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DAMAGE CAUSED BY TYPHOON-INDUCED LAHAR FLOWS FROM MAYON VOLCANO, PHILIPPINES

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ABSTRACT

Severe rainfall associated with the passage of super-typhoon ''Reming'' on November 30, 2006 triggered lahar flows, landslides and flash floods on the south-eastern quadrant of Mayon Volcano, resulting in extensive damage to life and property. Among the affected areas, the towns of Guinobatan, Camalig and Daraga suffered the most damage, with numerous houses, roads and other infrastructures either buried or swept away by the flowing lahar and rampaging floodwaters. This paper outlines the observations from the reconnaissance work conducted at the affected sites following the disaster, with emphasis on the hydro-geological aspects of the disaster and their impact on civil engineering structures and other infrastructures. Moreover, the properties of the lahar samples obtained near Mayon Volcano were analyzed and compared with the lahar deposits from Mt. Pinatubo.

Key words: grain size distribution, rainfall, site investigation, volcanic coarse-grained soil (**IGC**: B2/B3)

INTRODUCTION

On November 30, 2006, super-typhoon ''Reming'' (international code name: Durian) struck Bicol Region in the southern part of Luzon Island (*see* Fig. 1) and caused widespread flooding, damage to properties and triggered landslides and mudflows in eleven provinces. ''Reming'' had maximum sustained winds of 190 kph at its center and with gusts of up to 225 kph. The province of Camarines Sur was greatly affected by the strong winds and floodwaters, while Catanduanes Province was isolated after it was struck by strong winds. Thousands of passengers in Sorsogon ports were stranded. However, the province of Albay suffered the worst damage, with the intense rainfall triggering flash floods and lahar flows from the slopes of Mayon Volcano. Casualties caused by typhoon Reming reached a total of 655 deaths, 2,437 injured and 445 missing (OCD-5, 2007). Damage to properties all over the country, comprising of infrastructure damages and agricultural losses, was estimated to be over PhP 608 billion (OCHA, 2006).

Among the affected areas, hardest hit were the towns of Guinobatan, Camalig and Daraga, all in Albay Province and located at the southern foot of Mayon Volcano, with most of the fatalities occurring in these three towns. In addition, damage to civil engineering structures was also extensive, with numerous houses, several bridges and slope protection measures being either washed away by the moving debris and flash floods or covered by lahar, a rapidly moving mixture of volcanic ash, pyroclastic materials, debris and water.

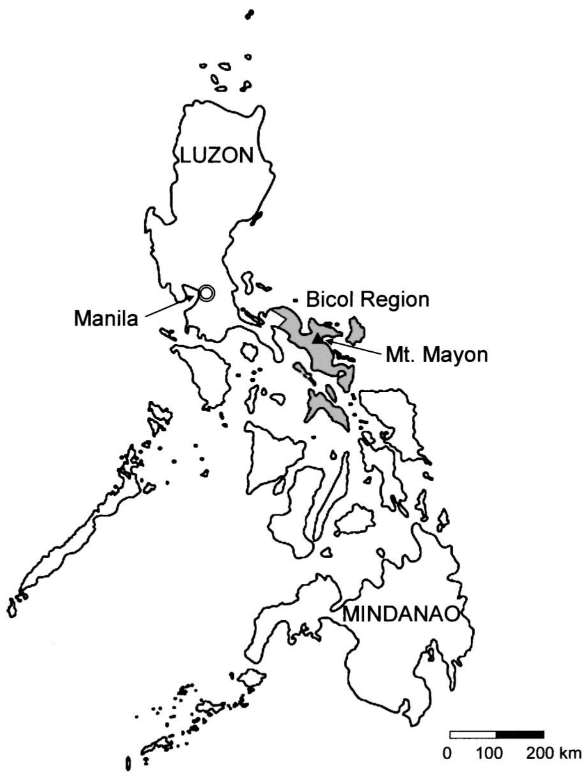

Fig. 1. Map of the Philippines showing the locations of Bicol Region and Mayon Volcano

In this paper, the observations derived from post-disaster investigation undertaken in the province of Al-

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bay on January 14-18, 2007 are presented, and the causes of slope failures and damage to civil engineering structures are discussed. Furthermore, lahar samples were obtained from several sites in the affected areas and the geotechnical properties were compared with the lahar sediments from Mt. Pinatubo, which devastated several towns in Central Luzon in 1991.

GEOLOGIC AND TOPOGRAPHICAL SETTING

The province of Albay is located in the south-eastern part of the Luzon Island known as the Bicol Region. It is bounded on the east by the Pacific Ocean, on the north-east by Lagonoy Gulf, west and southwest by Burias Pass. Two-fifths of the entire land area of Albay is characterized by plains and flat lands. The greater portion of these flatlands is in the north-western quadrant. The entire province is surrounded by mountain ranges. The western portion is characterized by low and rolling mountain ranges of less than 600 m in height. The eastern side of the province is where comparatively high and volcanic mountain ranges lie, including Mts. Mayon, Malinao and Masaraga.

