PRINCIPAL NEW ZEALAND EARTHQUAKES IN 1990

Warwick D. Smith[1]

During 1990 there were three shallow earthquakes which approached or exceeded magnitude 6. They were all felt very strongly, though damage was not extensive.

On February 10 there was an earthquake of magnitude 5.8 centred near Lake Tennyson, just north of Hanmer in North Canterbury. It was followed within 30 minutes by two large aftershocks, of magnitudes 5.5 and 5.3. Three hours later there was another, of magnitude 5.0. There are vivid eyewitness accounts from climbers in the mountains overlooking Lake Tennyson, who report that sections of the ridge they had recently been standing on were shaken down in the aftershocks. In forested areas, the earthquake caused healthy beech trees to snap off at a surprisingly constant height of 1.5 metres above the ground. A field survey using portable digital seismographs was mounted, and in one week recordings of over 4000 aftershocks were obtained. The three nearest stations of the national network were also particularly useful for this sequence: Tophouse, Kaikoura and near Lake Sumner.

Nine days later, there was another of similar size in southern Hawke's Bay of magnitude 5.9 and located near Weber, east of Dannevirke. It was followed on May 13 by a larger event (6.3) to which it was clearly related. The February shock was at a depth of 34 km and had a tensional mechanism. It was caused by tension in the subducting Pacific plate as it is being drawn down beneath the North Island. But this tensional earthquake actually increased the compressive stress in the overriding plate, thus triggering the compressional earthquake which eventually occurred in May. Aftershocks of these two were not as prolific as in the Lake Tennyson sequence, but there was one of magnitude 5.6 on August 16.

This phenomenon of one earthquake being followed a few months later by another, larger event, is one which has been observed elsewhere. The Loma Prieta earthquake in California in October 1989, of magnitude 7.1, was preceded several months earlier by a smaller shock. There have been similar instances in China. It presents a challenge to seismologists: can earthquakes which will be followed by larger ones be identified as such and be distinguished from moderate ones which occur in their own right? A clue may be in the characteristics of the aftershock sequence which follows the first earthquake, and this will be an area of investigation at the Seismological Observatory in the near future.

Damage in Dannevirke, the nearest town of any size, was surprisingly light. The epicentral distance was about 20 km for both earthquakes, and one might have expected damage, especially to old brick structures of which there are very many in the town. Detailed reports are available from engineers who visited immediately after the earthquake.

After the May 13 earthquake, an experiment was conducted to assess the effects of different soil conditions on intensities experienced in the Wellington region. A request for information on the severity of shaking, published in the Evening Post, brought nearly 3000 responses. Analysis of these results indicated markedly higher intensities on the areas of poorly consolidated sediments of Wellington and the Hutt Valley, and especially the sandy areas of the coastal strip from Paekakariki to Waikanae. Lower intensities were experienced in the hill suburbs. These were all moderate intensities, of course, up to MM VI. Extrapolation of the results to higher intensities needs to be done with caution.

There were 14 earthquakes of magnitude 5.0 or greater in the New Zealand region (south of 35°S): four were part of the Lake Tennyson sequence, four were near Weber, and four were to the north and east of the Bay of Plenty - East Cape region. The remaining two were in Jackson's Bay, north Fiordland, on July 10 (magnitude 5.1), and off Cape Palliser on October 6 (5.0).

The Cape Palliser sequence (from October 5 to 15) caused some alarm in the Wellington region. The October 6 shock displaced some goods from shelves in some southern Wairarapa localities, and there were reports of its being felt quite strongly in parts of Wellington.

There were also 13 earthquakes of magnitude 5.0 or more that were at depths of more than 100 km. Because they were so deep, felt effects were very modest, although reports came from widely spread locations.

It is not particularly common for earthquakes to be felt in greater Auckland, but on 21 December there was a shock of magnitude 4.1 on the Hauraki Plains which was reported felt in Papakura. It was felt most strongly in Morrinsville and Te Aroha.

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THE PHILIPPINES EARTHQUAKE OF JULY 16, 1990

Report on Field Visit

by the NZNSEE Reconnaissance Team

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ABSTRACT

On July 16 1990, an earthquake of magnitude 7.8 caused widespread damage, disruption and loss of life in Central Luzon, north of Manila.

This report presents the observations of a four person reconnaissance team (three engineers and an architect) sent to the Philippines two weeks after the earthquake, by the New Zealand National Society for Earthquake Engineering.

A summary and conclusions are presented first, with more detailed information following.

CONTENTS

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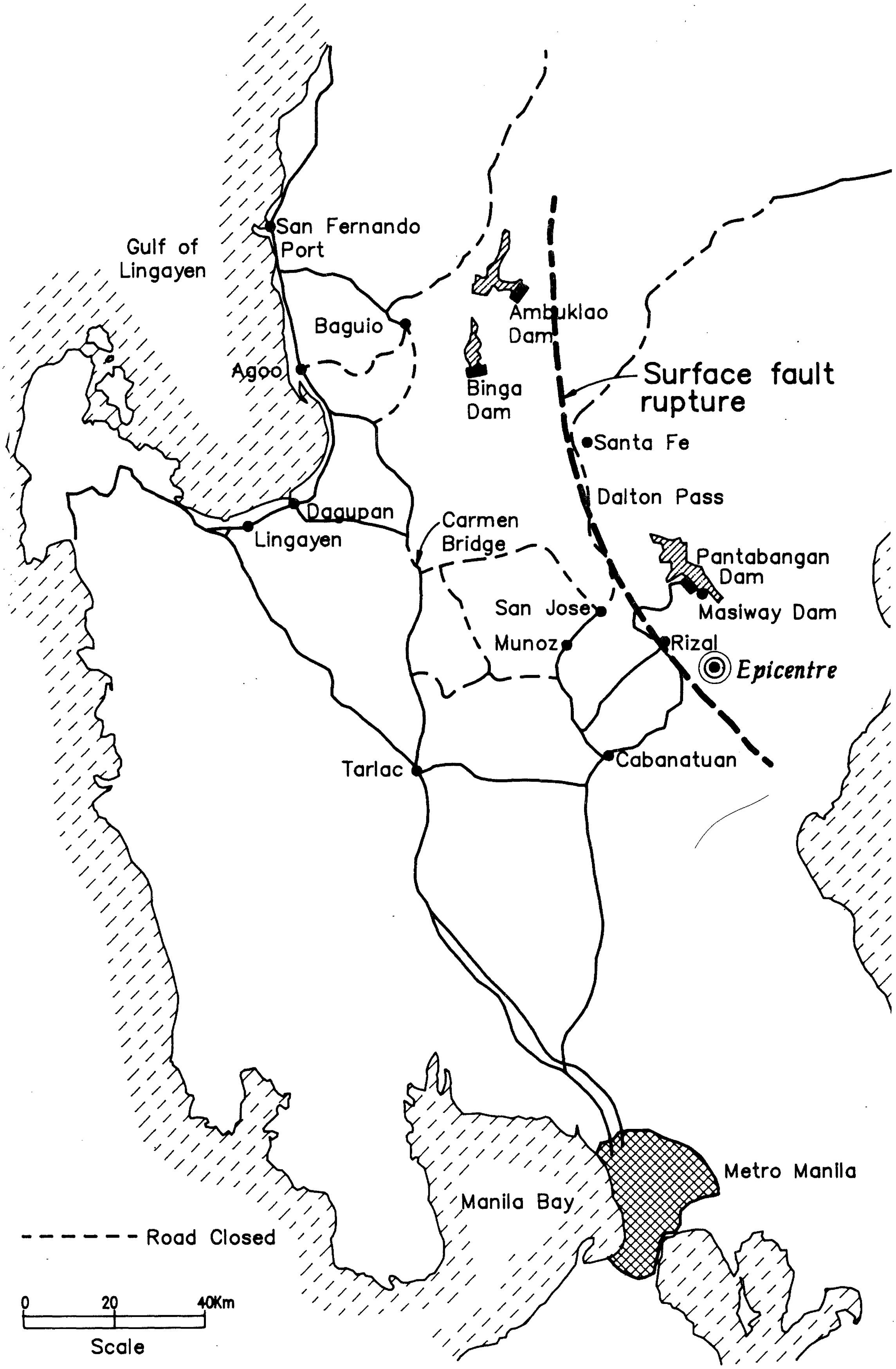


Figure 1.1: Central Luzon - Field Visit Map

SUMMARY AND CONCLUSIONS

INTRODUCTION

Background

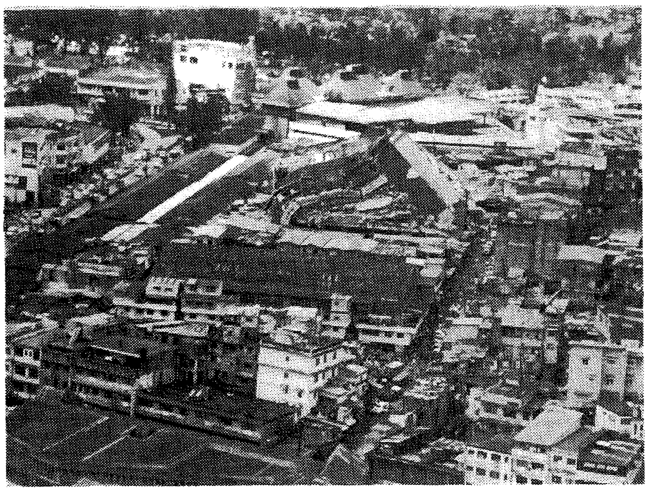
On July 16 1990, an earthquake of magnitude 7.8 caused widespread damage, disruption and loss of life in Central Luzon, north of Manila.

This report presents the observations of a four person reconnaissance team (three engineers and an architect) sent to the Philippines two weeks after the earthquake, by the New Zealand National Society for Earthquake Engineering.

During a ten day field trip the team visited the most affected areas, notably Baguio, Dagupan, Agoo, San Fernando Port, San Jose, Rizal, Cabanatuan and Manila, as well as three dams in mountainous areas. (Refer Figure 1.1). In addition to observing damaged and surviving buildings and infrastructure, discussions were held with various government and district officials and local consulting engineers and architects, who all provided valuable assistance, comments and introductions.

The report has two main objectives:

- to provide factual data based on first-hand observations
- to draw conclusions and derive lessons relevant to earthquake prone areas, particularly New Zealand.



Geology and Seismology of the Philippines

The Philippines is an archipelago of over 7000 islands and islets lying on the junction of two major tectonic plates, the Pacific and the Eurasian. The Pacific Plate is pushing the Philippines Sea Plate beneath the eastern side of the archipelago at the rate of 70mm per year, causing subduction along the Philippines Trench (Figure 2.1). The oceanic parts of the Eurasian Plate are being subducted along the western side of Luzon and Mindanao at a rate of 30mm per year.

The Philippines Fault Zone, 1200km long, runs from south of Mindoro to north of Luzon and plays a significant part in accommodating plate convergence. To the north, it splits into several important strike-slip faults including the Digdig Fault.

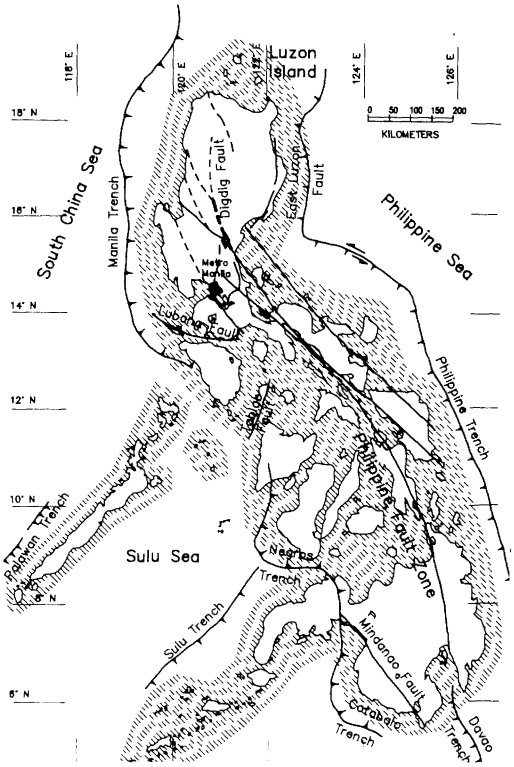
The land form of the Philippines consists of steep mountain ranges, alternating with basins and troughs, infilled with sedimentary material, forming valleys and plains. Damage in this earthquake was generally confined to the Luzon Central Cordillera (mountainous area) and the Luzon Central Plain (basin) where the worst affected cities and towns are located.

The city of Baguio, the scene of many structural collapses, is located high in the Central Cordillera. Dagupan City, where extensive settlement due to liquefaction occurred, is on a large river delta at the northern end of the Central Luzon Plain. Cabanatuan, San Jose and Tarlac are located on the plains, and are underlain by deep sedimentary deposits.

Manila, on the shore of Manila Bay at the south-west edge of the Central Luzon Plain, has loose sedimentary deposits to the west and outcrops of volcanic tuff to the east.

Like most places on convergent plate boundaries, the Philippines is characterised by high seismicity, and is recognised as one of the most complex regions of plate interaction in the circum-Pacific belt.

At least five earthquakes are recorded each day in the Philippines, and the occurrence of six major earthquakes of magnitude 7.3 or greater since 1954 is further testimony to the strong seismicity of the region.



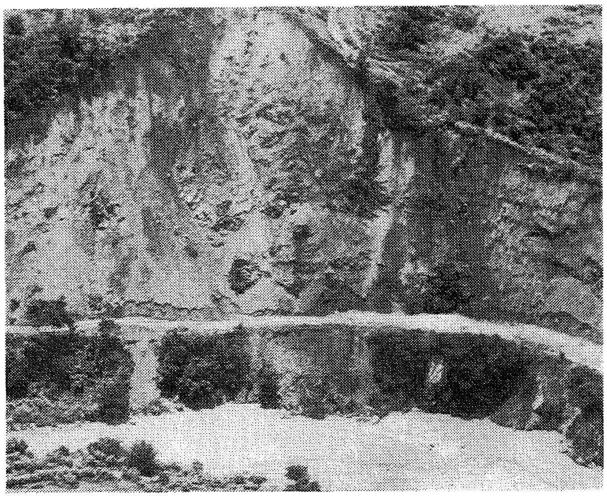
The July 16 Earthquake and Aftershocks

The earthquake of July 16 1990 struck at 4.26p.m. local time and was followed by numerous aftershocks. Surface fault rupture occurred over a 110km long section of the Philippines and Digdig faults, producing offsets of up to 6.2 metres horizontally and 2 metres vertically. Observers reported that the main shock consisted of two separate events, each lasting approximately 45 seconds.

There were no measurements of ground acceleration but the team assessed peak ground accelerations to be 0.4 to 0.5g near the fault rupture, 0.25 to 0.35g in Baguio and Cabanatuan, 0.15-0.25g in Dagupan and 0.1 to 0.2g in Manila.

PRINCIPAL EFFECTS OF THE EARTHQUAKE

The effects of the earthquake were notable for their wide geographical spread, due to the length of fault rupture, their variety, which included geotechnical (landsliding and liquefaction), and structural failures.



Damage and loss of life was caused by landslides, bridge collapses, settlement and lateral spreading due to liquefaction, building collapses and inundation of mines and of coastal villages.

The cities of Dagupan and Baguio each suffered extensive damage; Dagupan from liquefaction and Baguio from structural collapse, mainly of its hotels. The effects on the economies of these cities will be severe. Disruption of road transport, particularly to Northern Luzon and Baguio will also have serious economic consequences.

Liquefaction affected many areas, notably the commercial centre of Dagupan, where most buildings over two storeys settled, and a major bridge collapsed. Liquefaction effects were evident elsewhere at various places on the Central Luzon Plain, producing pockets of damage amongst otherwise undamaged areas. This highlighted an earthquake's ability to find the weak spots.

Notable features of the earthquake effects were:

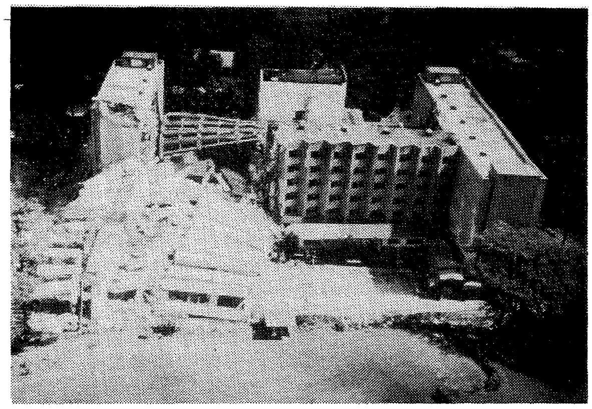
- The loss of over 1600 lives and over 3500 injured.
- 148,000 people were rendered homeless, with 1.63 million adversely affected.
- Damage to 93,000 homes, with 23,000 destroyed.

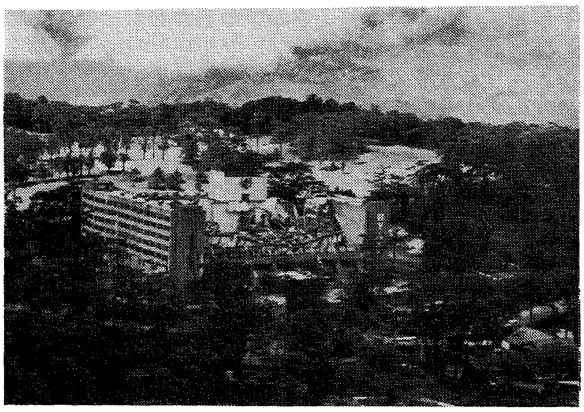
(Photo: Ian Gill, ADB)

- Isolation of 83,000 people in the mountain towns and villages, requiring major relief operations.
- Major economic impact generally and especially on agriculture, tourism and mining.
- Establishment of well organised relief centres in Baguio, Dagupan and San Jose, co-ordinating damage information and provision of relief.
- The rapid response of international rescue teams.
- The rapid response of Professional organisations in evaluating the effects of the earthquake.
- Failure of telecommunication and radio links with Baguio, for almost 24 hours, critically delaying advice to Manila on the extent and nature of the devastating effects.
- Closure of Baguio Airport for two days due to damage caused by subsidence at one end of the runway.
- Minor damage only to electricity lifelines, which were designed and constructed to international standards. A shortage of available spares caused delays in reinstatement.
- Severe disruption of road transport lifelines due not only to landslides and major bridge failures but also to settlement of bridge approaches, and numerous instances of subsidence.
- Extensive disruption to water supply due to sand intrusion to wells, and damage to buried pipes.
- Closure of all four main road access routes to Baguio City due to landslides.
- Extensive collapse of Carmen Bridge, an important link between Manila and

Northern Luzon. Three of the thirteen spans of this bridge collapsed, due to strong shaking and rotation of the reinforced concrete piers due to liquefaction. Collapse of several other important road bridges due to similar causes.

- Little effect on Manila's lifelines.
- Extensive road closures due to landslides, notably in the vital Dalton Pass link to important agricultural areas. Slopes were left exposed to monsoon rains, which caused further slips.
- Extensive denudation of mountainous areas due to landslides. Combined with seasonal monsoon rains huge quantities of debris were washed into river channels causing flooding and siltation affecting the extensive irrigation network vital for food production.
- Limited damage to major earth and rock fill dams located close to the fault rupture.
- Underwater slumping of accumulated silt in Ambuklao reservoir which entered power intake tunnel and blocked turbines.
- Poor performance of reclamation fills.
- Inundation of coastal villages and rice fields as a result of liquefaction-induced settlement.
- Settlement of most buildings in the commercial centre of Dagupan City due to liquefaction.
- Total failure of the multispan steel and reinforced concrete, Magsaysay bridge in Dagupan due to liquefaction and lateral spreading of the river banks.
- The collapse of most major hotels, and many other multi-storey buildings, in Baguio City, principally due to soft storey effects and inadequate detailing of reinforced concrete columns.
- Collapse of the Hyatt Terraces Hotel, Baguio a very large, luxury hotel of international class.
- Dramatic collapse of several low rise buildings in the coastal town of Agoo, including the Civic Administration Building.
- Manila high rise buildings were shaken noticeably but at only a fraction of design levels. Damage to building services and secondary elements was not extensive.
- Damage to 117 schools in Manila, which were closed pending inspection. Most were reopened, but strengthening will be necessary.
- Extensive damage to a large reinforced concrete wharf at San Fernando Port.
- Damage to oil storage tanks and pipelines at San Fernando Port.





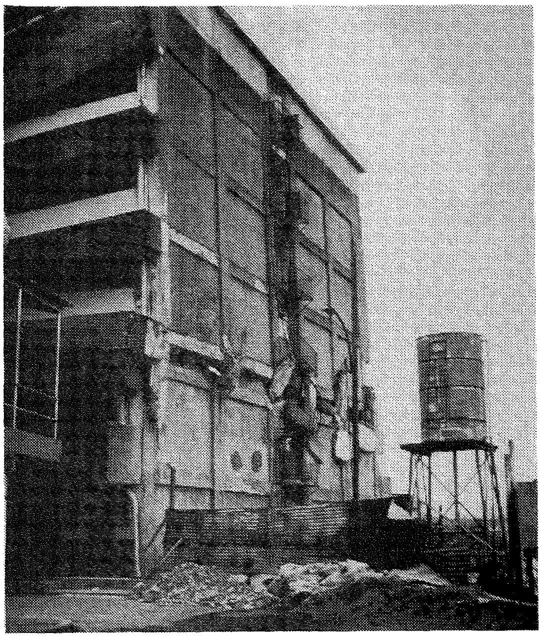
(Photos: Ian Gill, ADB)

Standards of Design and Construction

A wide variety of building standards exists in the Philippines. Seismic design is based on the SEAOC code which includes many provisions for special seismic details. Major consultants are familiar with the benefits of good concepts and detailing. Likewise, they are conscious of the damage potential of liquefaction and the value of extensive site investigations. Facilities built to international standards reflect this. Other buildings and facilities exhibit a wide range of standards of design and construction, which appear to be the result of commercial pressures. These varying standards contributed to the degree of damage.

Three lethal features of buildings stand out:

- The incorporation of soft storeys, especially at ground floors of hotels.



- The use of sparsely reinforced concrete block infill for walls which affect structural performance, but which are ignored in design. As in Mexico, these walls failed and fell out, creating a soft storey.
- Widely spaced and poorly anchored stirrups and ties in columns and walls.

LESSONS/CONCLUSIONS

The principal lessons and conclusions from this reconnaissance stem largely from the extensive geographical spread and variety of types of damage.

Seismotectonics and Seismicity

The level of information available from and about this earthquake was small compared with the Loma Prieta earthquake, highlighting the value of such information in the interpretation and setting of design standards.

Upgrading of the seismograph network and a greater commitment to research of the tectonics of the country are necessary to provide a rational basis for evaluating earthquake hazard.

A seismic hazard study of the Philippines should be undertaken to determine the likely levels of ground shaking which can be produced for various average return periods. Results would provide a rational and cost effective basis for setting code seismic design criteria for use in major infrastructure projects.

Measurement of Strong Ground Motions

The lack of definitive measurements on ground and building motions at various locations makes it difficult to draw firm conclusions on many aspects of the performance of buildings and infrastructure in the July 16 earthquake.

Development of a network of strong motion instruments in the Philippines would help in setting design standards and defining priorities for reducing risk.

Soil Liquefaction

The numerous and widespread failures due to liquefaction and landslides underlined the damage potential of these mechanisms. In many cases, **liquefaction failures could have been avoided** with appropriate geotechnical investigations and foundation designs. The knowledge and technology exists, but there needs to be a commitment to applying it. In the case of Dagupan, relatively shallow piles would have provided protection to buildings against the effects of liquefaction.

(Photo: Ian Gill, ADB)

Landslides

Extensive landsliding was triggered by the earthquake resulting in loss of life and severe economic and environmental consequences, (e.g. blockage of highways, destruction of homes, blockage of rivers and flooding, increased stream and sediment bed loads). The effects were exacerbated by the simultaneous seasonal monsoon rains. The identification of landslide prone areas and incorporation of appropriate measures to reduce the potential for landsliding should be considered whenever works or development are undertaken in mountainous areas. The combined effects of two natural hazards (i.e. earthquakes and monsoons) needs to be considered in design. Failure to do so can have long-term major detrimental consequences for the environment and economy.

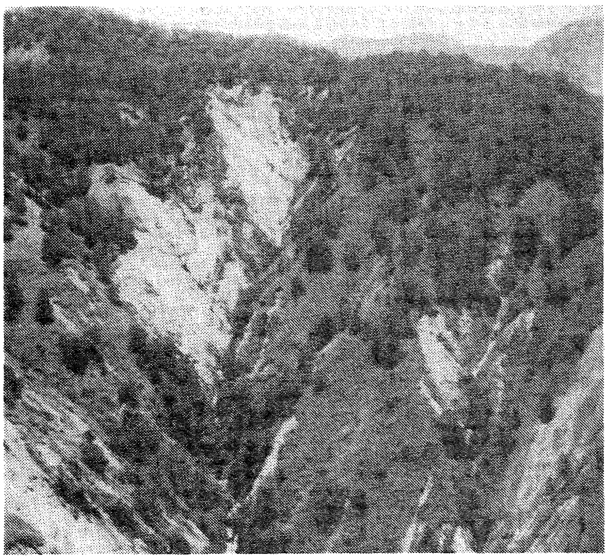
Soft Soil Effects

The importance of soft soil conditions in modifying ground motions was noticeable in this earthquake. This was found in recent earthquakes in Mexico (1985) and California (Loma Prieta 1989) and the Edgecumbe earthquake in the Bay of Plenty (1987). In Manila the worst effects were noted on reclaimed or alluvial soils, while along the Lingayen coast at Agoo the extensive structural damage was probably related to amplification of motions by the weak underlying alluvial soils.

On the other hand, the yielding of alluvial soils adjacent to the fault at Rizal may account for the low level of damage observed there.

Effects of Steep Topography

Amplification of ground motions due to steep topography was apparent in this earthquake as evidenced by the nature of landsliding (i.e. many landslides originated near the crests of ridges). Monitoring of aftershocks by the USGS (Newhall et al 1990) [7] indicated significantly higher levels of shaking at Baguio compared to other sites equidistant to aftershock epicentres. This is thought to be primarily due to the steep topography in the Baguio area.



Structural Concepts

Good structural concepts are vital to seismic resistance. Buildings of up five storeys, of reasonably regular shape and stiffness survived even though detailing for seismic resistance was deficient in present day terms. By contrast, failure of many buildings with a soft storey, some only two storeys high, provided more reminders for engineers and architects to employ good structural concepts in all building design. This earthquake showed, yet again, that consistent application of good structural concepts is the single most important factor in seismic resistance.

Non-Structural Elements

There are two major issues:

- The need to prevent 'non-structural' elements from adversely affecting the structural performance of the building.

- The need to avoid costly damage to non-structural elements by deliberately separating them from the structural elements.

The detrimental effect of 'non-structural' elements which participate in load resistance was again demonstrated - with tragic results. In the Philippines there is an urgent need to recognise these elements and either separate them or design them as participating structural elements. Responsibility rests with both architects and engineers. As in other parts of the world, co-operative effort and effective action is needed. Words in codes are not enough.

Lack of separation on non-structural elements was seen to cause expensive damage in some buildings in Manila. Had shaking been stronger the overall impact of this damage could have been very significant. Curtain walls and suspended ceilings were not visibly affected while tile and stone claddings, sunscreens and porticos did suffer damage. This reinforces the need for the design and construction industry to address the earthquake performance of all non-structural elements.

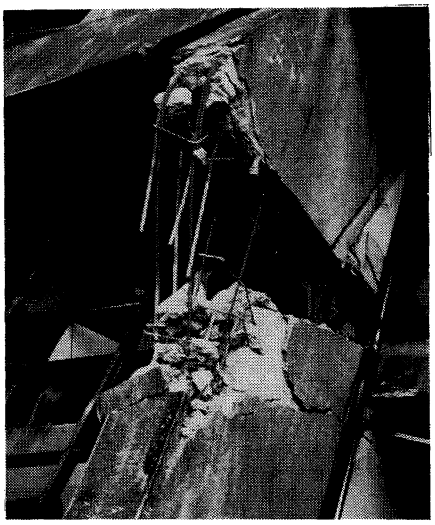
The Philippines experience provides further justification for continuing to include these aspects in the New Zealand Code and for continued education and training of architects and engineers to recognise the lethal potential of badly located 'non-structural' elements.

Detailing of Reinforced Concrete for Seismic Resistance

Many examples of inadequacies were evident, notably poor connection and splicing details, widely spaced transverse reinforcement, and ineffective anchorage of hoops and ties. Concrete was again shown to be brittle and to part company readily from reinforcement if not closely confined.

While design and construction standards in New Zealand may be generally higher than in the Philippines, the July 16 earthquake provided many reminders that a significant proportion of New Zealand buildings have similarly inadequate concepts and details to those which performed poorly in the Philippines. The results of such inadequacies demand attention and action on the part of the engineers, building owners and local authorities in New Zealand.

The lesson for New Zealand is - retain code provisions for joint steel and confinements. Relax them only on the basis of field performance and convincing research results.



Construction Practices and Supervision

The wide variety of standards evident in buildings in the Philippines indicates a need for general improvement in design, construction and supervision of buildings. Earthquakes find fatal flaws with unerring accuracy, and every effort needs to be made to prevent them. Recent trends in New Zealand have seen a reduction in independent supervision of construction. The Philippines experience demonstrates the dangers associated with inadequate supervision. It is essential that the New Zealand Building Industry Authority fully recognises the importance of the role of adequate supervision of construction in achieving desired levels of earthquake resistance in buildings.

Roads

One critically damaged area is enough to stop traffic. While many blockages can be cleared, those which may require significant time to reinstate should be identified and designed accordingly.

A balance is needed between damage prevention through high capital expenditure, and acceptance of certain levels of maintenance or reinstatement.

Thorough feasibility studies should be undertaken to determine the optimal alignment which takes into account landslide risk and the effect that construction of the road will have on land stability. Where possible, roads should only be in cut. Where fills are necessary they should be properly designed and constructed. Rehabilitation of vegetation destroyed as a result of construction activities should be undertaken.

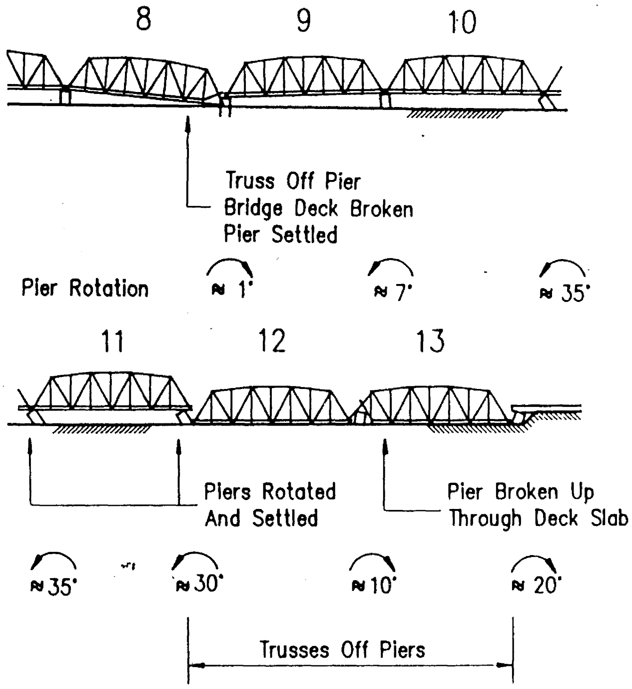
In many cases it may be better to reduce normal highway standards and adopt narrow and winding roads which have far less impact on the environment. Control of surface run-off is vital, particularly in countries such as the Philippines which are subject to monsoon rains.

Attention to transport lifelines overall in relation to earthquake vulnerability and development of viable alternative routes would prove worthwhile.

Bridges

The July 16 earthquake provides an emphatic lesson in the importance of bridges as vital transport links. They deserve corresponding attention in their design for seismic resistance.

Remedial measures need to be developed for the upgrading of existing bridge structures to combat the damage caused by liquefaction on the stability of abutment and pier supports, and the provision of longitudinal



continuity of the superstructure. Lack of adequate detailing in these two areas in particular, led to significant damage from earthquake shaking.

Although several key bridges failed, these were generally older, with non-continuous spans. More modern bridges with continuous spans performed better.

Other Lifelines

The diversity built into water, gas and sewerage systems proved beneficial. Multiple artesian wells for water and bottles for gas helped significantly to mitigate the overall effects of the earthquake.

The predominance of septic tanks rather than large sewage treatment and collection facilities had some advantage immediately following the earthquake. Diversity was an advantage, but reports emerged that many septic tanks cracked and were leaking, creating a major health risk.

This experience underlines the need for planning of these lifelines to take full account of earthquake vulnerability, and of the advantages and disadvantages of diversity.

Planning Implications

Although no specific links to planning issues were identified with damage in the earthquake, the effects on Baguio and Dagupan provided a reminder of the potential benefits of developing planning ordinances which take account of earthquake effects. Identification of seismic hazards is important in this respect, as input into land use planning. **Planning studies for new and existing towns should consider high risk geotechnical zones.** In particular liquefaction and landslide risk areas should be identified. Development in such areas may be possible provided appropriate engineering measures are taken.

Social Impact

Damage to key roads left many thousands of people inaccessible except by helicopter. Reduced effectiveness in communication during the prolonged reinstatement period is certain to affect the economy.

On the other hand, a lesson was provided by the determination of business people, especially in Dagupan, to carry on in the face of adversity. Such an approach could conceivably save a town or city from financial ruin following an earthquake.

Authorities in charge of emergency response in New Zealand must be prepared to relax normal standards as far as possible in the interests of preserving the financial viability of affected regions.

Economic Effects

The impact on regional and national economies will be considerable. The earthquake affected regions account for about 15% of the country's domestic output.

(Photo: Ian Gill, ADB)

On a countrywide basis this is expected to cause a reduction in the growth rate of 0.8% of the GDP (4.3% to 3.5%) and the GNP growth from 4.8% to 3.7%. [1]

On a regional basis the damage to crops, livestock, fish, commercial and tourist establishments and mining will have a serious effect on the regional economy.

Emergency Response & Preparedness

Once in place the Philippines Local Relief and Rehabilitation Organisations appeared to be very effective. There was a report of delay in them becoming fully operational - in some cases up to four days. This highlights the need for organisational preparedness.

Rapid response from other countries and international relief organisations was also a characteristic of this earthquake.

Heritage Structures

The heritage structures in the Philippines which had suffered damage due to the earthquake had obviously survived other seismic activity. San Augustin Church illustrated the danger of making changes to the fabric of the building which will affect its performance under seismic activity, underlining the point that general rules are difficult to apply to heritage structures - each case must be considered on its merits. Where a decision has been made to retain a heritage structure, a seismic study should be carried out taking into account structural and architectural elements and a seismic management plan prepared for use in both restoration work and maintenance.

