The November 15, 1994, M7.1 Mindoro Island Earthquake in the Philippines

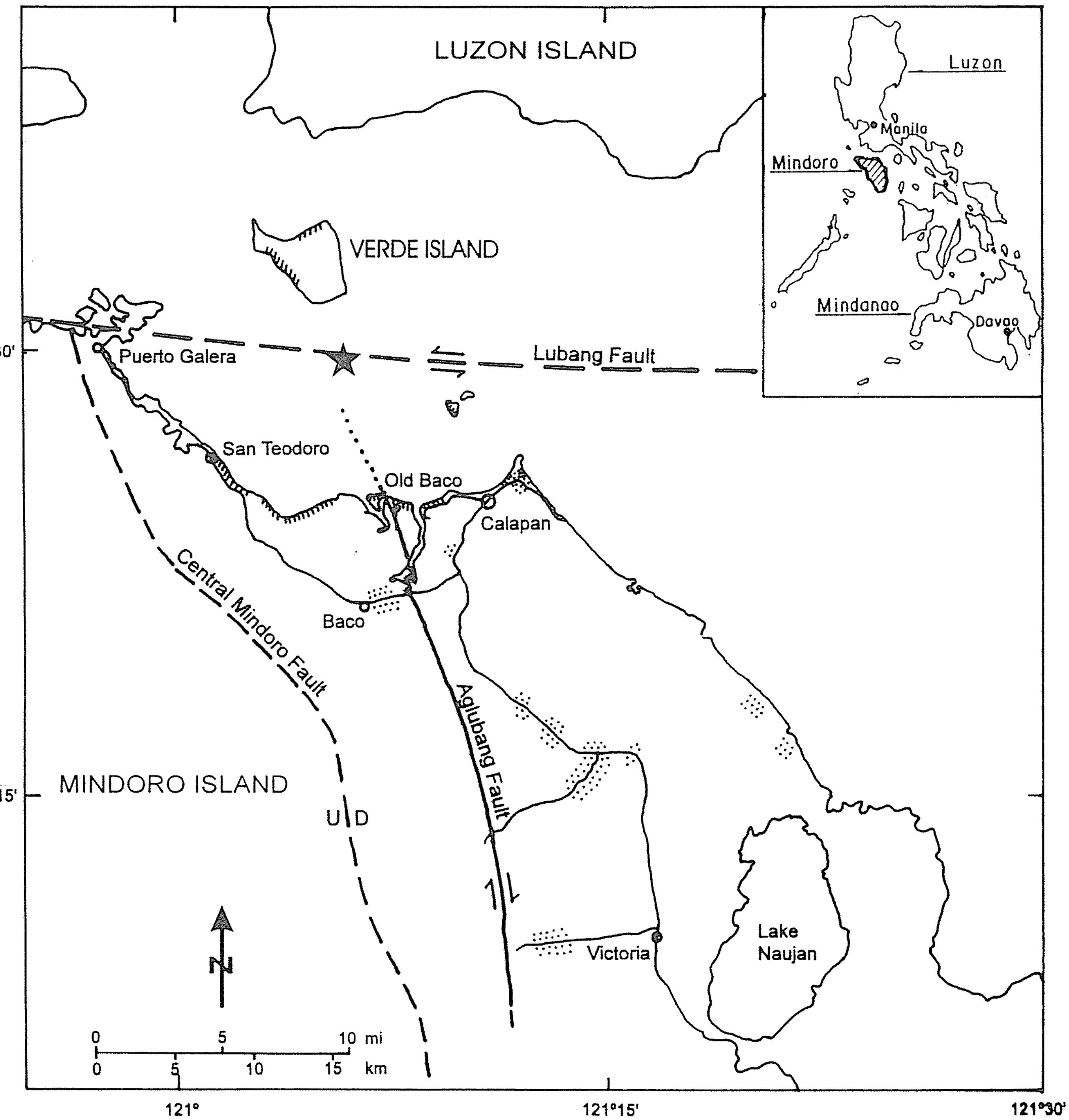

Figure 1—Map of northern Mindoro and southern Luzon islands showing location of surface rupture, liquefaction, and tsunami damage and other principal features associated with the earthquake. Stipple pattern shows location of liquefaction and lateral spreading, hachured pattern along coastline shows impact areas of tsunami, U—up, D—down on vertical slip faults, arrows show direction of movement of strike slip faults; star shows epicentral location of the M7.1 earthquake.

