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Seismic Observations and Seismic Hazard Studies in the Philippines[1]

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It has taken more than a hundred years for seismic observations in the Philippines to evolve to a modern observation system. The responsibility of seismic observations was likewise transferred from one agency to another during this same period of time. At present, the mandate of conducting seismic observations in the Philippines rests with the Philippine Institute of Volcanology and Seismology (PHIVOLCS). In 2000, through a grant aid from the Japan International Cooperation Agency (JICA), the Philippine seismic network was upgraded to a digital system. As a result, a new set of seismic monitoring equipments was installed in all of the 34 PHIVOLCS seismic stations all over the country. Digital waveforms are now available for high level seismic data processing, and data acquisition and processing are now automated. Included in the upgrade is the provision of strong motion accelerographs in all stations whose data can now be used for studying ground motion and intensity attenuation relations. The new setup is now producing high-resolution data that can now be used for conducting basic seismological researches. Earthquake locations have now improved allowing for the modeling and delineation of earthquake source regions necessary for earthquake hazard studies.

Current seismic hazard studies in the Philippines involve the estimation of ground motion using both probabilistic and deterministic approaches, seismic microzonation studies of key cities using microtremor observations, paleoseismology and active faults mapping, and identification of liquefaction-prone, landslide-prone and tsunami-affected areas. The earthquake database is now being reviewed and completed with the addition of historical events and from data from regional databases. While studies of seismic hazards were primarily concentrated on a regional level, PHIVOLCS is now focusing on doing these seismic hazard studies on a microlevel. For Metro Manila, first generation hazard maps showing ground rupture, ground shaking and liquefaction hazards have recently been completed. Other large cities that are also at risk from large earthquakes are the next targets. The elements at risk such as population, lifelines, and vertical and horizontal structures for each of these urban centers are also being incorporated in the hazard maps for immediate use of planners, civil defense officials, policy-makers and engineers. The maps can also now be used to describe possible scenarios during times of strong events and how appropriate socio-economic and engineering responses could be designed. In addition, a rapid earthquake damage assessment system has been started which will attempt to

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produce immediate or rapid assessments including identification of elements at risk during times of strong earthquakes.

Key words: Philippine seismic network; Seismological research; Earthquake hazard study; Earthquake database; Rapid earthquake damage assessment; Microzonation

INTRODUCTION

The Philippines lies in a seismically active region due to its tectonic setting. It lies between two-oppositely moving tectonic plates resulting in oblique subduction systems at its western and eastern tectonic margins. The east-dipping Manila-Negros-Sulu-Cotabato Trench system is found at its west boundary while the west-dipping Philippine Trench-East Luzon Trough system is found at its eastern side. Both subduction zone systems are sites of moderate to intense seismicity and some of the largest Philippine intraplate earthquakes. As a result of the oppositely-directed subduction systems, one of the longest strike-slip faults in the world had formed and now cuts through almost the whole archipelago. This structure, called the Philippine Fault, is about 1200 km long. Its trace can be seen from eastern Mindanao, then cutting across the islands of Leyte and Masbate, entering the Quezon province, disappearing in Dingalan Bay and entering back into Nueva Ecija province in northern Luzon, the biggest island of the Philippines. It then cross the land in a northeast direction and forms several splays northwards to north Luzon mountain ranges. The Philippine Fault, although it has not produced as big earthquakes as the trenches, poses a more serious threat since some of its segments are found on land. The largest earthquake associated with this fault movement was an earthquake in 1990 which had a magnitude of 7.8.