1. INTRODUCTION

The magnitude 7.8 earthquake which occurred in Central Luzon, Philippines on July 16 1990 caused major damage and loss of life, prompting the interest of the organisers of the New Zealand National Society for Earthquake Engineering Reconnaissance scheme. Furthermore, many facilities were known to have been designed to United States seismic standards, and their performance in a large earthquake promised valuable lessons for New Zealand.

Accordingly, a four man team of NZNSEE members visited the Philippines in late July and early August to observe the effects. The team, who are the authors of this Report, comprised three engineers and an architect, which allowed coverage of buildings, particularly hotels, lifelines, geotechnical and seismological aspects, roading and bridging.

The team arrived in the Philippines on 29 July and departed on 9 August. After two days in Manila making contacts and arrangements, the team travelled by van to the worst affected areas, notably Baguio, Dagupan, the Central Plains, Cabanatuan and Manila. Details of the itinerary are given in Appendix A. (Refer Figure 1.1)

The main purpose of the visit was to observe and learn about the effects of the earthquake and to assess the implications for seismic design in New Zealand, and internationally. Throughout the visit, a written Briefing Note explaining the New Zealand team's purpose was used to inform authorities and personnel concerned and to gain their co-operation. This note proved invaluable and is included as Appendix B.

This Report presents the team's observations and comments on what they saw and learned. Although some comment is made on various aspects, the essential aim of the Report is to provide factual information. As many photographs as possible have been included and it is hoped that the Report will provide a useful reference for those wishing to inform themselves on the effects of this important earthquake.

The Report does not claim to be comprehensive in its coverage of all effects of the earthquake. Further information is available through the reports of other technical reconnaissance teams from USA, Japan and Great Britain.

2. SEISMOTECTONICS

The Philippines is an archipelago of 7,107 islands and islets. It lies between two major tectonic plates of the World, the Pacific and Eurasian Plates. The north-westward moving Pacific Plate is presently pushing the Philippines Sea Plate beneath the eastern side of the archipelago at the rate of about 70mm per year. This subduction occurs along the Philippine Trench (Figure 2.1). The oceanic parts of the slower-moving Eurasian Plate are being subducted along the western side of Luzon and Mindanao at the rate of 30mm per year.

The Philippine Fault Zone, whose activity is demonstrated by seismicity, earthquake ground rupture and geomorphic observations, also plays a significant role in accommodating plate convergence (Figure 2.1). It originated from the oblique subduction of the Philippine Sea Plate and decouples the north-westward motion of the Pacific with the south-eastward motion of the Eurasian Plate. Extending through the archipelago from the south of Mindoro to the north of Luzon, it is a 1200km long active strike-slip fault zone, consisting of a number of faults, en echelon (overlapping) in part and branching or scissoring in part. To the north, the fault splits into several important strike-slip faults including the Digdig Fault. The current motion along the Philippines Fault Zone, based on studies of stream offsets, displacement of stream gravels and focal mechanisms of recent earthquakes, is mainly horizontal with a left lateral sense [3].

Like most convergent plate boundaries, the archipelago is characterized by high seismicity, Quaternary volcanism and intense recent deformation. In detail however, it proves to be one of the most complex regions of plate interaction of the entire circum-Pacific belt [4].

Table 2.1

Philippines Destructive Earthquakes and their Impacts

Date	Epicenter	Magnitude	Casualties	Injured
02Jul 1954	Bacon Sorsogon	8.3	13	101
01Apr 1955	Lanao Mindanao	7.5	291	713
02Aug 1968	Casiguran Aurora	7.3	270	600
07Apr 1970	Baler Quezon	7.3	15	200
17Aug 1976	Moro Gulf Mindanao	7.9	3739	8000

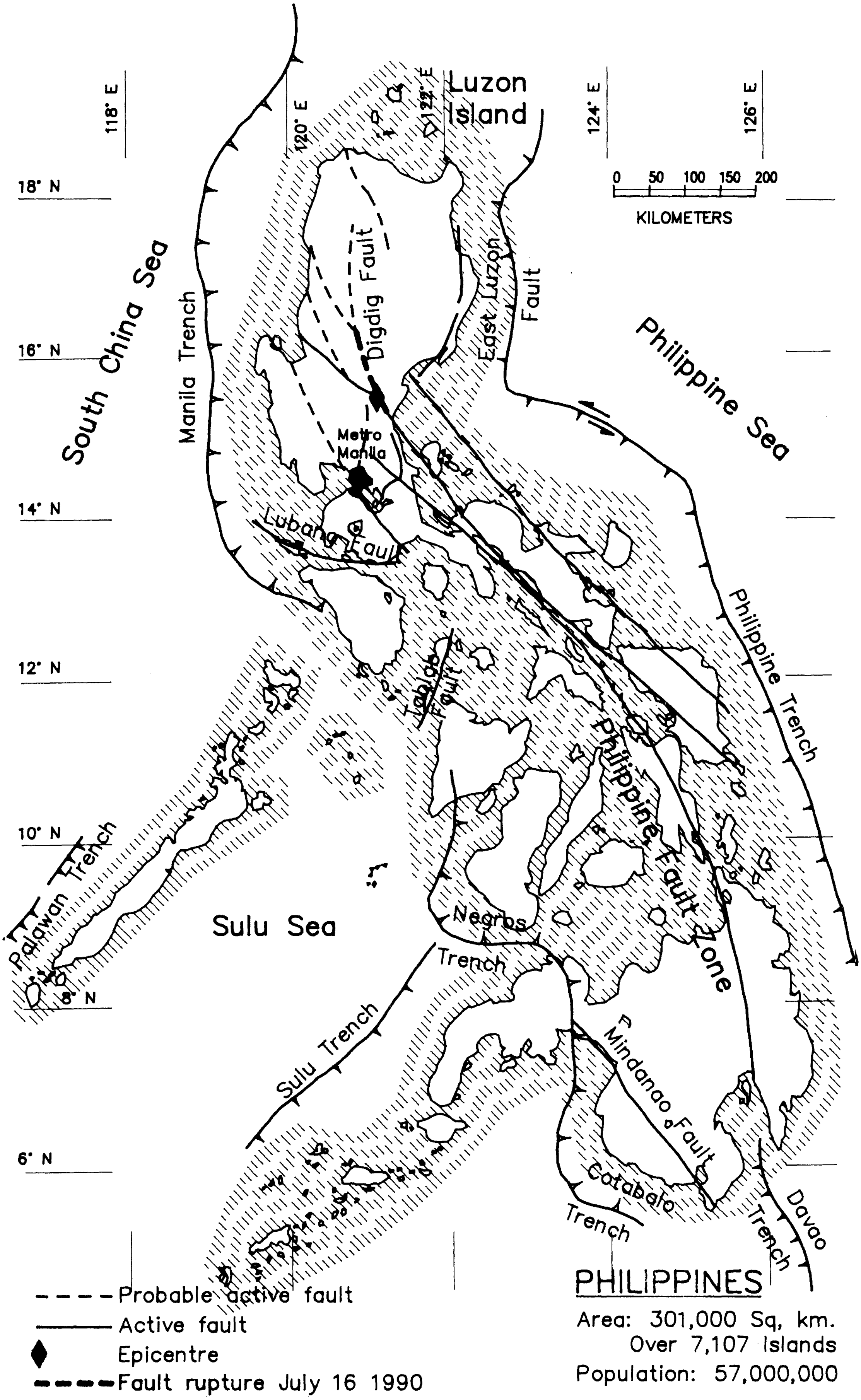


Figure 2.1: Major Tectonic Features of the Phillipines

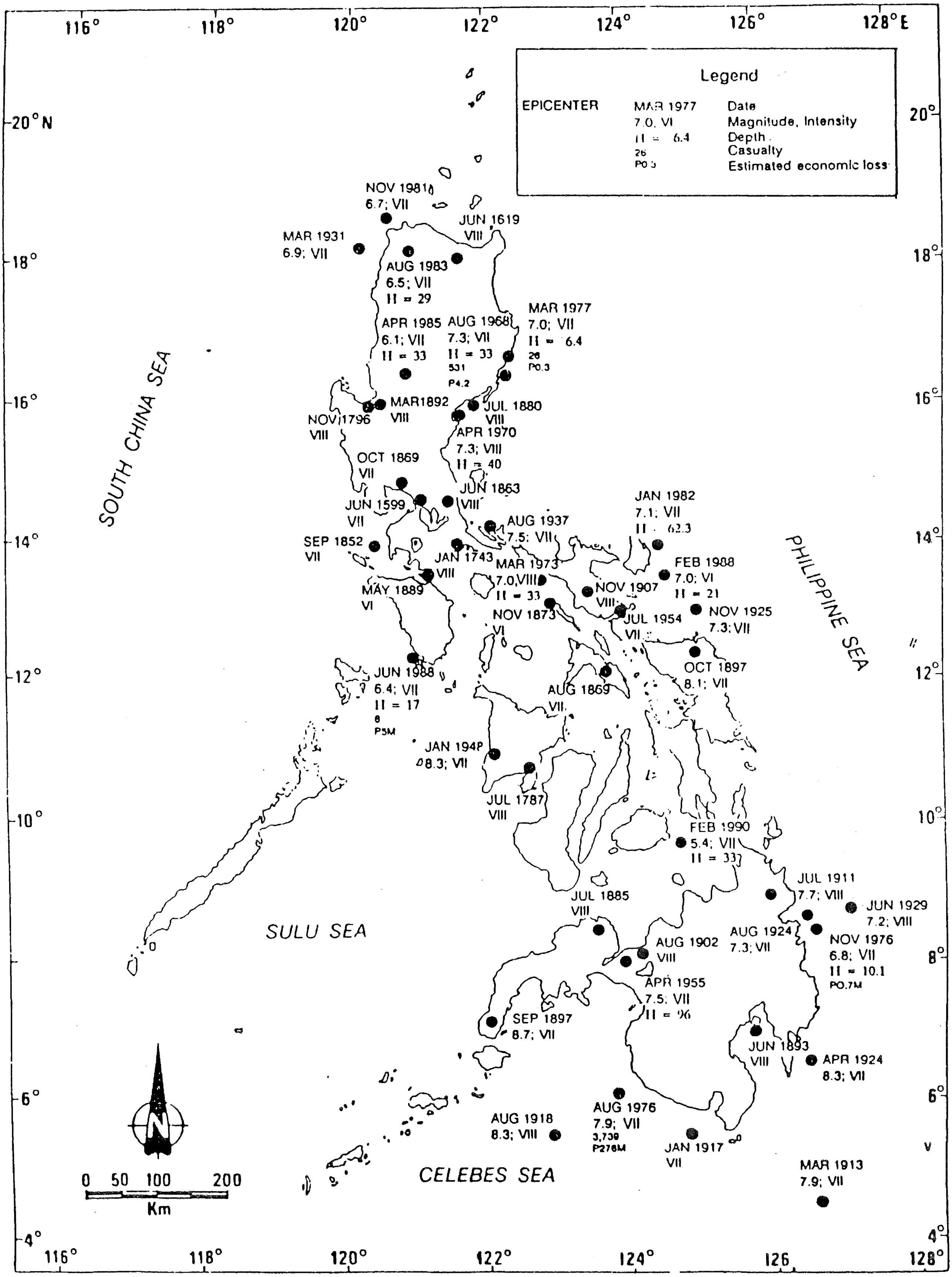


Figure 2.2: Distribution of the Major Earthquake Epicentres in the Phillipines

At least five earthquakes per day are recorded in the Philippines [3]. Based on the distribution of earthquake epicentres, the most seismically active part of the Philippines is its eastern section containing Mindanao, Samar and Leyte with an average of 16 perceptible earthquakes per year. This is due to the active subduction process going on along the Philippines Trench. The other relatively active parts are found at the eastern side of northern Luzon and the area in the vicinity of Luberg Island and Mindanao. Major earthquakes to occur in the Philippines are shown on Figure 2.2 and a listing of the most destructive earthquakes is summarised in Table 2.1.

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) is the principal government agency studying earthquakes in the Philippines. Presently PHIVOLCS maintains 15 seismological stations. The Institute's volcanological stations located at the country's five most active volcanoes can also serve as stations for detecting earthquakes. There are plans to add 60 seismological stations, mostly telemetered or unmanned, in order to adequately monitor Philippine earthquakes. At present no strong motion recording network has been established.

3. GEOLOGY OVERVIEW

Morphologically, the Philippines may be described as a composite of linear, sub-parallel ridges alternating with basins and troughs following the trend of bordering oceanic trenches. The ridges are upthrusted and/or uplifted belts of ophiolite and volcano-plutonic complexes. These constitute the main mountain ranges. The intervening lows are sedimentary basins and troughs exposed partly on land areas following uplift or folding.

The 16 July earthquake affected the central portion of the island of Luzon. The physiography of this part of the country is described below with reference to Figure 3.1. Also shown on this figure is the Philippine Fault Zone and Digdig Fault. The fault rupture occurred along the western border of the Southern Sierra Madre and then northwards, along the Digdig Fault, into the Luzon Central Cordillera. To the west of the fault rupture lies the extensive Central Luzon Plain.

The Southern Sierra Madre and Luzon Central Cordillera are rugged mountainous areas. The Southern Sierra Madre is underlain by Cretaceous to Middle Miocene strata intruded by Oligocene Diorites, and overlain on the south by Pleistocene lava flows and pyroclastics. The Luzon Central Cordillera is composed of intermediate to mafic plutonic masses with intercalated volcanics and meta sediments along the marginal area. Luzon Central Plain is covered with alluvial deposits consisting of silts, sands and unconsolidated or poorly consolidated and assorted pebbles, cobbles and small boulders of the underlying rock types. The thickness is variable and may locally reach 20 metres. These overlie middle Tertiary sediments and Quaternary pyroclastics and lava flows, unconformably overlying Cretaceous to Lower Tertiary basement rocks.

A more detailed description of specific sites of interest which are referred to later in this report follows. Since details of the geology of many parts of the country is not known, some of the descriptions are generalised.

Baguio

Baguio is located in the mountainous Central Cordillera area. Thick deposits of volcanic pyroclastics (up to 300m deep) overlie limestone and alternations of sandstone, shale and siltstone. The pyroclastic materials consist of bedded silty to agglomerate tuffs.

Agoo, Aringuay

These towns are located along the west coast of Luzon Island on alluvial deposits which have been washed down from the mountains to the east. Deposits along the coast are predominantly loose, unconsolidated silts, sands and gravels and there is a high groundwater table.

Dagupan

Dagupan is located on a delta plain near the confluence of a number of rivers including the Agno, which drain the highlands of Central Luzon. The city is underlain by loose, unconsolidated, poorly sorted mixtures of sand, silt and clay which are saturated.

Tarlac, San Jose, Cabanatuan

These towns and cities are all located on the Central Luzon Plain. The Plain is generally covered with alluvial deposits of silts, sands and unconsolidated or poorly consolidated and unsorted pebbles, cobbles and small boulders of the underlying rock types. The thickness is variable and may locally reach 20m.

Metro Manila

Metro Manila is underlain by generally well consolidated and cemented deep deposits of volcanic tuff and welded tephras. These outcrop in the eastern side of Metro Manila (i.e. Makati, Mandaluyong, San Juan, Quezon City) but towards the west, along the coast, are overlain by transported materials deposited as deltaic sediments on top of the tuff bedrock. These sediments are up to 90m thick and consist of plastic clays, silts, sands and gravels with inclusions of marine shells, corals and decayed plants. Layers of these sediments are lenticular, with poor lateral continuity. These deep poorly consolidated materials can be expected to amplify ground motions from earthquakes compared to sites located on outcrops of the underlying tuff and tephras.

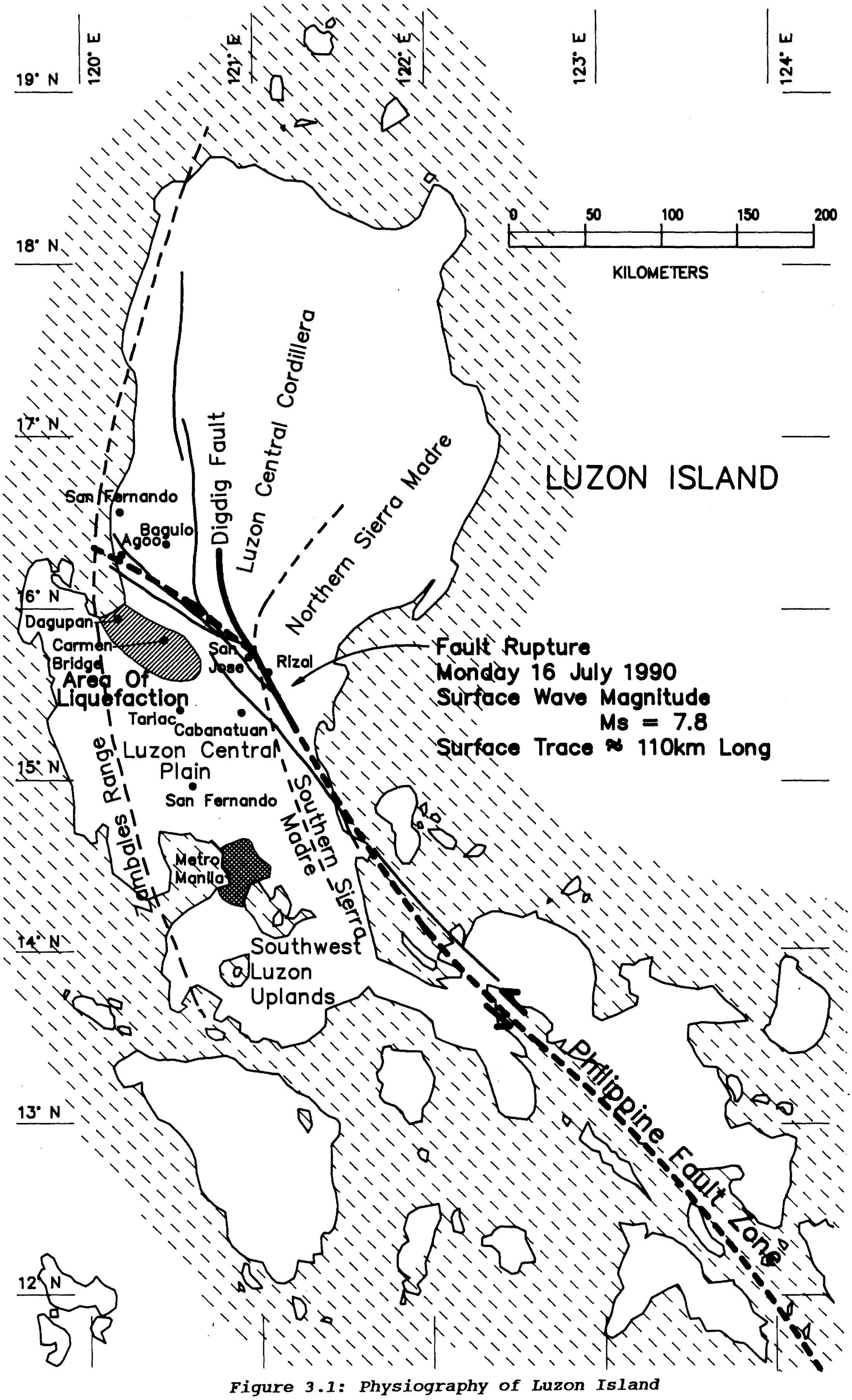


Figure 3.1: Physiography of Luzon Island

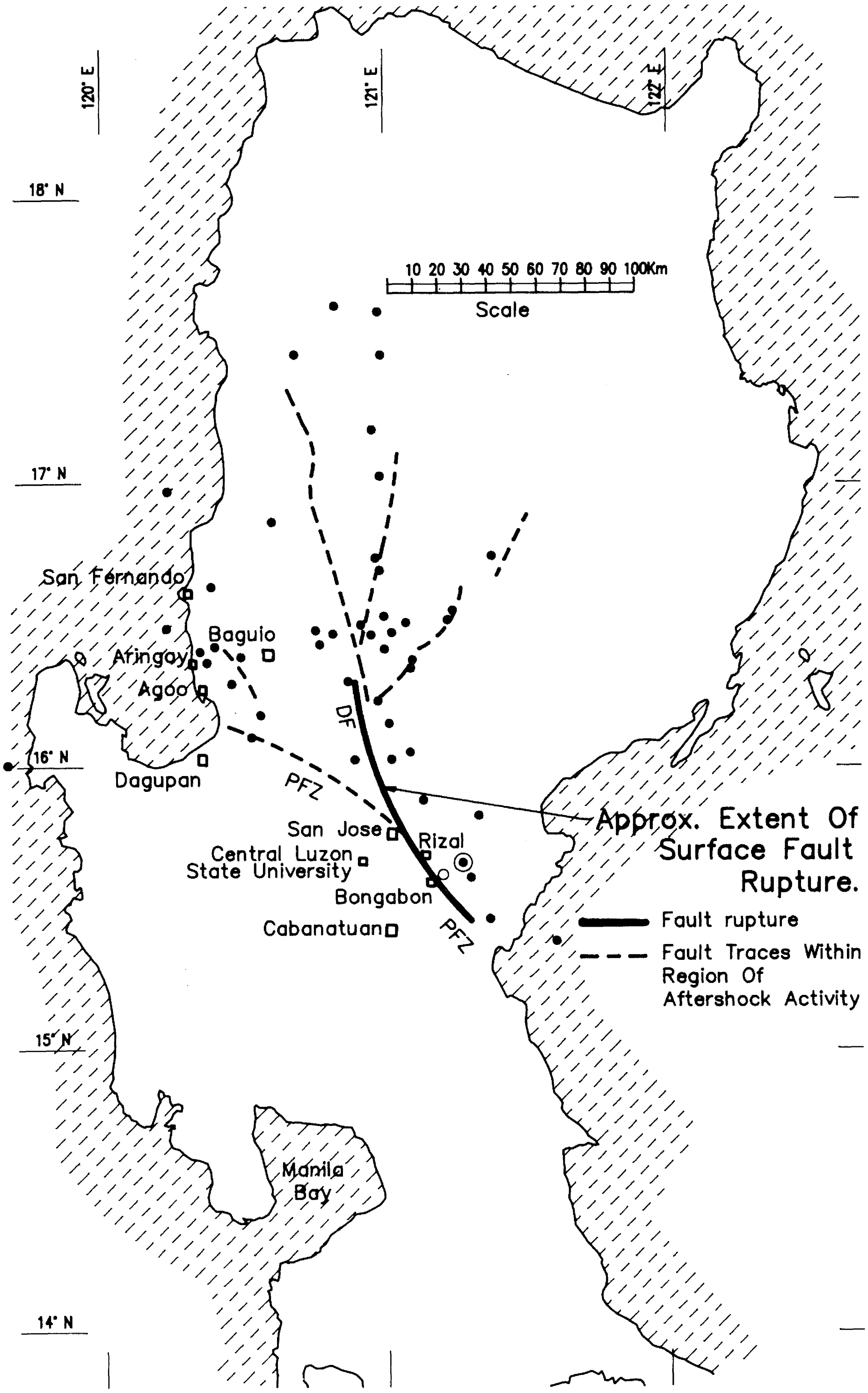


***Figure 4.1:* Map of surface faulting and aftershocks associated with the July 16 1990 earthquake.**

Heavy lines indicate left-lateral fault ruptures that were observed and measured on the ground. Dotted lines represent other fault traces within the region of aftershock activity; surface displacement on these is either absent or unknown (locations from Geologic Map of the Phillipines, Bureau of Mines, 1963). Heavy dots are NEIC-located epicentres of aftershocks (4.44 ≤ M ≤ 6.5) within 27 days of the mainshock (circled dot). **Open circle** *near Bongabon shows approximate epicentre of aftershock associated with small creep displacement observed at Rizal. All epicentral locations are approximate. Labels PFZ and DF indicate Phillipine fault zone and Digdig fault, respectively (after Newhall et al., 1990)*

4. EARTHQUAKE DESCRIPTION

4.1 SEISMICITY

The earthquake occurred on 16 July 1990 at 4.26pm local time. Initial assessments of the epicentre put it approximately 10km south-east of Rizal at about 15.6N and 121.2E.

Preliminary assessment by the USGS Newhall et al [7], indicates a bodywave magnitude (m_b) of 6.8 and, a surface wave magnitude (M_s) of 7.8. The earthquake was of shallow focal depth (approximately 25km). Aftershocks located by the USGS portable seismograph array indicated focal depths between 5km and 30km, but mostly between 10km and 15km.

According to local seismologists it appears possible that two large separate earthquakes may have occurred 3 minutes apart, each of about 45 seconds duration. The relatively long duration of shaking of two closely spaced events undoubtedly contributed to the overall level of damage, and especially the extent of liquefaction. Newhall et al estimate 50-75 second duration of shaking based on the length of fault rupture and typical fault rupture velocities. Numerous strong aftershocks followed the main earthquake(s). Within 24 hours following the main shock, at least ten aftershocks with bodywave magnitudes (m_b) of 5.0 or greater had been reported by the USGS. According to one person we spoke to at Baguio City, five strong aftershocks occurred within 30 minutes of the main shock and these resulted in collapse of many structures which had been severely damaged in the main shock. Aftershocks were still being felt three weeks after the earthquake near Baguio City, and one resulted in closure of the only highway to the City for a short time due to a rockslide on 6 August, while the team was there. However, the total number and magnitude of the aftershocks is not considered unusual for an earthquake of this magnitude.

Preliminary plots of aftershocks indicate most occurring to the north of the epicentre, towards Baguio, and over a relatively large area as shown on Figure 4.1. The large scatter may be due to errors associated with preliminary determinations. It also suggests that movement may have occurred on faults other than those observed to rupture.

4.2 SURFACE FAULT RUPTURE

Extensive fault rupture accompanied the earthquake and the extent of this is shown on Figure 4.1. It extends north-west from Gabaldon to San Jose along the Philippine Fault and then along the Digdig Fault from near San Jose northward to a point 6km south of Kayapa. The total distance of surface fault rupture was close to 110km. The rupture also probably extended an additional 50km to 100km north, based on the extent of aftershocks.

It is postulated that if two earthquakes did occur within three minutes then they might correspond to separate rupture of the two faults, with rupture on the Digdig Fault following rupture along the Philippine Fault.

Fault movement was predominantly left lateral with horizontal displacements of up to 6.2m and vertical displacements of up to 2m. An aerial photograph of the fault rupture near Digdig is shown on Figure 4.2. Horizontal displacements caused damage to roads and numerous structures built across the faults (Figures 4.3 and 4.4). Vertical displacements disrupted irrigated rice fields. Some became submerged while others were lifted above the existing irrigation channels.

No major earthquakes have occurred for many years on the segments of the faults which ruptured on 16 July. However, a magnitude 6.1 earthquake occurred in 1985 damaging some buildings in Baguio and it is possible that it occurred on the Digdig Fault. Hirano et al [8] inferred rupture of the Philippine Fault in 1645 along the same segment as the 1990 earthquake based on historical records, geomorphic evidence and radiocarbon dating.

4.3 GROUND MOTION

Unfortunately no strong motion recording network exists in the Philippines. Reports indicated the earthquake was felt over a large part of Luzon Island. Damage was reported from Metro Manila, approximately 120km south-west from the southern extent of fault rupture.

Of interest was the fact that ground shaking seemed to have caused relatively little damage in the epicentral area at Rizal and San Jose. Newhall et al [7], suggests that the limited damage at Rizal may be because the high frequency seismic energy (1-10 Hz) that would damage small to moderate sized structures was more completely absorbed by the near surface materials in the epicentral area. Greater damage occurred in Baguio and Dagupan although much of this can be explained by the type of structure (i.e. multi-storey hotel and apartment type structures in the case of Baguio, and the occurrence of liquefaction at Dagupan). Nonetheless, it would appear from spectral analysis of aftershock seismograms that ground shaking at Baguio was greater than at equidistant points located to the south near the July 16 epicentre.[7] . Initial indications are that the amplified motions are possibly related to the mountainous topography near Baguio. This is supported by the fact that ground motion frequencies relevant to causing building damage have wave lengths comparable to the size of the mountains around Baguio.[7]

The effect of site subsoil conditions on ground response was a major factor in the damage which occurred in many places. At Dagupan and Agoo, substantial damage occurred to structures located on loose alluvial deposits with high groundwater conditions. These sites were located some 55km to 65km from the fault rupture and sites located on stiffer sites much closer to the fault suffered considerably less

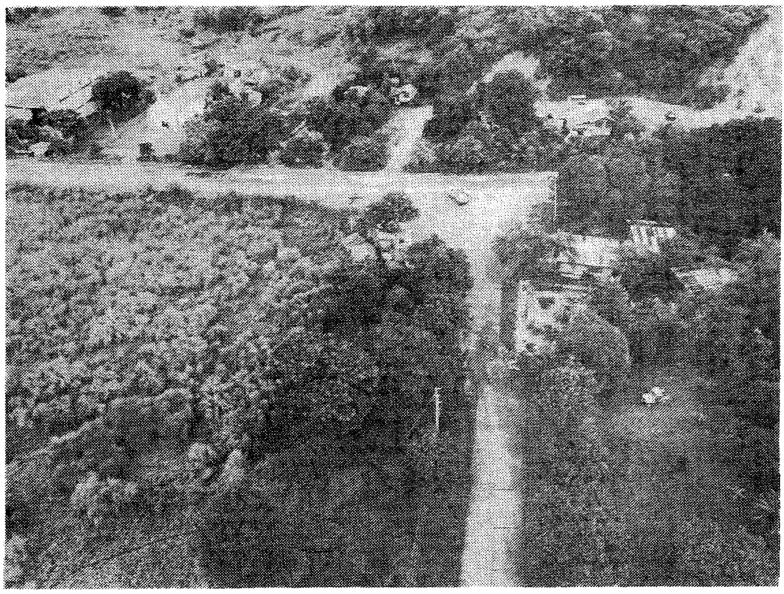


Figure 4.2: The 3 metre left lateral offset of the Digdig fault trace is clearly visible from the air - Carrangian Road, off main highway 20 km north of San Jose (Photo: Dodong Teves, PNOC)

Figure 4.3: From the ground, both the 3 m left lateral, 1.5 m vertical displacement are obvious, as is the damage to the road (Photo: Dodong Teves, PNOC)

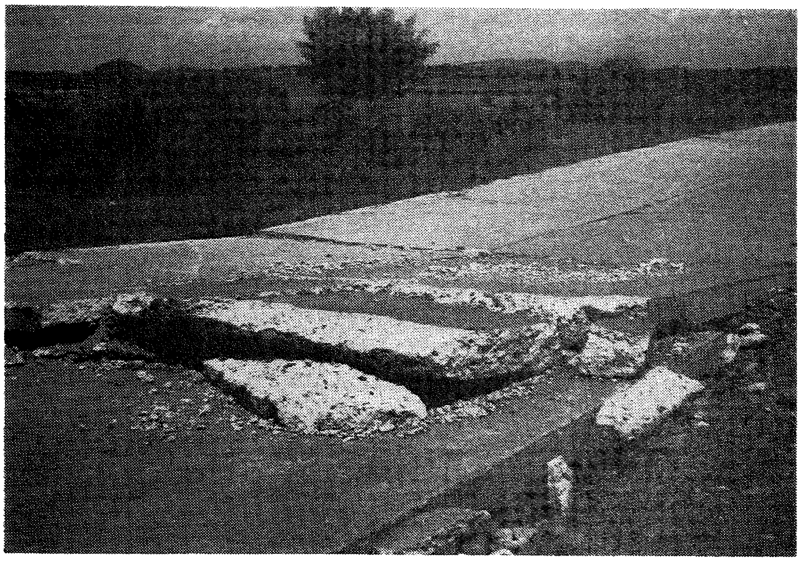


Figure 4.4: Damage to road pavement due to offset of Phillipines fault trace 3.5 km west of Rizal

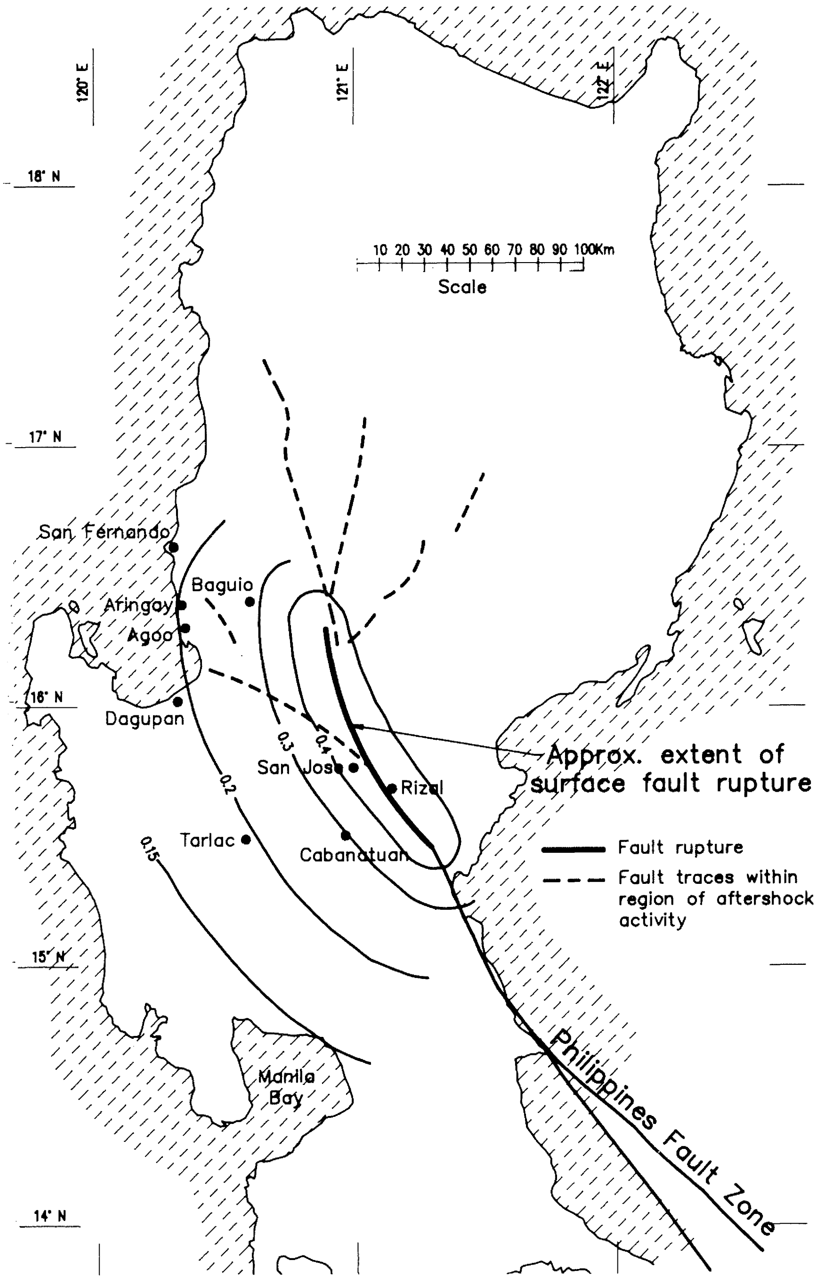


Figure 4.5: Estimates of Peak Ground Acceleration (g)
(Fault locations after Newhall et al., 1990)

Table 4.1

Estimates of Peak Ground Acceleration for Specific Sites

Site/ City	Distance from Fault Rupture (km)	Typical Soil Conditions	Peak Ground Acceleration (g)
San Jose	6	Alluvium	0.4 - 0.6
Baguio	28	Stiff volcanic soils	0.25 - 0.35
Cabanatuan	29	Alluvium	0.25 - 0.35
Carmen Bridge	40	Alluvium	0.2 - 0.3
Agoo	56	Alluvium	0.15 - 0.25
Tarlac	62	Alluvium	0.15 - 0.25
Dagupan	63	Alluvium	0.15 - 0.25
Metro Manila	105	Alluvium/Fill Rock	0.1 - 0.18 0.07

damage. Although much damage at Dagupan and Agoo was due to liquefaction of the surficial soils, amplification of the bedrock motions by the overlying weaker alluvial soils also caused structural damage from vibrational effects. The influence of site soil conditions was also apparent in damage reported in Manila. More damage appeared to have been reported from areas closer to the coast where depths of alluvium are greatest. In the Baguio Export Processing Zone, two identical factories were located adjacent to one another. One was founded on a cut platform and the other on fill. The factory founded on the fill collapsed, possibly as a result of amplification of ground motions on the softer filled ground.