Introduction

At 3:15 a.m. on the morning of November 15, 1994 (local time), a major earthquake occurred near the northern coast of Mindoro, Republic of the Philippines. The immediate effects of the earthquake included a devastating tsunami along the northern coast of Mindoro, surface rupture, widespread liquefaction, and shaking damage to structures in northern Mindoro.

This report is compiled from information provided by the Philippine Institute of Volcanology and Seismology (PHIVOLCS) in *Special Report No. 2, 15 November 1994 Mindoro Earthquake: Preliminary Report of Investigation, PHIVOLCS Quick Response Teams*; and from observations made during several field trips to the epicentral area during the period of November 18-27. Field reconnaissance was carried out by the PHIVOLCS Quick Response Team; V. F. Porrazzo (Philippine Department of Public Works & Highways); and the Luzon Geohazard Mapping Project Team (D. Wells, A. Thomas, Geomatrix Consultants, San Francisco; B. Bulley, A. Bowden, Ove Arup and Partners, Manila; R. Quiambao, N. Tungol, Certeza Surveying and Aerophoto Systems, Manila; V. Villanueva, Department of Public Works and Highways, Manila). This report was contributed by EERI members V. F. Porrazzo and D. L. Wells.

The Earthquake

The Mindoro earthquake occurred at 3:15 a.m. (local Philippine time) on November 15, 1994, between Verde Island (13.5° N, 121.1° E, PHIVOLCS), between the islands of Mindoro and Luzon. The surface wave magnitude was M_s 7.1. A preliminary moment magnitude (M) of 7.1 was measured by the National Earthquake Information

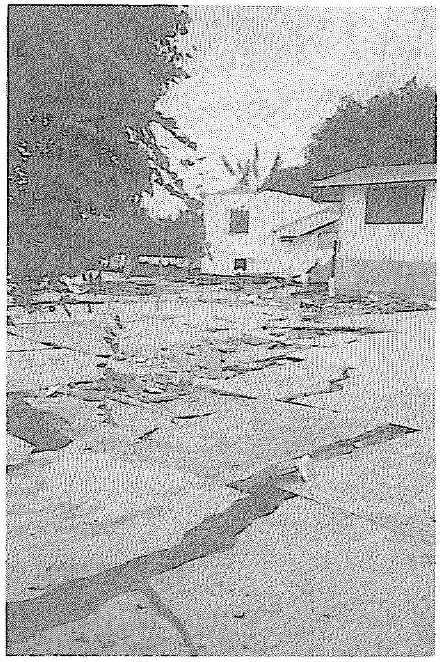

Figure 2—Trace of fault rupture as it passed through a residential lot, shattering concrete slab and displacing adjacent buildings. Fault movement in this area was slightly more than 2 m horizontal and 0.3 m vertical. Damage to these buildings appeared to be largely related to ground displacement rather than a result of strong shaking.

Center of the U.S. Geological Survey (USGS). The peak intensity in Calapan, capital and largest town of Mindoro Oriental, 10 km from the epicenter, reached Intensity VII of the adapted Rossi-Forel Scale. The earthquake and some of the stronger aftershocks were felt as far away as Manila, 125 km to the north of the epicenter.

The centroid moment tensor solution released by NEIC indicates dominantly right-lateral slip along a steeply dipping north-south trending fault. This is consistent with the orientation and sense of displacement of the mapped surface rupture. The focal depth was 7 to 12 km, and the rupture apparently propagated from north to south. Surface rupture has been mapped over a length of about 35 km from the northern coast of Mindoro to west of Victoria along a previously unmapped structure named the Agulubang fault (Figure 1). The sense of slip is dominantly right lateral, with a variable component of vertical displacement. The fault displaced numerous roads, irrigation canals, rice paddy dikes, and several residential buildings (Figure 2). The maximum right-lateral slip of 3.45 m was measured in the central reach of the rupture, the maximum vertical slip of 1.2 m was measured near the southern terminus of the surface rupture.