Mayon Volcano (*see* Fig. 2), a strato-volcano known for its almost perfect cone, has a height of 2,462 m and has a base circumference of 62.8 km (Albay Province website, www.albay.gov.ph). Famous for its extraordinary symmetry, Mayon is also one of the most active volcanoes. Mayon has erupted 49 times since the first documented activity in 1616. Thus, its symmetric cone was actually formed through alternate pyroclastic and lava flows. The upper slopes of Mayon are steep, reaching up to 35–45°. Punongbayan and Ruelo (1985) have shown that lavas are the dominant content of Mayon edifice only from the summit to the 500 m elevation. Pyroclastic flows characteristically occur during each major episode. Some pyroclastic flow materials accumulate between 2000 m and 500 m, principally in flunk gullies, but the principal zone of pyroclastic flow deposition is between 500 m and 300 m. From 300 m to 200 m, pyroclastic flow and lahar deposits are roughly equal in abundance; and below 200 m, lahars are almost exclusively the transport and deposition mechanism (Punongbayan and Ruelo, 1985).

Fig. 2. A view of Mayon Volcano and the buried villages and rice fields at its foot

Lahars occur during approximately one-third of Mayon's eruptions, when humid, near-surface air is entrained by eruption updrafts, generating heavy rains on the volcano slopes. The resulting runoff mobilizes hot ashfall and pyroclastic flow debris into lahars that flow down gullies which existed prior to the eruption, and scour out new channels. These flows caused the greatest damage to the heavily cultivated and populated volcanic apron during eruptions. Two thirds of Mayon eruptions of record did not immediately trigger lahars, but debris often has been mobilized into lahars by monsoonal and typhoon rains of appropriate density and duration months or even years after an eruption (Fernandez, 1971).

DAMAGE CAUSED BY RECENT VOLCANIC ACTIVITIES OF MAYON

Mayon volcano has been a site of frequent pyroclastic flows, lava flows and minor ashfalls accompanied by eruptions. The vulcanian eruptions in 1984, 1993 and 2000 resulted in large quantity of volcanic products which were re-deposited on the slopes of the volcano. These erodable pyroclastic materials were the ones mobilized by the intense rainfall associated with tropical rainfalls and typhoons in the form of lahar and debris flows. The 1984 eruption produced large volume of hot ejecta and large pyroclastic flows that descended along numerous southern gullies. Heavy rains during the eruption resulted in 41 lahars of varying sizes in 17 gullies (Umbal, 1986). At least 7 of the eruption lahars overtopped their banks and buried their surroundings with up to 5 m of debris. An estimated 10^7 m^3 of coarse debris inundated an area of about 3.9 km^2, and caused damage to crops, roads, and bridges and destroyed 158 houses (Umbal, 1986). One year later, a typhoon packing winds of only 56 km/h induced a 2-day rainfall of 127.8 mm in the area, triggering lahar and debris flows, with estimated volume of 0.3 million m^3 burying an area of 0.2 km^2 (Rodolfo, 1989; Rodolfo et al., 1989).

The 1993 event produced pyroclastic flows which descended 6 km down through the gullies at the southeast side of the volcano. Secondary lahars triggered by tropical rainfalls were also generated after the eruption, amounting to between 1–2 million m^3. A total of 70 people were buried alive due to the pyroclastic flow while more than 100 people were injured by this event (Okada et al., 1993). The eruption in 2000 was characterized by relatively quiet dome extrusion at the summit crater and emission of lava flow to the southeast flanks followed by the occurrence of pyroclastic flows which also descended along the gullies southeast of the crater. Vigorous pyroclastic ejection with tall ash columns and voluminous and multiple pyroclastic flows generally characterized the peak of eruptions. The 2000 eruption was preceded by 7 months of precursory phreatic explosions, forcing the authorities to evacuate thousands of people living within the radius of 8 km around the volcano. All in all, some 24,000 people were evacuated out of the danger zones with no deaths attributed to direct impact by the eruptions (Corpuz and Punongbayan, 2000).

On the other hand, the eruptions in 2001 and in August 2006 were strombolian in nature, where lava flows were produced. The 2001 eruptions were characterized by strong explosions, multiple pyroclastic flows around the volcano and lava that flowed into gullies on the southeastern flanks of the mountain (OCHA, 2001). There were no reported injuries but more than 25,000 people were evacuated as an Alert Level 5 (hazardous eruption ongoing) was declared. The July-August 2006 eruptions were preceded by a swarm of earthquakes followed by small-ash emissions and small lava flows. Volcanic activity gradually became more intense, and large explosions produced incandescent ejections of lava fragments, ash, gas, and steam. Lava flows from Mayon travelled south-southeast along the Mabinit Channel to a maximum distance of 6.8 km from the summit, while small lava flows and incandescent blocks descended adjacent gullies. The volume of lava discharged was estimated to be between 36–41 million m^3. Voluminous steaming accompanied the lava extrusion. More than 40,000 people were evacuated