The effects of topography in amplifying ground motions undoubtedly occurred, because of the very steep nature of the mountainous areas. Many landslides originated over the upper half of the mountains due to greater intensity of shaking because of amplification of ground motion within the mountains.

It was difficult to determine if ground motions were amplified due to the dynamics of the fault rupture process. The fault rupture propagated northwards and may have led to more intense shaking in the north such as at Baguio.

Estimates of ground motion in terms of peak ground acceleration are shown on Figure 4.5. These are based on the attenuation model by Idriss [5] for rock sites but modified for alluvial sites, such as found within the Luzon Central Plain and along the coastline. The modifications for alluvial ground were based on correlations between peak ground acceleration on rock and other ground conditions proposed by Seed et al [6], but also taking into account the results from the 1989 Loma Prieta earthquake. Contours of peak ground acceleration shown on Figure 4.5 correspond to those which would be expected on the actual typical ground conditions. Values less than about 0.3g are for alluvium sites which occupy extensive areas to the west of the fault rupture in the Central Luzon and coastal areas.

Estimates of ground shaking at specific cities and sites of interest are summarised in Table 4.1.

5. OBSERVED EFFECTS

5.1 GEOTECHNICAL

5.1.1 Ground Failures

Ground failures due to liquefaction (settlement and lateral spreading) and landslides, and their effects on structures were the major cause of damage associated with this earthquake.

Liquefaction

Considerable damage associated with liquefaction occurred over a huge area from north of Agoo on the Lingayen Gulf to Metro Manila, a distance of over 200km. Liquefaction occurred in naturally deposited alluvial soils adjacent to rivers and coastline areas and on loose sandy fill areas. Structures damaged by liquefaction included buildings, bridges, roads and pipelines.

The most dramatic examples of liquefaction occurred in Dagupan. Within the city centre the two main commercial streets (A B Fernandez Avenue and Perez Boulevard, Figures 5.1.1 and 5.1.2) were mostly severely affected. Typically buildings were 2-5 storeys in height and more than 50% had been badly affected by settlement and/or tilting associated with liquefaction. Settlements of up to 1 m occurred along the two main streets, with probably greater settlements on average occurring along Perez Boulevard. Liquefaction also occurred in residential areas away from the two main streets, particularly adjacent to river channels where settlement and lateral spreading occurred.

The commercial centre of the city was originally a marshy area used for fish farming which was subsequently infilled with sand and sawdust. There are no records which document the infilling. A B Fernandez Avenue parallels a large river channel and Perez Boulevard parallels a smaller, possibly older channel, as indicated in Figure 5.1.2. Boreholes put down following the earthquake indicate the presence of very loose silty fine sand to a depth of up to 6 m along Perez Boulevard and up to a depth of about 3.5 m along A B Fernandez Avenue. Locations of the boreholes are indicated on Figure 5.1.2 and borelogs are shown on Figure 5.1.3. With the water table at a depth of about 0.5 m - 1.5 m, foundation conditions were favourable for liquefaction to occur. Fine slightly silty blue-grey sand ejected from the ground during the earthquake was evident along the footpath and road some three weeks after the earthquake. There were reports of 'marshy gas' in areas of liquefaction during the initial cracking of the roads and pavements during and immediately after the earthquake. This may have been associated with decomposing organic material contained within the subsoil, possibly including sawdust which was reportedly used as filling in some areas. Alternatively, it may have been associated with sewage effluent as the city operates on septic tank systems.

Although the two main streets were very badly affected, the streets in between were not. The differences may be due to subsoil conditions or that possibly the consequences of liquefaction were exacerbated along A B Fernandez Avenue and Perez Boulevard because of the higher buildings along these streets and greater foundation bearing pressures. Virtually all buildings are founded on shallow pads or strip foundations with interconnecting beams or concrete slab floors, and so the differing response could not be related to differences in foundation type.

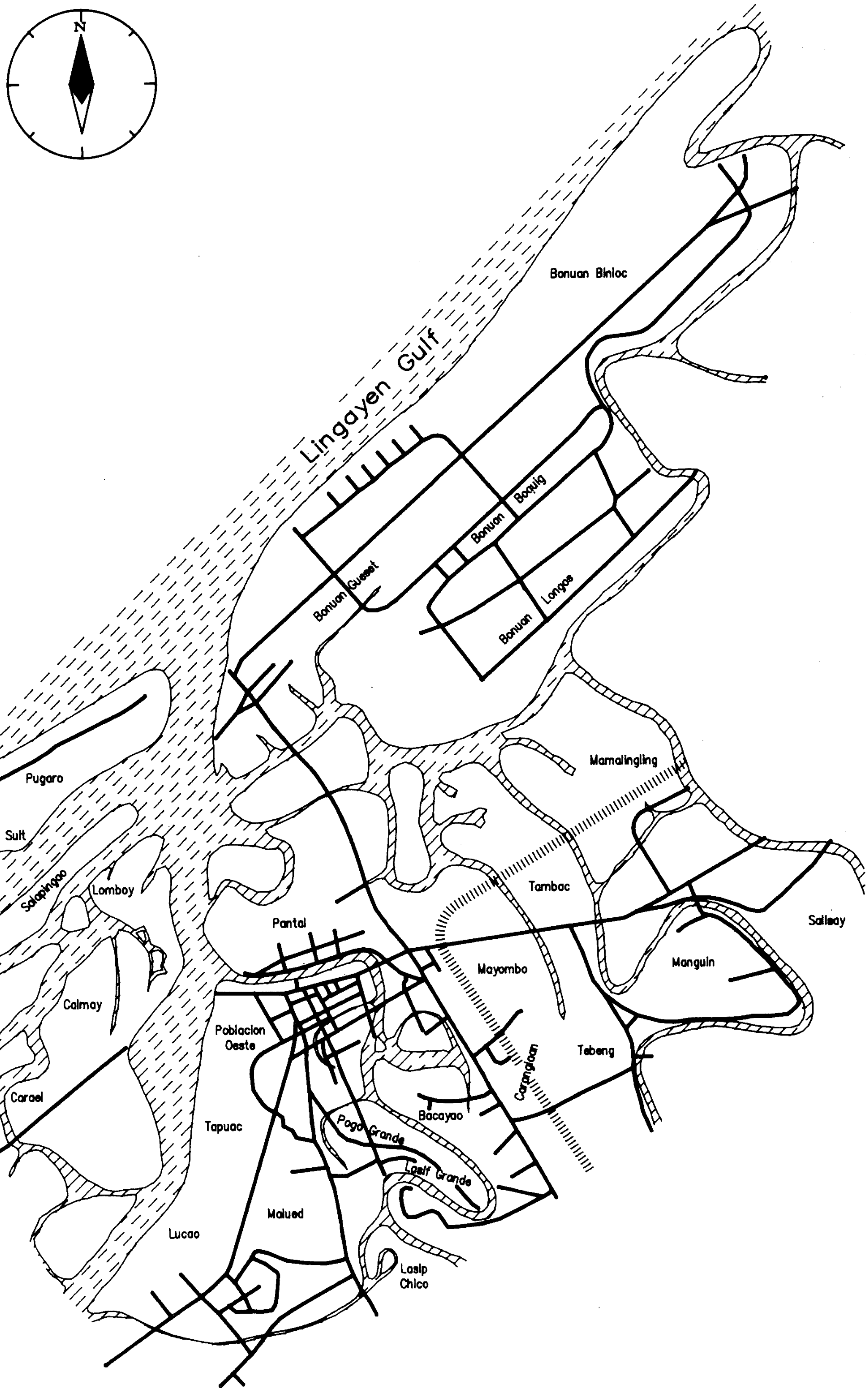


Figure 5.1.1: Map of Dagupan City

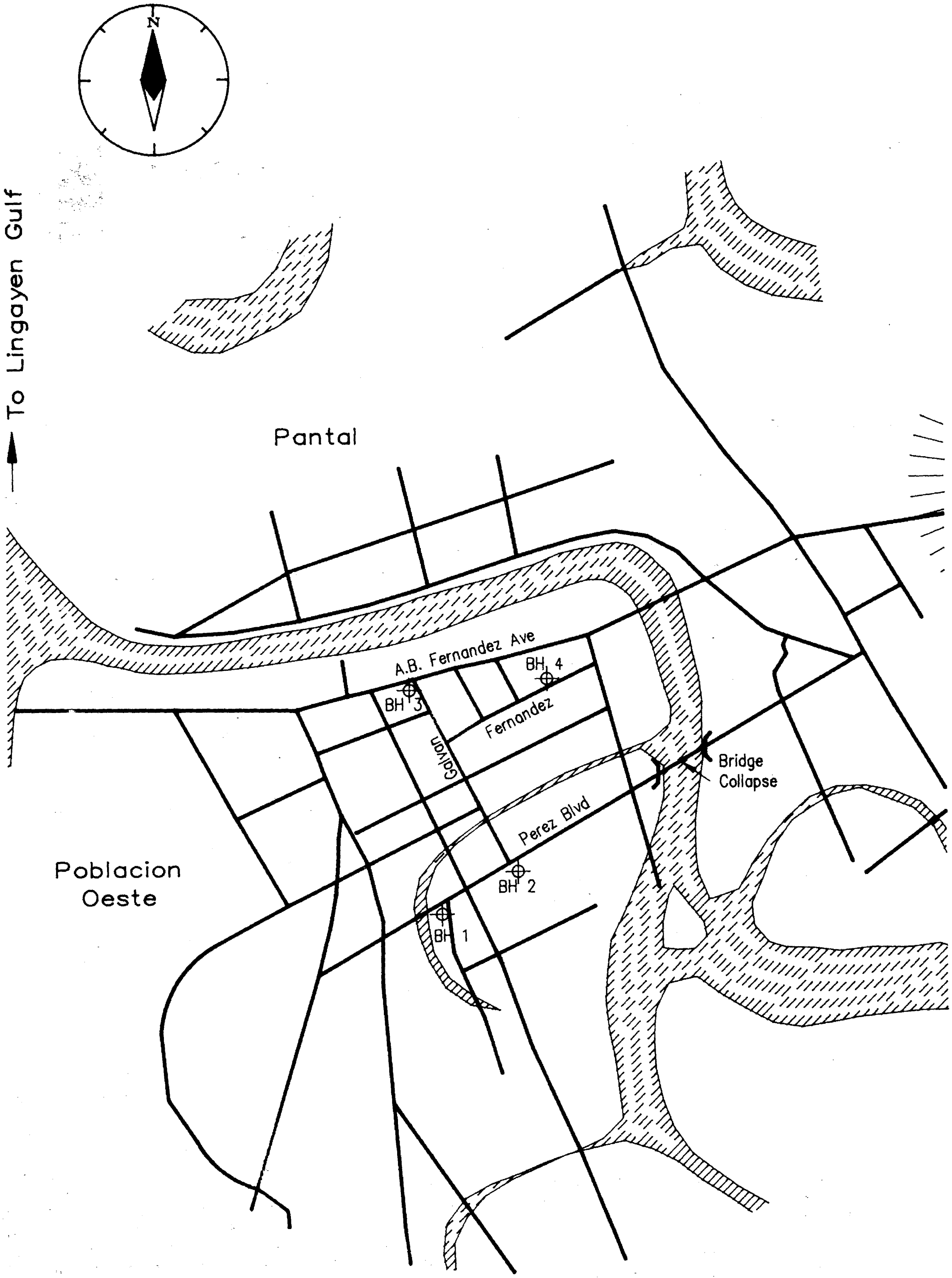


Figure 5.1.2: Map of Dagupan City commercial area showing borehole positions

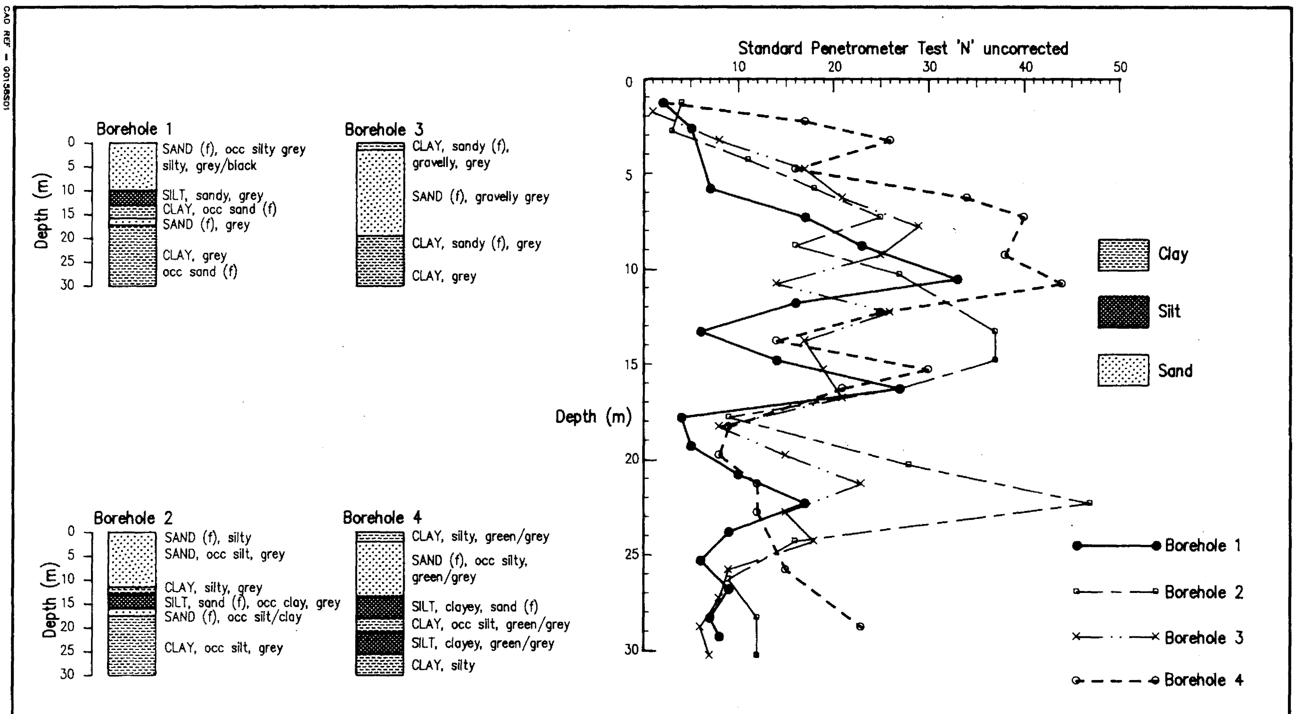


Figure 5.1.3 Bore Logs, Dagupan City

Figure 5.1.3: Bore Logs, Dagupan City

In Figure 5.1.4 general settlement of buildings along Perez Boulevard is indicated with basements being flooded. In some cases, basement floors had been heaved upwards in the centre as the buildings settled. Figure 5.1.5 shows settlement of buildings relative to the road with the once level footpaths now badly tilted. Figures 5.1.6 and 5.1.7 show buildings which had settled and tilted. Figure 5.1.8 indicates relative settlement between two buildings with different foundation bearing stresses. Other dramatic examples of settlement were observed along the coast north of Dagupan at Aringuay. Figure 5.1.9 shows a dwelling which has settled approximately 1m into the underlying liquefied ground.

Underground gasoline storage tanks at a service station in Perez Boulevard floated to the surface due to their buoyancy in the liquefied sands. This behaviour was also observed at a service station in Agoo.

Buried pipelines were also severely dislocated due to a combination of settlement and flotation. Storm water pipes in Dagupan which had floated to the surface were blocked with sand.

In Dagupan, along A B Fernandez Avenue and Perez Boulevard there was little damage due to lateral spreading. However, immediately adjacent to the banks of the San Pablo River, lateral spreading was significant. Some dwellings here were severely affected by lateral spreading. The most significant damage in Dagupan due to lateral spreading was the collapse of the seven span Magsaysay Bridge. Here lateral spreading of the riverbank was of the order of 3.5 - 4m. Refer to Case Study C.7 for details.

Settlement in Dagupan and other coastal towns will aggravate existing flooding problems during the typhoon season. The problem of flooding is further exacerbated by the enormous quantities of landslide debris which will be washed down from the mountainous areas and cause further siltation of the rivers.

Liquefaction contributed to the damage of several other bridges due to lateral spreading of the riverbanks and settlement of the piers. Figure 5.1.10 shows settlement of the central pier of the Binalonan Bridge. The Carmen Bridge across the Agno River collapsed due to liquefaction of the foundation soils and closed the primary north-south route through the Luzon Central Plains. Liquefaction resulted in numerous fissures up to 0.3m wide parallel to the riverbank with quantities of ejected fine sand (Figure 5.1.11). On the north side of the channel, slump scarps up to about 0.75m high were evident. (Figure 5.1.12). Some piers were rotated towards the river channel suggesting lateral spreading but others were rotated the other way. Details are given in Case Study C.6. Because the floodplain is relatively flat, lateral spreading is not considered to have been the principal reason for collapse. It is postulated that failure may have been initiated due to out of phase oscillations of liquefied blocks of soil which led to inadequately anchored spans dropping off the

Figure 5.1.4: Dagupan City, Perez Blvd, building settlement with ground floor flooding

Figure 5.1.5: Dagupan City, Perez Blvd, building settlement relative to road

Figure 5.1.6: Dagupan City, Perez Blvd, building settlement and tilting

Figure 5.1.7: Dagupan City, Perez Blvd, 3 storey building tilted and impacted on adjacent building

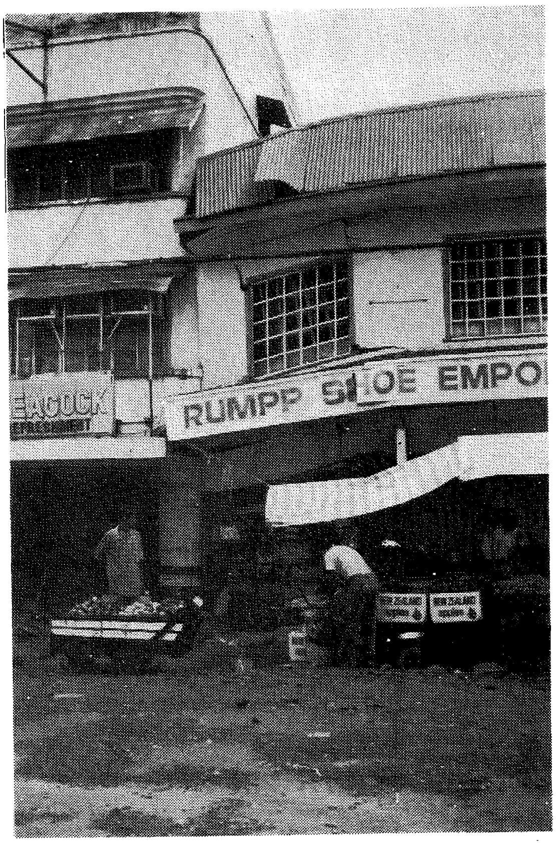


Figure 5.1.8: Dagupan City, A.B. Fernandez Ave, relative settlement of building with different bearing stress

Figure 5.1.9: Settlement of house at Aringay due to liquefaction of foundation soils. The house has settled approximately 1 metre

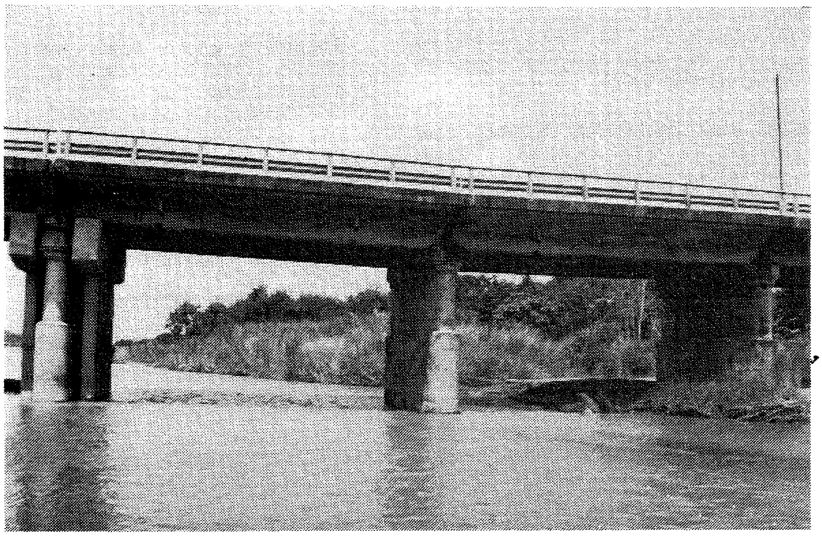


Figure 5.1.10: Binalonan Bridge, settlement of central pier by approximately 0.3 metre. Note previous work to pier on left

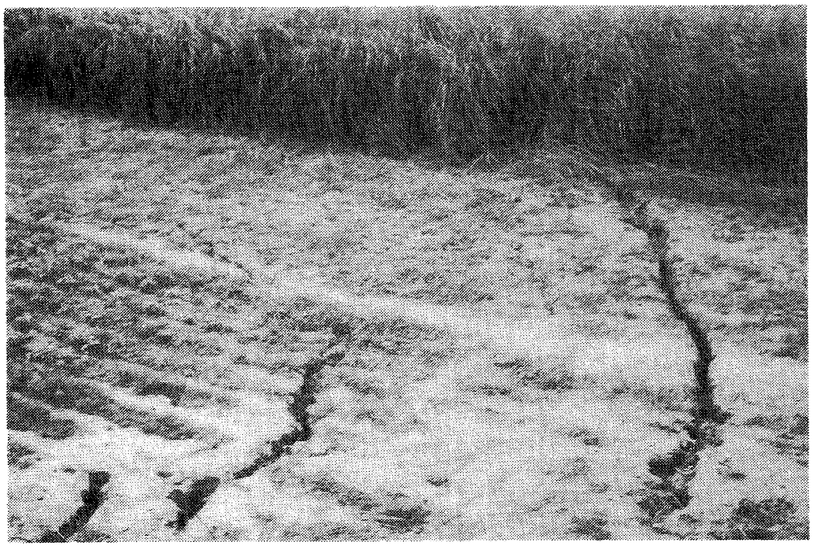


Figure 5.1.11: Fissures and ejected fine sand associated with liquefaction, Carmen Bridge (south river flood plain)

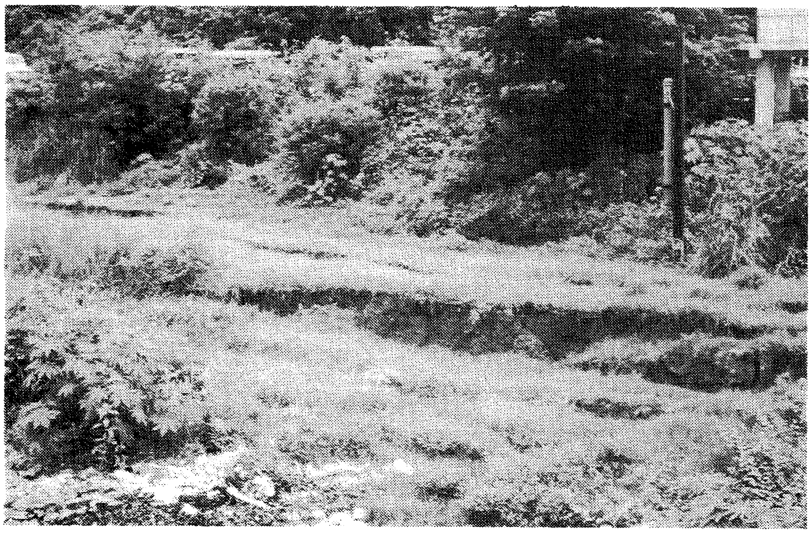


Figure 5.1.12: Slumping towards river channel, Carmen Bridge (north bank)

piers. The large rotations of bridge piers may have been due to failed connections of piers to piles or shallow pile depths.

Lateral spreading was apparent along the banks of many rivers in the Central Luzon and Lingayen coastal regions (Figure 5.1.13).

Liquefaction also affected roads constructed over low lying alluvial areas. Loss of bearing capacity resulted in settlement and distortion of road fills and the pavement surface (Figure 5.1.14).

We understand that settlement of low lying coastal areas in the Agoo area, due to liquefaction, has resulted in flooding of rice fields and disruption to irrigation channels. Liquefaction has also resulted in silting up of many water supply wells which are the prime source of water in the Philippines.

Liquefaction effects were observed in downtown Manila, associated with a hydraulic fill reclamation, some 120km from the epicentre. Large structures in this area are supported on deep piles (up to 40m long) and so were not damaged although the ground settled relative to some of the structures. Up to 0.3m settlement was observed at the Film Centre.

Landslides

Extensive landsliding was triggered by the earthquake in the mountainous areas mainly to the north and west of the fault rupture, resulting in loss of life and severe disruption to transport.

Landslides were mainly shallow, less than 1m deep, and involved sliding of a thin soil mantle and weathered rock. It was noticeable, particularly in the very mountainous areas, that many landslides originated at the crests of steep slopes and ridges (Figure 5.1.15). The triggering of landslides at these locations is probably due to amplification of ground motions caused by the dynamic response of these features.

Many people in small mountain villages were reportedly buried by landslides triggered by the main event and aftershocks. One aftershock triggered a landslide on the Dalton Pass Highway from San Jose to Santa Fe that reportedly struck a bus along the highway and killed 17 people.

The impact of landslides on roads was severe (Figures 5.1.16 and 5.1.17). Millions of cubic metres of material was involved affecting major highways to the north. This had a major impact on search and rescue efforts and in transporting food and medical supplies, and particularly affected Baguio and small villages located north. All three roads to this city from the south were blocked, and only one (Naguilian Road) was passable three weeks after the earthquake. It took five days to open this road and then only to one way traffic at a time. An active rockslide requiring continual clearing is shown in Figure 5.1.18. The other two main roads (Kennon Road and Marcos Highway) were more severely affected with whole hill-sides sliding and totally destroying the road. It will probably be necessary to abandon portions of these roads and realign. The other major road affected was to the Cagayen Valley from San Jose City via Dalton Pass. The road was affected by landslides and fault rupture. The volume of landslides to be removed is estimated by DPWH at approximately 1.4 million cubic metres and it is estimated to cost $NZ40-60 million to reconstruct.

The 1990 monsoon season began shortly after the earthquake and compounded the landslide problem by reactivating some landslides and generating debris flows. A large amount of vegetation including trees was removed with the landslides and was deposited in rivers at the time of the earthquake or when the slides were reactivated by heavy monsoon rains. This caused blockage of some rivers, which upon breaching released floods which resulted in loss of life. Apparently on the Dipalo River, debris flows began three days after the earthquake and continued at least until 31 July 1990 [7]. The debris flow started two hours after heavy rain and lasted for 3 to 4 hours. The debris flow front was about 4m high, stretched 30m across the channel, and consisted of boulders, logs and sediments. Newhall et al, [7] also reported that on August 27-30 1990, Typhoon Abe triggered floods and landslides that killed 85 people in central and northern Luzon, swept away 250 houses and left 1,500 people homeless in villages along Dalton Pass. Hundreds of people bound for the rice-producing Cagayan Valley were marooned by new landslides blocking the Dalton Pass Highway. On August 27 1990, a landslide buried 12 students of the Kalahan Academy, Sante Fe. On areas where the extent of denudation of hillsides by landsliding was estimated to be as high as 60% after the earthquake, the area was 100% bare after passage of the typhoon.

Landslides affected few transmission towers. A minor tower was left hanging from transmission wires near the Ambuklao Dam. An important transmission tower conveying electricity from the Magat Dam, a major source of power to the north east of Baguio, only just avoided being undermined by landslides. Rockfalls caused problems at the Ambuklao Hydroelectric Plant by submerging the outlet of a low level scour pipe and by damaging some switchyard equipment.

Increased sediment bed load content of streams and rivers due to landslide debris will add to the flooding problems which exist in the Central Luzon Plains area. In some dams there is an existing problem with siltation and the addition of landslide debris will only compound this.

Underwater slides occurred in silt which had accumulated in the reservoir at the Ambuklao Dam. The silt entered the inlets to the underground powerhouse and stopped the turbines.

5.1.2 Earth, Rock and Retaining Structures

Man-made geotechnical structures affected by

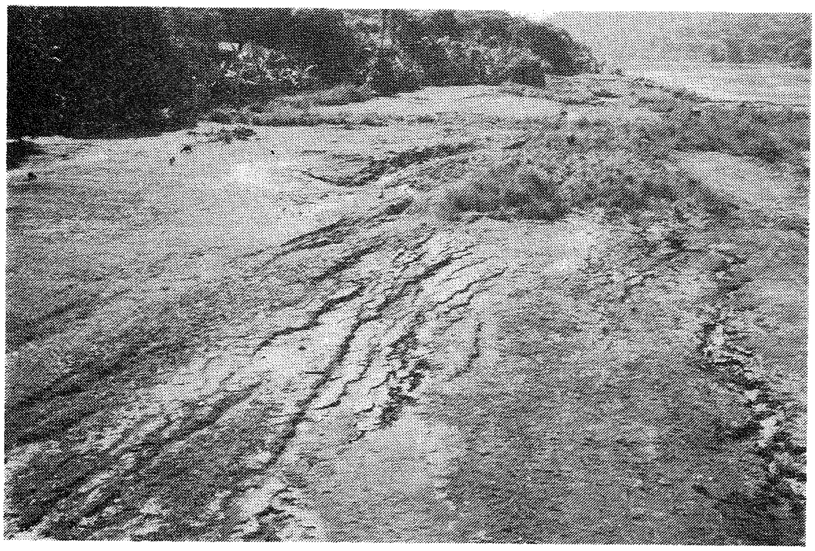


Figure 5.1.13: Lateral spreading of river bank showing ejected sand

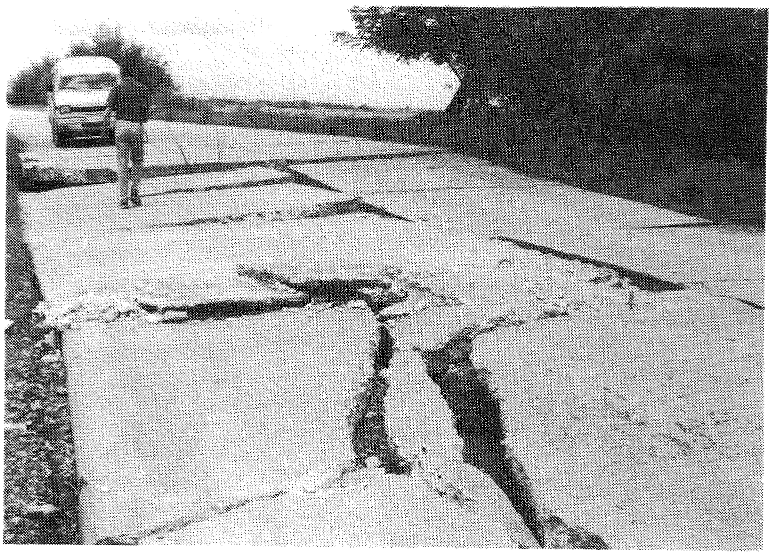


Figure 5.1.14: Liquefaction in low lying alluvial areas distorting road fills and pavement surface

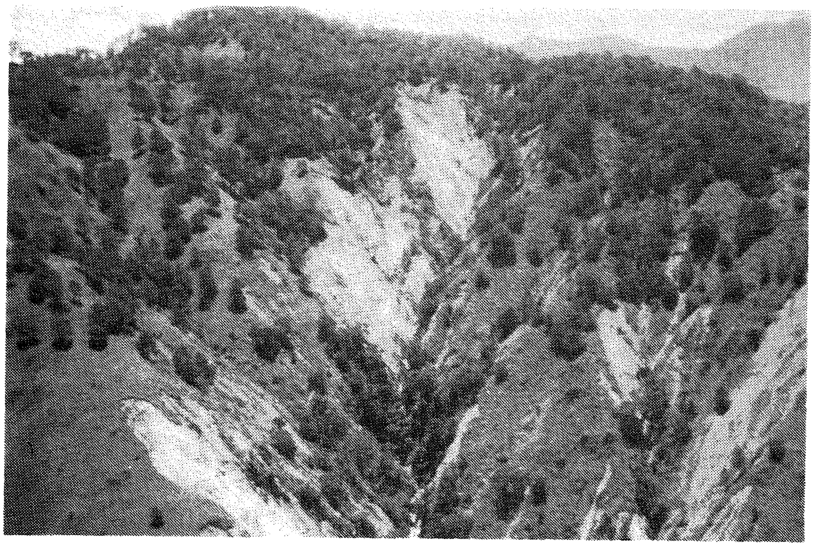


Figure 5.1.15: Landslides in mountainous area north of Baguio; many originated at crests of steep slopes and ridges

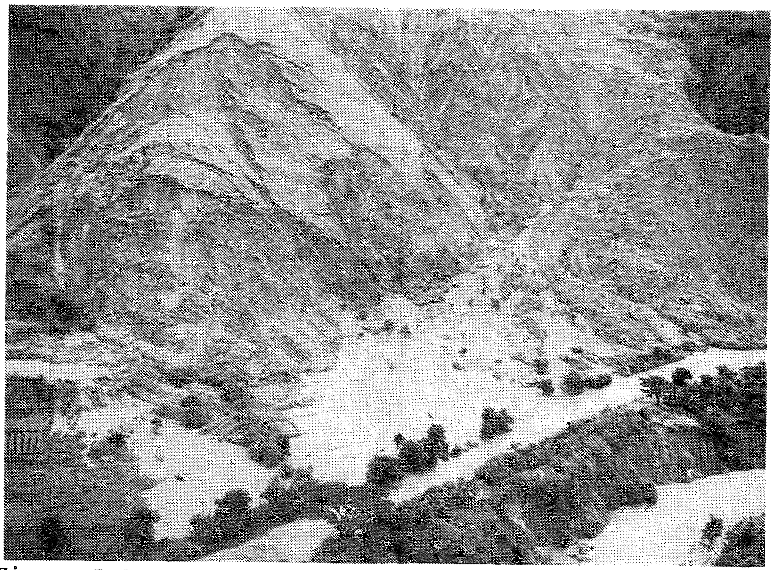


Figure 5.1.16: Dalton Pass road; landslides and mud flows obliterating houses, rice fields and roadway (Photo: Dodong Teves, PNOC)

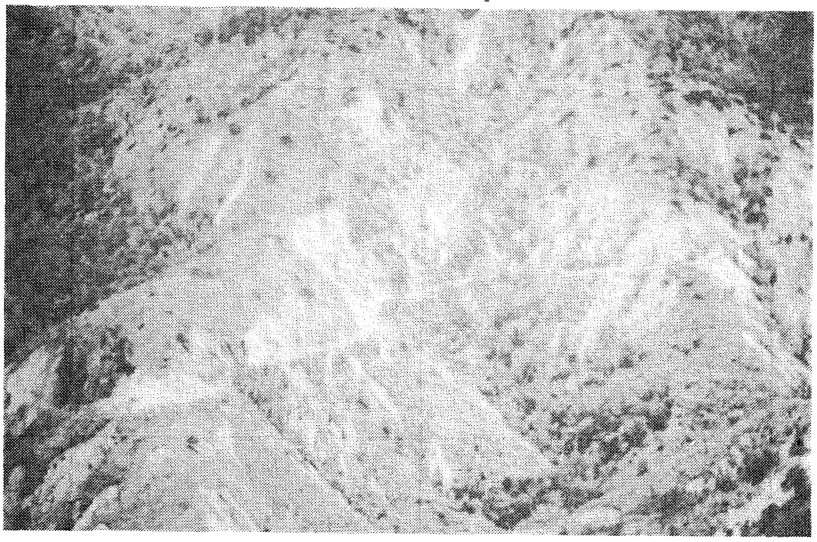


Figure 5.1.17: Landslides in mountains north of Baguio blocking road to Ambuklao hydroelectric plant and villages

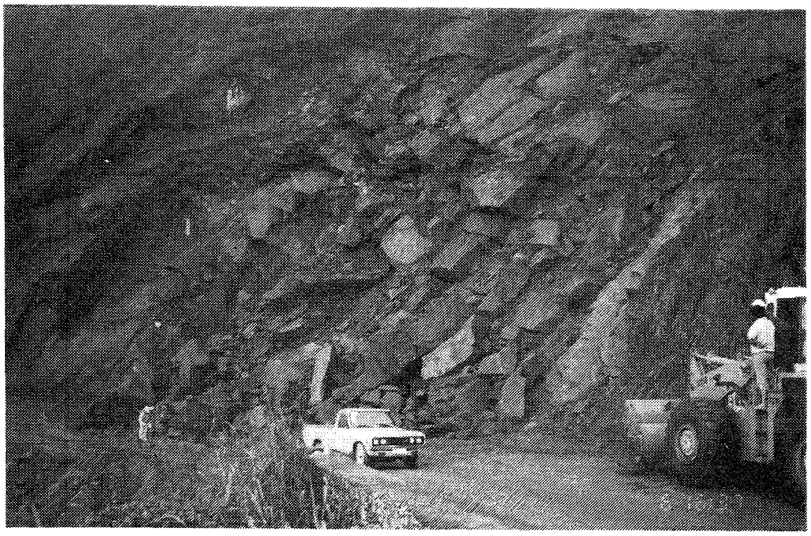


Figure 5.1.18: Naguilian Highway; rock slide due to aftershock, 3 weeks after main event

the earthquake included reclamation fills, road fills, dams and retaining walls.