1. CURRENT STATE OF SEISMIC OBSERVATIONS IN THE PHILIPPINES

Seismic observations started in 1863 when simple seismoscopes were operated by the Manila Observatory, a Jesuit-run institution that initiated systematic meteorological and seismological observations in the Philippines. The Manila Observatory collected and became the repository of early earthquake reports. It was more than 50 years later in 1945 that the responsibility of conducting seismic observations was transferred to a government body, the Weather Bureau. The bureau was later reorganized as the Philippine Atmospheric, Geophysical, Astronomical and Services Administration (PAGASA). More than 40 years later in 1986, the seismological observations function were transferred to the Philippine Institute of Volcanology (PHIVOLC) by virtue of an executive order. PHIVOLC thus became the Philippine Institute of Volcanology and Seismology (PHIVOLCS).

PHIVOLCS is mandated to issue earthquake information as soon as earthquakes occur and are felt by the populace. The Institute is also required to gather seismic data for use in conducting seismological researches. To achieve its number one mandate, it has to conduct 24-hour seismic monitoring. This means that each of the nine field stations must be manned by staff at all times for the whole year. Each time a moderate-to-large earthquake occurs, a staff member reads the phase readings and sends the report to the central station at Quezon City. A similar situation exists at the central office where seismologists also take turns in conducting a 24-hour daily monitoring shift.

When PHIVOLCS took over the responsibility of seismic monitoring from PAGASA, the takeover included the turnover of nine seismic stations equipped with the seismographs installed during a 1970s project of the United Nations Development Programme. These were analog, short period, single component instruments. There were also some photographic type accelerographs included in the transfer but they were not operating when PHIVOLCS acquired them because of a problem with the film needed to process the records. Seismic data processing while at PAGASA made use of computer main frames. Since this computer setup was also being used in meteorological observations, the computing setup was not included in the transfer to PHIVOLCS. Hence, manual plotting using paper and compass had to be employed in the early years of seismic observations at PHIVOLCS. It was two years after the reorganization that computerization of parameter determination started. Seismic equipment consisted of short-period analog seismographs. Seismic data was transmitted daily via single-side band radios which became noisy with static noise at night and clears only during the day. Since most of the stations were in remote areas and the telephone system in the Philippines was limited to urbanized cities, no efficient telephone system was in place in the PHIVOLCS stations for use in data transmission. When the July 16, 1990 earthquake occurred, the said situation existed. Realizing that any upgrade of its network would entail a huge cost, PHIVOLCS sought grant aid from the Japan International Cooperation Agency (JICA) to upgrade its seismic network to a modern, digital system. In preparation for the project's approval, PHIVOLCS constructed new buildings, hired and trained technical personnel in seismic observations to man additional seismic stations. These stations were designed in such a way that these stations were ready in terms of space for additional equipment as well as to house field observers and their families. This arrangement helped assure the continuous presence of staff in the stations. Finally in the year 2000 after several years of negotiations, PHIVOLCS finally realized its dream when instrumentation in each of its 34 seismic stations was upgraded to a digital recording system.

This upgrading had contributed much to the improvement of the quality of seismic data being collected by PHIVOLCS. The provision of GPS clocks and the use of digital data processing computers and software has improved the accuracy of phase arrival time data. The provision of three component short period seismometers and recorders facilitated accurate determination of the S-wave arrival time. This used to be very difficult using a single component instrument. The above resulted in more accurate determination of the earthquake hypocenters and magnitudes. Digital recording has improved data archiving since digital data is much easier to store, retrieve and process than analog data. More advanced and high level data processing can be applied to the digitally recorded data and more in-depth information can be extracted which was not possible before using analog records. In addition to this, it is now possible to record not only weak motions but also strong motion due to strong earthquakes through the provision of three component strong motion sensors and digital recorders in each of the 34 seismic stations. This will result in the generation of a digital strong motion database which will be very useful for studying the regional seismic attenuation properties of the crust and for conducting regional seismic hazard evaluation.

