# Preliminary Report on the Geotechnical Aspects of the Philippine Earthquake of July 16, 1990

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**Synopsis:** The Philippine earthquake of July 16, 1990 ($M_s$=7.8), of which epicenter is about 100 km north of Manila city, was one of the most costly single natural disasters in Philippine history. The loss of life of over 1,600 persons resulted. Extensive damage to buildings, roads, embankments, natural slopes, and bridges was observed in a widespread area of approximately 20,000 square kilometers. One of the major causes of the damage was liquefaction of various sandy soils including artificially fills, alluvial deposits of river delta, and sandbars. This paper presents a preliminary overview of damage aspects of the earthquake, with emphasis on liquefaction-induced damage of various structures.

## INTRODUCTION

On July 16, 1990, at 4:26 P.M. local time, the central part of the Luzon Island, Republic of the Philippines, was shaken by an earthquake of magnitude 7.8. It affected a widespread area of about 20,000 square kilometers, and caused extensive damage. This was one of the most costly and serious single natural disasters in Philippine history.

At least 1,600 persons were killed by this event and its aftershocks, and more than 900 were still missing two weeks later. Over 3,400 were seriously injured. More than 25,000 homes were totally destroyed, and some 60,000 were partially damaged.

It also caused extensive damage to commercial and residential buildings, roads, embankments, natural slopes, and bridges. The major cause of the damage is associated either with a combination of strong shaking and inadequate design of structure or with ground problem including soil liquefaction. This paper presents a preliminary overview of damage aspects of the earthquake, with emphasis on liquefaction-induced problems of various structures.

## GEOLOGIC SETTING

The Luzon Island is the largest and most heavily populated in the archipelago of more than 7,000 Philippine islands. Fig. 1 shows the geological map of the Luzon. The region between the Gulf of Lingayen and Manila city is the Central Plains, classified as quaternary alluvium, which is surrounded on both sides by mountain ranges including Cordillera Central and Sierra Madre.

Tracing the northeast edge of the Central Plains is a part of the Philippine Fault zone of which total length exceeds 1,000 km. One of its branches entering the Cordillera Central is the Digdig Fault. The July 16 earthquake occurred along the Philippine Fault zone including Digdig Fault, with its epicenter being near Cabanatuan city at a depth of about 25 km, as shown in Fig. 2. Also shown in the figure is the trace of a 110 km surface faulting resulting from this event. The fault showed a left lateral movement up to 6 m. Photo 1 shows the surface faulting observed in a small town called Rizal about 30 km north of Cabanatuan. Although structures on the fault collapsed due to differential lateral movement of footings, no apparent damage was observed in nearby structures which were not on the fault.