Reclamation Fills

Reclamation fill at Dagupan apparently consisted of sand and sawdust, but there do not seem to be any records. Extensive liquefaction occurred on these deposits as previously discussed. In downtown Manila, large buildings were constructed on piled foundations through a hydraulically placed sand fill reclamation. Settlement of the hydraulic fill, up to about .3m, occurred around some of the buildings.

Road Fills

Numerous road fills performed poorly. In the Central Plains area many roads are constructed on low fills which cross swampy areas. Close to the fault rupture on the road from Rizal to San Jose a number of these fills had failed by what appeared to be liquefaction of the underlying natural saturated soils which led to settlement and spreading of the overlying fill (Figure 5.1.14). Numerous bridge approach fills settled with this being most obvious at the fill and bridge abutment contact (Figure 5.1.19). Few bridge abutments seemed to have been badly affected and the bridges were quickly reopened by placement of fill to bring the pavement up to bridge deck level. Lateral spreading of some bridge approach fills occurred, due to liquefaction of the underlying natural soil. In most cases this did not result in major failure of the bridge approach fills.

Failure of many road fills in the mountains occurred. This was not surprising given the mountainous terrain which required high fills for a relatively narrow road. Most road fills appeared to be unretained. Some had a rock facing (Figure 5.1.20). The nature of failures varied from subsidence with associated cracking (Figure 5.1.21) to complete failure. Due to the mountainous terrain it will be very difficult to reconstruct these failed areas. In such mountainous areas it is better to construct roads in cut, but this is not always possible. Due to relatively cheap labour costs, the use of gabion or crib gravity-type retaining walls may be cost effective in these situations. Because of the presence of relatively hard rock at shallow depths the construction of piled retaining walls would be difficult.

Retaining Walls

In Baguio many steeply cut and filled banks were not properly retained but rather faced with either loose or cemented limestone rock. Many of these failed, particularly those which were uncemented.

A large landslide occurred in an approximately 18m high bank at the site of the St Mary's Cathedral in Baguio (Figure 5.1.22). Directly below this bank was a four-storey building and slip debris completely covered the lower two-storeys. The bank was inadequately retained, only being faced with a combination of reinforced concrete and concreted rock. The removal of slip debris and reconstruction of a new retaining wall will be extremely difficult because of the restricted access.

Dams

A number of large dams were located relatively close to the fault rupture and were subject to strong ground motions. They included the Pantabangan and Masiway Dams located approximately 15km east of the fault rupture and not far from the earthquake epicentre, and the Ambuklao Dam, north of Baguio, and which is located approximately 15km west of the inferred fault rupture. Ground accelerations at these sites would have been in the range of 0.35 - 0.5g with horizontal dam crest accelerations possibly as high as 1.2g.

The Pantabangan Dam is 110m high and consists of two embankments which meet at a ridge near the centre. They are zoned earth/rock fill structures and a typical section is shown on Figure 5.1.23. One is concrete faced. At the time of the earthquake water levels were low (estimated to be about RL180 on section shown in Figure 5.1.23) and little damage was suffered except for some minor cracking due to settlement near the centre ridge and towards the right abutment.

The Masiway Dam is a rockfill dam with a central earth core. This dam is estimated to be about 40m high. It was severely stressed and settlement of more than 0.3m occurred along much of the crest with settlement of up to 0.6m apparent at the fill and concrete spillway interface (Figure 5.5.24). Longitudinal cracks were apparent along the upstream shoulder (Figure 5.1.25) and on the upstream side of the crest. These cracks appear to be associated with relatively shallow sliding within the saturated upstream rockfill shoulder and do not affect the central earth core. Apparently drain pipes at the base of the northern wall directly downstream of the power intake were emitting a steady and unusually high discharge. The source of this seepage was not certain.

The Ambuklao Dam is a 129m high rockfill dam with a central earth core. It is described more fully in Case History C.4. The behaviour of this dam was similar to that of Masiway but the amount of stressing was not as great. Crest settlements of about 0.3m occurred which were most noticeable at the interface with the spillway. Intermittent longitudinal cracks developed along the crest and on the upstream shoulder. These are postulated to be associated with shallow slumping. This movement in the rockfill shoulder caused some tilting and separation of the spillway wing walls.

The behaviour of both the Masiway and Ambuklao Dam is considered to be much as would be predicted for dams of these types when subjected to very strong earthquake shaking. More severe slumping in the upstream direction would be expected because of the effect of saturation. It is important to understand that this mode of behaviour does occur. Although slumping was probably shallow and did not affect the

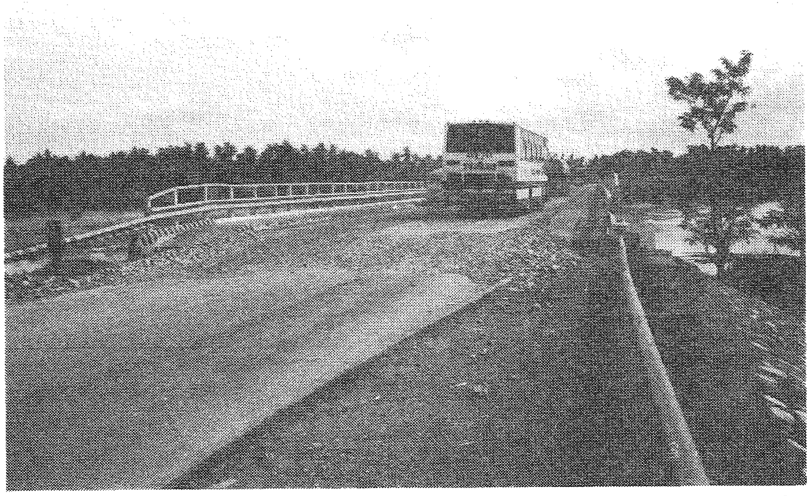


Figure 5.1.19: Cayanga Bridge north of Dagupan; approach fill settlement showing temporary reinstatement with a fill ramp to deck level

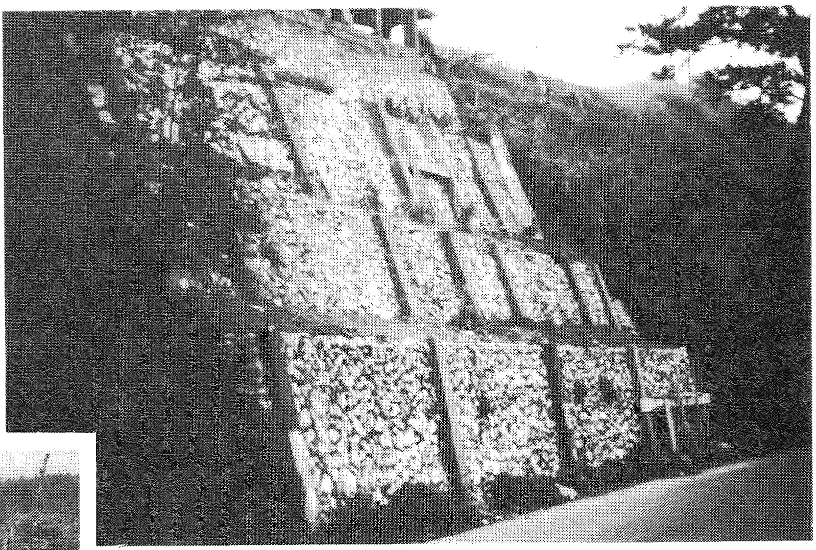


Figure 5.1.20: Rock-faced cut along Naguilian Highway near Baguio

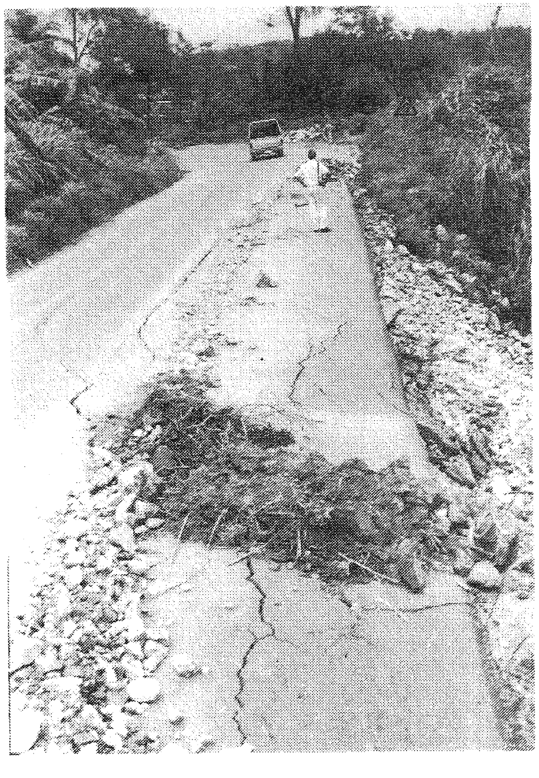


Figure 5.1.21: Road slumping due to failure of rock facing to retain fill

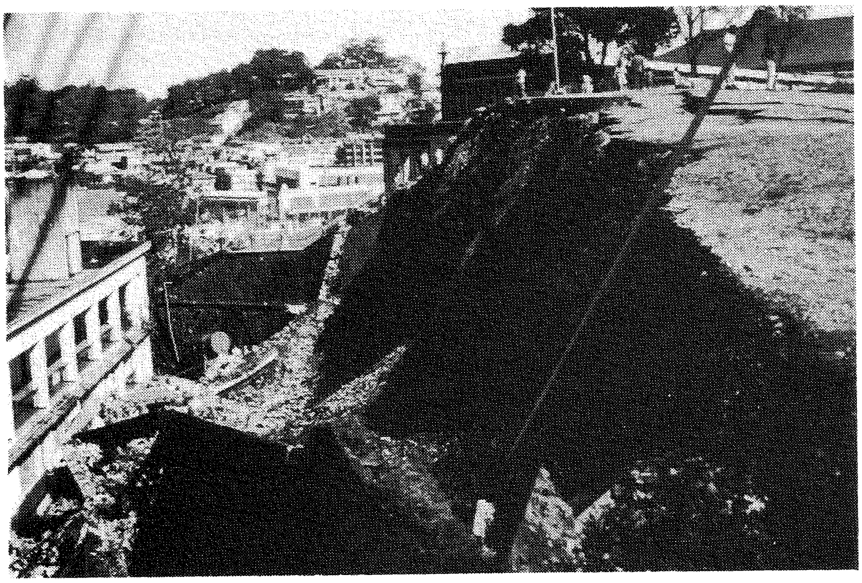


Figure 5.1.22: St Mary's Cathedral, Baguio; approximately 18 m high bank of volcanic pyroclastic material faced with cemented rock and concrete panels

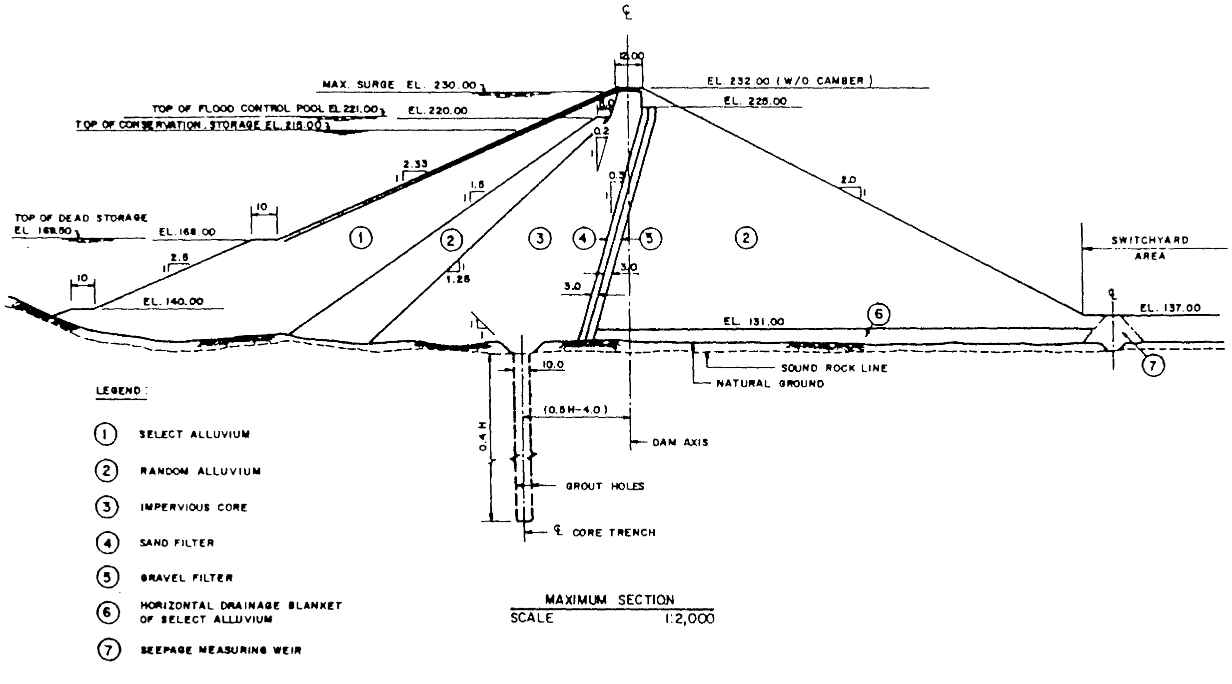


Figure 5.1.23: Pantabagan Dam; design cross-section

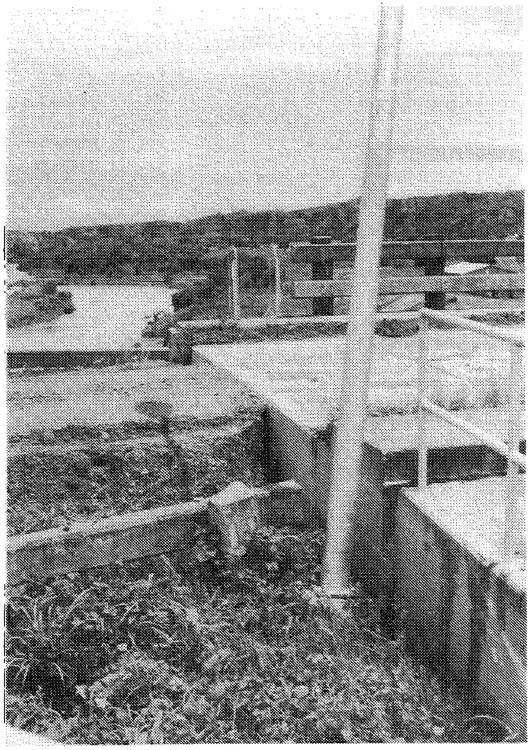


Figure 5.1.24: Masiway Dam; settlement of rockfill dam at spillway interface. Note temporary approach fill

Figure 5.1.25: Masiway Dam; longitudinal cracking in upstream shoulder of rockfill dam

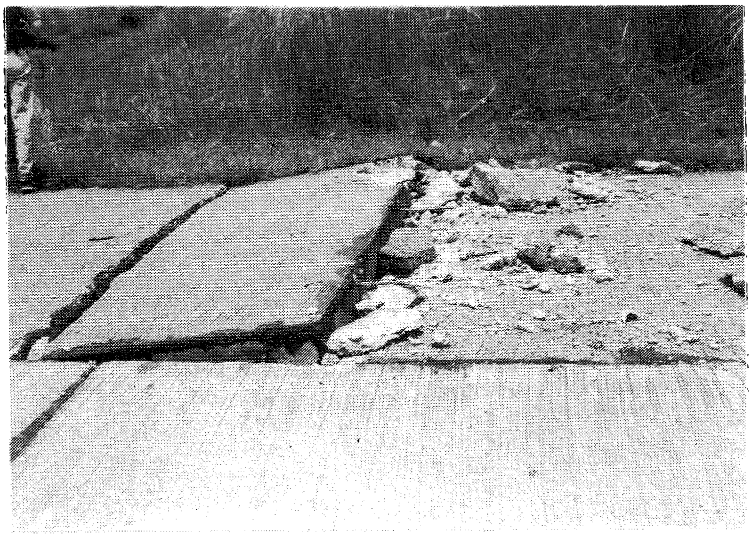


Figure 5.2.1: West of Rizal; compression failure of conrete road paving

central core it did affect adjacent spillway structures. The displacements which can occur in earth and rockfill dams need to be considered in the design of structures which pass through or abut the dam.

In all three dam reservoirs extensive land-slippage took place involving large quantities of soil and debris. Siltation of the reservoirs was a problem before the earthquake, but will now be substantially worse. The high sediment bed load also affects rivers and channels downstream. Extensive irrigation schemes are used for rice growing and siltation of the irrigation channels is an on-going problem. Careful management of reservoir catchment areas cannot be over-emphasised to avoid the siltation problems that can otherwise arise.

Mines and Tailings Dams

In the Baguio region there are a number of major underground and opencast mines. No damage was reported to tunnels and no rockfalls. However, some workings have become flooded. In addition, damage to access roads and bridges resulted in problems in transporting output from the mines.

We understand that PHILEX mines have three large tailings dams. One is full, one is being filled and the other is under construction. They are approximately 200m high with downstream shoulder slopes of 45° and are constructed in the upstream direction with a combination of compacted mine waste and cycloned tailings. Apparently they suffered no damage, which is quite remarkable and suggests that the phreatic level in the tailings must have been depressed.

5.2 CIVIL ENGINEERING STRUCTURES

5.2.1 Roads

The roading network to northern Luzon is fed principally by two highways, one servicing the west coast north of Lingayen Gulf, and a second more central route across the Dalton Pass through to the Cagayan River Valley which lies between the Luzon Central Cordillera and Northern Sierra Madre. Both highways initially pass north from Manila across the Central Luzon Plain. Off the western highway, three means of road access were available to Baguio City, located in the south-west of the Central Cordillera at an elevation of 1500 metres. The three routes were:

(a) The Kennon Road from Sison (43kms)
(b) The Marcos Highway from Agoo (48kms)
(c) The Naguilian Road from Bauang (63kms)

with a single road extending beyond Baguio, through the Cordillera, to Bontoc (90kms) and northern Luzon.

Road construction varied from the very best international standard motorway construction to basic metal surfaced roads. The majority of the arterial routes are concrete paved on a gravel sub-base, built to international standards. Generally, the metal roads have also been built to a high standard with a compacted gravel sub-base. However, on a number of roads seen by the team, heavy traffic loading and high rainfall had adversely affected the metal surface, generating extensive potholing. Road maintenance in the Philippines' climate and topography is very demanding on available resources, particularly when faced with the disruption and competing demand of a major earthquake in the area.

The central highway north of San Jose, through the Dalton Pass to Santa Fe (60kms), and the three roads to Baguio City were impassable due to earthquake induced land slides in the steep country. The following monsoon rains exacerbated the earthquake effects by causing debris flows to spread across the carriageways. The road north from Baguio to Bontoc was also severely affected by landslides, completely cutting off all road access into the central Cordillera area. On the Luzon Plain, particularly from the epicentral region east of Rizal across to Lingayen Gulf, liquefaction had caused road foundations to slump and bridge structures to collapse severely affecting road transport. However, in this area sufficient secondary routes were available to allow a particularly severe obstruction to be bypassed. This increased transport times, hence cost, and increased the loading on roads not designed for heavy traffic densities.

In the area of Luzon Island that the team visited, arterial roading may be considered in three categories:

1. Two lane carriageways in each direction built to international standards in the last 20 years, with asphaltic or cement concrete paving.
2. Single lane carriageways in each direction, each lane of paving built in reinforced concrete 225mm thick on a compacted gravel sub-base.
3. Two-lane carriageways with gravel surfacing on a compacted gravel sub-base.

The roading in the epicentral region and up through the La Union coast is generally of the category (2) type. These roads have been built to a high standard during the 1920's and 30's with a sound sub-base down through the soft silts of the rice fields.

Maintenance is obviously a problem with heavy modern trucks taking their toll by causing consolidation or spreading of the sub-base. This is leading to cracking of the pavement, exposing the sub-base to water penetration which exacerbates the detrimental effect of the heavy traffic. Short term remedial measures are being taken with asphaltic concrete overlay, whereas longer term replacement is being carried out in a number of areas with cement concrete paving on the existing upgraded sub-base. For the amount of traffic these roads carried, they appeared to stand up well under excessive loading.

In the epicentral regional between Rizal and San Jose, where the road alignment is generally parallel to the fault trace and within 1km of it until the fault trace diverged towards the north, two types of road structure failure appeared to have occurred. They were:

1. Slumping and lateral spreading of the road embankment due to liquefaction of the soils below or adjacent to the road embankment. Failure of the road foundation then led to breakup of the unreinforced concrete paving. Figure 5.1.14.
2. Longitudinal compression failure of the reinforced concrete road pavement, resulting in one section of paving riding over the next (see Figure 5.2.1).

In 2 above, the overlap varied from about 200mm to over 1.500 metres. This pavement overlap did not necessarily occur across the two carriageways on one line, but adjacent carriageway failure zones could be displaced by up to 40 metres, with signs of horizontal shear movement along the centre line joint between the two strips of paving. It was noted that where the carriageway failure zones were offset, the Northern side point of failure appeared to be east of the southern carriageway failure zone. Refer Figure 5.2.2, which is viewed looking west.

It is thought that this type of pavement failure was due to high amplitude surface waves in the near flat alluvial plain, travelling in a north-west direction from the south-east, parallel to the fault as fault rupture was initiated. The consistent offset of carriageway failure may be due to the oblique angle of the wave front as it passed under a length of road pavement aligned in a more westerly direction.

The major concern in the northern plain area with its extensive road network, is the cost implication of protecting the roads near rivers and along coastal areas where settlement has made flooding more prevalent. River siltation due to increased bed load from the massive land slips in the river source areas will also increase the risk of road flooding. A consultant's preliminary report prepared for DPWH [1] suggested that NZ$0.2M per kilometre would be required to raise road grade levels in 'at-risk' areas, and NZ$50,000 per kilometre for other earthquake affected roads.

In the mountainous Central Cordillera area all road access was cut due to earthquake induced land slips. This had a major impact on search and rescue efforts and in transporting food and medical supplies. Baguio City was particularly affected, and hence the population in smaller centres to the north as well as the large number of individual family units throughout the area. The only means of moving in personnel and supplies was to air freight into Baguio City airport, then helicopter distribution into the isolated areas.

The Naguilian Road to Baguio City was opened to limited traffic five days after the earthquake, and was still the only means of road transport into the area three weeks later. At the time the team was in the area, one-way traffic only was available (up to Baguio in the a.m., down in the p.m.). Road blockages were still occurring due to aftershocks continuing to bring down rock slides across the road, (Figure 5.1.18). Stoppages to clear slip material and carry out urgent reconstruction work were causing long delays in traffic movement. The DPWH preliminary report suggested that NZ$2.4M would be required for landslide removal and reconstruction work on the Naguilian Road. It was also recommended to upgrade the road as an emergency route to Baguio City despite being the longest route from Manila, as it would be relatively easily maintained against landslides.

The other two main roads into Baguio City (Kennon Road and Marcos Highway) were more severely affected with whole hillsides moving, totally destroying the road formation. It will probably be necessary to abandon portions of these road alignments, and cut the road-bed into the mountainside, rather than rebuild on side fills which

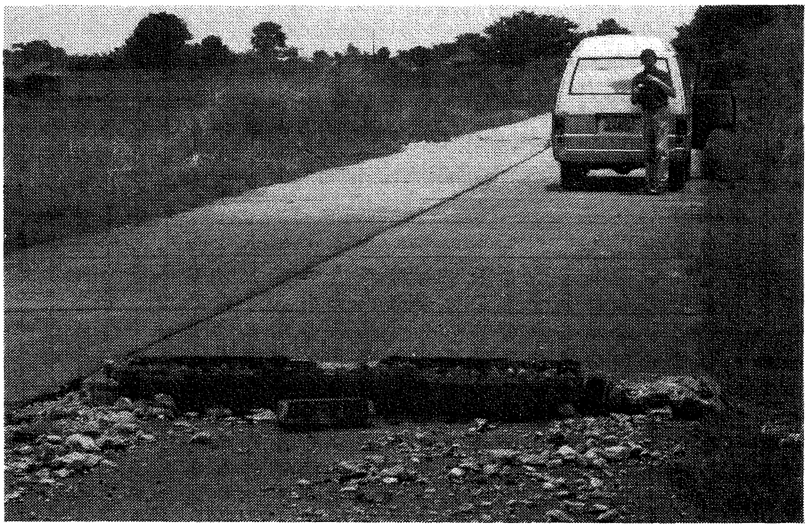


Figure 5.2.2: West of Rizal; compression failure of concrete road paving, typical offset of failure in each carriageway

failed. Initial cost estimates for full reconstruction, dressing of slopes and building of proper retaining structures is assessed at NZ$15M and NZ$20M respectively for the Kennon and Marcos routes. The DPWH report also suggested that before these large sums be committed, consideration should be given to a lesser standard of reconstruction and acceptance of the fact that these two routes would not provide primary access to Baguio.

The road between Baguio and Bontoc was in the process of reconstruction prior to the earthquake, with new formation in many areas. Landslips were again a major problem, with an estimated cost of NZ$16M for slip removal and reconstruction over a 30km total length of roadway.

The Dalton Pass road was severely disrupted by fault movement as well as massive landslides. Fault movements of up to 6 metres horizontally and 0.7 metres vertically across the road have been recorded by USGS at a number of locations. The volume of landslide material to be removed has been estimated by DPWH at approximately 1.4 million cubic metres, and a cost of removal and reconstruction in the order of NZ$40M to NZ$60M. Due to the vital nature of this road link to the Cagayan Valley, consideration is being given to upgrading another pass route to provide alternative access in a similar emergency.

5.2.2 Bridges

General

The arterial roading network and associated bridging in the epicentral region was developed in the 1920's-30's with a strong USA influence on use of materials and structural form. The majority of bridging is of one or two spans, cast in-situ reinforced concrete, to cross local streams and rice field drainage dikes. Where there are wide flood plains associated with larger rivers, multispan bridging has been built with reinforced concrete piers supported on piles. Cast in-situ reinforced concrete beam and slab superstructures were built between piers and abutments for spans up to 35 metres. Where larger spans were required, rivetted steel Warren Truss bridging was commonly used with a concrete deck cast on stringers at lower chord level. Refer Figure 5.2.3.

A standard 50m span, rivetted steel truss, to form multispan bridging has been used quite extensively on the main route from Manila to Northern Luzon. Refer Figure 5.2.4.

More modern replacement bridging is evident, built with a cast in-situ reinforced concrete superstructure supported on driven precast octagonal piles rising to support the abutment blocks or a diaphragm cast between the main bridge beams. Refer Figure 5.2.5.

The bridge beams and deck were cast integrally, incorporating the diaphragms over the piles, except the closing threequarter span to the abutments which are pinned at each end.

Earthquake induced damage to bridging appeared to be initiated by soil failure such as liquefaction or lateral spreading of river banks. This foundation failure caused gross movement of piers or abutments. Due to a lack of continuity in the superstructure, this movement allowed deck beams or trusses to fall free of their supports. Lack of continuity was particularly evident with steel truss superstructures supported on pier or abutment rocker type bearings. Refer Case Study No. 6, Carmen Bridge.

Approach fill settlement was universally a major cause of initial disruption to bridge use until temporary fill could be put in place. This appeared to have been quickly achieved.

Reinforced Concrete 1 and 2 Span Bridges

These bridges are generally formed with massive abutments and piers of cast in-situ reinforced concrete built up off driven reinforced concrete square piles. Bridge beams, deck and guard-rails are also built up in reinforced cast in-situ concrete, but not integrally connected to pier or abutment. A cast-in steel bearing plate is provided in the pier top surface to carry each bridge beam. Refer Figure 5.2.6.

This plate has two longitudinal ribs formed on its lower and upper surfaces to provide a key into the pier and beam to resist transverse loading. No longitudinal continuity is provided from one span to the next, or to the abutments.

At all but four bridge sites in the epicentral region, the only damage appeared to be settlement of the carriageway approach fill by 100 to 300mm. This approach fill settlement was seen to be general throughout the region. Temporary fill had been placed to form an access ramp on to each of the bridge decks.