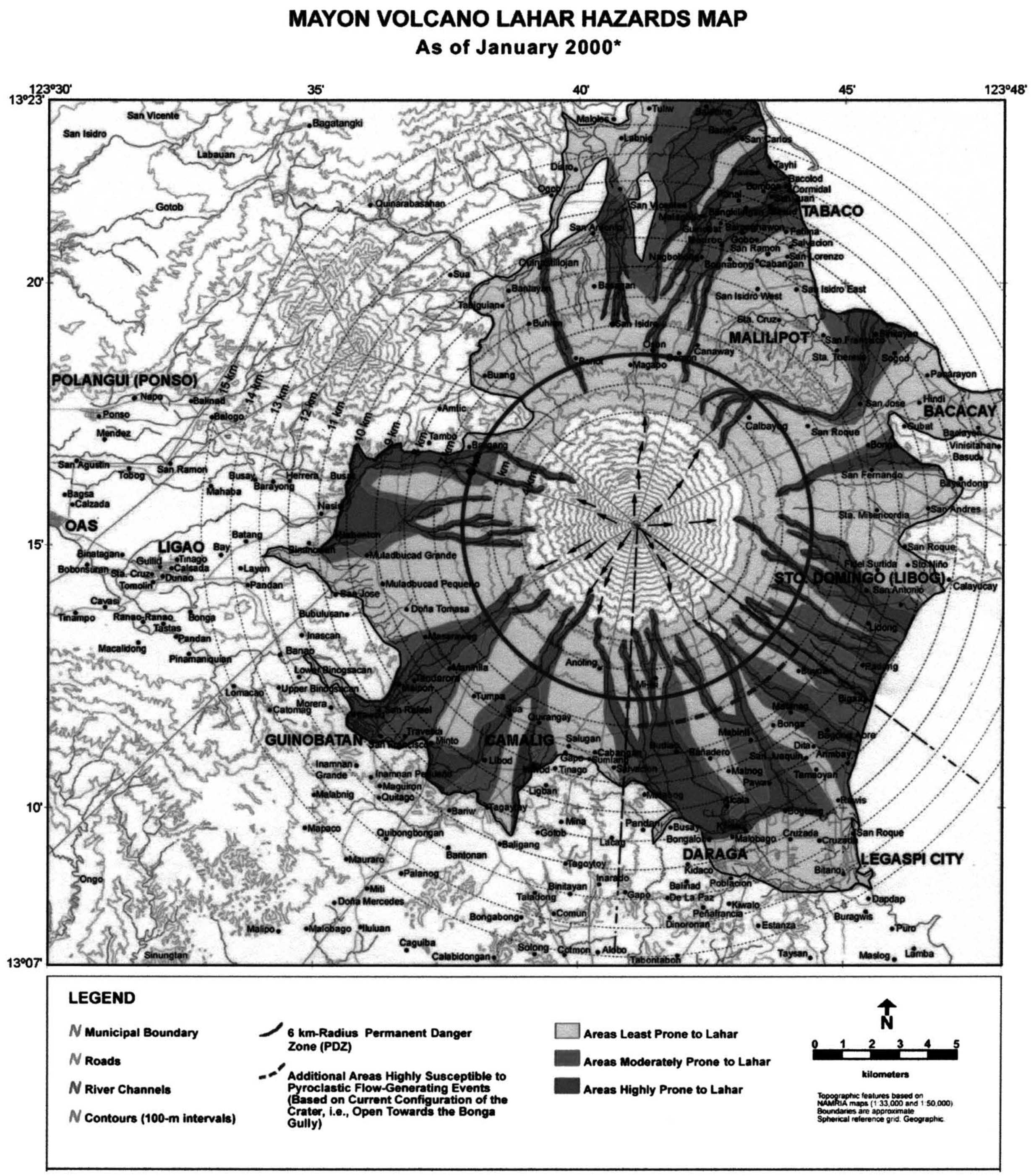

Fig. 3. Hazard map as of January 2000 showing areas in the vicinity of Mayon Volcano susceptible to lahar flow (Map courtesy of PHIVOLCS)

from inside the Extended Danger Zone (PHIVOLCS, 2006a). The lavas hardened along the flanks of the slope and, in the process, they stabilized the underlying older deposits and prevented them from being washed down.

From these eruptions, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) has produced a hazard map to delineate areas adjacent to Mayon Volcano which are highly susceptible to lahar flows. The map has been modified regularly to account for changes in the topography of the volcano after each major eruption. The latest hazard map (as of January 2000) in the vicinity of Mayon Volcano is shown in Fig. 3. Note that areas highly prone to lahar flow are those adjacent to active river channels. Also indicated in the figure is the permanent danger zone (PDZ), the area within 6-km radius from the summit of the volcano, where danger is present at all times and the hazard involved during eruption is high. Entry to the PDZ is prohibited once eruption becomes imminent. The PDZ is extended to 7-km radius in the southeast sector of the slope where the crater rim is low.