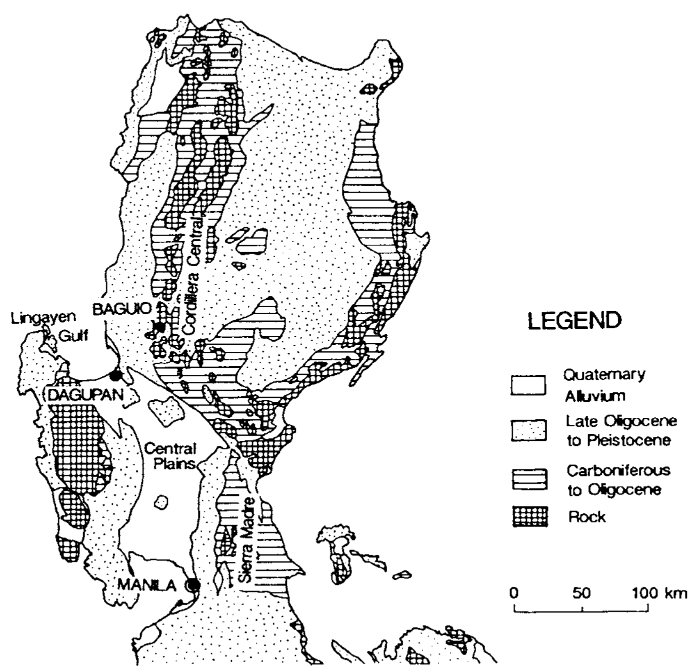


Fig. 1 Geological map of Northern Luzon


Fig. 2 Distribution of seismic intensity

**SEISMIC INTENSITY**

No strong motion records were registered for the main shock. A preliminary assessment of the regional distribution of modified Rossi-Forel intensity resulting from the event is shown in Fig. 2. Ground failure such as liquefaction and landsliding is related to Intensity VIII or greater. Intensity VIII was registered in Cabanatuan, Baguio, Agoo, Dagupan and Tarlac. Baguio is in the Cordillera Central, Cabanatuan and Tarlac in the middle of the Central Plains, and Agoo and Dagupan in the northern end of the Central Plains and facing the Lingayen Gulf.


Photo 1 Surface faulting near Rizal

**DISTRIBUTION OF AFFECTED AREA**

The damage associated with a combination of strong shaking and inadequate design of structure was observed mostly in Baguio and Agoo. Many multistory reinforced concrete-frame buildings collapsed, as a result of one of the following two failures: soft first story failure and multistory failure called pancake crush. Photos 2 and 3 show typical examples of these failures observed in Baguio city. Over 600 persons were killed or missing within the city as of July 29. It is interesting to note that only one old reinforced concrete building collapsed in Cabanatuan city near the epicenter.

Ground problems including soil liquefaction, in contrast, affected a widespread area including the sparsely populated epicentral area, the Central Plains from Tarlac to the Gulf of Lingayen. Most of the damage to roads, embankments, and bridges in these area was related to soil liquefaction. Soil liquefaction also caused extensive damage not only to wooden houses but also reinforced concrete buildings. A large number of buildings in Dagupan city suffered extensive settlement and titling due to

Photo 2 Soft first story failure of a building in Baguio

Photo 3 Pancake crush of a building in Baguio

soil liquefaction, raising up the total damage of the city.

Considerable damage to wooden houses also occurred in several towns along the Lingayen Gulf, and some towns in the Central Plains. Some of the villages facing the Lingayen Gulf were totally submerged below sea level due to considerable settlements of the ground surface as a result of soil liquefaction. The port of San Fernando was reportedly damaged due to soil liquefaction, and rendered useless.

## DAGUPAN CITY

### Affected Area

Dagupan city extends over the delta of several rivers which flow into the bottom of the Lingayen Gulf. The city has a population of about 110,000. The altitude of the city is only about 1 meter, and the water table is very shallow. Fifty eight percent of the total area of the city is for fishponds or rivers, 27 % for cultivated lands, and only 15 % for commercial and residential areas. Thus, downtown Dagupan is surrounded by fishponds and rivers.

Fig. 3 shows a map of downtown Dagupan which is bisected by the Pantal River. The figure indicates the approximate zone in which buildings and houses were severely damaged as a result of bearing failure due to liquefaction of its foundation soil. The zoning was made based on quick inspection during our site visit. Most of the commercial buildings concentrated in the area from Burgos Ave. to M. H. Del Pilar St. and from A. B. Fernandez Ave. to Perez Blvd.

Also shown in the figure is the area which is considered to have slid toward the river, due to liquefaction of underlying soils. By and large, ground sliding or lateral spreading occurred on both sides of the river shown in the map, making structural damage within the area much worse. The slide which occurred on the right side of the river extended 150 m wide by 300 m long, causing extensive damage to over ten reinforced concrete buildings on them.

The bridge on Perez Blvd., called the Magsaysay Bridge, which has seven spans collapsed due to lateral movement and bearing failure of its piers. Photo 4 shows the collapsed bridge and the river which has been narrowed due to lateral spreading of both side of the river. The lateral displacement on the left side of the river appears significantly larger than that on the right side. Thus, at least 5 piers from the left side titled toward the right. Many wooden houses near the river were found to be submerged. The bridge on A. B. Fernandez Ave. appeared to be unaffected.