Fortunately, most of our field personnel operating the stations have engineering degrees and have been previously trained in the use of computers and digital data processing software so that they had an easier time in learning the new system. We also have a group of well trained instrumentation personnel who are in charge of repair and maintenance of the PHIVOLCCS instruments. A sufficient amount of spare parts and appropriate test equipment was also provided for quick trouble shooting and repair. Each station is operated and manned on a 24 hour a day basis and at least two personnel take turns in operating the station. Every morning, the station operators are tasked to discriminate earthquake signals from the record and pick the phase-arrival times, amplitude, frequency and duration using a digital data picking software. The picked data are transmitted to the main office in Quezon City using telephones, fax machines and single side band radios. In cases of felt or large magnitude earthquakes, all station operators are required to immediately process the data from their respective stations and send the data to the main office. At the main office, received data from the field stations is immediately evaluated and processed to determine the location and magnitude of the earthquake. If it has sufficient magnitude and has potential to cause damage, a bulletin is rapidly disseminated to the public. A regular check up of the instrument health and calibration is also done by the station operators. At the end of every month, a summary of the station operation is prepared and mailed to the main office together with an MO disk containing the copies of triggered and continuous recordings. Final archiving of all the waveform data from the field station is done at the main office using data from all the collected MO disks. One special feature of the new system is the capability for automatic picking and transmission of phase data to the main office. Appropriate software and hardware is installed in every field station with available phone lines. At the main office, a corresponding computer setup anticipates and receives the automatically transmitted data. Another computer setup connected on LAN to the data receiving computers will automatically evaluate the received data and discriminates if an earthquake event has occurred. If an event is declared, automatic location of epicenter and magnitude calculation is done and a bulletin for that earthquake is automatically generated and made available to the Fax-on Demand system for easy downloading by the public. With the use of the new setup, PHIVOLCS can release information to the public in about 15 to 20 minutes after the occurrence of an earthquake. Before, it used to be 1 to 11/2 hour.

2. FUTURE PLANS FOR SEISMIC OBSERVATIONS IN THE PHILIPPINES

The planned Phase II of this project will provide for a sufficient number of telemetered stations in the seven most active volcanoes of the Philippines for a near real-time evaluation of their seismic activities. In addition, each of the other remaining volcanoes will be supplied with at least one telemetered station. The aim is to detect any anomalous pattern in seismicity that may indicate an impending abnormal volcanic activity. This setup will allow PHIVOLCS to be able to put into place a more dense seismic network should any volcano shows signs of unrest and to adequately monitor and keep track of their future activities. Likewise, in areas which are seismically active, telemetered seismic stations will also be established in order to complete our network coverage. The resulting dense network shall improve the detection capability of the Institute and will allow for the recording of smaller magnitude earthquakes which usually precede large earthquakes. If foreshock activities are adequately monitored and their pattern properly recognized, the probability of an impending large magnitude earthquake could be confidently evaluated and sufficient warning could be provided to the public. Phase II will also give us the capability to install temporary observation setups consisting of portable seismographs equipped with GPS timing systems, portable data processing setups and advanced communication systems. This is to enable PHIVOLCS to quickly respond to seismic crises through the rapid deployment of a suitable network of monitoring instruments. The communication facilities will enable the field investigating team to quickly relay scientific findings to PHIVOLCS Central Office or other authorities who have to make immediate decisions and warnings.

3. SEISMIC HAZARD STUDIES IN THE PHILIPPINES

3.1. Paleoseismology and Active Faults Mapping

Mapping of active faults had been done by various groups of earth scientists in the Philippines such as the groups of the Mines and Geosciences Bureau (MGB), the Philippine National Oil Company (PNOC), the University of the Philippines (UP), etc. Unlike their work, however, PHIVOLCS was the only one who went further and did trenching of some of these faults for paleoseismological studies. At present, PHIVOLCS actively pursue paleoseismological studies of the West Valley Fault and portions of the Philippine Fault zone. Aerial photo interpretation, remote sensing analysis and field checkings are being done to delineate accurate location of these faults.