RAINFALL CHARACTERISTICS

Albay has two climatic regions. On the western side, rain is evenly distributed throughout the year. On the eastern side, on the other hand, there is no dry season but there is pronounced maximum rainfall from November to January. The average monthly rainfall recorded in Legazpi rainfall station, located on a plain near the eastern coast of the province and about 12 km from the crater of Mayon Volcano, obtained by PAGASA (Philippine Atmospheric Geophysical and Astronomical Services Administration) from 1971–2000 is shown in Fig. 4. The average monthly rainfall during the rainy season (November-January) is 457 mm, while the average annual precipitation is 3487 mm.

Prior to the passage of typhoon ‘‘Reming’’, several other strong tropical cyclones visited the Philippines' area of responsibility. Among these, ‘‘Henry’’ (known internationally as Prapiroon) cut across Luzon as a mere tropical depression beginning on July 31st but still killed 6 people. ‘‘Milenyo’’ (known as Xangsane) passed through the central Philippines in late September. This strong storm made its initial landfall at Category 2 intensity on September 27th and was responsible for at least 200 fatalities in the country. Super Typhoon ‘‘Paeng’’ (known as Cimaron) struck Luzon on October 29th as a powerful category 5 storm and left behind at least 19 people dead. This was followed less than two weeks later by ‘‘Queenie’’ (known as Chebi), which also hit Luzon. The storm made landfall at Category 3 with only 1 fatality (TRMM, 2006).

The biggest disaster for the season came at the end of November when Super Typhoon ‘‘Reming’’ (known as Durian) struck Albay province in the central Philippines on November 30th. The storm dumped a tremendous amount of rain, which combined with loose volcanic ash and sediments on the slopes of Mayon Volcano to generate massive landslides and lahar flows. The rainfall records for the period November-December 2006 obtained in Legazpi Rainfall Station is shown in Fig. 5. It can be seen that during the passage of typhoon ‘‘Reming’’ on November 30th, 466 mm of rainwater fell in the area.

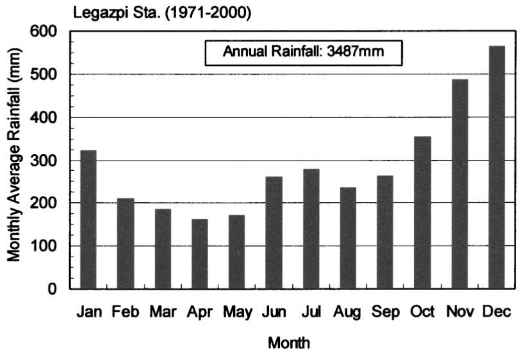

Fig. 4. Monthly average rainfall in Legazpi City (data from PAGASA)

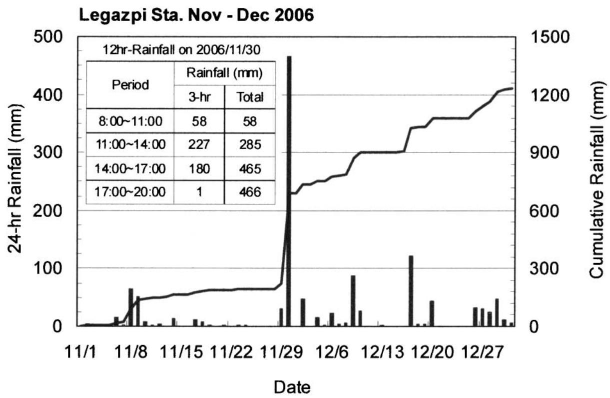

Fig. 5. Rainfall records for November-December 2006 in Legazpi City and rainfall details during the passage of Typhoon Reming (data from PAGASA)

A detailed time history of the rainfall event is also shown in the figure. Rain started to fall on the area before 8:00 AM and during the next 9 hrs, the rain intensified and dumped intense rainfall, measuring about 465 mm. By 5:00 PM of the same day, the rain stopped. This is consistent with the observation by witnesses that heavy downpour, accompanied by quick rise in flood water and the occurrence of lahar flow, occurred during the period between 10 AM and 3 PM.

Comparing this rainfall record with the average precipitation in the area, it can be said that the 9hr-rainfall during the passage of ‘‘Reming’’ on 30 November 2006 is almost equal the average November rainfall of 486 mm, indicating that it was indeed an extraordinary event. Officials claimed that this is the highest recorded rainfall in Legazpi in over 40 years (Daep, 2007).