Over 80% buildings in the left side of the river suffered extensive damage, with buildings on and in the west of Galvan St. from Jovellaros St. to Gomez St. remaining intact. Much of the buildings on Perez Blvd. (Photo 5) and some buildings on Fernandez St. (Photo 6) settled and tilted considerably, whereas settlement and tilting of the buildings on A. B. Fernandez Ave. appeared generally smaller. The damage to super-

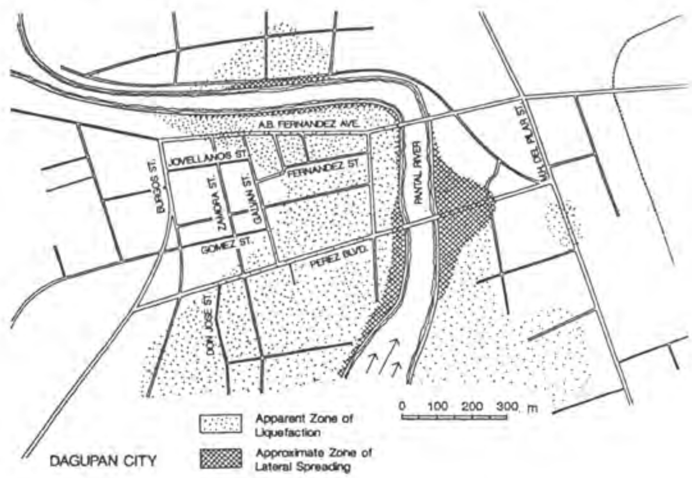


Fig. 3 Map of downtown Dagupan

Photo 4 Collapsed bridge and narrowed river

Photo 5 Bearing failure of three-storied building in Perez Blvd.

Photo 6 Damage in Fernandez St. - building is supported by a trapped van

Photo 7 Three-storied building settled by 2 meters

structure was significant in many buildings on this avenue, however.

Several multistory reinforced concrete buildings distributed within wooden houses in the south of Perez Blvd. suffered extensive settlement and tilting (Photo 7). Wooden houses in this area were also badly damaged. The ground surface along Don Jose St. settled by about 50 cm.

The damage to reinforced concrete buildings on the right side of the river was almost restricted within the sliding zone, though many wooden structures including two schools were significantly damaged in the south of Perez Blvd. The playgrounds of these schools were largely covered by ejected black fine sand. Many wooden houses on the sliding zone slid into the river and became submerged.

Uplifts and/or breaks of buried light-weight utilities such as tanks in automobile service stations, sewage tanks, and water and sewer pipes, and resulting pavement damage can be seen everywhere within the affected area. Many telegraph poles tilted considerably due to foundation bearing failure.

Most part of the affected area is considered artificial fills and/or alluvium deposits of river delta or old riverbed which are underlain by clay at a depth below 10 to 15 meters. The fills were reportedly built over fishponds or swampy lands several tens of years ago with fine sand. Several boring logs available suggest that, in general, the surface layer to a depth of 3 to 6 meters is a very loose sand in the affected area. It is conceivable therefore that the fills and some loose alluvium sandy deposits liquefied. Grain size distribution curves for the ejected sands indicated that they are very fine and contains significant amount of fines.

Damage Statistics of RC Buildings

According to the damage statistics of the city as of July 31, some 200 buildings were destroyed beyond repair and over 400 buildings were partly damaged, due to foundation failure. Nevertheless, only 13 persons were killed within the city. This contrasts well with the many fatalities in Baguio which were mainly attributed to the collapse of superstructures.

Fig. 4 summarizes damage statistics of some 120 RC buildings made by our team in the affected region. Over 90 % buildings were sampled from A. B. Fernandez Ave. and Perez Blvd. Most of the buildings are two to four storied with shallow footings and without pile foundations. It appeared that very few buildings have pile foundations and that no consideration was made in the foundation design to mitigate liquefaction hazards.

Also shown in the figure in dotted line are similar data for the damaged buildings in Niigata city after the 1964 Niigata earthquake. The figure indicates that over a half of the buildings tilted by more than 1 degree. The average settlement is found to be on the order of 50 cm which is considerably smaller than that observed in Niigata.