The occurrence of a large tsunami suggests that the rupture extended offshore towards the Lubang fault, or that a submarine slump occurred in the offshore region. Preliminary aftershock locations occurred over a broad area of northeast Mindoro and into the offshore region along the Lubang fault. Rupture may have extended southward in the subsurface along the Agulubang River fault, towards the Central Mindoro fault.

Tsunami

The earthquake generated a tsunami that devastated several small villages on the northern shores of Oriental Mindoro and adjacent islands (Figure 1). Accounts from residents living in these areas indicate that the tsunami arrived approximately 2 to 5 minutes after the main shock. The tsunami appeared at a distance as a white curtain-like formation moving from northwest to southeast. Residents reported hearing a loud roaring sound, like a gust of extremely strong rain, prior to arrival of the tsunami. It was also reported that the ocean receded about 50 m seaward before the tsunami arrived. Measured and estimated high water marks range up to a maximum height of 3-6 m at several locations (without tidal correction). The wave runup extended 50 to 300 m inland.

The tsunami scoured and eroded parts of the original coastline and nearshore sea bottom and deposited sand and debris inland. The waves transported small boats and massive pieces of coral inland, smashed concrete and nipa (light frame bamboo) huts (Figure 3), and swept occupants away. A power barge originally located near the mouth of Baruyan River at Calapan was separated from its moorings and transported about [illegible] km upstream by the tsunami. At least 58 deaths were attributed to the effects of the tsunami.

Figure 3—Severely damaged residence in the coastal town of Wawa. The tsunami was estimated to have attained a vertical runup of 2.5 m and a horizontal runup of 200 m in this area. The wave apparently exited back to the sea as indicated by the direction of compressed grass and bushes.

At Lake Naujan, located about 35 km south of Calapan, the earthquake generated a minor seiche with vertical runup of about 0.5 m on the northern shores. Residents reported that the lake became heavily silted, due probably to the agitation of lake bottom, and that the water did not become clear again for more than a week.

Figure 4—Liquefaction and lateral spreading cracks developed in a low-lying fluvial floodplain. Site is located within 1 km of the surface rupture. Note absence of damage to small concrete frame and hollow block structure.

Liquefaction

Ground failure due to liquefaction and lateral spreading was observed in numerous inland and coastal areas. Liquefaction resulted in the formation of sand boils in fields, lateral spreading of river banks and road embankments, and settlement of low-lying areas. Field observations indicate that liquefaction occurred extensively in fluvial settings, such as recently filled stream meanders and floodplains, and in coastal settings, such as nearshore and beach deposits (Figure 4). The liquefied materials were dominantly fine to coarse sands, containing some silt and clay. The liquefied beach sands included abundant shells and fragments of coral. The effects of liquefaction were particularly

Figure 5—Large collapse near airport and beach area formed in dirt road by venting of sand into low-lying area at right side of photograph. Road constructed on loose fill placed on sand deposits. Throat of sand boil is in center of photo, at rear. Note shallow water table and large volume of sand expelled towards top of photo.

where large fissures, some as large as 5 to 10 m long and 0.5 to 2 m deep, developed subparallel to the shoreline (Figure 5). In the inland areas, lateral spreading occurred along river banks and in point bar deposits, while sand boils occurred near the river banks, in abandoned stream meanders, and in overbank deposits on floodplains. Lateral spreading was observed along highways and roads especially in areas near the ground rupture (Figure 6). The damage to roads included large fractures up to 1 m in width and 2 m in depth; these fractures were especially well developed in areas where the roads were constructed on loose fill placed on saturated ground. The fill typically failed laterally towards lower ground, such that the road surfaces were split open along fractures parallel to the margins of the fill.

Liquefaction resulted in minor to moderate settlement of the ground, cracks in the floors and walls of buildings and adjacent pavement, and tilting and partial to total collapse of several buildings. Lateral spreading and settlement of the approach embankments occurred at many bridges throughout northern Mindoro. Some portions of the grass runway at Calapan airport settled due to venting of sand from boils on the airfield.

Changes in the groundwater system were manifested by the appearance of springs and by increases in discharge rates of existing artesian wells. In some areas, flow from existing wells decreased. Some of the new springs discharged warm water.