OUTLINE OF DAMAGE

The combined impact of the floods and mudflows/la-

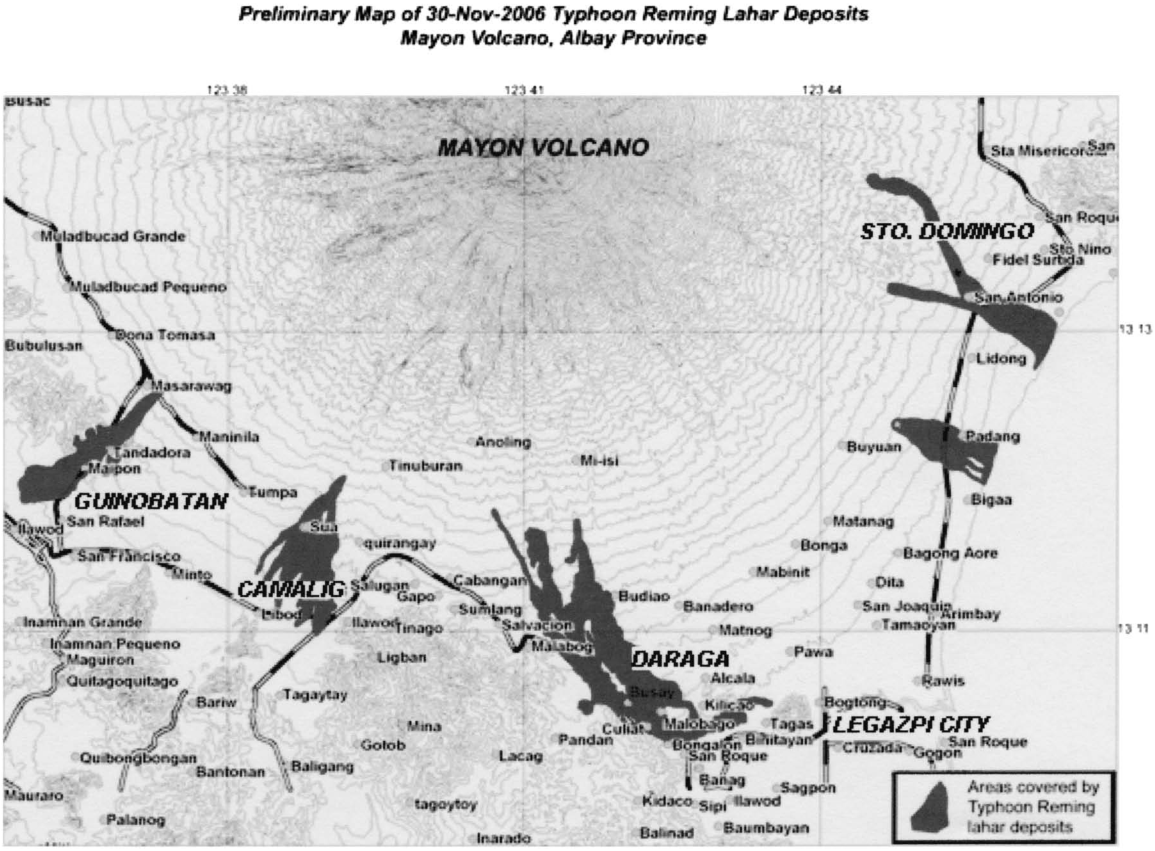

Fig. 6. Preliminary map showing areas covered by lahar deposits caused by the passage of typhoon Reming (Map courtesy of PHIVOLCS)

har flows triggered by heavy rains from typhoon ''Reming'' buried at least 8 villages (locally known as barangays) in Albay and caused significant loss of life and damage to property, severe disruption to daily life and damage to infrastructure. The lahar flows were induced after the intense rain washed down old sediments and boulders deposited from previous eruptions on the Mayon slopes. The sediments flowed down to the populated areas, well beyond the 6-km permanent danger zone from the crater of Mayon Volcano, through active river channels and drainage basins. When these were filled up by the sediments, the succeeding lahar flows followed the natural topography, destroying rice fields, roads and houses along the way. Lahar flows buried extensive areas and back-flooded debris-choked tributaries. Reming's fury also caused widespread floods and power outages in the province, knocked out telecommunications, and brought transportation in many areas to a standstill.

Disaster reports (OCHA, 2006; OCD-5, 2007; Albay Provincial Government, 2006) indicate that in Bicol Region alone, more than 1100 people were killed or missing, 2437 were injured and 130,220 were displaced. Moreover, 231,566 houses were totally destroyed while another 314,401 were damaged. The Department of Agriculture documented damages to various agricultural commodities and infrastructures amounted to PhP 2.7 billion. Damage to infrastructures, such as national roads and bridges, flood control, seawalls, drainage structures, lahar mitigation and other infrastructures amounted to PhP 1.5 billion. Damage to school buildings exceeded PhP 1.8 billion (Note: US$1 = PhP 46).

Based on the results of damage investigation, the areas affected by lahar flows were concentrated in the towns of Guinobatan, Camalig and Daraga, all located to the south of Mayon Volcano. In addition, Barangay Padang in Legazpi City and Barangay San Antonio in Sto. Domingo town, both located on the east side of the volcano, were also affected. Preliminary assessment made by PHIVOLCS (2006b) indicates that the affected areas are those as shown in Fig. 6. It can be observed that these areas coincide with the locations identified by PHIVOLCS as highly prone to lahar flows, as shown in Fig. 3. Details of damage observed in various towns are discussed below.