Significant settlement and tilting were observed in corner buildings, in buildings without adja-

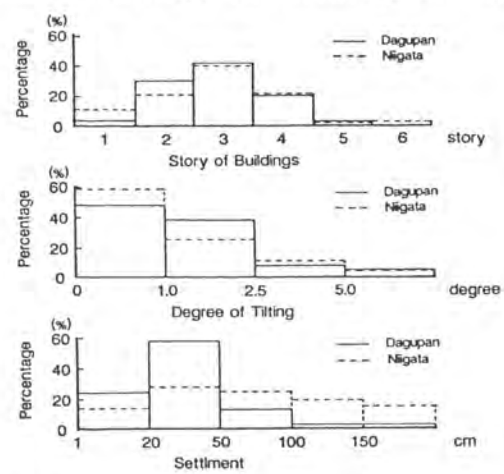


Fig. 4 Damage statistics of RC buildings in Dagupan compared with those in Niigata

Photo 8 Heaved slab due to bearing failure of footings

Photo 9 Inclined columns due to lateral movement of footings

cent buildings on one or both sides, and in buildings surrounded by light weight structures. The building shown in Photo 7 is the one that settled most in the city. It was in fact surrounded by wooden houses, and settled by about 2 meters and tilted by 17 degrees.

As stated previously, the settlement of buildings in A. B. Fernandez Ave. appeared small compared with that in Perez Blvd. This is partly because the buildings in A. B. Fernandez Ave. were constructed with little or no separation, which increased apparent width of foundation. Previous study by Yoshimi and Tokimatsu (1977) indicated that liquefaction-induced settlement of structure decreases with increasing foundation width.

Damage Patterns of Buildings

Relatively new buildings that have continuous foundations or mat foundations appear to have settled or tilted with their superstructures remaining intact or with little damage, as shown in Photos 5 to 7.

On the contrary, extensive damage to first floor slab and superstructure was apparent in many buildings that have individual shallow footings without tie beams or, if any, with beams of low rigidity. Photo 8 shows unreinforced slab which was heaved and broken due to foundation settlement and sand intrusion of a three-storied school. Photo 9 shows shear failure of exterior columns in a three-storied store, possibly caused by lateral movement of footings. No apparent damage was observed in interior columns. It appears that bearing failure and resulting settlement of the building pushed both foundation soil and exterior column footings outward. Photo 10 shows a two-storied building that suffered serious damage to its entire superstructure due to differential settlement. These types of failure were particularly noted in many old buildings in A. B. Fernandez Ave.

Much of obvious damage to wooded houses was associated either with differential settlement, large settlement, or differential lateral movement of their foundations. Otherwise, the damage was invisible from outdoor. However, more than 1,200 residential houses were report-

Photo 10 Significant differential settlement in two-storied school

Photo 11 Differential settlement due to partial bearing failure

Photo 12 Damage to house in sliding area

edly destroyed beyond repair and some 6,000 houses partially collapsed, affecting over 44,000 persons only in the city of Dagupan.

Photo 11 shows inclined corridor of a two-story wooden frame school which suffered significant differential settlement. Photo 12 shows a typical damage observed in the sliding area in which a wooden house was destroyed due to differential lateral movement of its foundation soil toward the river. Many wooden structures in the sliding area were submerged due to lateral spreading and subsidence of foundation soil.

Lateral spreading may also cause considerable damage to superstructure of reinforced concrete buildings. Photo 13 shows a warehouse which suffered differential lateral movement of footings. It was elongated by about 2 meters in the direction perpendicular to the river.

Photo 13 Warehouse in sliding area

Damage induced by structure-to-structure interaction was also evident in many places. For example, settlement and tilting of heavy concrete buildings affected damage patterns of adjacent structures of lighter weight. Photo 14 shows damage of a structure caused by the overlying building. Photo 15 shows differential settlement and associate damage of a light-weight structure, induced primarily by a larger settlement of the adjacent structures of heavier weight.

It is interesting to note that Dagupan experienced liquefaction about 100 years ago during the earthquake of March 16, 1892. This was the only earthquake that shook Dagupan with Intensity XIII or greater in the last 100 years. Soil liquefaction and associated damage in the city are clearly described in the following statement (Series on Seismology, 1985):

"Part of the court sank, the rest rendered useless; girls' school and pharmacy of Sr. Saston damaged, bridge of Bagoas made useless; masonry houses damaged; cracks in the ground, giving out water and black sand."