3.2. Ground Shaking Hazard Studies

Early seismic hazard assessment studies in the Philippines were done by various authors. Hatori (1979) computed the maximum acceleration for rock for 50-, 100- and 200-year period for different places in the world including the Philippines. However, Hatori failed to consider the location and activity of tectonic structures such as faults and subduction trenches and used a limited earthquake database from 1901 to 1977. Su (1988) prepared regional probabilistic maps using data from 1964 to

1983. His work was the first attempt to consider earthquake source zones based on current understanding of Philippine tectonics and seismicity at that time. Daligdig and Besana (1993) computed the maximum peak ground acceleration (PGA) in the Metro Manila area assuming an epicenter located on the west Valley Fault System. They however assumed the epicenter to be a point source rather than a line source which results in high intensity close to the point source and lower intensity in other segment of the fault away from the assumed epicenter. Their report also failed to discuss details of how the location of the epicenter was selected and how the values were derived. Molas and Yamazaki (1993) computed the probability of certain peak ground acceleration values occurring in the Philippines but like Hatori's work, they did not consider earthquake source zones (faults) although their earthquake database covered a much longer time than that of Hatori's work. The work of Thenhaus et al (1994) perhaps is yet the most comprehensive work on probabilistic seismic hazard assessment for the Philippine region. Their work made use of a longer seismic database covering the period 1589 to 1992 and also considered seismic source zones and tectonic structres. Despite differences in database and source zones, Thenhaus et al's results compared quite well with the results of Su. High peak ground acceleration (PGA) values were both observed in the Casiguran Fault-East Luzon Trough source zone while low values were noted in the Cebu-Negros-Bohol, in central Visayas. The Metro Manila area got values from 0.22 g for hard rock to 0.60 for soft soil at 10% probability of not being exceeded for the next 50 years. With the availability of the historical earthquake catalog from the work of Bautista and Oike (2000), attempts are being made now to make updated probabilistic hazard maps for the Philippines. More recently, Bautista et al (2001) prepared a deterministic seismic hazard assessment of Metro Manila. In their study, they first identified the earthquake source zones and then they divided the metropolis into small grids. The peak ground acceleration (PGA) from each of the source zones on each grid was computed using Fukushima and Tanaka's attenuation equation. The inputs to the equation are the maximum magnitude from each source zone, which in this case are the maximum credible earthquakes (MCE) and the nearest distances of the grids from the fault lines or fault planes. The highest possible PGA contributed by each source zone was then computed. The study also included the possible effects of local site condition in the calculation of the final PGA. They used the ratios from observed horizontal peak ground acceleration to actual deposits given by Fukushima and Tanaka (1990). Then, the resulting grid file was multiplied with the gridded Horizontal PGA map to obtain the amplified PGA map. The study showed that based on the distribution of the calculated PGA values that the VFS is the dominant structure contributing to ground motion hazards in Metro Manila. This is despite the larger magnitude values assigned to other earthquake source zones. High horizontal PGA values were aligned and followed the trends of the fault lines of the East Valley fault and the West Valley fault.

3.3. Liquefaction Hazard Studies

Most of the liquefaction hazard studies started after the July 16, 1990 earthquake. These studies were limited to liquefaction-environment identification and sedimentological studies of the liquefied sand layers (e.g. Torres et al). Among the results is the generation of a regional liquefaction prone map of the Philippines. More recently, a project on liquefaction hazard studies of Metro Manila was initiated. The study made use of local geology and borehole information to produce a liquefaction susceptibility map of the metropolis. The next steps involve inclusion of ground motion hazard in the susceptibility map to produce the liquefaction potential map. Future studies are proposed to apply the same methodology for other key cities in the country.

3.4. Tsunami Hazard Studies

Not very many studies had been done concerning tsunamis except for mapping tsunami impacted areas of recent earthquakes. The thrust being aggressively pursued is the numerical simulation of possible future tsunami affected areas. Meanwhile, a historical tsunami catalog is being prepared as one of the primary inputs to the simulation.