4km west of Rizal, a two-span bridge across an irrigation feeder canal was completely demolished due to fault movement through or close to the site. It would appear the bridge collapse, with liquefaction slumping, temporarily dammed the water flow. The water over-topped the collapsed bridge structure, cut through the canal embankment into the adjacent rice field, then scoured out any trace of surface faulting. At the time of the team's visit, the water supply to the feeder canal had been cut off. The two abutments and central pier had all tilted towards the east by varying degrees. The eastern span had dropped completely into the stream bed as the eastern abutment had tilted more than the pier. The abutment had moved back towards the approach carriageway and fill which had slumped away downstream, through the scoured out embankment, to a level below the 2.5m deep abutment apron wall. The western span had pulled off the western abutment due to greater easterly movement of the pier, but the pier was still supporting the second beam in from the southern side (there being four beams per span). Refer Figures 5.2.7 and 5.2.8

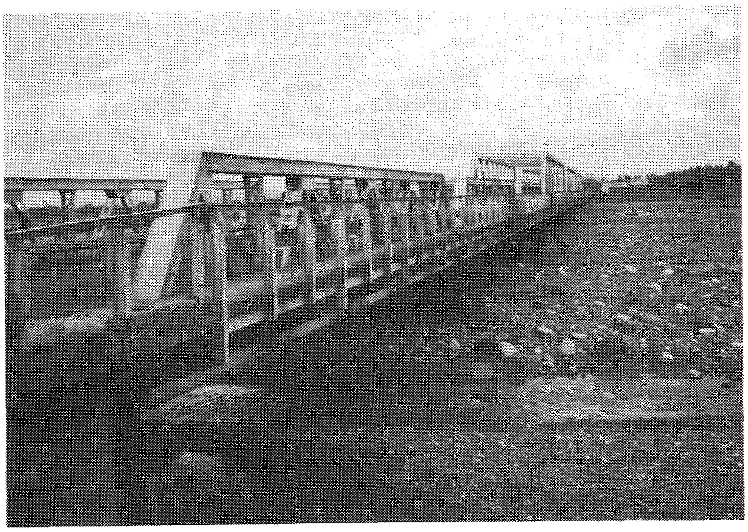


Figure 5.2.3: Rivetted steel Warren truss bridge with concrete deck

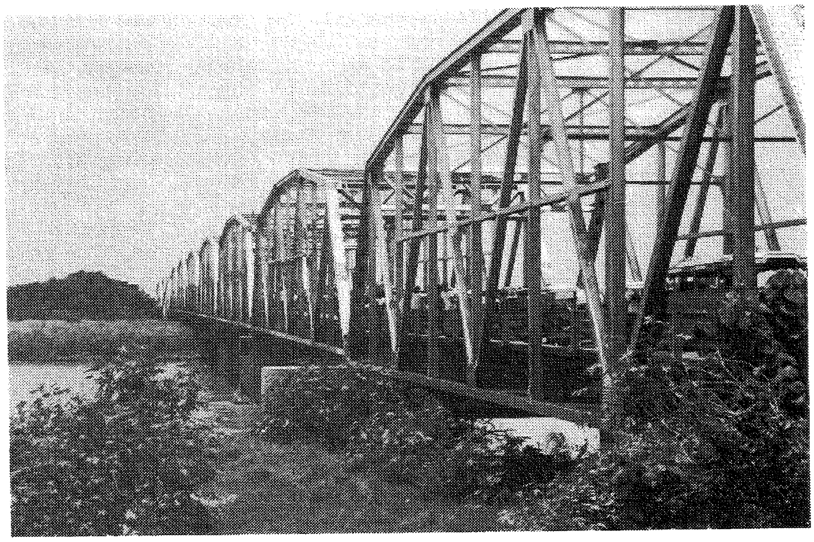


Figure 5.2.4: A standard 50 m span rivetted steel truss bridge with concrete deck - Carmen Bridge

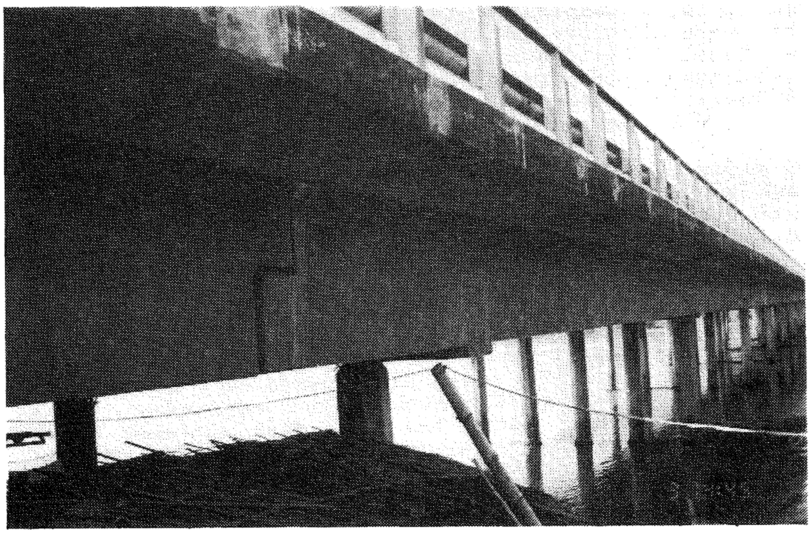


Figure 5.2.5: Reinforced concrete bridge supported on concrete piers and transverse diaphragms

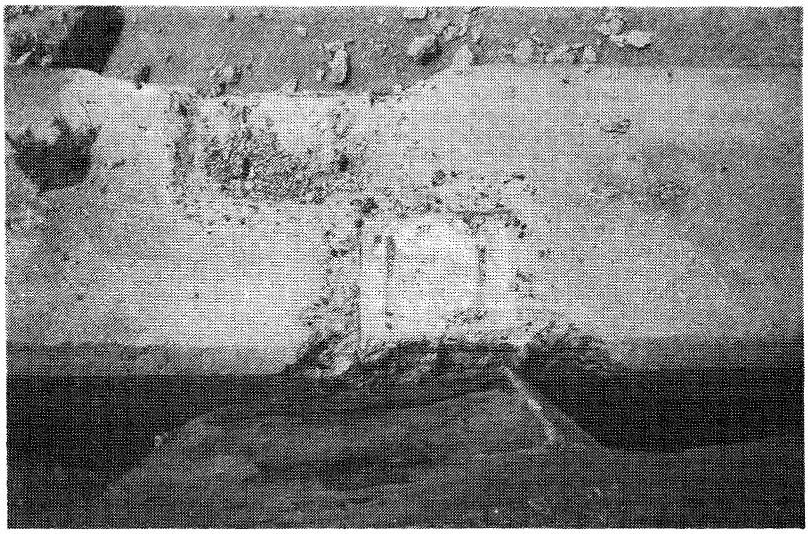


Figure 5.2.6: *Rizal Canal Bridge; cast-in steel bearing plate to support reinforced concrete bridge beams, view down onto pier cap. The bearing plate has two longitudinal ribs, 25mm high, formed on the lower and upper surfaces to provide a key into the pier and beam to resist transverse loading*

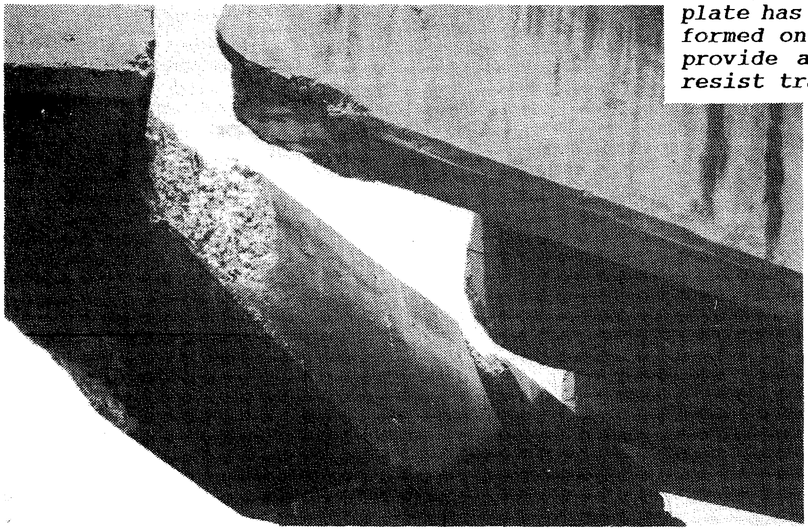


Figure 5.2.7: *Rizal Canal Bridge; beams pulled away from the pier but still supported on far end cantilever section of pier. This cantilever section had failed in bending*

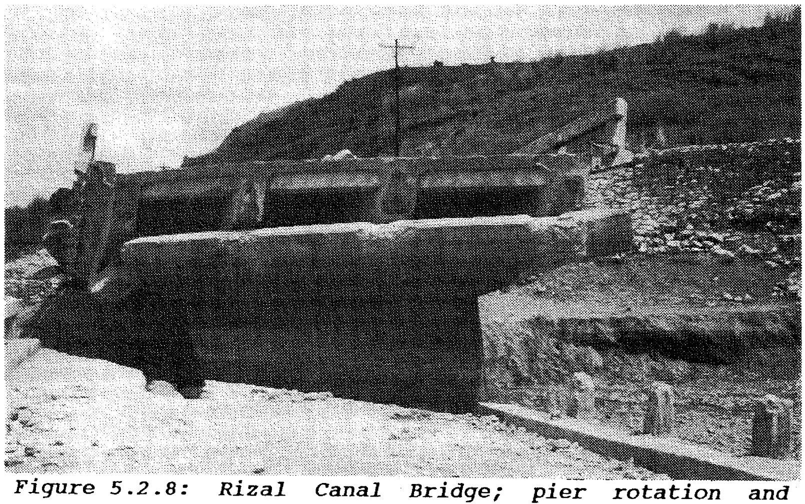


Figure 5.2.8: *Rizal Canal Bridge; pier rotation and collapse of deck, view towards north west. Initial demolition work had commenced with removal of the handrail and cutting a slot in the deck*

The southern cantilever section of the pier cap had broken away under the full load of the span as the southern deck beam tried to take all the load of the distorting bridge structure. At the western end, the abutment had rotated approximately 45 degrees to be lying over the end of the bridge deck. It was not possible to see whether the piles had hinged at the junction with the abutment apron, as the western approach fill and higher ground to the north had slumped down on to the apron wall.

Reinforced Concrete Multi-Span Bridges

None of this bridge type seen by the team sustained significant damage, except for pier settlement. This lack of major damage was possibly due to sufficient longitudinal continuity provided by fixed bearing plates cast into the bridge beams and piers, or fortuitous bridge site location. Carriageway approach fills would need regrading, but otherwise normal bridge maintenance would cover any required repair, such as patching of spalled concrete and grouting of cracks.

Two bridges the team noted had piers in the river channel that had settled prior to the earthquake. In one case, the Carmen Bridge, a new pier had been cast around the old with large diameter bored piers placed up and down stream of the pier. In the second case, holes had been cut in the bridge deck, between the beams, to drive 5 square reinforced concrete piles on either side of the settled pier. The bridge beams and deck had been jacked up to level, and pile caps cast on either side of the old pier, over the new piles, to support the bridge beams. The next pier into the river channel had also settled, reputedly due to earthquake shaking. This bridge south of Sison was further damaged by mass ground movement rotating pier bases and supporting piles towards the river, generating compression in the bridge beams and deck. A number of abutment beam bearings had seized, or the gap filled with dirt or packed with mortar during maintenance to prevent corrosion of the bearing plates. As the abutment base rotated towards the adjacent bridge span, the beams bore down on the pier outer edge due to lack of clearance, spalling off the cover concrete, hence exposing the reinforcing steel. Refer Figure 5.2.9.

In the case of a more recent bridge, north east of Dagupan (Cayanga Bridge), the ground slumping extended into the river channel, beyond the first line of piles. This movement of the pile base was restrained at bridge deck level, so that the long piles yielded at the junction with the concrete diaphragm between the bridge beams, breaking away the cover concrete of the piles to expose the reinforcing steel. Refer Figure 5.2.5.

The stability of the bridge did not look to be impaired, due to longitudinal continuity through the beam/deck structure providing overall support. However, repairs would need to be undertaken before further deterioration took place.

Steel Truss, Multi-Span Bridges

Steel truss bridges of the 1920's vintage have been fabricated from rolled channel sections rivetted to flats for the main hanger members of the Warren Trusses, and top and bottom chords built up from flats rivetted to connecting angles. Rolled steel 'I' or channel sections were placed across the bridge, supported by the bottom truss member, to form the deck supporting joists. A cast in-situ, reinforced concrete deck was then placed across the joists. The steel bridge super-structure is supported on reinforced concrete pier and piles through pin or rocker bearings. Standard 50 metre span steel truss bridges have been used quite extensively on the main routes to provide major river and flood plain crossings. Rolled 'I' sections are used to form the plated and riveted side trusses and top bracing. The concrete deck is also supported on rolled 'I' sections spanning between the truss bottom chords.

Pin and rocker bearings showed little capacity to take excessive movement or load generated by earthquake ground movement. (Refer Figure 5.2.10). In a number of cases the bolting of the bottom chord girder to the bearing plate had sheared off. (Refer Figure 5.2.11). Where this was coupled with excessive lateral movement of the pier due to liquefaction, there was nothing to restrain the bridge super-structure sliding off its bearings and hence off the abutment or pier cap.

Liquefaction associated with damage to structures appears to take two forms:

1. Liquefaction causing mass ground movement which has a gross effect on the structure. For example, flood plain liquefaction which generates slumping of the soft river silts towards the river channel. Bridge abutment and piers supports are affected with vertical, and more particularly, horizontal movement on a large scale.

2. Localised liquefaction due to a coupling of the ground and structure response to the earthquake motion. For example, building raft foundations bearing directly on to liquefiable material, or liquefaction produced around bridge piers in the flood plain. Refer Carmen Bridge Case Study.

Despite the failure of the Carmen Bridge (principally liquefaction failure), the steel structures performed well under earthquake action, with minor damage similar to that described for the other bridge types. A number of the steel truss bridges had withstood significant shaking as indicated by shearing off of bearing holding-down bolts, and steel handrails buckling between bridge abutment and deck guard-rail. Maintenance of these bridges appeared to be conscientiously undertaken, but did highlight the need for the work to be professionally directed. This level of technical input is required to ensure bridge bearing movements are maintained, movement gaps kept cleared, and the integrity of primary structural systems maintained.

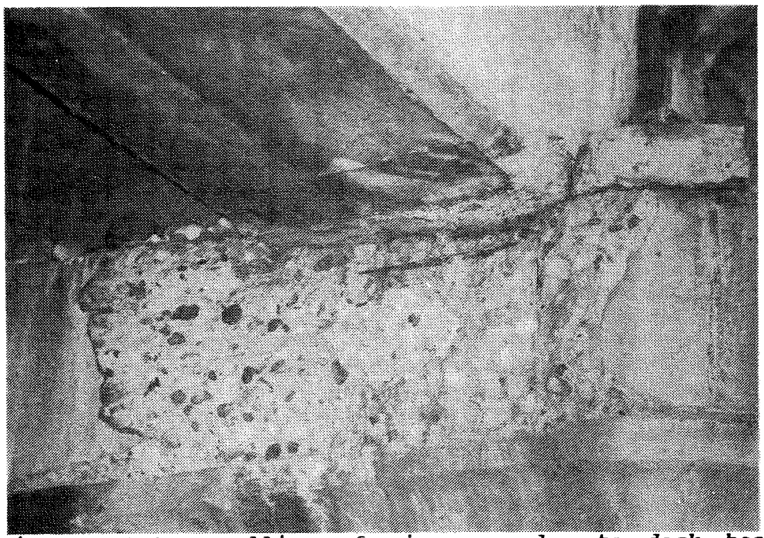


Figure 5.2.9: Spalling of pier cap due to deck beam bearing down on outer edge. The gap between pier cap and beam soffit had been packed with mortar to protect the bearing plate from corrosion

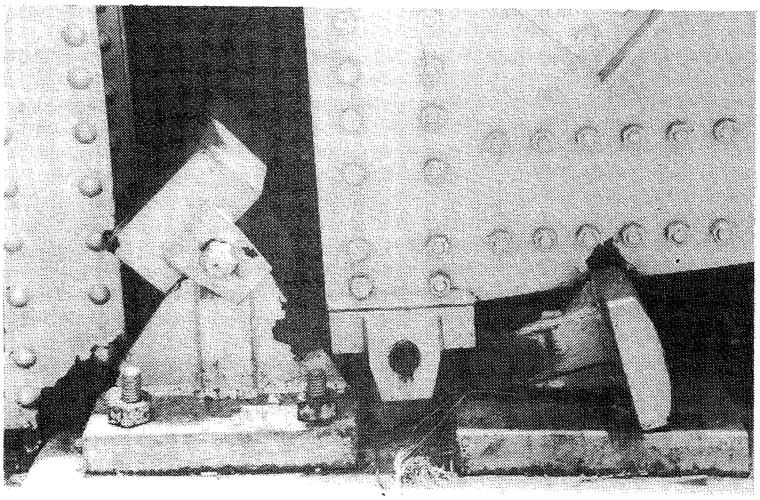


Figure 5.2.10: Carmen Bridge: pin and rocker bearing failure at the pier between spans 1 & 2. Refer Figure C6.1. There was no longitudinal tie between the girder spans

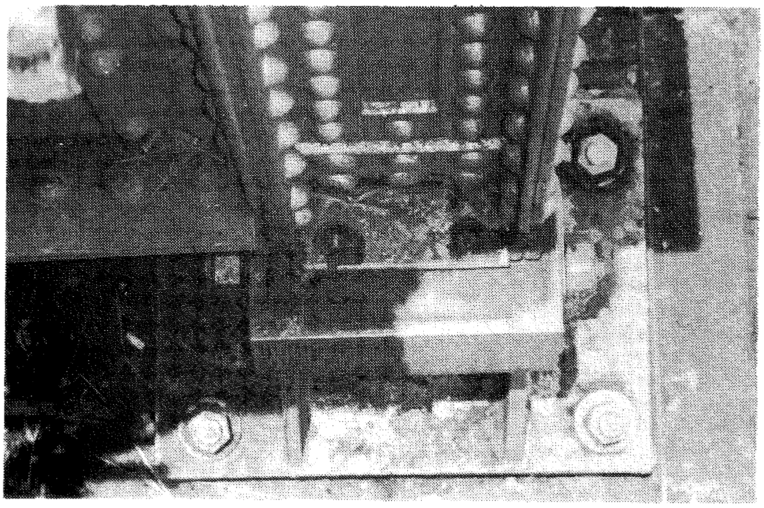


Figure 5.2.11: Shear failure of bolts at a girder support of the bridge shown in Figure 5.2.3

The three principal areas of failure in the bridging system appeared to be:

(a) Bridge approach settlement,

(b) Loss of support to pier piles from foundation soils. It would appear that liquefaction had a major part to play in this type of failure.

(c) The failure of pin bearing or rocker support to the bridge super-structure from pier or abutment. This primary failure coupled with lack of continuity between spans, allows the bridge superstructure to move off its supporting pier/s.

5.2.3 Port Facilities

At San Fernando port on the La Union coast, the team inspected one of two piers which had been damaged due to relative movement between the pile supported structure and fixed abutment at the landward end. The 150 metre long pier structure is built from cast in-situ reinforced concrete forming a deck with integral longitudinal deck beams supported on driven, vertical and raked, precast concrete octagonal piles. The earthquake-generated motion caused the pier to fail in tension across the deck to give a 600mm wide gap approximately 20 metres out from the abutment. Also, a right angle section of wharf has pulled away from the main pier (where they abut) in a tension failure. The main pier shows a number of additional areas of tension failure with transverse cracks in the deck up to 100mm wide. Associated movement damage has occurred to the top of piles with hinging, loss of concrete and exposure of reinforcing.

A number of raked piles had failed completely, with steel reinforcing breaking away from the longitudinal beam. Pile settlement of up to 400mm had occurred, particularly landwards of the deck tension failures. Severe corrosion had previously occurred to the pier steel reinforcing, particularly to the deck bottom bars and tidal section of the piles. The top surface of the 150mm thick deck was protected by a 70mm layer of asphaltic concrete topping. The corrosion of the longitudinal reinforcing had contributed to the tension failure of the deck and general disintegration of the pier components. Refer Figures 5.2.12 and 5.2.13.

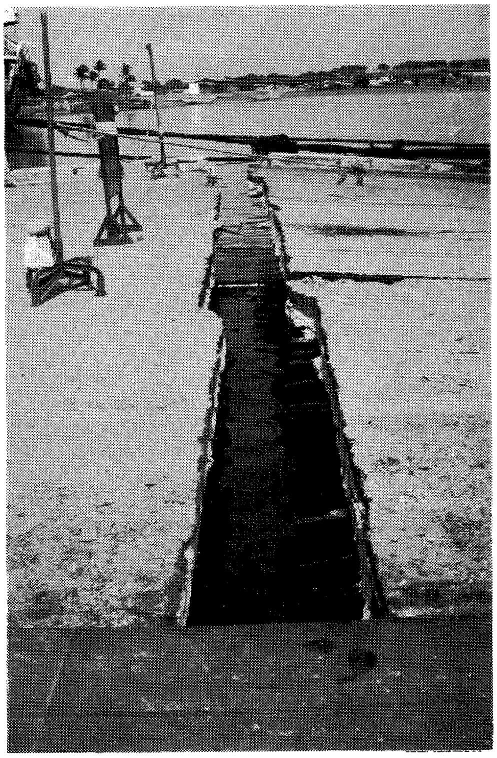


Figure 5.2.12: San Fernando port; tension failure of pier deck

No damage to port facilities in Manila was reported.

5.2.4 Petroleum Storage Tanks

Adjacent to the San Fernando port area, the team inspected a petroleum storage and distribution facility consisting of six main liquid storage tanks, blending and LPG services. Some damage was sustained affecting storage and distribution of product. For details see Case Study No.8.

Another similar installation nearby was not inspected closely but little damage was evident from the boundary fence.

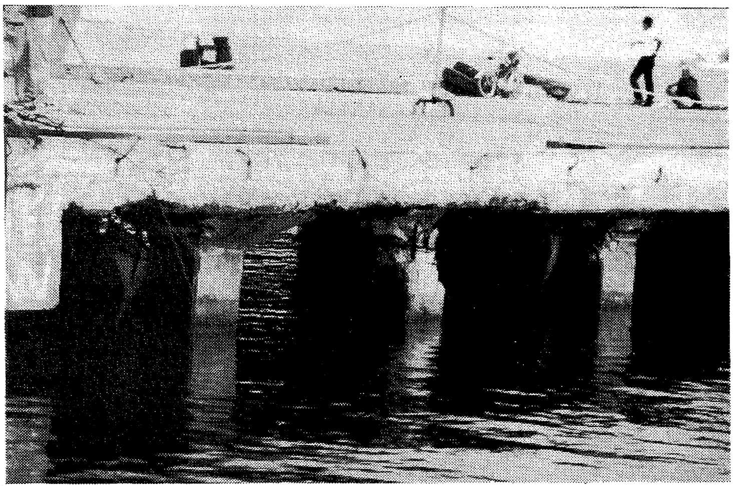


Figure 5.2.13: San Fernando port; failure of pier supports at the junction of vertical and raking piles

5.3 BUILDINGS

5.3.1 General

The majority of buildings survived the earthquake without significant damage. Nevertheless many buildings collapsed or were extensively damaged. Damage was widespread and varied.

Buildings in Manila suffered relatively little damage, although 117 school buildings, generally of 3 to 5 storeys, incurred structural damage. High rise construction generally fared well.

In the coastal city of Dagupan, building damage was almost entirely due to liquefaction of underlying sands. (Refer Section 5.1.1).

The tourist resort and University City of Baguio suffered the greatest building damage, particularly to hotels. Some University, commercial, residential and industrial buildings collapsed or were badly damaged. Soft storeys coupled with inadequate detailing were common features. Most buildings of five storeys and lower with regular structural layouts and vertical stiffness performed well.

Buildings which collapsed or were extensively damaged generally had one or more serious inadequacies:

(a) soft storeys

(b) vulnerable lateral load system

(c) lack of proper attention to foundation conditions

(d) lack of confinement steel in columns.

(e) poor detailing of joints

(f) construction defects

(a), (b) and (c) relate to **conceptual** design, (d) and (e) to **detailed** design and (f) to the **construction** process.

Many hotels which collapsed had soft storeys, presumably as a result of the need for open spaces at reception level. Even the most careful detailing of columns cannot be expected to sustain the forces and movements which result from this configuration.

Buildings with a vulnerable lateral load system include Montepino Apartments (Case Study No.5) and the University building in Baguio. Both had reinforced concrete frames infilled with blockwork. The blockwork was of average to poor quality with inadequate reinforcing. Once lost from a particular level, a soft storey is formed. Collapse can result, especially when detailing of columns provides little confinement to the concrete. In the case of Montepino Apartments, better detailing of the failed columns would have prevented the partial collapse of the column and the resulting tilt of one block.

There can be few better examples to illustrate the importance of concepts and detailing than the dramatic collapse of the Hyatt Terrace Hotel in Baguio (Case Study No. 1).

A feature of the overall inspections was the variable standard of construction observed in a number of buildings. The best is equal to any elsewhere, but standards were inconsistent and reliability questionable.

The importance of three aspects: concepts - details - construction was thus emphasised strongly in this earthquake.

Good concepts come from education and training of engineers and architects. Proper detailing requires specific education of structural designers. Good construction requires an appreciation by the owner, builder and building inspector of the importance of key details, and an effective interaction of these parties determined to build to recognised standards.

5.3.2 Hotels

A feature of this earthquake, almost exclusive to Baguio, was the dramatic collapse or serious damage to major hotel buildings. Baguio is a city of 300,000 population, some 1500 metres above sea level and its cool climate attracts large numbers of tourists. Accommodation ranges from large multi-storey hotels to individual holiday homes. Most of the biggest hotels collapsed or were damaged beyond repair. Most notable of these was the Hyatt Terraces, Baguio, a huge complex with world class facilities. See Case Study No. 1.

The Nevada Hotel (Figure 5.3.1) collapsed spectacularly, pitching forward into the entrance roadway. It appears that the demand for open space at entry level created a soft storey and a particular lack of stiffness at the front. Detailing of reinforced columns and walls was incapable of sustaining imposed displacements and brittle failure of the front walls/columns occurred. A further possible contribution to this collapse was failure of the retained ground on one side. The six metre high retaining wall formed the foundation for the hotel side wall. Sideways movement of this would have added to the lateral displacements on the first floor columns.

The Siesta Inn, a small five storey reinforced concrete building lost its first floor completely. There was little evidence of the existence of what was its ground floor - a classic soft storey.

The FRB Hotel, (Figure 5.3.2) had a circular shaped tower of three storeys perched above a two storey rectangular podium. The tower is stiff and solid, the podium flexible and open. Collapsed first floor columns showed minimal reinforcing and sparse lateral ties. It is not a large building, and more resilient detailing may have prevented collapse.

The Royal Inn (Figure 5.3.3) a rectangular hotel of four storeys suffered a similar fate, losing the first floor completely and

Figure 5.3.1: Effects of soft storey at Hotel Nevada, Baguio

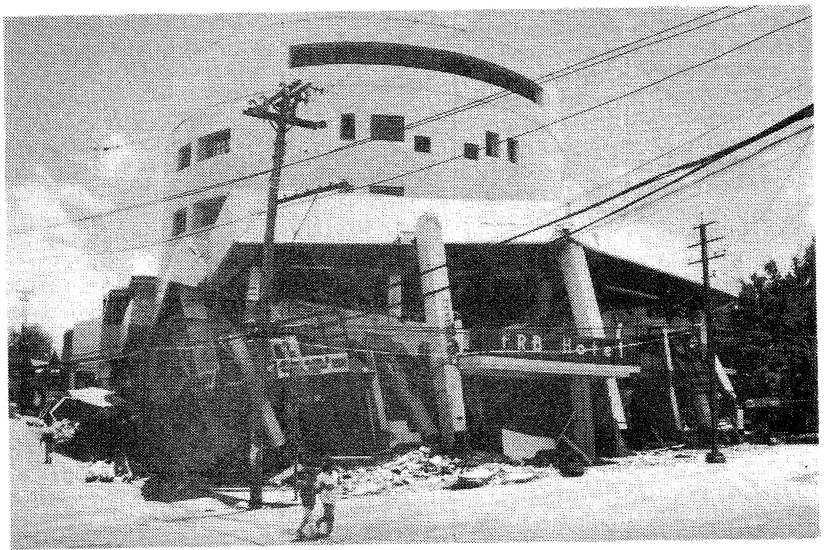


Figure 5.3.2: Two soft storeys at FRB Hotel, Baguio

much of the second. Reinforcement of failed columns is light and ties are widely spaced, each terminating in a 90° bend, not a 135° hook.

The Baguio Park Hotel (Figure 5.3.4), a modern reinforced concrete structure of nine storeys, faced on to Burnham Park, the central feature of Baguio City which includes a large boating lake. The ground floor entry and rooms facing the park were made as open as possible and this, coupled with inadequate reinforcing details appears to have contributed to its total collapse.

The Prime Hotel, a building of six storeys (Figure 5.3.5) apparently survived the earthquake well, but it has been condemned structurally. In the short direction it appears to have good shear walls at each end, but the longitudinal framing is suspect. The lintel beams are not well connected to the columns and the bow shaped walls have no visible reinforcement.

We did not see the Baguio Country Club, but this five storey hotel-type building collapsed at the ground floor level. At the time of the earthquake, 37 managers and representatives of a soft drink company were at a seminar on the open ground floor. At first they took refuge under steel legged tables, but as shaking continued and the building began to collapse they crawled out. The tables were subsequently crushed. The upper floors remained intact. Clearly another case of a soft storey, but with some indications of a slow rather than instantaneous collapse.

Hotels in Manila are of all shapes, sizes and qualities. Few if any suffered significant damage. Shaking intensities were considerably less in Manila than in Baguio and design and construction standards are generally higher.

In Dagupan, the large hotels were either piled or on firm ground, and suffered little. Some were without water, forcing their closure. The team stayed at Hotel Victoria, a six storey reinforced concrete structure on piles with its own artesian well. There was no evidence of damage, and

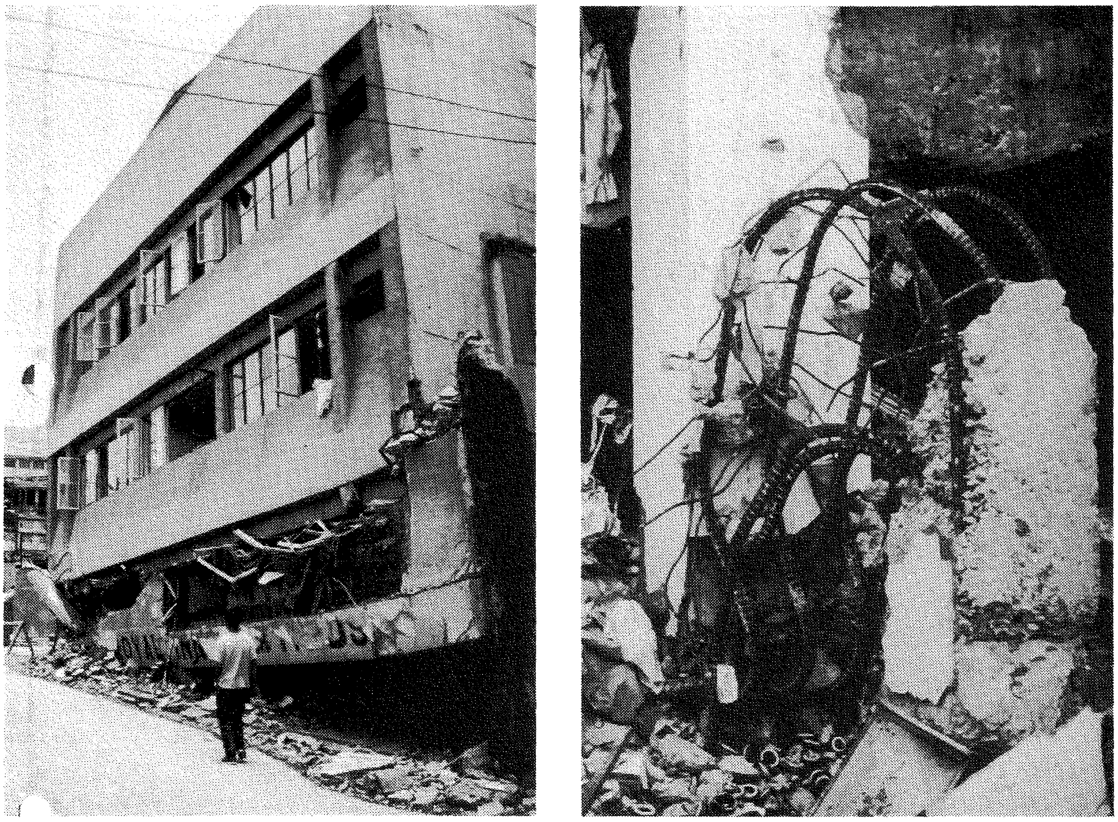


Figure 5.3.3: Soft storeys would test better reinforced columns than this one at the Royal Hotel, Baguio

Figure 5.3.4: Demise of the Baguio Park Hotel, damaging its neighbour

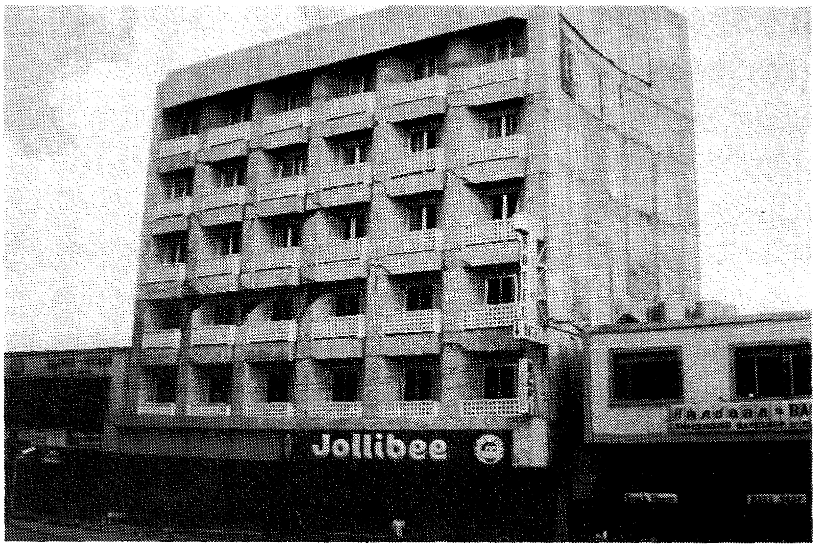
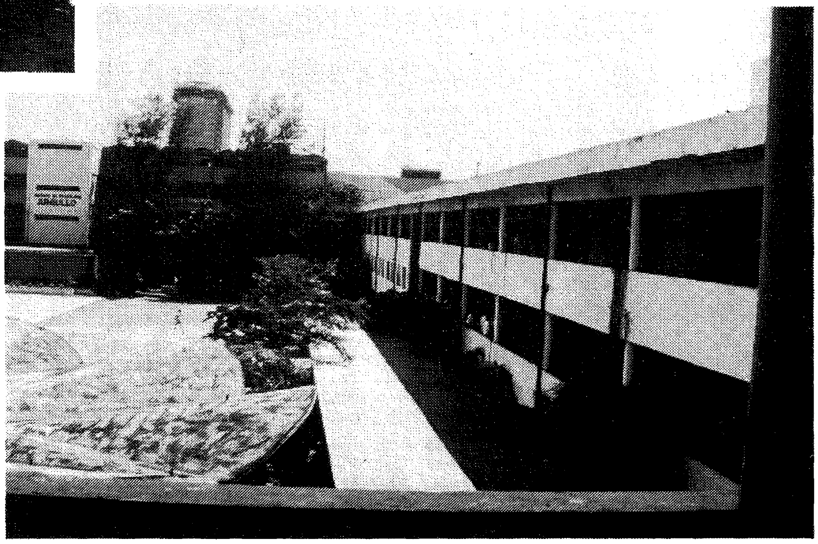


Figure 5.3.5: Apparent survivor - Prime Hotel, Baguio

Figure 5.3.6: Deprived of sewer and water, the International Palace Hotel, Dagupan, could not operate. It was understood the building is supported on deep piles

Figure 5.3.7: Damage to 117 schools in Manilla caused widespread concern about their safety for continued occupation; most suffered minor damage only. The Araullo High School was partly closed off due to damage to block shear walls



with the substantial disruption in the city, the owners were pleased to have customers.

Another hotel, the International Palace (Figure 5.3.6), the largest in Dagupan, was out of service due to lack of water and power, but was undamaged, indicating that ground shaking in Dagupan was not extreme.

5.3.3 Schools

Considerable publicity surrounded damage to school buildings in Manila and in Cabanatuan.

The total collapse of the six storey Christian Church School in Cabanatuan which killed 138 people, mostly pupils, was an isolated incident in that city. Adjacent buildings were undamaged. We were told that three additional storeys had been added to this building without structural strengthening of the lower three.

The building was of reinforced concrete with well reinforced slab and beam floors, supported on circular reinforced concrete columns, spaced at 3.5 metre centres. A typical column was 300mm diameter with up to 12 R16 bars held together with an R6 spiral at 75 centres. Details vary from one column to another for no obvious reason. Significantly, the diameter of the column cage was 170mm, providing little moment capacity. Collapse was total and probably occurred quickly, and early on in the earthquake.

A nearby school of three storeys was undamaged.