Guinobatan Town

The town of Guinobatan is considered the hardest hit municipality in Albay, with Barangay Maipon almost fully covered with lahar. Numerous houses in the area became uninhabitable as they were buried by about 2–3 m thick lahar deposits (*see* Fig. 7). Large boulders, some with diameter greater than 1 m, were strewn all over the area. Trees and houses disappeared, and the area became a virtual wasteland. Before the typhoon struck, the Department of Public Works and Highways (DPWH) performed dredging operation in the nearby Maninila River. Residents claimed that as a result of this operation, Maipon became a catch basin of mudflows and

Fig. 7. Houses in Barangay Maipon buried by lahar

Fig. 8. Large channel created by the flowing lahar in Masarawag River is shown on the left photo. Photo on the right shows the river dike which successfully prevented the lahar from damaging residential houses on the west side of the dike

floodwaters. However, the sheer volume of lahar that flowed from the mountain slopes and the observation of how lahar flooded other areas negate this contention.

In Barangay Masarawag located further north of Maipon, a large channel, measuring 50 m wide and 10m deep, was formed by the moving lahar as it flowed from the volcano toward the downslope direction, demonstrating its erosive nature (*see* Fig. 8). The pre-typhoon river was located about 20 m to the west of this channel. Apparently, the initial lahar flows filled up the river channel and the subsequent flows sought alternate paths. Fortunately, the lahar eroded only rice fields and coconut plantations in this area and spared several houses located to the west of the former river channel which were guarded by a 2 m-high dike, which is also shown in the figure. During the site visit, many residents were seen inside the said channel, now the site of a new river formed, unmindful of the instability posed by the vertical channel walls.

Another site of heavy damage caused by rampaging floodwaters was Barangay Travesia. In this area, a large chunk of the bank adjacent to San Francisco River was scoured by the floodwater and debris, carrying with them numerous houses built along the bank (*see* Fig. 9). In the same location, at least 4 piers of the Philippinc National Railways (PNR) rail track which crossed the river were lost as their foundations were scoured, resulting in collapse of the track girders.

Fig. 9. Scoured river bank in Barangay Travesia, Guinobatan Town. The dotted line on the photo indicates the former location of the river bank. The collapsed rail track can be seen at the background

During the first three days after the disaster, the town of Guinobatan was not reached by the Legazpi-based disaster officials because of power interruption, downed communication facilities and roads blocked by rocks washed down by lahar, floods and landslides.

Camalig Town

In Camalig town, large areas were damaged by flooding and lahar flows. In Barangay Gapo, several houses built adjacent to the river were covered by lahar as high as 2–3 m. As in other places observed, the sediments filled up the river channel and the flowing lahar sought other paths, preferably those of least resistance.

Some evacuees interviewed at the nearby Camalig North Elementary School, which was serving as evacuation center, remembered loud sound before the lahar occurred–sounds of boulders crashing down as the floodwaters carry them from the slopes of the volcano. On the other hand, some also heard the whoosh of winds, the impact of intense falling rain on roof tops, as well as the panic voices of people trying to flee from the typhoon's wrath.

Residents mentioned that the roads in the town proper were also covered by floods and lahar sediments. However, none was observed during the site visit as town officials undertook extensive cleaning operation in the days following the disaster.

Daraga Town

One of the worst-hit areas in Daraga was the area adjacent to Cagsawa Ruins, a popular tourist attraction in the area. The February 1814 eruption of Mayon Volcano buried Cagsawa Church, leaving only its belfry protruding on the surface. In the present case, the site of the ruins was not damaged because it was located in a higher ground. The river forked into two, with the Ruins in the middle, destroying almost all structures along the way. The debris-choked river channels overflowed their banks, flooded most of the houses built on the side and buried others with several meters of lahar (*see* Fig. 10). The floods and lahar forced residents to run to the roofs of their houses and emergency workers had to rescue them from the roof tops.

In Barangay Binitayan, the lahar sediments filled the river channel, causing the river to swell and flood the nearby areas. Some of the residents fled to higher grounds and evacuated to the nearby school. Some villagers said they wanted to run away, but the wall of water rushing to them forced them to stay indoors.

Legazpi City

Legazpi City, the capital of Albay Province and the center of its commercial and trade activities, was not spared from damage due to typhoon Reming. Ricefields between Lingnon Hills and Mayon Volcano were littered with scars of eroded channels. The eastern side of the city, especially in Barangay Padang, was also covered by lahar flows (*see* Fig. 11). Evacuees interviewed mentioned that the event transpired very fast. The whole barangay was devastated and wiped out by the lahar flow and several people were injured by boulders and roofing materials. Residents now call the place "black desert", referring to the color of the volcanic debris.