3.5. Other Studies in Seismology and Seismic Hazard Assessment

(1) Seismic Microzonation of Key Cities in the Philippines

For the last ten years, PHIVOLCS has been co-implementing a project on Seismic microzonation of Metro Manila using microtremor observations. This year, the results of their study were published in a proceeding. Future plans include the application of the same methodology to other quickly-developing cities.

(2) Geophysical Studies in Metro Manila

A Monbusho-funded project to generate data in Metro Manila that could provide information on subsurface characteristics was performed. To achieve this aim, geophysical experiments such as seismic refraction, array microtremor, operation of strong motion instrument and gravity measurements were done. Results of these have recently been published. The same project also produced software that computes ground shaking hazard using active fault locations and earthquake epicenters.

(3) Databasing of Digital Strong Motion Data

This project aims to create a database of strong motion data that could be made available on the internet for other researchers. This is in cooperation with the Earthquake Disaster Mitigation (EDM)-EQTAP-RIKEN and the Tokyo Institute of Technology.

(4) Regional and Global Data Exchange

PHIVOLCS sends data to the National Earthquake Information Center (NEIC) and the International Seismological Center (ISC) every month to help improve global location. Exchange of digital data is also being performed as part of the project "Global Alliance of Regional Networks" (GARNET), a project funded by Japan's Science and Technology Agency. The data is sent to the GARNET headquarters in Japan using a compatible format. In return, PHIVOLCS gets consolidated seismograms and catalogs. Another regional data exchange cooperation is the Asian Network-Rapid Exchange of Strong Earthquake Data (ASNET-RESED). This is a typical data exchange where earthquake phase arrivals are exchanged between cooperating countries during large earthquakes. Two STS-2 Streickheisen instruments have been deployed in two of the seismic stations of PHIVOLCS as part of a collaborative project with Kyoto University. Data is sent to Japan regularly for consolidation with other results from other STS-2 stations.

(5) Ground Deformation Studies of Active Faults

Some collaborative projects are being implemented to monitor regional plate motion using GPS. No sustained project exists for a continuous monitoring of active faults using any ground deformation instrument.

(6) Short-term Earthquake Prediction

A collaborative project on short-term earthquake prediction is being implemented together with Chinese scientists and the United Nations. This project uses crustal stress anomalies to detect any impending earthquake. A network of 10 crustal stress monitoring stations was established in the period 2000 ~ 2001. Data is read by local people and is sent by fax or email to PHIVOLCS for processing. PHIVOLCS and the Chinese scientists process the data together. Another possible collaborative project is the use of electrical signals to predict earthquakes. This is still in the planning stage.

(7) Seismic Vulnerability Analysis

Seismic vulnerabilities of buildings, bridges and lifelines have been started in Metro Manila. Measurements of the natural period of about 100 buildings in Metro Manila was conducted for the purpose of databasing them and comparing the results with existing structural codes. A technique to assess vulnerabilities of horizontal structures like bridges was also developed together with the Association of Structural Engineers of the Philippines. Lifelines (electric power, telecommunications substations and water pipelines) have also been databased and plotted on seismic hazard maps preparatory for assessment.

(8)Rapid Earthquake Damage Assessment System

A project to develop capability to make a rapid earthquake damage assessment system is now underway. The project aims to develop or adopt the most appropriate models for each of the ground shaking, liquefaction, tsunami and landslide hazards. A computerized system will be developed that can immediately compute the possible effects of these hazards after an actual earthquake. This is an important stage because the first few minutes after a large earthquake are very crucial in making decisions pertaining to relief and rescue operations, and for having an idea of the possible impacted areas. It is also important to know the expected level of ground shaking at different areas and the probability of the occurrences of liquefaction, tsunami and landslide. This project aims to develop a system where all this information, including the corresponding elements at risk can be rapidly assessed and identified.

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