In Manila, 117 schools were affected and closed immediately following the earthquake, pending inspection. Damage was generally slight but about one quarter were listed as having major structural damage. One of these was inspected, the Araullo High School in Manila (Figure 5.3.7). Buildings between 3 and 5 storeys form the perimeter of a large courtyard approximately 100 metres square. Structural damage, though significant, was not extensive and most of the school had been reoccupied.

In common with many school buildings, bracing walls in the short direction are plentiful since these divide classrooms. Walls in the long direction are interrupted by openings for doors and windows between head height and ceiling. At corners, walls have been incorporated around stairs and these had cracked noticeably. The walls are not solid concrete but block infill to reinforced concrete frames. Although such construction performed poorly in taller buildings in Baguio, the block infill was sufficient to protect these buildings from greater damage, possibly collapse. Nevertheless, more substantial walls of reinforced concrete, or alternatively steel bracing, would be needed for stronger shaking and the need to review the integrity of school buildings has been recognised.

5.3.4 RC Frame and Block Infill Buildings

The majority of commercial buildings in the cities visited are between two and five stories. Almost without exception these are of reinforced concrete with infill block to the framing. Construction of all elements is normally in-situ. Block infill is of variable quality, generally poor, plastered to give an acceptable appearance. Reinforcement of these walls is minimal and connection to columns and beams is nominal only.

The greatest test of these buildings was undoubtedly in Baguio and Agoo. In Manila and Dagupan, shaking was less. In Baguio, buildings of this type which had regularly spaced walls in both directions, continuous to the ground, performed well. Even those with full walls in one direction and interrupted but regular wall elements in the other, survived with little damage, provided there was no soft storey.

Buildings with RC frames and block infill six storeys and over suffered greater damage, even when reasonably regular walls were incorporated. It seems that the additional mass and response caused forces to exceed the capacity of the block infills.

The Montepino Apartments in Baguio comprised three 10 storey interconnected blocks with well located wall elements. Considerable damage resulted from the softening of the block infill, and in one block, a ground floor section of this had fallen out, causing the columns to shear and the building to settle and tilt about 300mm. Refer Case Study No.5.

Skyworld in Session Road, one of the main streets in Baguio (centre right in Figure 5.3.8), is a 10 storey building, triangular in plan. Upper levels were condominiums with commercial and retail space at the lower levels. This, coupled with its corner site location meant that the two long sides had numerous penetrations for display windows. Although the building did not collapse, columns near the corner sheared and settled, producing a tilt. (Figure 5.3.9). The presence of cross walls not far back from the corner may well have saved this building from total progressive collapse. Some sections of the adjacent footpath had settled and may have contributed to the response or failure of the building, which was condemned by the city authorities.

A further example of failure of this construction is in a science building at Baguio University (Figure 5.3.10). In this case, the block infill has been forced out at about the fourth floor leading to column failure. This parallels numerous situations in Mexico City in 1985. Fortunately the collapse of this floor did not cause total collapse of the building.

Low rise buildings of RC infill frame construction survived well, again with exception of the occasional two storey building with a soft storey. One such was

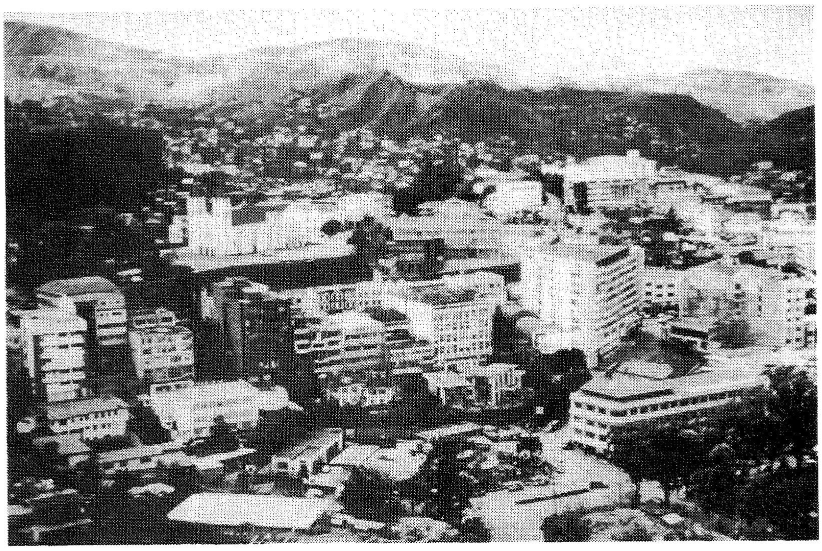


Figure 5.3.8: *Baguio City's variety of buildings (Ian Gill, Asian Development Bank)*

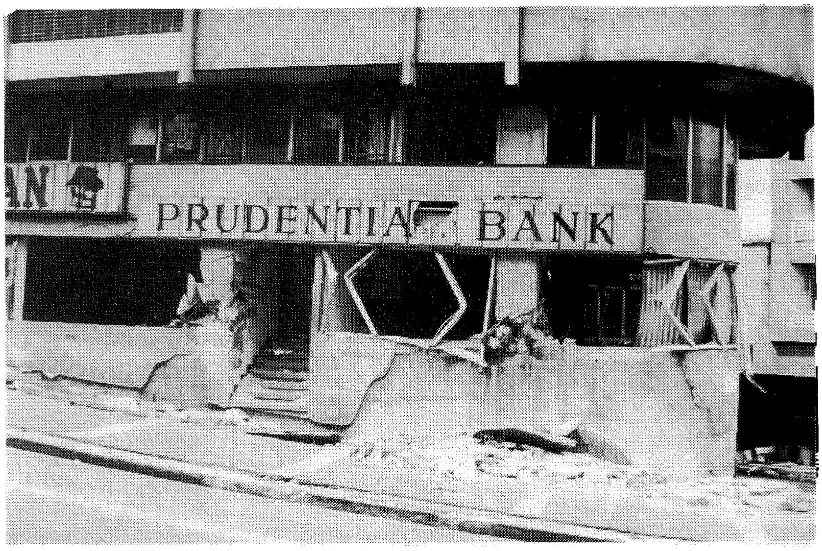


Figure 5.3.9: *Failure of columns; even just one or two can result in demolition. The large triangular shaped Skyworld Building in Baguio was condemned*

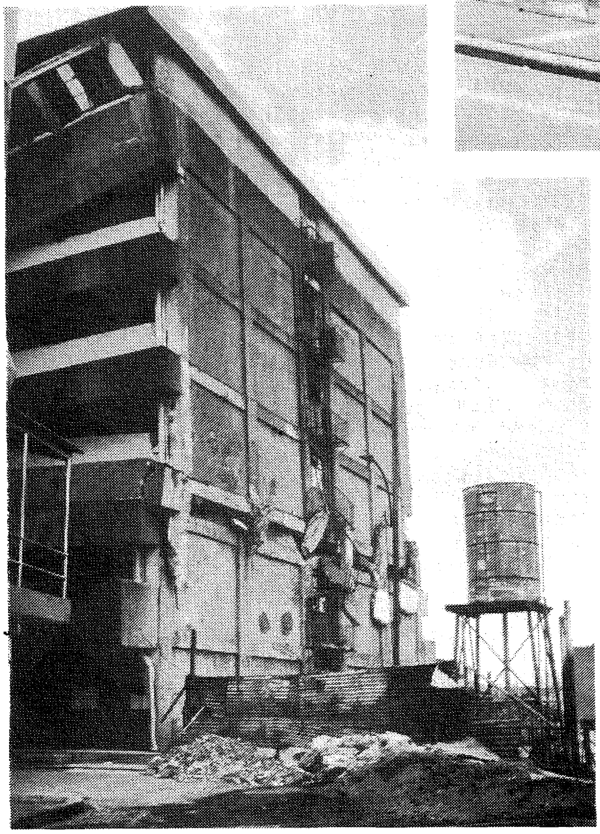


Figure 5.3.10: *Loss of infill produces a soft storey - Science Building, Baguio University*

in Agoo, where a combination of local soil effects, poor quality construction and conceptual flaws produced a pocket of greater than average damage.

5.3.5 Houses

Damage to houses followed predictable patterns. Examples included:

- Sideways movement of upper storey due to flexible ground storey.
- Collapse of inadequately tied block exterior walls.
- Settlement due to liquefaction (in coastal areas).
- Settlement, tilting and collapse due to loss of foundation support.

In the steep country surrounding Baguio, local slips were numerous, partly a reflection of the intense and uncontrolled development of the area. Overall, Government estimated that 93,000 houses were damaged, of which 23,000 were totally destroyed. Damage was 20% in cities, 30% in towns and 50% in rural areas.[1] Costs of reconstruction which were Government funded, were assessed at NZ$190 million, representing approximately 40% of the households affected. The remainder would be repaired by individuals without government assistance.

Two surviving houses in Baguio were notable for the height and eccentricity of their foundations. Three levels of reinforced concrete framing supported one side while the other was at ground level (Figure 5.3.11). In Agoo an owner was strengthening the lower storey of his house, while across the road a new house was being constructed with plywood walls, a wise alternative to block infill.

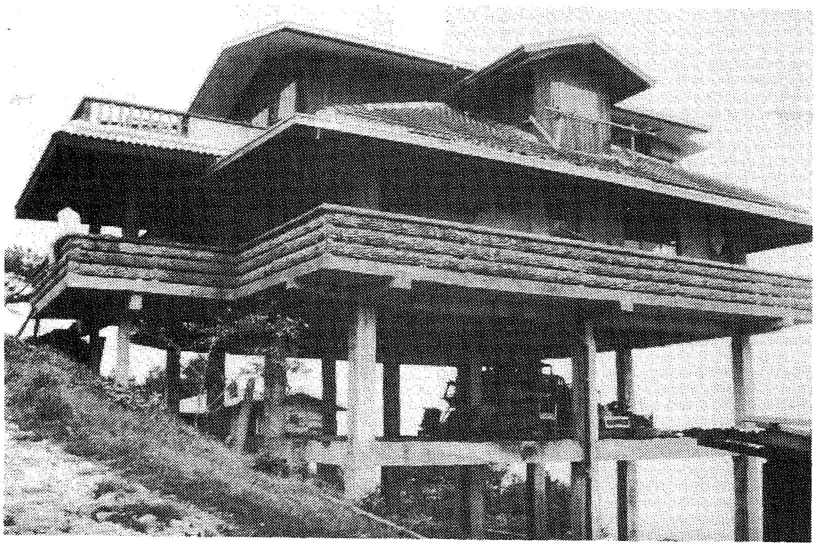


Figure 5.3.11: Notable survivor; a reinforced concrete house in Baguio. Even the balustrade is concrete, not timber

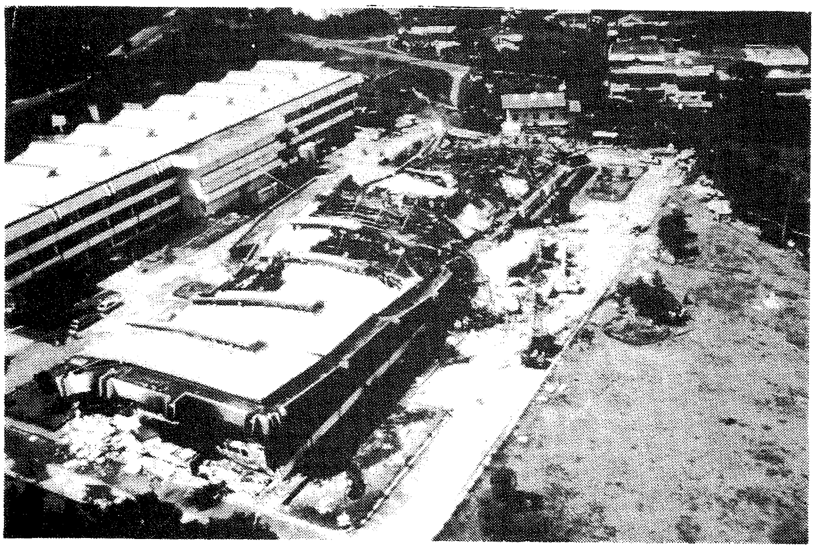


***Figure 5.3.12:** Soft soil effects? Two identical buildings after the earthquake in the Baguio Export Production Zone. The surviving one is on 'cut', the other on fill (Ian Gill, ADB)*

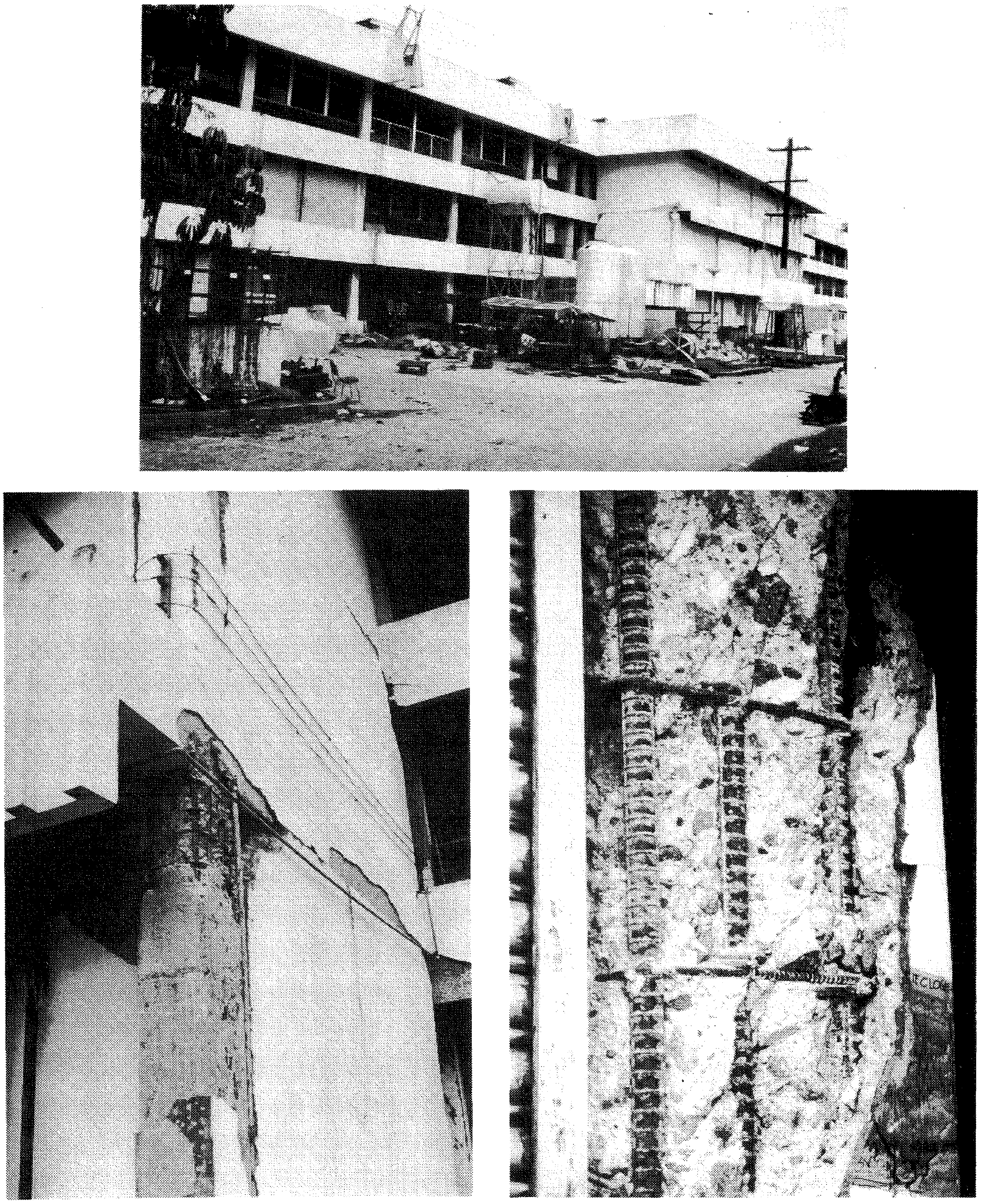


Figure 5.3.13: The survivor in the Baguio Export Production Zone was not unscathed. Damage to critical elements indicated this building was not far from collapsing like its neighbour

5.3.6 Industrial Buildings

(a) Baguio Export Zone

Few industrial buildings were inspected, but the Baguio Industrial Export Zone suffered considerable damage and loss of life as a result of collapse.

Notable were two almost identical buildings, (Figure 5.3.12) one of which collapsed totally, while the other survived with significant damage.

Each building was approximately 100 metres long and 30 metres wide and three storeys high. Column and slab construction was used throughout, with some lateral support available from the protruding ablution blocks. The surviving block suffered extensive damage but was still standing. (Figure 5.3.13).

On the collapsed building, columns disintegrated allowing the deep spandrels on the three floors to come together. It is difficult to tell what caused collapse, but the following probably contributed:

- Eccentric bracing effect of the ablution block walls, (these showed signs of damage in the remaining building).
- Lack of confining steel in the columns, and resulting inability to accommodate lateral forces and movements.
- Foundation soil effects. The collapsed building was on fill, the surviving one on cut. Amplification of response and/or foundation failure could have contributed to the difference in result.

The quality of concrete in the columns appeared good, suggesting a reasonable standard of construction.

(b) Cement Works

A Cement Works at Sison reportedly suffered damage in the earthquake. We were unable to gain access and were told by the gatekeeper that there had been no damage.

5.3.7 Institutional and Civic Buildings

In general, these were built to higher standards than commercial buildings. Performance however was mixed, pointing up the ability of earthquakes to find the weak spots in otherwise well built buildings.

(a) Munoz Church

Some spectacular damage occurred to one of two buildings at a complex owned by the Mormon Church in the village of Munoz. Built to a standard design, the building lost a heavy reinforced concrete barge board, suffered cracking and settlement in parts, and lost veneer from its spire. Footpaths and steps cracked and settled, especially those nearest to the adjacent stream. Refer Case Study 3.

(b) Library, Central Luzon State University

This solidly constructed, three storey building partially collapsed at the ends of the second floor only. (Figure 5.3.14).

The ground floor is well braced throughout with a mixture of full and part-height bracing walls. The third floor has an almost full height wall, built in-situ, providing lateral bracing between floors two and three. The earthquake has picked out the comparative weakness of the second floor. Reading rooms at the ends have extensive windows while only the centre, with librarians offices and stairwell, has bracing walls.

The floor consists of a deep waffle slab supported on circular columns. Collapse at the ends of the second floor appears to have been due to the lack of bracing walls possibly compounded by torsional response. The existence of stiff storeys above and below, coupled with the long cantilever at the ends of the building, would have demanded much from the end columns. Although well constructed, they lack closely spaced ties. (Figure 5.3.15).

The fact that collapse was partial, provided graphic images of the chaos inside. (Figure 5.3.16). Only one person was killed in the earthquake. Students in the reading rooms ran for the central stairs, and, as it happened, to the safety of the well braced centre section.

The nominal connection of the heavy balustrade to the beams was evident in the collapsed section.

(c) Baguio Cathedral

This large reinforced concrete structure (Figure 5.3.17) showed few outward signs of damage, and yet was closed. Access inside was impossible, but it seemed unlikely that damage inside could have been significant.

(d) Church at Agoo

This reinforced concrete structure lost its front gable above roof level, immediately over the entry. Again, access to the inside was not possible. Pews had been brought out on to the adjacent lawn - but still in the shadow of the Church walls, showing some confidence in the performance of these structures.

(e) San Augustin Church

This typical Basilican Church dates from the early 17th century. It suffered damage to the vault over the crossing and the vaulted nave ceiling was damaged. Additionally there had been some damage through the impact of an adjoining building that could have been constructed without seismic separation.

(f) Camiling Church

This Basilican Church was typically 17th century. It suffered damage at one end where the ceiling and roof over the east end of the nave had partly collapsed into the building. This has caused serious damage to historic decoration and appendages. The balance of the Church, i.e. the nave crossing and altar, were still in use.

(g) Baguio City Hall

This is a two storey reinforced concrete building with an impressive facade, heavy columns and a tower. (Figure 5.3.18). The building suffered no damage in the earthquake, though it was undoubtedly shaken - the team felt a strong aftershock while visiting the City Engineer's office in this building.

(h) Baguio Convention Centre

This large 33 metre square building with auditorium and service areas suffered

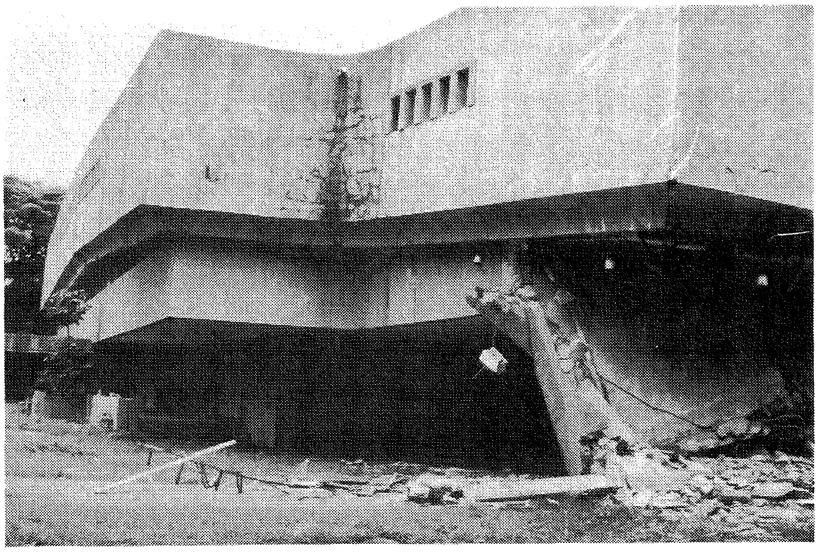


Figure 5.3.14: All but one student survived the collapse of the Library Building at the Central Luzon State University

Figure 5.3.15: Burst column ties reveal sparse confinement steel

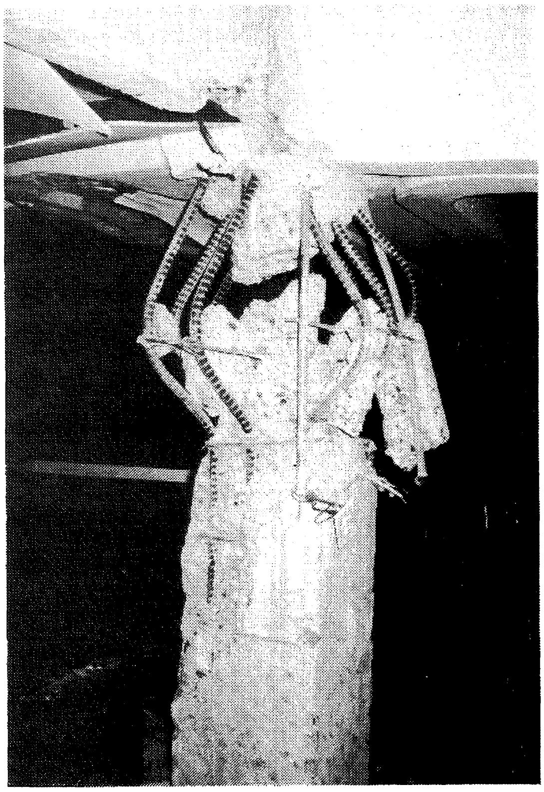
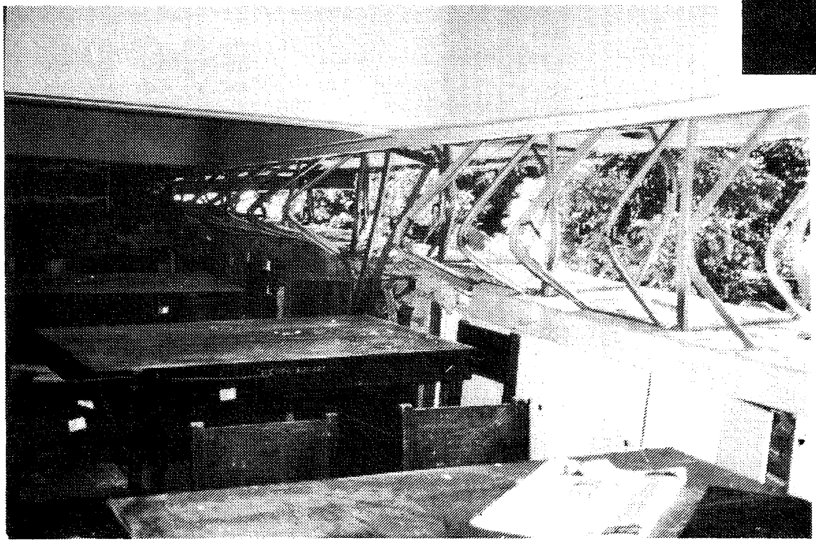


Figure 5.3.16: Interior of Central Luzon State University Library showing tapering collapse of the window mullions



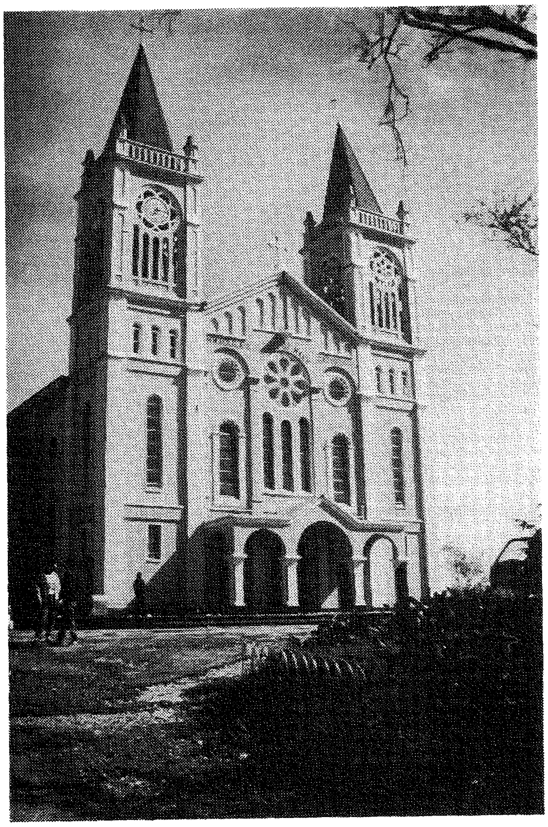
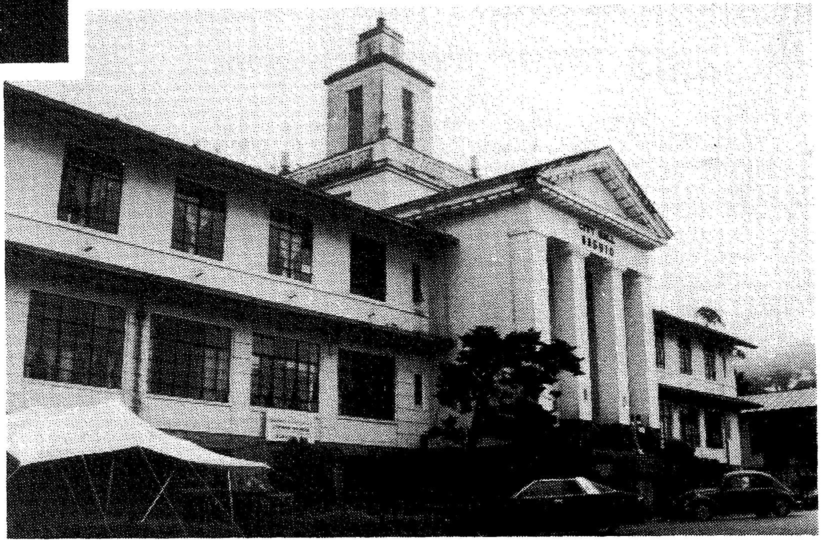


Figure 5.3.17: The reinforced concrete structure of Baguio Cathedral was virtually undamaged but the doors were firmly closed and services held outside. Note the tilt to the right hand tower roof

Figure 5.3.18: City Hall in Baguio was the centre of building assessment operations under the direction of the City Engineer. No damage to this building was evident. The team experienced a memorable aftershock while meeting with the City Engineer



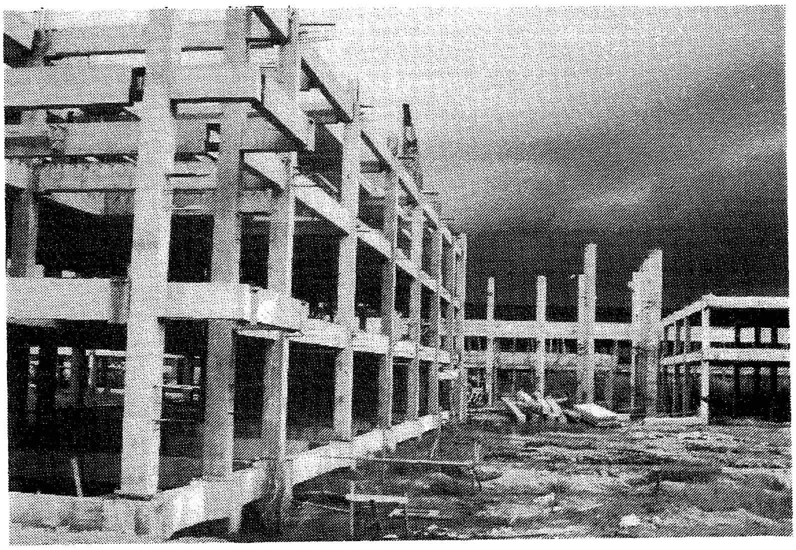


Figure 5.3.19: Precast building under construction near Tarlac. Site connections relied on the welding of large reinforcing bars

little damage. Some light fittings in the auditorium dropped during shaking.

An intricate system of orthogonal steel trusses three metres deep supported the roof. The ceiling hangers, unusually, are of double timber members. Occupants reported loud creaking noises during shaking. They also advised that all those inside the building ran outside before the shaking stopped.

(i) Mount Provinces Museum, Baguio

This sturdy looking two-storey building suffered unusual damage to the entry stair. The base appeared to have been forced upward and outward. The top support connection to the first floor failed and the stair dropped about 300mm before being held up by catenary action in the steel.

Damage to the remainder of the building was slight.

(j) Philippines General Hospital, Manila

This large complex of buildings generally seven storeys high was an example of regular reinforced concrete frames performing well. Cracking in some walls was evident but the hospital remained functional.

(k) Precast Concrete Hospital Building, Tarlac

This large four storey group of buildings was being constructed with precast concrete beams and floors. Beam to column connections relied on cast in channels and rebars. Continuity of beam reinforcing at this junction depended entirely on the adequacy of site welds. (Figure 5.3.19).

Floor units were hollow core supported on a continuous corbel on the beam.

This was the only example of precast concrete structural components seen during the team's visit. It is most unusual in a country where in-situ construction is relatively inexpensive and very common. Precast concrete requires greater than normal attention to construction tolerances and quality of site connections.

5.3.8 High Rise Buildings, Manila

In excess of 10 high rise buildings under construction were noted by the team in Metro Manila: principally in the Makati, Pasay City and Mandaloyong areas. (Refer Figures 5.3.20 and 21). These buildings were all in the 15 to 20 storey range, constructed in cast in-situ reinforced concrete to form perimeter frame, shear wall or shear core structures. The beam/column sections appear heavier than is common in New Zealand, with high percentages of reinforcing. Precasting of building elements was not much in evidence. However, concrete block infill was used extensively to form spandrel panels and interior partitions. In general, these masonry walls did not appear to be separated from the gravity/seismic frames. A number of long span floors were being post-stressed, as were a series of perimeter beams which ended in a cantilever element.

Current design philosophy for seismic resistance appeared to be followed with capacity design (strong column/weak beam) and close spacing of ties, for confinement, through the beam/column joints, and in column and beam hinge regions. Column lap splices appeared generous at the inter-storey mid height. (Refer Figure 5.3.22).

Despite the large tributary floor area to each seismic frame, the overall building structure gave the impression of being stiff with fairly short period of natural vibration. This would lead to high response during a significant earthquake, hence generating high reinforcing demand in the design for the over capacity columns.

Workmanship appeared good with little sign of 'honeycomb' in the heavily reinforced sections. (Refer Figures 5.3.22 and 23). Good quality reinforcing steel and ready mix concrete appeared to be used extensively in multi-storey construction work. Apart from tower cranes, the construction activity was heavily reliant on manual labour for the main trades of carpentry, steel fixing and concrete placement. The falsework was generally in proprietary tubular steel, supporting timber forms built on site. (Refer Figures 5.3.23 and 24). The niceties of tying back column cages against wind loading, cleaning out forms before placing concrete etc., tended to be not so well carried out, and only minimal access provided for construction personnel.

5.3.9 Building Services

The effect of the earthquake on Building Services depended on the location, the damage to the particular building and its relationship to the local service and infrastructure.

In Manila, apart from the Veterans Bank Building, damage to buildings was largely superficial so there was no apparent impact on Building Services. One of the effects of the earthquakes was to make management review the services operations of the buildings under seismic activity. In the Gulf Star building - 30 floors high - an evacuation procedure had been in place. Evacuation normally takes 6-10 minutes but in the earthquake, it happened in approximately 3 minutes. The building Management Company is investigating the possibility of having detectors to switch the elevators on to an emergency supply under seismic activity. This is seen as being desirable because the management was not particularly happy with the evacuation procedure that occurred.

In areas where buildings had been affected by liquefaction, the impact on Building Services was not a major issue. In the event of a building being rendered uninhabitable or unusable by settlement, then presumably the Services were not operational.