Photo 14 Damage to structure caused by overlying building

Photo 15 Damage to light-weight structure sandwiched in between heavier buildings

Photo 16 Homes submerged below sea level in Alaska, Aringay

Photo 17 Aerial view of a village submerged below sea level

**OTHER TOWNS ALONG LINGAYEN GULF**

Extensive liquefaction that occurred in sandbanks, sandbars, and alluvial river deltas along the coastline of Aringay and Agoo caused enormous damage to private homes. The total number of damaged houses possibly exceeded 10,000. Some sandbars settled extensively, making several towns submerged below sea level.

Photo 16 shows submerged homes in a village called Alaska, Aringay. Sandbars and levees enclosing fish ponds sank or slumped on the order of 1 meter due to soil liquefaction, making some 260 homes submerged below sea level. The affected area in the village extends about 1 km inland from the original seashore and stretches about 4 km along the coast. The total area submerged below sea level is at least 50 ha.

A similar ground subsidence was also observed in a small village on a sandbar in the south of Agoo. Photo 17 shows an aerial view of the village. Most of the homes in the village are now below sea level.

**CENTRAL PLAINS AND EPICENTRAL REGION**

Liquefaction also occurred in many alluvial sandy deposits in the sparsely populated epicentral region and the middle of the Central Plains, causing lateral spreading, and failure of embankments and roads. Photo 18 shows large ground fissures occurred along unpaved road crossing riceland near Rizal. Numerous large sand boils observed on riceland indicated that the liquefaction of underlying soil is the primary cause of the failure. Photo 19 shows damaged road near Rizal due to slope failure associated with soil liquefaction. Liquefaction induced damage of many houses was also reported in Gerona north of Tarlac.

Many bridges collapsed as a result of lateral spreading due to soil liquefaction. Photo 20 shows a collapse portion of the Carmen Bridge which crosses the Agno River in the north of Tarlac and connects Rosales to Villasis. This has thirteen 48 meter span trusses. Several piers on the Rosales side settled, tilted by up to 26 degrees, and possibly moved toward the

Photo 18 Large fissures near Rizal



Photo 19 Damage to road near Rizal

Photo 20 Carmen Bridge destroyed by lateral spreading due to soil liquefaction

Photo 21 Damage to Carvo Bridge and lateral spreading of its foundation soil

center of the river due to liquefaction and associated lateral spreading. As a result, first six span trusses from Rosales were destroyed or badly damaged, causing cut-off of the main root from Manila to the Northern Luzon. No structural damage was observed in the rest part of the bridge, except breaks in pin joints on the first piers from Villasis. Sand volcanoes were seen in the damaged area.

Similar lateral movement of pier also damaged the Carvo Bridge in the north of Tarlac, as shown in Photo 21. It has four 42 meter span trusses connecting Bautista and Bayambang. The first pier from Bautista moved toward the river by about 1 meter, causing a fall of the truss. Ground fissures occurred parallel to the river near the damaged pier.

## CONCLUDING REMARKS

The Philippine earthquake of July 16, 1990 ($M_s$=7.8), caused extensive liquefaction in artificially fills, alluvial deposits of river delta, sandbars, and sandbanks, which in turn caused extensive damage to buildings, private homes, embankments, roads, and bridges not only in the epicentral region but also the Central Plains between Tarlac and the coastline of the Lingayen Gulf. The most significant features associated with the earthquake are the liquefaction induced bearing failures in Dagupan and the ground subsidence in several towns in the coastline of the Lingayen Gulf. Although much of the damage resulted simply from the lack of engineering consideration for mitigating liquefaction hazards, the following aspects of the damage should be kept in mind: (1) damage caused by lateral spreading and/or differential lateral displacement in sliding and spreading zone, (2) damage amplified by structure-to-structure interaction during liquefaction, and (3) damage induced by significant subsidence of loosely deposited sandbars. Further research appears to be needed for developing method to identify area which is vulnerable to lateral ground spreading, sliding, and significant subsidence due to soil liquefaction.

## ACKNOWLEDGEMENTS

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