Casualty and Damage Reports

The Mindoro earthquake affected all 15 municipalities in the island province, including 273 villages. According to the Provincial Social Welfare and Development Office, a total of 22,452 families were affected with 77 people confirmed dead and 430 injured. The municipality of Baco sustained the largest number of casualties, with 41 confirmed deaths resulting from drowning due to the tsunami that hit the coastal area of Malaylay, San Andres, and old Baco. The capital town, Calapan, had the second largest casualty count, with 17 deaths in the village of Wawa, another coastal area struck by the tsunami. Almost half of these casualties were young children who drowned during the tsunami.

The municipalities of Calapan and Baco had the largest number of damaged houses, the majority of which were located along the coastal areas that were partially to totally damaged by the tsunami. The total number of houses affected was placed at 7,566; 1,530 were totally destroyed and 6,036 were partially damaged.

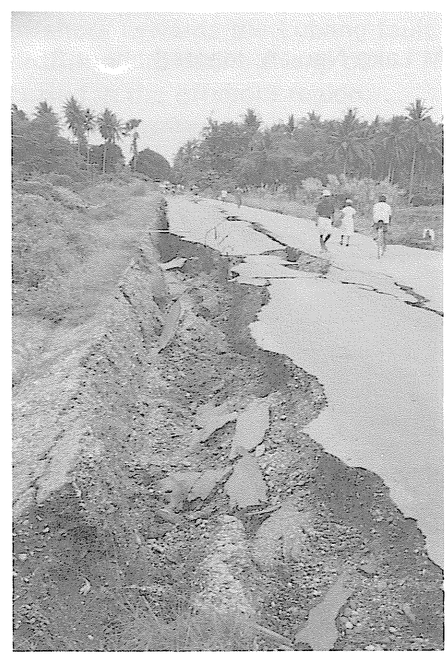

Figure 6—Typical liquefaction and lateral spreading damage along highway near Baco. This was probably one of the more dramatic and pervasive aspects of the earthquake. Site located within 2 km of surface rupture.

Eighteen bridges were damaged, and there was extensive road damage due to liquefaction and lateral spreading. The main pier and adjacent terminal building at Calapan Harbor was damaged, limiting ferry access for a period immediately after the earthquake. The loss of the power barge near Calapan, which supplies electrical power for much of northern Mindoro, resulted in extensive power outages. Another power barge was brought to Calapan and power was restored on November 28. Water supplies were disrupted due to ruptured water lines and the lack of electricity to run pumps.

Initial estimates of damage to infrastructure and private properties are placed at 156 million Philippine pesos (approximately $US 6.25 million).

Response of Buildings

Calapan, the capital of Mindoro Oriental Province and largest population center in the area, is situated approximately 10 km from the epicenter of the earthquake and was reportedly strongly shaken. As in most areas of the Philippines, small commercial and residential buildings consist of light wood structures, while larger commercial and some residential buildings are constructed as reinforced concrete frames with hollow-block infill walls.

The altar table (marble slab) at the main Catholic church in Calapan was shifted approximately 2 m horizontally. The slab was supported on square concrete legs which were not firmly attached to the slab or to the floor. The slab reportedly shifted with the concrete legs, but did not fall. No damage was apparent in the church's high tower. Damage was limited to separation along a floor slab joint and cracking of the concrete slab of a covered walkway connected to the main church structure. An adjacent three-story L-shaped school building showed damage due to pounding at an expansion joint and slight displacement of hollow-block infill walls.

The main customs building at the Calapan port was inspected and found to have sustained heavy damage due to displacements associated with localized liquefaction in the site fill. Displacements and settlements in the paved areas around the building continued into and under the building resulting in damage to walls and openings. The building's steel structural frame, while slightly distorted, did not appear to have been seriously damaged. The nearby ferry pier structure had been affected by pounding of the pier structure at expansion joints and the transition sections to the pavements on shore.

The Department of Public Works and Highways compound, which is situated in a former rice paddy, southwest of Calapan, suffered extensive damage due to liquefaction-induced ground failure. The compound is located on a thin fill (1-2 m thick) placed directly over saturated sediments in the rice paddy. Lateral spreading fractures extended across the width of the filled area, and light frame hollow block retaining walls at the margins of the fill collapsed outward as the fill settled. Concrete slabs and walls in several buildings were cracked, and buildings separated at joints between sections above the fractures in the fill.