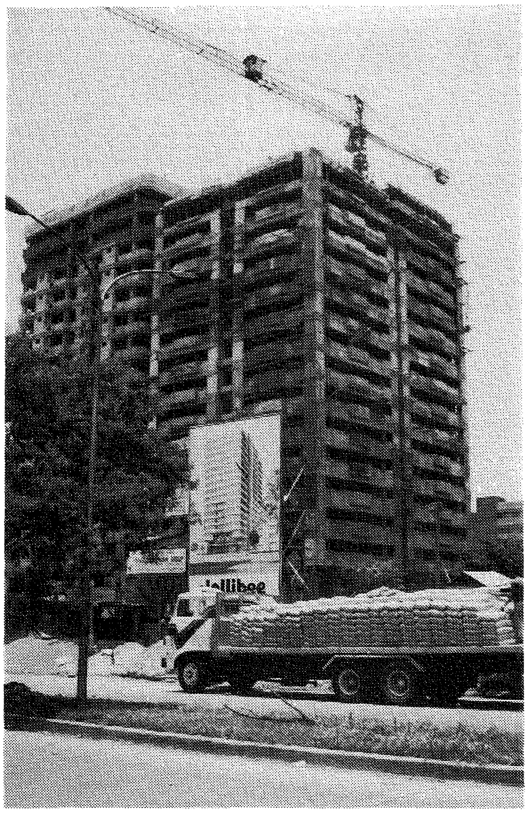


Figure 5.3.20: Multi-storey, cast insitu concrete frame, Manila

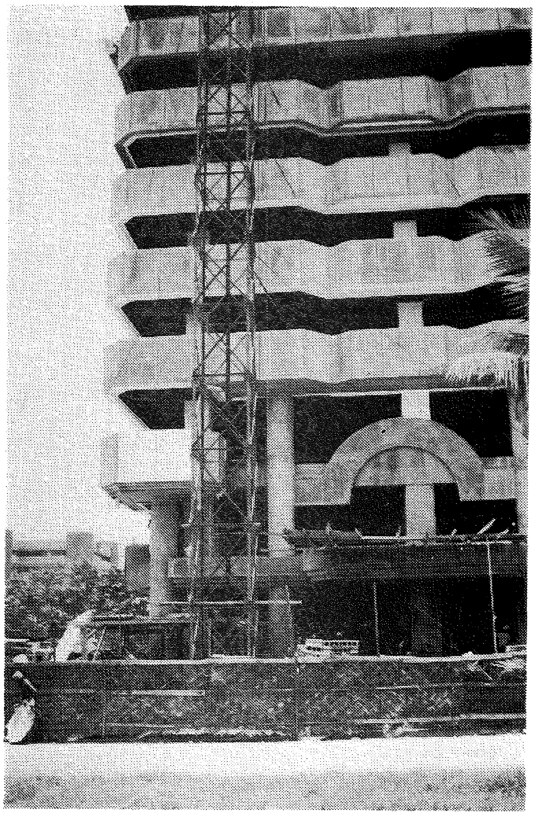


Figure 5.3.21: Multi-storey, cast insitu concrete frame, Manila

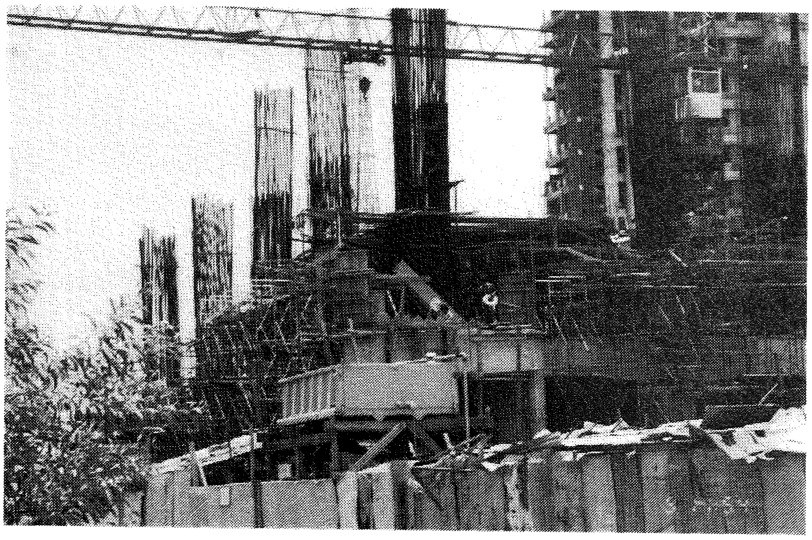


Figure 5.3.22: Multi-storey, cast insitu concrete frame, Manila. Note well confined beam-column joint region

Figure 5.3.23: Multi-storey, cast insitu concrete frame, Manila

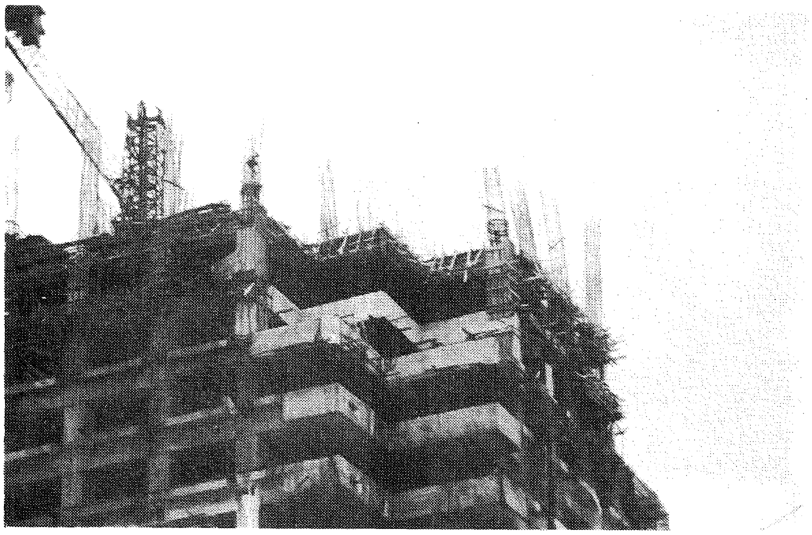


Figure 5.3.24: Multi-storey, cast insitu concrete frame, Manilla; column and beam falsework and formwork

In Baguio, the one example of Building Services being affected, was the advice that some individual water supply lines had fractured. Also the only fire that occurred in Baguio during the earthquake resulted from an LPG container exploding (the only other fire resulted 3 days later in an industrial building which had collapsed but this was due to chemical actions).

In the Baguio Convention Centre, there had been considerable loss of luminaires in the main space. This was approximately 30 metres square and the lighting systems were suspended from steel trusses which apparently moved considerably during the earthquake.

5.3.10 **Secondary Elements**

When buildings have failed totally it is always difficult to determine what the causes were. In partially failed buildings, it becomes evident that secondary elements can contribute to the failure of buildings, and to the total cost of repair.

In the Philippines large concrete elements are often hung on the outside of buildings - sunscreens, verges, barge boards, canopies etc. (Refer Case Study No. 2, NPC Building). In a number of cases failure of these elements was evident.

In Manila cracking was observed in concrete sunscreens and canopies. In the Legaspi Towers Hotel a crack in the canopy support appeared to emanate from the location of the downpipe penetrating the concrete perimeter beam. In a Manila office building the cracking in the sunscreens was evident at right angle corners of the screens. (Refer Figure 5.3.25).

In the Mormon Church in Munoz, damage to the base of the spire at the front of the building had occurred due to it oscillating through what the building manager claimed to be + or -30°. This had blown the tile and plaster finish from the base. Inside the Church the cantilevered verge and gutter beams had collapsed. A timbered coffered ceiling slid off its supports.

In the Baguio Museum, the front portico stairs had been torn away from the building - this appeared to have been as a result of an upthrust in this area. Additionally there was evidence of cracking in decorative buttresses so that although the main part of the building was apparently undamaged, the secondary elements around it had been quite seriously affected.

The brick veneer on a building in Baguio had failed in a number of areas. Bricks had flown off the face of the concrete work on the 6-storey building. It appeared that there were no ties and the failure of the brickwork appeared to have resulted from this. In other respects the building seemed to have performed satisfactorily and was still in use. (Refer Figure 5.3.26).

In Manila the National Power Corporation building had suffered some damage from the earthquake. (Refer Case Study No.2). The building is made up of two large rectangular structures of three storeys. They had originally been designed with large concrete cantilevered overhanging concrete eaves, however soon after completion, some failure was becoming evident so the whole thing was replaced with ferro covered styrene panels which reduced the weight dramatically. This was probably fortuitous as they would most likely have failed in the earthquake if they had been the original concrete.

In a number of buildings, tile and stone finishes suffered from seismic activity. In the Pacific Star Building in Manila, damage was evident to marble cladding around the elevators on most floors although only approximately 150 square metres in total needed to be replaced. Plastered finishes and tiled linings suffered damage which, although superficial, will be relatively expensive to rectify. Buildings such as The Holiday Inns of America, and the Western Philippine Plaza Hotel in Manila were still fully operational although remedial work would be required on damage to finishes.

Manila has a large area of harbour reclamation. The National Film Unit Building is one constructed on this area. It has large precast cladding to the external columns. Most of these exhibited superficial failure and extensive cracking. Separation was evident on the wide staircases and concourses approaching the building. The building was apparently sound and in use, however considerable remedial work will be required to the finishes.

One issue that was apparent in the Philippines was that of corrosion on the fixing systems for external building elements. Because of the high rainfall and salt laden winds near the coast, water ingress is very common and it is commented by consultants that buildings normally leak after three or four years. Corrosion is evident in many buildings clad in concrete panels and curtain walls. This may contribute to failure of external elements under seismic activity in future.

The detailing of infill walls obviously contributed to a number of failures. In our meetings with structural engineers in Manila, it was agreed that there had been generally a lack of co-ordination between architects and engineers in detailing with secondary elements. This had resulted in masonry walls being constructed within structural frames without earthquake separation. (Refer Case Study No. 2, NPC Building and Figure 5.3.27).

These had been plastered over so that they appeared structural and no doubt acted at least partly as such under earthquake load. In the Montepino Apartments in Baguio it appeared that one wall had substantially contributed to the failure of one of the three towers in the building.

Elements that apparently did not have a major effect on the building performance were window systems and suspended ceilings. In the Pacific Star Building ceilings had generally stayed intact except for ventilation grilles which had dropped out but had quickly been replaced. There was no

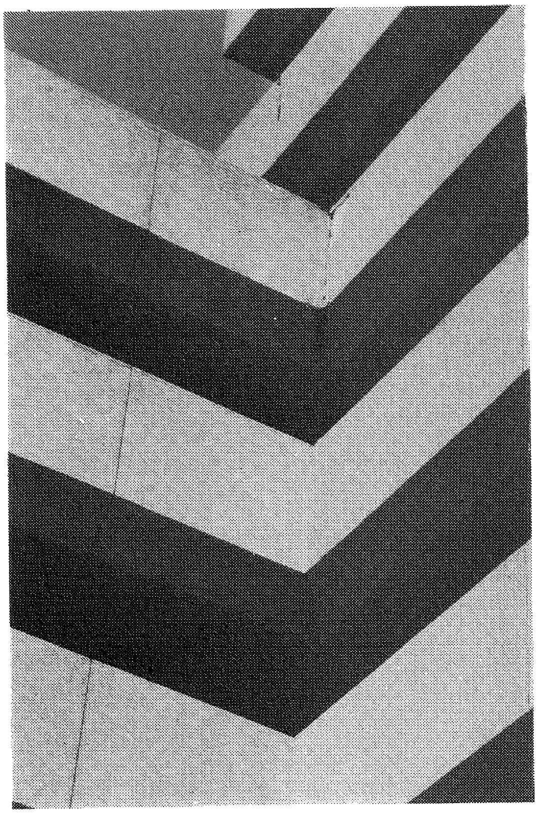


Figure 5.3.25: Manila office building; cracking at junction of sunscreen

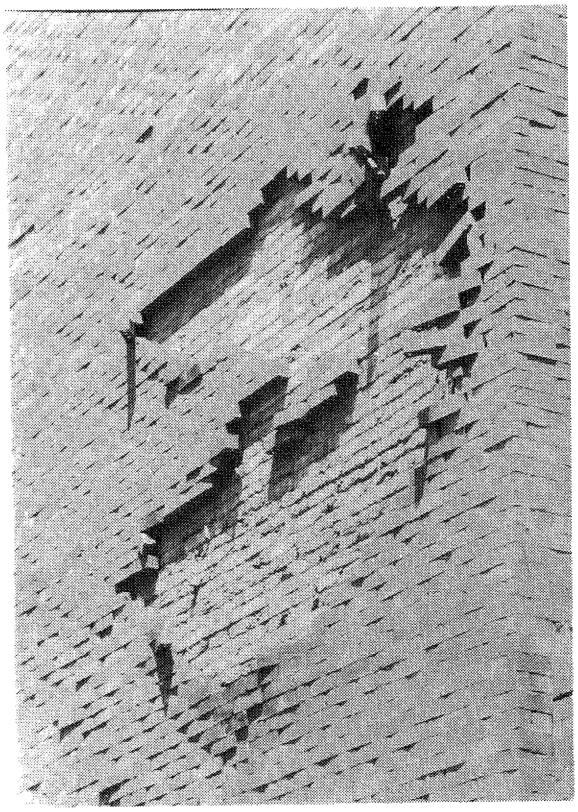


Figure 5.3.26: Loss of brick veneer - Baguio City

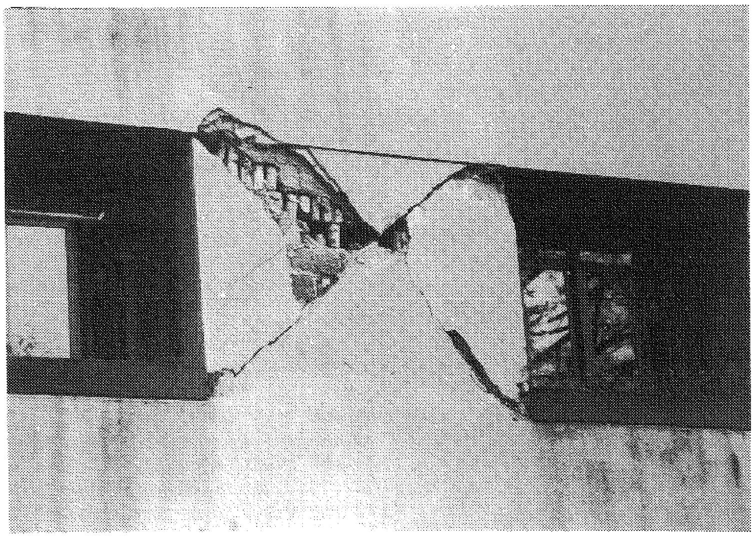


Figure 5.3.27: Hyatt Terraces Hotel, Baguio; infill masonry wall?

evidence of failure of window systems. No seismic separation was designed into window frames - they depended on separation of the glass from the frame within the rebate.

5.3.11 Heritage Structures

Three cases of damage to Heritage structures were observed. These were the San Augustin Church in Manila, part of the old Manila fortified City wall and the Basilican Church in Camiling.

Parts of the Manila city wall have been retained. This is the remains of Intramuros, the original walled quarter of colonial Manila. There was no apparent attempt to maintain or restore it. A part of the wall had collapsed as a result of the earthquake.

San Augustin Church was built from 1587 to 1606. It is contained within Intramuros, the original walled quarter of colonial Manila and was the only building in the area to survive bombing during World War II. It is a large vaulted Church typical of 16th and 17th century European churches with a large dome over the crossing. This dome was badly damaged. It is on a drum penetrated by a number of large windows. Two of the windows had been filled in over the years and plastered over and this is where the cracks originated that had damaged the dome.

The building had obviously withstood a number of earthquakes over the centuries - and the priests had driven timber wedges into the cracks and replastered them over. These may have created 'seismic' joints as they had opened up as a result of this earthquake.

A building had been constructed against the older building without any earthquake separation. Movement of the newer building against the older building had cracked the plaster around the inside of the adjoining rooms.

The body of the San Augustin Church performed very well. The main damage was in the dome and the reopening of old cracks. While these would be able to be repaired it will only be at considerable cost due to the very ornate painting that covered them.

It was difficult to form conclusions from San Augustin Church in respect to Heritage buildings. This large load bearing masonry structure had basically survived this earthquake as it had many previous ones. Major damage had occurred as a result of alterations to the drum of the dome. The other damage was suffered by the building being constructed too close to it not allowing earthquake separation.

The Church in Camiling suffered some damage at the end of the nave. (Refer Figure 5.3.28). The damage was not dissimilar to that in the San Augustin Church and it is difficult to see what measures could be taken to avoid it without major stiffening or reconstruction of the building.

Heritage structures pose particular problems. If, like the San Augustin dome, they were inherently stable but had been modified subsequently, reinstatement work would be warranted. Major structural alterations to bring the buildings in to conformity with modern codes is probably either impractical or out of the question economically.

Where a decision has been made to retain a heritage structure a seismic study should be carried out taking into account both structural and architectural elements and a seismic management plan prepared that can impact on both restoration work and maintenance.

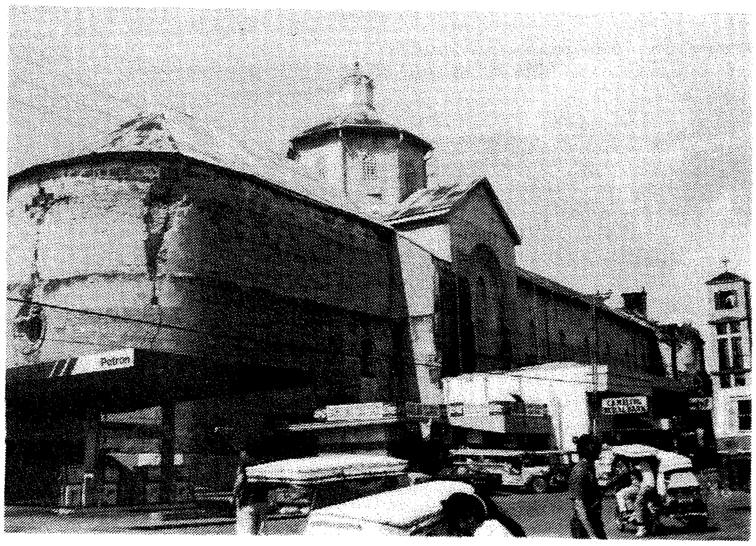


Figure 5.3.28: Camiling Cathedral; damage to nave as well as partial collapse of entrance tower (right hand end of church building)

5.4 LIFELINES

5.4.1 Water

Water supply in most cities and towns in the Philippines is supplied by local systems operated by the Local Authority. Most systems are agglomerations of small interconnected systems rather than a unified system with a major infrastructure. Physical damage was often less than expected.

This reflects the limited coverage of piped services (the ADB Reports [1] that 32% of urban and 12% of rural services are piped) which existed prior to the earthquake. An example is Baguio Water District which operates 35 pumping stations to serve a population of some 200,000 people through approximately 19,000 service connections. A major system such as this might be expected to suffer total shut-down if a major source or transmission pipeline was to be destroyed. Soon after the July 16 earthquake, because of the multiplicity of sources available to them, the Baguio Water District was able to re-establish 65% of services on an uncommitted basis.

The ADB reported that damage to water supply infrastructure was observed to be quite terrain-specific:

(i) Lowland plains: tilting, sinking and/or floating of structures due to soil liquefaction; sand intrusion into deep and shallow wells decreasing well yield and fracturing of pipelines close to fault areas.

(ii) Upland hills/mountain regions: Failure or collapse of spring capping structures and pipelines due to ground shaking and land slip; secondary damage due to additional land slips caused by aftershocks or heavy rainfall; very little damage was apparently caused directly to deep wells - most damage being to pumping equipment caused by a collapse of a pump building or surrounding building.

In the earthquake region, the most seriously affected areas in respect to water supply were Dagupan and Baguio.

The ADB team inspected a large number of areas, but it was not possible to physically visit and assess all the damage. They estimated that 40 smaller cities/town water districts or municipalities and more than 300 rural systems were known or assessed to have sustained damage to their installed facilities.

In Dagupan water is controlled by the Dagupan City Council. A typical system comprises 2 or 3 deep wells or springs as a source pumping to one or more elevated or ground level reservoirs. This normally services 200 to 400 connections either by gravity or combined gravity and pump systems. Damage to these systems was restricted to sanding in deep wells and damage to some reservoirs. Of the 17 pumping stations, 11 remained operational after the earthquake and 6 were rendered non-operational. Some transmission lines were severed, but this was not widespread. Breakages in the transmission lines did not appear to be restricted to any particular pipe materials.

Supply to much of Dagupan had not been restored three weeks after the earthquake. This resulted in people carrying water from central wells and the USA supplying water purification tablets. The high water table and its effect on the stormwater and sanitary system no doubt made this a prudent move.

Table 5.4.1 summarises the assessed impact of the earthquake on the Dagupan city water districts system. [1]

In Baguio water is supplied to the City through an underground piping system. The water is drawn from local wells and the system includes a number of pumping stations and concrete storage tanks. None of the 15 storage reservoirs was damaged, and of the 35 pumping stations, 15 were rendered non-operational by the earthquake, 8 were partly operational and 12 remained fully operational. There were 3 breaks in the main water supply and a number of breaks in individual transmission lines. These lines were generally cast iron or PVC.

As is common in the Philippines many buildings have elevated water storage tanks

Table 5.4.1

Assessed Impact on Water System in Dagupan [1]

Component	**Pre-earthquake**	**Post-earthquake**
Service Connections	6,000	4,800
Pumping Stations -		
operational	17	11
part operational	-	-
non-operational	-	6
Major reservoirs		Damage to 2 inlet pipes
Transmission line damaged -		
		150mm diameter : 11,500m
		100mm diameter : 1,500m

Table 5.4.2

Assessed Impact on Water System in Baguio [1]

Component	**Pre-earthquake**	**Post-earthquake**
Service Connections	19,000	16,000
Pumping Stations -		
operational	35	12
part operational	-	8
non-operational	-	15
Major reservoirs -		
operational	15	15
Transmission line damaged -		
400mm diameter :		2650m
300mm diameter :		130m
250mm diameter :		950m
200mm diameter :		400m
150mm diameter :		400m
100mm diameter :		1100m

to ensure steady water pressure. These tanks are typically mounted on roof tops or on braced steel or concrete frames to elevate them above the building and are often open at the tops to take advantage of the frequent rain. This would have provided temporary water supply for those buildings which had lost service. A number of tanks had fallen from their stands and toppled into roofs of buildings below.

By the time we were in Baguio, it was reported that most water had been restored and where this had not happened, fire trucks were supplementing the supply. Refer Table 5.4.2.

In other parts of the earthquake area, most inground or low level reservoirs performed well from a structural point of view and remained sound. Elevated water tanks performed less well. Many suffered structural damage - especially elevated steel tanks which totally collapsed in a number of areas. Elevated concrete tanks tended to suffer less damage and most remained intact.

The total cost of repairs and restoration to the water supply in the earthquake affected areas is estimated at 102.5 million pesos ($US4.7M).

5.4.2 Sewage Disposal

In Dagupan sewage disposal was a problem. This city is built on a river flood plain and consequently has a high water table. There is no centralised system so all buildings have septic tanks, but due to the high water table the effluent has often been put straight into the stormwater system (something which is illegal but difficult to police). There was no knowledge of the extent to which these systems have been affected by the earthquake.

The City Engineer indicated that there was a plan to construct a centralised sewer system and he believed that the earthquake may help the funding availability to become a reality.

Baguio has a small sewage collection system with a new treatment plant. It was reported to be undamaged.

In Baguio and elsewhere, many septic tanks, traditionally of concrete block construction were damaged and the resulting discharge of raw sewage represents a significant health hazard.

5.4.3 Electricity

Electric power generation and distribution has been highly developed in the Philippines to supply industrial and household consumers. The National Power Corporation (NPC) manages a generation and distribution system with a capacity in 1988 of 5700 Megawatts, 4100 Megawatts of which are in the island of Luzon. Sources of power generation in the Philippines are:

Oil based	41%
Hydro	37%
Geothermal	15%
Coal	7%

This power is distributed by 230kv lines to area substations for stepping down to 115kv, or more generally 69kv, for transmission to local independent utilities, who further step down power for consumer distribution. NPC are responsible for 13,500km of transmission line, with 7,500km on the Luzon Island.

In the areas seen by the team, the NPC power distribution system incorporated up-to-date equipment and appeared to be well maintained. Refer Figure 5.4.1.

The power transmission system stood up well to the earthquake ground shaking, particularly adjacent to the epicentral region of Baguio, and from the Ambuklao to Masiway Dams. The La Trinidad substation, near Baguio, was out for three days due to fracture of the ceramic columns on several lightning arrestors and capacitor devices. Breakage of the columns was due to whiplash of connecting cables and tilting of the arrestor unit foundations causing the connecting cables to pull up tight on the ceramic columns. These arrestor units were to the north-eastern side of the substation, where the switchyard has been built on the filled section of a cut and fill platform. The earthquake caused the fill to settle and move down the steep slope towards the adjacent valley by approximately 400mm. This movement opened up slip planes under the arrestor foundations, inducing tilting of the equipment. This damage was readily repaired once the tower bases were jacked back to level and backfilled, and new ceramic columns could be flown in to the substation. The supply of essential equipment and plant was the most critical requirement to reinstating services, as all access roads into the area were disrupted by landslip. (Refer Figure 5.4.2).

To the east of Baguio, the substation at Ambuklao Dam was damaged to a minor extent by rock from a rockslide entering the switchyard area. Refer Figure 5.4.3. The massive slide started high up the steep valley side with scree building up behind and overtopping two reinforced concrete scree barriers. One rock that entered the yard was at least a two metre cube. This damage did not have a direct effect on the power station shutdown. The station shutdown was caused by lake silts entering the low level intake to the penstocks, hence blocking the draft tube.

Transmission lines and towers survived well despite the extensive landslips that occurred in the steep country around Baguio. This was due to the adequacy of tower design and construction, and considerable thought into tower siting. In one case the tower survived only due to the adequacy of the pile foundation. Refer Figure 5.4.4.

5.4.4 Telecommunications & Radio

Damage to these systems was slight. Manila was not affected. In Dagupan, the effect on telephones was not referred to by officials, indicating little effect, in spite of the fact that power was out for two days.

The most significant effect was in Baguio, which was isolated for 24 hours. 6000 telephone lines were affected by lack of power. Radio stations were also without power and it took radio hams and one continuous radio link to Manila to convey the city's plight. The full impact of the catastrophe did not reach the outside world for 24 hours, since air and road links were all severed as well.

5.4.5 Gas

Gas is not reticulated to any great extent in the Philippines. Bottled gas is used quite extensively for domestic cooking, particularly in areas with little in the way of naturally available fuels.

The only fire in Baguio at the time of the earthquake was reported to be due to a domestic gas cooker overturning. It is understood this fire was quickly brought under control before spreading. Three days later, a fire occurred in a building that had collapsed in the EPZ at Baguio during the main earthquake. This fire is believed to have been caused by a chemical spillage.

5.4.6 Transportation

A major feature of this earthquake was its effects on transportation lifelines, due to two principal effects:

- blockage of roads by slips
- collapse or damage to bridges

These and other factors affected many of the vital links in the region, with resulting disruption to communication, movements of goods and personal mobility.

(a) Air Transport

Manila Airport was unaffected and operated without interruption. Baguio Airport, located in rugged mountainous country, was closed for several days due to slumping of an end section of runway. (Figure 5.4.5). Pavement was temporarily reinstated and the flights resumed. Permanent reinstatement and stabilisation of the failed slopes will require extensive engineering measures.

(b) Road Transport

Figure 1.1 highlights the roads which were rendered impassable by either slips or bridge failures.

Most notable was the closure of the three access routes to Baguio, the Naguilian Road, Kennon Pass Road and the Marcos Highway. These roads climb from sea level to 1500 metres through steep country where subsidence of the road will not be readily restored. Three weeks after the earthquake, only the Naguilian Road was open and then only partially, having been completely closed for three days.

Continued closure of the Kennon and Marcos roads, requires extensive detours, for the main proportion of traffic which comes from Manila to the south. These were made worse by the closure of the road between Sto Tomas and Urdaneta due to the collapse of the Carmen Bridge. Until a temporary replacement bridge was constructed, traffic from Manila to Baguio was forced to go via Tarlac, Camiling, Lingayen, Dagupan and Agoo. The coastal road from Lingayen to Bauang had suffered minor damage to bridges and their approaches, slowing traffic and thus compounding the disruption.

In Dagupan, collapse of the Magsaysay Bridge did not greatly affect through traffic but it was an important link within the city and caused major disruption of vehicle and pedestrian movements within Dagupan.

Closure of the Dalton Pass Road connecting San Jose and Sante Fe has caused major disruption. It is the main route to Northern Luzon and is thus a vital link. So extensive is the damage that an alternative route is being considered rather than reinstatement of the section which follows the earthquake fault.

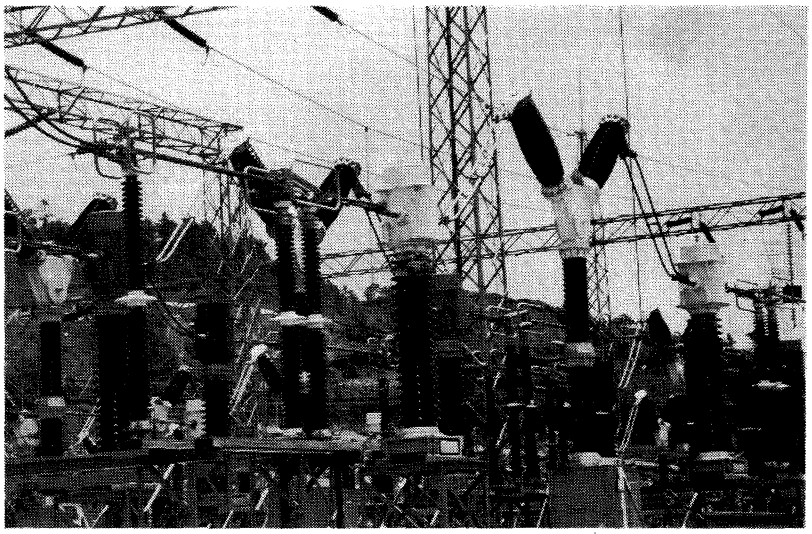


Figure 5.4.1: La Trinidad substation, Baguio, designed and built to international standards

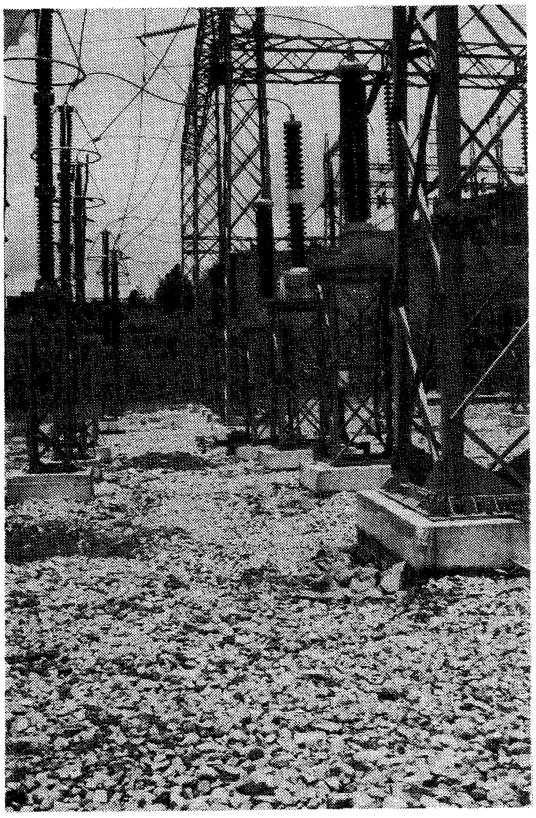
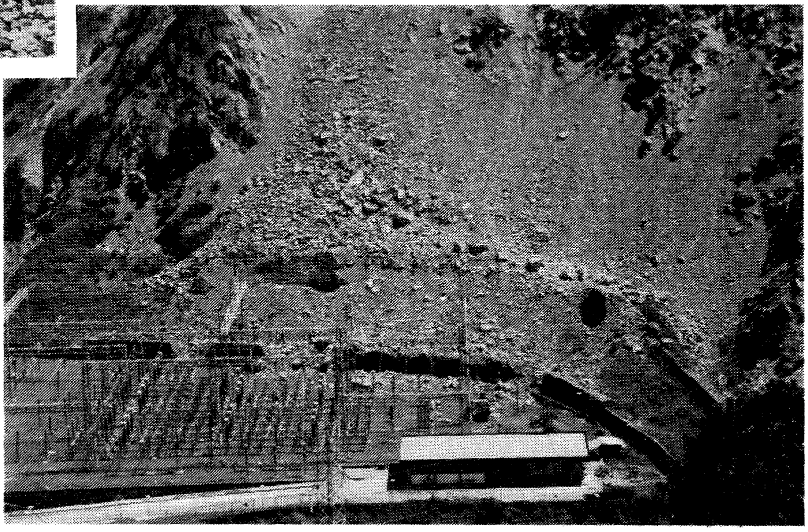


Figure 5.4.2: La Trinidad substation, Baguio; arrestor frames jacked back to level and foundation backfilled

Figure 5.4.3: This large rockslide was stopped just short of the switchyard at the Ambuklao Hydroelectric Scheme by two rock barriers



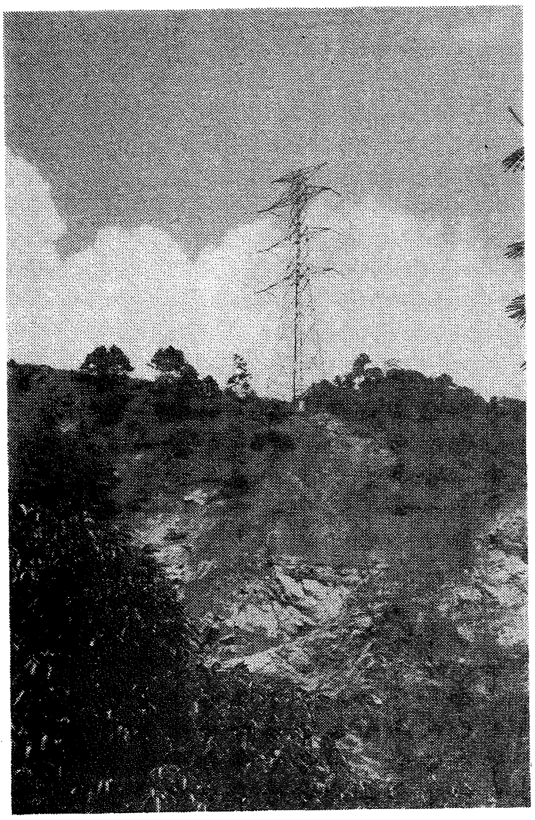
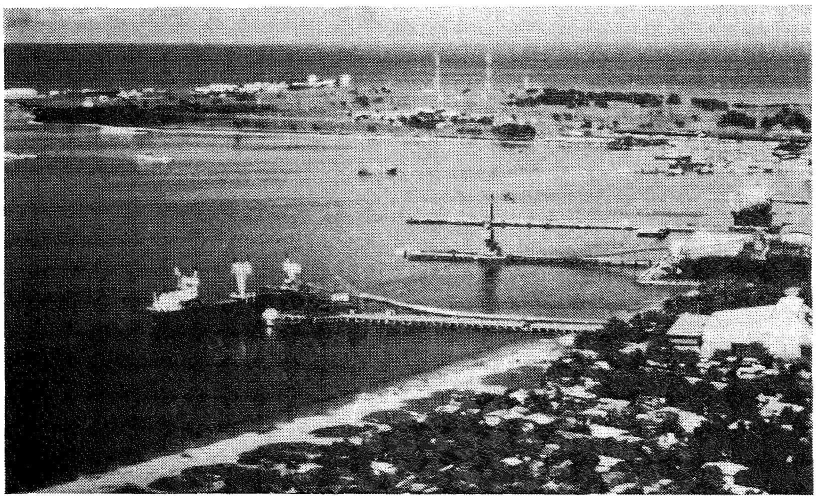


Figure 5.4.4: Power transmission line; east of Ambuklao Hydroelectric scheme. Being sited a spur, the tower is very vulnerable despite deep bored pile foundations, one of which is now exposed

Figure 5.4.5: Baguio airport *(Ian Gill, ADB)*

Figure 5.4.6: San Fernando Port. Damaged pier is third one along *(Ian Gill, ADB)*



Disruption to these lifelines can be expected to have severe effects on the economies of affected communities, and on the region as a whole.