Legazpi Airport was shut down for a couple of days after the passage of the typhoon as debris littered the runway and the windows and part of the roof of the terminal were destroyed by the typhoon. Fortunately, the com-

Fig. 11. Aerial view of the lahar flows in Barangay Padang. Note on the left side of the volcano slope the trace of lava flow from the August 2006 eruption

Fig. 10. Buried houses in Cagsawa

mercial district of Legazpi was spared from lahar flow. Nevertheless, floodwaters inundated most of the area, especially those adjacent to the Yawa River, disrupting transportation and affecting the business activities in the whole Bicol region.

LAHAR CHARACTERISTICS

The rivers of debris and rocks that thundered down from Mayon Volcano at the height of Super Typhoon ''Reming'' were part of the massive deposits of volcanic debris deposited on the volcano's slopes by its series of eruptions. Devastation from sediment-laden floods and lahars were concentrated on the southern portion because most of the ash fall and pyroclastic flow deposits during previous eruptions were concentrated in this region. PHIVOLCS estimate that previous eruptions deposited as much as 140 million m^3. On the northern side, there were no lahar flows observed, primarily because of dense vegetation and not so significant deposition of pyroclastic flow materials in recent times (PHIVOLCS, 2006b). The total volume of lahar washed down from the slopes was estimated to be in the order of 20 million m^3, covering a total area of approximately 10 km^2. It should be mentioned that the lahar flows were not in anyway associated with the activity of Mayon Volcano, which was on Alert 1 (the lowest level indicating that there was no threat of hazardous eruptions) since a month before the typhoon.

Similar widespread devastation caused by lahar flows was observed following the eruption of Mt. Pinatubo in 1991, considered as one of the largest volcanic events of the 20th century. In the case of Mt. Pinatubo, an estimated 6 billion m^3 of pyroclastic materials and volcanic ash were deposited over a 4000 km^2 area, including the eight river basins that drain the volcano (Tayag, 1991). Thus, although similar patterns of damage were observed in the case of Mayon Volcano, the volume of materials and the affected areas were of much smaller scale than the one in Pinatubo.

To investigate the geotechnical characteristics of lahar from Mayon Volcano, samples were obtained at four sites; three at downstream locations buried by lahar flows (Cagsawa, Masarawag and Gapo), and one at the northern slope of Mayon Volcano adjacent to the Planetarium (located at Elev. 1600 m). All the lahar materials were dark in color. The grain size distributions are shown in Fig. 12, while the index properties are listed in Table 1. It can be observed that all the lahar samples from Mayon Volcano were of similar grain size distribution. They are generally gravelly sand in nature with very low fines content (F_c = 2–6%). The mean diameters were also very similar (D_{50} = 0.44–0.61 mm).

Also indicated in the figure and table are the index properties of lahar samples obtained from Mt. Pinatubo, which were investigated earlier by Orense and Zapanta (2002). Pinatubo 1 sample was collected in the downstream section near the town of Guagua (about 40 km southeast of the crater), while Pinatubo 2 sample was collected in the upstream section adjacent to Angeles (near the location of the former Clark Air Base, about 20 km southeast of the volcano). Pinatubo lahar was brownish white in color. The grain size distributions of Mt. Pinatubo lahar are very much similar to those of Mayon Volcano, although the mean diameter (D_{50} = 0.80–1.06 mm) is a

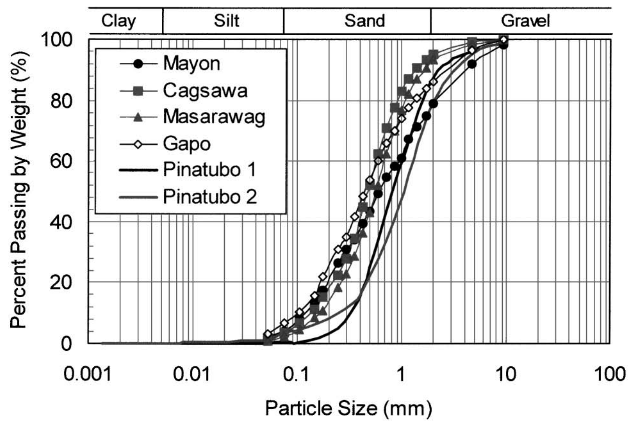

Fig. 12. Grain size distribution of lahar samples obtained from various sites in Albay. The figure also contains grain size curves for samples obtained near Mt. Pinatubo

Table 1. Index properties of various lahar samples

Sampling Site	Soil particle density (g/cm^3)	Permeability coefficient k (cm/s)	Gravel content (%)	Sand Content (%)	Fines Content (%)	Mean Diameter D_{50} (mm)	Uniformity Coefficient C_u	Curvature Coefficient C_c
Mt. Mayon								
Mayon	2.81	1.56	20.88	75.09	4.03	0.61	7.76	0.72
Cagsawa	2.93	1.96	4.73	91.83	3.44	0.48	4.14	1.34
Masarawag	2.83	2.89	6.80	91.07	2.12	0.58	4.00	1.15
Gapo	2.78	1.06	13.71	79.77	6.52	0.44	5.87	0.92
Mt. Pinatubo								
1. Guagua	2.67	11.6	12.39	87.22	0.39	0.80	3.06	5.31
2. Angeles	2.74	6.00	20.80	75.41	3.79	1.06	0.95	1.33
Typical Soil								
Toyoura	2.65	2.89	0	100	0	0.20	1.24	0.91

k is estimated empirically using Hazen's equation based on effective grain size D_{10}.

little larger. The coefficients of uniformity are also very similar. This would suggest that the permeability characteristics, and probably the transportability, of the two materials are similar. The coefficients of permeability, estimated empirically using Hazen's equation based on the effective grain size, D_{10}, support this contention. Nevertheless, further tests are needed to confirm this.