A large, two-story wooden building in Calapan that collapsed after the earthquake was inspected; the wooden supports were severely rotted at ground level, indicating that any moderate level of shaking would have caused it to collapse. While a considerable number of houses in Calapan were reported to have been damaged (over 500), it is believed that many of these were, in fact, located in the nearby coastal villages that were struck by the tsunami. Damage to buildings also seems to have been largely associated with liquefaction and other ground failures rather than due to strong ground shaking. No serious cracking of building walls that might be associated with ground shaking was apparent in any walls of major structures in or around the town of Calapan. This might be considered to be rather less damage than would be expected considering the magnitude of the earthquake, proximity of the main population center to the epicenter, the generally low-quality associated with concrete construction in provincial areas, and the historically poor performance of weak hollow-block walls with respect to seismic shaking. Similarly, in areas immediately adjacent to the fault, severe damage to structures appeared to have resulted from tilting or subsidence related to liquefaction and lateral spreading or fault movement, rather than due to the effects of structural shaking *per se*.

Response of Bridges

A total of 18 bridges sustained damage due to the earthquake. The damage was often limited to settlement and cracking of the approach embankments due to liquefaction and lateral spreading effects. Five multi-span bridge structures were more seriously damaged and will need partial or complete replacement.

As in most of Mindoro Island, the surrounding locale is mostly devoted to agriculture, and the infrastructure is of a fairly basic nature. Many bridges in this area are old and poorly detailed for seismic resistance. Due to limited funds for infrastructure development, bridges are often constructed over periods of many years, through a number of construction contracts, necessitating the use of simply supported structures that can be easily lengthened. Such structures often consist of spans containing markedly differing types of piers and superstructures. Most existing bridges inspected were of reinforced concrete construction with some larger spans consisting of steel trusses or steel girder construction. All bridge superstructures were observed to be simply supported, often with narrow seat widths and high, rocker-type bearings. Most of the damage seems to be associated with extensive liquefaction of approach embankments and under piers rather than strong ground shaking effects. Abutment failures were often associated with large lateral spreading effects rather than due to acceleration of the superstructure into the backwalls.

A few of the damaged bridges located in the immediate vicinity of the surface rupture exhibited more extensive damage due to ground shaking effects, resulting in severely rotated abutments and broken pile heads (Figure 7); bridges located further from the surface rupture were observed to have undergone moderate movements of the rocker bearings, causing light damage to abutments and some pounding damage at bridge expansion joints. A number of bridge abutment failures also appear to have been associated with the presence of a deeply buried tie-beam connecting the bottom edges of the abutment wingwalls and serving to magnify the effects of soil movements. Poor repair procedures, such as the use of horizontal lagging between the piles supporting abutments (apparently placed to help retain previously scoured fill), was noted at one bridge abutment; such procedures probably contributed to the damage to the abutments. Bridge damage patterns for this earthquake appear to follow the classic cases as found to occur in many less-developed, seismically active areas: loss-of-seat failures, tilting of rocker bearings, foundation failures associated with pier tilting and liquefaction, subsidence of approach fills, etc.

Figure 7*—A simply supported, reinforced concrete deck and girder bridge that was badly damaged as shown by the severely rotated seat-type abutment with broken piles. Area is within 2 km of the fault in an upland terrace area. Damage to nearby concrete frame and hollow block structures indicates that this area experienced significant strong ground shaking, as well as extensive liquefaction and lateral spreading.*

Response of Other Engineered Structures

A number of elevated water towers were reported to have been damaged as a result of ground settlement and at least one small steel water tower was observed to have failed due to buckling of its steel leg supports. Several large welded-steel fuel tanks, located east of Calapan at two fuel depots, apparently were not damaged by the earthquake. These sites are underlain by medium- to coarse-grained beach sands. Only minor cracking, possibly due to settlement of the underlying sand, occurred in the concrete pads near the tanks. According to the site manager, fuel levels in the tanks ranged from nearly empty to full at the time of the earthquake. Excavations at the site show that groundwater is more than 2 m below the surface.

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