of the resulting historical catalog and the results show that only events from 1850 onwards may be considered well reported. Earlier than 1850, there are still numerous accounts that must be found, studied and parameterized to complete the Philippine earthquake catalog.

Meanwhile, out of the 487 earthquakes, only the parameters of 52 events may be considered as very reliable (quality A) and 80 events as quite reliable (quality B). The remaining events are not so reliable and were given quality C. Good quality estimates for both magnitudes and epicenters are only concentrated from the 1850 period onwards due to the increase in number of towns. Earlier than this time, magnitude and epicentral determinations had a lesser number of historical accounts.

The review of both historical and recent earthquake accounts also pointed out some important observations on the nature and source of damages and collapse of structures. Throughout the four centuries of Philippine earthquakes, damages were mainly due to poor construction practices and effects of local site conditions where these structures were built. This type of observation had been noted even by historians who wrote about some of these past earthquakes. For example when the November 30, 1645 earthquake occurred, it damaged many churches and houses in Manila. Moreno (1877) described how people constructed their houses and that after previous earthquakes "as if no living man remembered them, they erected many buildings of masonry, almost the whole city, against every good rule of architecture, raising walls seven or eight *estados*, with little more than one *estado* of foundation, one *estado* wide below groun, and above the ground one vara and a quarter (about one meter) wide up to the top." One *estado* is about seven to eight feet. He also noted that walls of houses were "high and weak, without any kind of buttress, with very weak mortar of lime and sand,…". Meanwhile, Retana (1896) observed that Manila residents used to build their homes using wood and palm leaves before the 1645 earthquake but the threat of fire had caused, at the least for the Spanish residents, them to build their homes with stone and tile. Since there had been no earthquake for at least 40 years before the 1645 earthquake, the residences in Manila when the earthquake struck in 1645 were characterized by tall, spacious and palatial homes. These houses were built with minor support. About 150 of this kind of houses collapsed during the main shock of the 1645 earthquake (Repetti, 1946).

Meanwhile, some accounts mentioned about the effects of local site conditions to earthquake damages. Murillo Velarde (1749) gave this observation, after observing that the church in Antipolo had withstood 100 years of activity including strong earthquakes on November 30, 1645 and August 20, 1658. He observed that intensities are almost always higher in Manila, an area underlain by soft, alluvium deposits, than in Antipolo, an area underlain by pyroclastic flow deposits or "adobe". He said that "the earthquake-resistant qualities of Manila and Antipolo are quite different. The underground structure of Manila is made up of sand, gravel, alluvium and volcanic debris to an unknown depth, whereas Antipolo is a region of dense igneous rock. Many earthquakes are felt in Manila which pass unnoticed in Antipolo, even when the latter is nearer to the center." During the 1645 earthquake, Retana (1896) also wrote that many of the houses which collapsed were those along the river banks. A similar observation was noted by Centeno y Garcia (1882) during the July 18, 1880 earthquake.

An earthquake on October 26, 1824 destroyed the churches of Lucban town in Quezon province and that of Cavinti town in Laguna province. High intensities were also experienced by Antipolo town in Rizal province and Manila. The quite significant intensity at Manila and Cavite during this particular earthquake may be attributed to site response since both sites are underlain by thick alluvium deposits. Meanwhile, during the September 16, 1852 earthquake, most of the existing structures in Manila were partially to totally collapsed especially those located near the Pasig River. In other places like in Camarines Sur for example, an earthquake on October 19, 1865 caused houses in swampy places in the towns of Nabua and Iriga to collapse (Gaceta de Manila, November 9, 1865).

4. SUMMARY AND CONCLUSIONS

This study discusses the methodology for estimating the magnitudes and epicenters of Philippine historical earthquakes and the lessons learned why damages to structures occurred. The first step involved the determination of magnitude-felt area relations for Philippine earthquakes. After this, the parameters (epicenters and magnitudes) of 487 historical earthquakes were estimated and the important lessons learned on why damages had occurred were studied. The magnitude-felt area relations may be used for estimating magnitudes of other earthquakes with no magnitude values but with sufficient number of earthquake reports. Putting all together these earthquake data had allowed us to extend the coverage of the Philippine earthquake catalog, a step that is very important for seismic hazard assessment studies. The two more important lessons learned from the review of historical earthquakes are that damages were due to poor construction practices and to effects of site response. It is important that we keep the lessons learned from these historical earthquakes in order that we can avoid them in the future.

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