For comparison purposes, the index properties of typical soil, such as Toyoura sand, are also indicated in Table 1. Note that the densities of soil particles from Mt. Mayon are much higher than those from Mt. Pinatubo and Toyoura sand. Generally, soil particles which are colored black are relatively heavy-weight ($Gs = 2.7$–4.0) and have high aluminium and iron content, while soil particles which are colored white are relatively lightweight ($Gs =$ 2.5–2.7) and have high silica content. Indeed, mineralogical investigation showed that Pinatubo bi-products consisted of 64.5% silica (Bernard et al., 1997); on the other hand, volcanic products from Mayon mainly composed of plagioclase and pyroxene, which are high in magnesium and iron (Ui and Catane, 1993). Thus, from mineralogical and chemical point of view, the source materials of the two volcanoes are very different. Currently, however, there are no existing literature connecting the mineralogical composition of Pinatubo and Mayon lahars to their geomechanical properties; therefore, this may be a good subject for future research.

LESSONS LEARNED AND RECOMMENDATIONS

With its climatic and mountainous conditions, the Philippines is one of the most disaster-prone countries in the world. With large-scale natural disasters occurring almost regularly, such the 2004 landslides and debris flows in Quezon Province and 2006 Guinsaugon (Leyte) large-scale landslide, implementation of disaster mitigation strategies is very important. Moreover, as previous events have shown, the lahar flows of 2006 would certainly be not the last to occur in the region.

First is in the area of hazard assessment. Considering that the affected areas have been previously mapped by PHIVOLCS as highly prone in the event of lahar flows, it is obvious that technical knowledge is available to evaluate the hazard. Existing hazard maps should be re-assessed as the deposited lahars modified the existing landscape. Since present river channels have already been filled-up by sediments, adjacent areas deemed safe may now be prone to lahar flow.

Second is in the area of hazard management. Although sites prone to lahar have been previously identified, it appears that this information was not properly or adequately disseminated to disaster officials and to the community as a whole. Also, the development and/or further strengthening of community-based early warning system are recommended. Moreover, it appeared that some people became complacent after surviving Typhoon ''Milenyo'', the first of four typhoons that recently battered Bicol region. In Padang, for example, warnings were issued to the residents prior to the disaster, but they countered that they will vacate their houses once they see lahar coming. Apparently, the people mistook the fast-moving lahar flow as lava flow, which moves more slowly.

Disaster preparedness strategy was inadequately implemented. Because of the strong winds, rising floodwaters and thick lahar deposits covering some areas, access to the affected sites was difficult. Communication facilities were down and power outage was prevalent. These have greatly hampered collection of data and the process of damage and needs assessment, as well as actual delivery of relief goods and services. These highlight the need for redundancy in communication systems.

Land-use zoning in the slopes of the volcano should be strictly implemented. During the site visit, residents were observed to be living in houses situated well within the 6-km radius permanent danger zone.

Finally, existing engineering measures for lahar intervention should be re-evaluated and additional facilities be constructed. Prior to this event, sabo dams have been constructed at several sites to control lahar/debris flows, as well as spur dikes to channelize their movements (Baba, 1993). Moreover, dredging operations were conducted from time to time in some channels which have been filled up by previous eruption and sedimentation. However, subsequent lahar flows have destroyed some dams while rendering others useless because the topographic conditions on the south and south-eastern slopes of the volcano were considerably changed. Modifications in the upper stream condition of the channels made some spur dikes ineffective. Lahar sediments have choked up major tributaries, raising their bed elevations. Therefore, engineering measures, such as sabo structures, dredging/excavation, river improvement, shelter mounds, flood/lahar proofing of roads and houses, etc., need to be implemented. These disaster prevention measures should be planned and executed in accordance with the topographic formation process considering a long-time frame. Moreover, all measures require prompt action for maintenance and rehabilitation.

CONCLUDING REMARKS

The passage of typhoon ''Reming'' induced lahar flows and flooding in many areas in Albay Province, resulting in extensive damage to life and property. The combination of intense rainfall and the presence of loosely deposited volcanic sediments on the slopes of Mayon Volcano are the main culprits in this disaster. Although the ''overwhelming phenomena'' of heavy rainfall and the associated damage may be considered beyond the present capability of the region's disaster officials, valuable lessons have been learned from this disaster. Moreover, hard and soft countermeasures should be implemented to mitigate the effects of future disasters.

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