The above descriptions of affected roads and bridges, focuses on major items. However, many other main roads suffered minor slippage, settlement and other damage which restricts and slows traffic. On top of this, secondary roads are of a very much lower standard than the main highways, making re-routing via minor roads impractical.

(d) Rail

Failure of rail bridges was reported with a repair bill of approximately NZ$6 million. No examples of damage to rail bridges were inspected but damage was similar to that on road bridges. The rail system was not extensively used before the earthquake and is not a significant lifeline in the region. In one section of line, between Agoo and Bauang, the raised embankments supporting the railway track had been built upon - providing the villagers safety from flooding and liquefaction.

(e) Sea

The pier at the port of San Fernando (Figure 5.4.6) needs to be replaced and its failure in the earthquake will disrupt shipping to some extent. Light loading can probably be tolerated until its planned replacement is completed.

No effects on shipping in the Port of Manila were reported.

6. SOCIAL/ECONOMIC EFFECTS

6.1 NATIONAL

The 16 July earthquake seriously disrupted communication systems from Baguio. The long distance microwave transmission station serving Baguio failed following the loss of power supply and was not restored until Friday 20 July. During this time it was reported that a local radio station was the principal means of official information being transmitted to Manila. The poor communications meant that news was slow to reach Manila - and mountain areas which had been cut off by landslides took some time to reach. Consequently the death toll and the effects took some time to impact on the country.

The impact on the regional and national economies will be considerable. The earthquake affected regions accounted for about 15% of the country's domestic output and substantial reductions are expected. On a countrywide basis a 0.8% reduction in the growth of the GDP (from 4.3% to 3.5%) is anticipated. Correspondingly, the GNP growth is anticipated to slow to 3.7% from the original forecast 4.8%. [1]

The balance of payments is expected to decline by US$73M in 1990, US$25M in 1991 and US$42M in 1992 giving a total of US$140M compared to pre-earthquake estimates. This reduction can be attributed to the expected decrease in tourist receipts and exports.

Natural resources were seriously damaged in the region by earthquake induced landslides which buried many crop land areas. The displacements of land structures and the incidence of liquefaction had a major impact on urban infrastructures and submerged some agricultural lands in water. Reforestation and water shed areas were also damaged by landslides and by the trampling of animals that stampeded during the earthquake. The value of damage to crops, livestock and fisheries was estimated at P520 million (US$20 million).

Additionally, the flooding of underground mines has resulted in an estimated 30% decline in production capacity or an estimated US$28M decrease in monthly income.

The damage to some 400 commercial establishments displaced an estimated 1,100 workers. Damage to the 15 tourist establishments in Baguio was valued at US$21M. Five totally damaged hotels displaced an estimated 715 workers. When this is combined with the effect on infrastructure and land use and ecology, it can be seen that this earthquake has had a very serious effect on both the region and the national economy.

6.2 PROFESSIONAL

Professional organisations responded quickly and positively to the earthquake. The Association of Structural Engineers of the Philippines met the day after the earthquake and formed teams to go out to each area and evaluate damaged buildings. They saw this as giving immediate appraisals of buildings and also giving confidence to local people who preferred often to camp out rather than risk being in their buildings. They reported on each building in terms of damage and its future.

One professional consortium of planners, engineers, architects and economists had volunteered to carry out a study for Dagupan - looking at the prospects of relocating the town centre, partially relocating it or restoring it. As they were working on a voluntary basis they were very keen to get our ideas as to how to approach the study.

We understand that this study will contribute to a Master Plan for Dagupan which had been endorsed by the government for external financing.

Professional staff from Government agencies also played an important role. The Philippine Institute of Volcanology and Seismology collected and analysed seismograph records to determine the locations and magnitudes of the main shock and aftershocks. They were also assisted in this task by Japanese and US seismologists. The dissemination of this information was important to enable the extent of the area affected and to allay fears regarding the possibility of even greater earthquakes occurring. They also provided an important briefing role to overseas scientists, engineers and architects such as ourselves. Staff from the Mines and Geoscience Bureau had teams of geologists into the field quickly recording the effects of the earthquake. The focus of their work was recording the surface expressions of the fault rupture, but they also assisted in reviewing the extent and nature of landslides. Engineers from the Department of Public Works and Highways and from the National Power Corporation played an important role in assessing the extent of damage, providing temporary services, opening roads and preparing cost estimates for repair of damage.

Many areas are no longer suitable for the current land use, so alternative sites and livelihood activities affected communities will need to be identified. In developing new land use plans, zoning and updated town plans, it will be necessary to include the results of further soil studies and establish the physical environmental constraints that they will have on land use. This will be particularly relevant in Dagupan and the coastal areas around it.

6.3 AID/RELIEF/REHABILITATION

Following the earthquake the Government mobilised all its available resources and encouraged private sector participation to assist in assessing and overcoming the impact of the earthquake. Offers of aid from other countries were accepted. These ranged from water purification tablets, relief camps for people without homes, emergency food kitchens and medical organisational assistance. Major aid and relief focussed primarily on the worst affected areas - particularly Baguio and Dagupan. The presence of American bases clearly assisted the US aid programme in the supply of medical teams.

Specific projects and activities that were considered necessary for rehabilitation and reconstruction were being identified. Preliminary estimates for the total funds required for the four regions heavily hit by the earthquake are P22.9 billion (US$900 million). Of this, it was estimated that 64% will be spent for rehabilitation and recovery and the remainder for reconstruction and development.

By the time we visited the Philippines local relief and rehabilitation organisations were well in place. Areas were divided into Disaster Control Zones and relief organisations established for each zone. A Regional Disaster Co-ordinating Committee (RDCC) is set up and this appoints a number of individuals or agencies to carry out specific functions. These functions include the dealing with buildings, checking that services are closed off in buildings due for demolition or badly damaged, price control, traffic etc. The Head of the RDCC has extensive powers.

The RDCC appoints a Council Demolition Committee which is normally made up of the City Engineer, the Fire Chief and the Chief of Police. This committee receives reports from council officers and issues demolition orders. Building inspection forms were used to make initial assessments and evaluations (Table 6.1). These were developed by the Association of Structural Engineers of the Philippines and the Department of Public Works and Highways. In Baguio some 40 orders had been issued. These orders required demolition within 15 days. The owner is required to engage an engineer to supervise demolition and if they dispute the order they are recommended to obtain an independent engineer's report for presentation to the Council. If the owner has not responded or, as is the case in some buildings they cannot be located, and if the committee considers the building hazardous, then they have the right to demolish the building and charge the owner.

The RDCC also establishes a Regional Relief Operation. Typically this will be established in a school. The classrooms are taken over as offices and the different areas within the relief zone are allocated a classroom in which updated records are maintained of needs and supplies. A media/information centre is also established to update geographic and demographic information. Helicopters are used to ferry relief into affected areas - mostly medical supplies.

This relief operation began four days after the earthquake. Between the earthquake and that time, relief was carried out by the US army. However there are still a lot of rebels in the hill country and they like to shoot at American helicopters. Each helicopter has a gunner operating a machine gun from a back door.

In the San Jose regional relief area for example, 406 people had been recorded dead and 568 injured and 49 missing. There a total of 85,000 in this particular region and the operation had at the time we were there air lifted 503,000 pounds of equipment into areas of need. In Dagupan there were 10 people killed. Most of these were killed in the stampede to leave movie theatres. Here the major impact was on buildings and infrastructure. The estimated cost of reconstruction of commercial premises in Dagupan was 2.22 billion pesos (US$85M) and of roads 1.8 billion (US$69M).

One function of the RDCC here was to establish an Economic Research Group who were reviewing long-term planning for the year. They will analyse the reports of the various specialist teams to determine the future of the commercial centre. The ultimate decision was to be made first in the regional government then through a recommendation to the President.

The demand for relief and rescue services during the emergency phase after the disaster was huge and temporarily stopped the regular development programmes and projects being undertaken by various agencies within the affected areas. The relief and rehabilitation organisations are not only required to address the provision of basic emergency supplies like food, emergency shelter, clothing, medicine, etc., but also address the trauma caused by the earthquake particularly to those who have lost relatives, properties etc.

The displacement of workers will almost certainly exacerbate the state of poverty in the areas, and together with the dislocation of many people from dwellings may also cause a rise in the incidence of crime.

6.4 PUBLIC RESPONSE/PREPAREDNESS

It was obvious that the earthquake had come as a surprise even though the Philippines has a history of seismic activity. The fact that it took approximately four days for relief agencies in the Philippines to activate is an indication of the lack of preparedness. Notwithstanding this, the public response appeared to be one of determination to continue with their lives. For example, in Dagupan, traders and commercial people had quickly re-established their businesses even though this often meant continuous pumping of subsided lower floors or even working from upper floors where lower floors were flooded. Already there was a strong political move to resist any relocation of a central Dagupan even though serious subsidence had occurred in a large number of the buildings and roads. This was being championed by a local politician.

One local effect in Baguio was the number of people electing to live in tents through a fear of what after shocks might do to their house. Large numbers of tents were located in green areas.

INITIAL ASSESSMENT OF BUILDING
ASEP-DPWH TASK FORCE

INSPECTION FORM

I. **Interview (BASIC DATA)**

A. Name of Building:
B. Location:
C. Owner:
D. Complainant:
E. Building Type (Residential, Commercial, Industrial, etc.)
F. Building Information:

1) Number of storeys:
2) Approximate floor area:
3) Age of Building:
Start of Construction: Finish:
4) Structural Engineer:
5) Architect:
6) Contractor:

G. Describe Framing System (RC, Steel, Slab-beam & Girder System, Post-tension, Precast, etc).
H. Name of Interviewer:

II. **Building Inspection**

A. Note Complaint on Structure
  1. Document the following with description and sketches
    a. Location
    b. Type of Damage (AR/ST)
    c. Severity
  2. Pictures (Note Roll Number/Frame)

B. General Ocular Inspection
  1. Presence and nature of cracks
  2. Spalling of concrete
  3. Large deformation
  4. Observable Settlement

C. General Comments/Recommendations

III. **Evaluation** (Subject to detailed assessment of original or qualified structural engineers).

A. No occupancy
B. Partial occupancy
C. Occupancy

Table 6.1 - Building Assessment Form - Baguio

7. ENGINEERING PRACTICE IN THE PHILIPPINES

7.1 GEOTECHNICAL

Geotechnical investigation techniques and the application of geotechnical engineering to foundation problems is not as advanced as in many western countries, although this is changing. Geotechnical engineering is taught in the Engineering Schools and so engineers do have a knowledge of the subject. It is now a requirement of the Building Code to undertake site investigations for buildings greater than 4 stories in height. In addition, some cities have their own special requirements. At Baguio a requirement was introduced two years ago that if a building is greater than 3 storeys then a soil plate bearing test is required. If the safe bearing capacity is less than 2000 psf (96kPa) then shallow footings are not considered acceptable.

It is not common practice to require assessments of land stability for steep sites. Even on steep sites in Baguio most houses are supported on .6 x .6m reinforced concrete pads. Many houses consist of substantial reinforced concrete frames with lower storeys undeveloped as shown in Figure 7.1.1. Nonetheless residential structures performed very well in the earthquake.

The level of expertise in geotechnical engineering varies considerably and there appears to have been a problem in convincing property owners and building officials that geotechnical problems, such as liquefaction are real. This is understandable in a country of limited resources and because structures can stand for many years without problems occurring. Therefore it is difficult to convince owners or building officials to spend more money on foundations for rare events such as earthquakes when adjacent buildings are apparently standing quite happily on other types of foundations. This situation certainly seemed to have existed at Dagupan and the unfortunate reality of this thinking was brought home in this earthquake.

There do exist specialist site investigation drilling companies, often associated with large consulting engineering practices or large government organisations such as the Department of Works and Highways (DPWH). For major projects overseas expertise is often used to supplement local consultants.

Foundations for small buildings (less than about 4 storeys) are typically isolated pads. Larger buildings are sometimes founded on rafts and on weaker ground piles are adopted. In Manila piles are typically .4m square precast reinforced concrete prestressed piles continuously driven. Near the coast such piles are up to 40m deep through the reclamation and alluvial soils. In some cases raked piles are sometimes used (1:5 or 1:6) to provide lateral restraint. Buildings are founded on shallow foundations where volcanic tuff outcrops in Manila. Bearing capacities of 10,000 psf (480kPa) are typical, although in some cases values of up to 20,000psf (960kPa) have been adopted.

Typical foundations for bridges consist of driven timber piles although more modern bridges often have driven steel or precast reinforced concrete prestressed piles.

Inspection and confirmation of geotechnical conditions during construction does not seem to be standard practice.

7.2 CIVIL ENGINEERING STRUCTURES & BUILDINGS

Construction practice in the Philippines can be considered in four categories as the country has developed over the years of social change and economic development:

1. Light weight, small scale structures, principally for housing and for farming or fishing, made of locally available bamboo and/or hardwood timbers that can be worked with hand operated tools.

Figure 7.1.1: Baguio City; reinforced concrete frame support to house at road level

2. European stone and brick, brought by the Spanish from the mid-sixteenth century was used for housing, commerce and Church building construction.

3. North American design and construction practice has had a fundamental influence on the use of materials in the Philippines and how structures are detailed in the last 70 years. This influence is particularly noted in arterial roading and bridging built in the 1920's - 30's, and again after the Second World War. In recent years, to achieve cyclone and earthquake resistance, the use of reinforced concrete is almost universal for single dwelling structures to multi-storey office developments.

4. Development Aid Projects which are designed to high International Standards (principally Northern American). Projects range from power supply schemes, irrigation, roading, to building construction.

The field team's main interest was in structures built in the last 40 years, and more particularly since the mid 1970's, when modern ductility requirements were better understood and were being incorporated into building construction in the earthquake prone areas of Europe, Japan and North America. The USA influence in the Philippines from 1898 to 1940, and the aid available from North America after the Philippines became a republic in 1946, has set design and construction in the Philippines firmly towards following American practice, as developed by such regulatory authorities as:

- International Conference of Building Officials (Uniform Building Code)
- Structural Engineers Association of California, Seismology Committee (SEAOC Code)
- American Concrete Institute (ACI)
- Portland Cement Association (PCA)
- American Institute of Steel Construction (AISC)

Philippine code development has been particularly directed at determining the seismicity of the Philippine islands, and to produce zoning maps which relate levels of seismicity to those used in USA codes. Through the local Universities, training of technical expertise has been provided to take advantage of modern construction practices as set out in the International Codes. Efforts have also been made to develop the manufacture of construction materials to meet the high quality standards inherent in these International Codes. This appears to have been achieved, particularly for cement and reinforcing steel production.

During the 1950's and 60's there had been a rapid international development in the understanding of how building structures resisted and survived earthquake shaking. In the USA, this understanding was synthesised into a design guide by the SEAOC Seismology Committee with their publication in 1959 of the 'Recommended Lateral Force Requirements'. These requirements were specifically directed to providing a concise statement of design principles and minimum design criteria for earthquake resistant structures. The 1960 edition included a commentary to elaborate on specific statements, provide background data, explain intent of recommendations and generally furnish a guide to their application. There followed very rapid progress in the understanding of building dynamics and how structures withstand earthquake attack. This was aided by computer based analysis, and full scale testing of building elements subject to ductility demands during intense earthquake shaking. As data became available, the SEAOC Code was amended, with the 1966 Revision defining 'ductile reinforced concrete' and requiring it for buildings over 160 feet in height. In 1968 a new section was introduced into the Code on "Ductile Moment Resisting Frames in Structural Steel". Further revisions were made to concrete shear walls in 1970, and in 1971 ductility requirements were introduced for all concrete frames of the lateral load resisting system regardless of height. From that time significant advances have been made in the detailed design for various materials and structures to achieve ductility. However these later advances have been based on the earlier concepts developed in the 1950's and 60's.

From early in the 1970's, particularly the 1976 Edition, the "Uniform Building Code" has incorporated the then current recommendations of SEAOC Code for earthquake resistant design.

In the Philippines, professional designers have adopted the USA code requirements as the recognised means to achieve earthquake resistance. This development of understanding in earthquake resistant design has been encouraged by the College of Engineering at the University of the Philippines.

Zoning maps have been developed and local design texts published such as Abelardo B Carrillo, 'Structural Design Data and Specifications'[10], relating USA Code requirements to the Philippine situation.

The overseeing of design and construction standards is in the hands of the Department of Public Works and Highways (DPWH) on a National scale, and local Authority Engineers within the Regional/City areas.

The quality of design and construction standards achieved has been quite variable. Efforts are being made to raise standards of construction, particularly buildings over four storeys. This is being achieved by Regulatory Authority review of construction documentation for high rise buildings in Manila and all major bridge structures. In addition, the designer is required to certify that the structure has been built in accordance with the construction documentation.

7.3 LIFELINES

Many of the major lifelines in the Philippines are designed and constructed to international standards, with commensurate attention during construction. This applies to electric power, telecommunications and oil storage installations.

By contrast, water supply and sewerage systems have a wider range of quality, depending on local conditions. The extensive use of septic tanks and small sewerage and water supply systems provides a diversity which is beneficial. The variable standards of construction do, however, make these facilities prone to damage and thus constitute a potential health hazard.

Gas reticulation is not extensive, with bottled gas predominating - again a fortunate diversity.

Security of land transport lifelines was shown to be particularly vulnerable in this earthquake. The roading system in the region had considerable redundancy, for example, the three separate access roads to Baguio. Without the Naguilian Road, which was opened quickly, Baguio would have been isolated for much longer.

With hindsight, it is clear that many key bridges were excessively vulnerable. Construction of bridges is generally to international standards, reflecting the importance of major bridges in transport lifelines. The failure of several major bridges suggests that more attention is needed to design concepts and foundation conditions.

As a result of damage in this earthquake, greater attention will almost certainly be paid to strategic planning and to strengthening the weak links in all lifelines, especially transport.

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Many people and organisations made this field visit possible, assisted with its organisation, or provided valuable assistance before, during and after it.

We gratefully acknowledge all assistance, without which the field visit would have been either impossible, or far less informative. The willing co-operation of Filipino professionals, both those in key authorities, and consultant groups was a feature. The following list, which we hope contains no serious omissions, should provide convincing evidence that successful field visits following a major earthquake, rely on assistance and co-operation from many quarters.

The assistance of the following is gratefully acknowledged:

- N Z National Society for Earthquake Engineering, for initiating and funding the trip.
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- Philippines Embassy, Wellington, especially His Excellency Mr Ernesto Llamas, Ambassador for the Philippines, for valuable factual information and letters of introduction.
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- The City Engineer in Dagupan for information on the effects of the earthquake.

- Dagupan Relief and Rehabilitation Centre for information on relief work.

- City Engineer's Office, Baguio for information on general effects of the earthquake.

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- Engineering Geology, KRTA, Morrison Cooper, Sinclair Group for making personnel available to make the visit and for providing resources in preparing the report.

APPENDIX A

NEW ZEALAND EARTHQUAKE ENGINEERING FIELD TEAM

Itinerary

Sunday	29 July	Arrived Manila
Monday	30 July	Visits & Contacts in Manila
Tuesday	31 July	Visits & Contacts in Manila
Wednesday	1 August	Visits & Contacts in Manila Travel to Cabanatuan
Thursday	2 August	Cabanatuan San Jose Relief Centre Rizal Pantabangan Dam Masiway Dam Travel to Dagupan
Friday	3 August	Dagupan Agoo
Saturday	4 August	San Fernando Port Naguilian Road Baguio
Sunday	5 August	Baguio Ambuklao Dam
Monday	6 August	Baguio Naguilian Road Bauang
Tuesday	7 August	Bauang to Manila Bridges en route
Wednesday	8 August	Visits in Manila
Thursday	9 August	Visits in Manila Return to New Zealand

APPENDIX B - BRIEFING NOTE USED DURING VISIT

NEW ZEALAND EARTHQUAKE ENGINEERING FIELD TEAM

This team of volunteers consist of three engineers and an architect, visiting on behalf of the NZ National Society for Earthquake Engineering.

The team's main purpose is to observe and learn about the effects of the July 16 earthquakes from a scientific and technical viewpoint.

Like the Philippines, New Zealand is subject to strong earthquakes and makes extensive use of reinforced concrete in its buildings.

Of particular interest will be the impact on buildings and major lifelines such as power supply, water supply, transportation and communications.

The objective of the visit is to assess the implications for earthquake design in New Zealand and internationally.

Inspections will not be limited to buildings and facilities which performed badly. Many valuable lessons can be learned from those which survived the strong earthquake shaking.

The group hopes to discuss aspects of the earthquake's effects with engineers, scientists and architects in the Philippines in order to gain a better understanding of the problems faced, and to further the exchange of ideas between New Zealand and Filipino professionals.

New Zealand earthquake engineers and scientists commiserate with the Filipino people affected and their professional colleagues in the Philippines. It is hoped that the NZ team's observations, discussions and reports will help reduce the effect of future earthquakes in both countries.

Members of the team are:

- Dr David Hopkins, team leader, is a structural engineer and Director of KRTA Limited in Wellington. Dr Hopkins is past President of the New Zealand National Society for Earthquake Engineering.
- Mr John Sinclair, director of Sinclair Group Architects in Auckland, and is currently Chairman of the Auckland Branch of the New Zealand Institute of Architects.
- Mr Win Clark, a Civil and Structural engineer from Morrison Cooper and Partners, Wellington.
- Dr Trevor Matuschka, Director of Engineering Geology in Auckland and is a specialist in geotechnical engineering and analysis of seismic hazards.

The New Zealand team expects to be in the Philippines for approximately 10 days.

APPENDIX C - CASE STUDIES

CASE STUDY NO. 1

HYATT TERRACES HOTEL, BAGUIO

Principal Features

The Hyatt Terraces Hotel in Baguio was one of the Philippines largest and most prestigious hotels, built in the late 1960's early 70's. The hotel was formed from a complex of five buildings grouped around a large atrium. Refer Figure C1.1.

Tower Block

A 12-storey building set at the south-eastern corner of the atrium, containing four identical luxury suites per floor, each with a large cantilever balcony area. Refer Figures C1.2 and C1.3. Building construction was cast in-situ reinforced concrete flat slab floors with a system of primary and secondary beams, supported by columns and short walls. These shear walls were located around the lifts and stair, and one at each of the four sides of the building orientated at right angles to the general line of the building perimeter. The outer perimeter of the balconies a heavy reinforced concrete, cast in-situ balustrade. The whole structure was supported on a 1 metre thick raft foundation.

Terraces Block.

A 7-storey building on the western side of the atrium. Constructed in reinforced concrete with cast in-situ slab and beam floors, supported by wall/columns which raked back towards and over the atrium. This allowed each floor to be set back relative to the floor below, providing a series of terraced apartments.

Remaining Three Blocks

Conventional reinforced concrete frame structures with slab and beam floors. Wall elements were formed from infill masonry with cement plaster finish.

Earthquake Performance

Both the Tower and Terraces blocks collapsed and the other three wings suffered extensive structural damage. The Tower block collapsed during the main shock, tipping back towards the atrium. Approximately one hour later, during an aftershock, the Terraces block collapsed into the atrium. Collapse of the Tower block may have contributed to the failure of the Terraces block. Refer Figure C1.4.

Columns in both the Tower and Terraces blocks had widely spaced ties, and therefore provided limited core confinement. Longitudinal bars were all spliced at the same level at every second floor. Figure C1.5 shows tie configuration and Figure C1.6 shows column fracture in the Tower block.

The Tower block clearly tilted towards the atrium before column and walls disintegrated. The floors collapsed on to one another ending up in a nearly vertical orientation. See Figure C1.7. Torsional displacement of the building and wall elements was evident, although this could have been the result of the collapse itself. The Tower block was said to have settled appreciably in the ensuing weeks after initial collapse. During this time successful rescue operations were made by local miners who cut tunnels for access, shoring them with heavy timbers.

Lap splices at floor levels had no effective confining reinforcing and bars were pulled free of the concrete.

Conclusions/Comment

Terrace Block

Failure of the raking column/walls highlights the critical nature of these elements. Careful detailing is essential to achieve modern concepts of ductility and to retain the strength of elements such as at lap splices.

Tower Block

It was not possible to determine the cause of collapse but the following aspects may have contributed:

(a) Lack of torsional stiffness. The shear core walls provided little rigidity and the perimeter walls were at right angles to the torsional movement.

(b) Lack of ductile detailing in supporting columns and walls. This greatly reduced the ability of the structure to absorb earthquake induced forces and displacements.

(c) High axial loads in outer columns. The columns marked 'A' in Figure C1.2 carry larger than normal load from the cantilever action of the beams supporting the heavy balustrades.

It seems possible that collapse was brought about by the combined effects of the above, initiated by high moments and shears induced by torsional displacement in the columns marked 'A'. Brittle failure of the columns may have followed, producing a 'domino' effect on adjacent columns, causing the building to topple.

Reinstatement

Rebuild to current seismic design requirements with full consideration of building dynamic response, ductile detailing, and site conditions.

Lessons/Questions

There can be few better examples to illustrate the importance of concepts and detailing than the dramatic collapse of the 12-storey Tower Block.

Current methods of design and requirements for detailing would address the problems highlighted by this collapse.

A number of multi-storey buildings in New Zealand built in the 1950's and 1960's could have similar deficiencies when compared with current requirements. This highlights the advances that have been made in the last twenty years in the understanding of how structures respond to ground shaking and the design detailing required to provide earthquake resistant buildings.

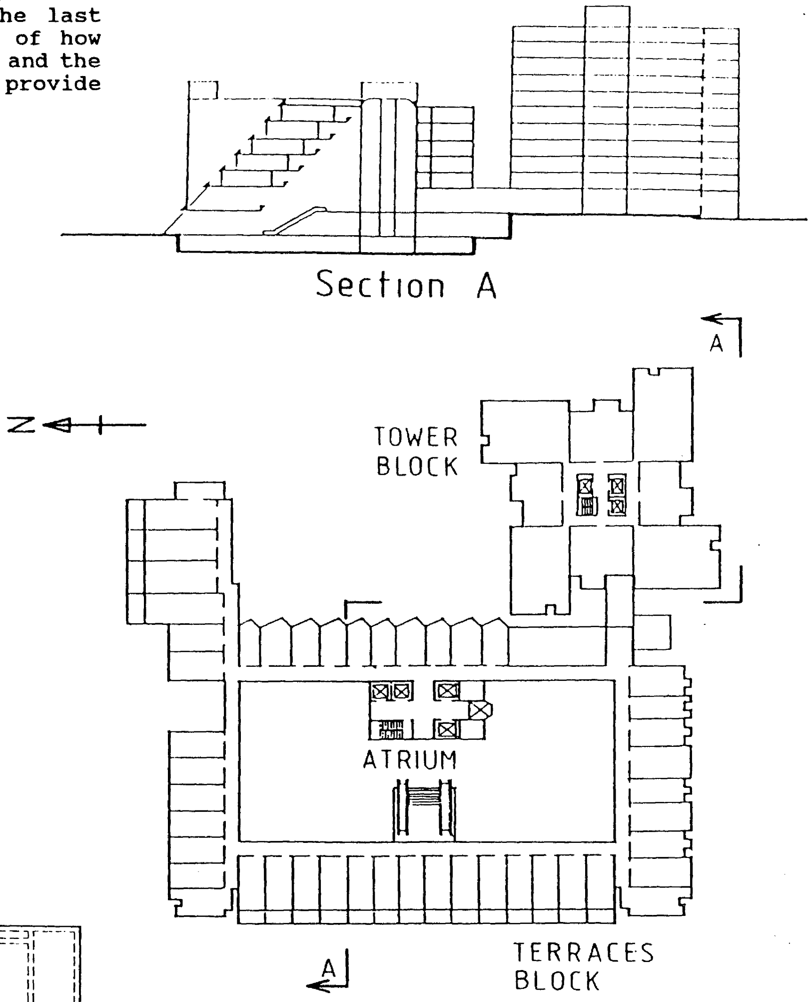

Figure C1.1: Hyatt Terraces, Baguio - plan and section

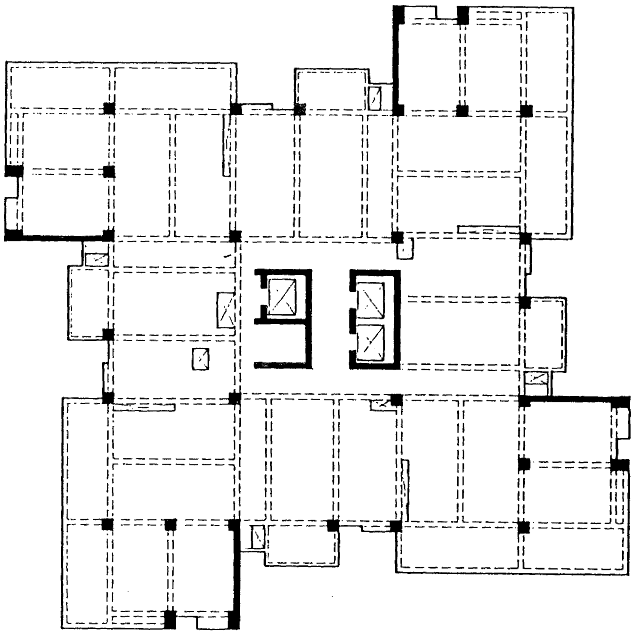

Figure C1.2: Hyatt Terraces, Baguio - tower plan

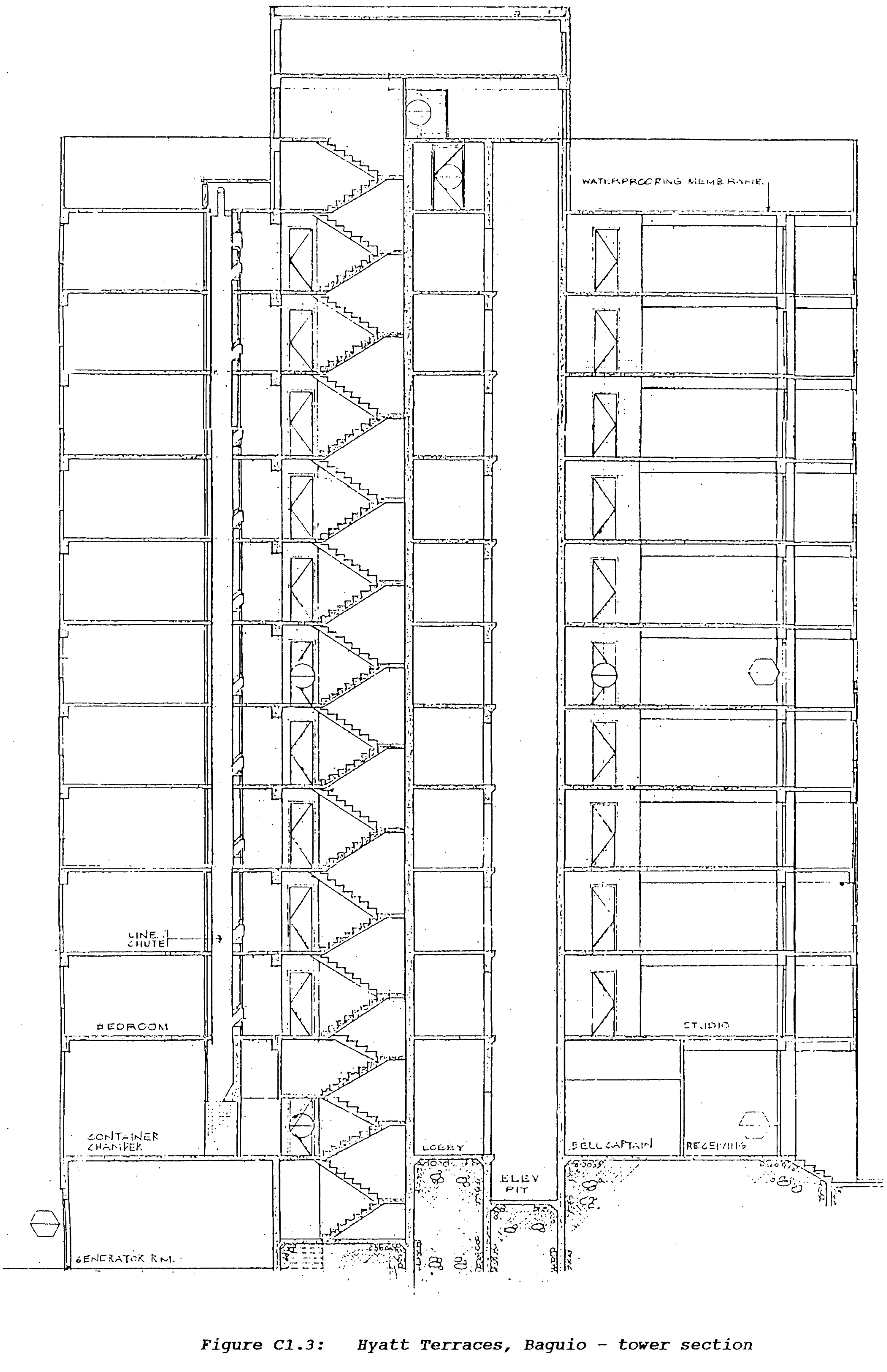

Figure C1.3: Hyatt Terraces, Baguio - tower section

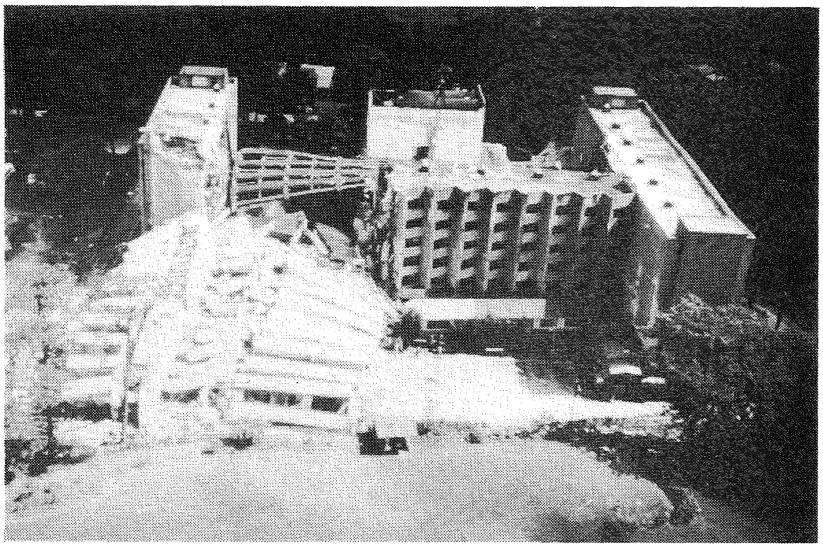

Figure C1.4: *Hyatt Terraces, Baguio; aerial photograph taken looking towards the west*
(Ian Gill, ADB)

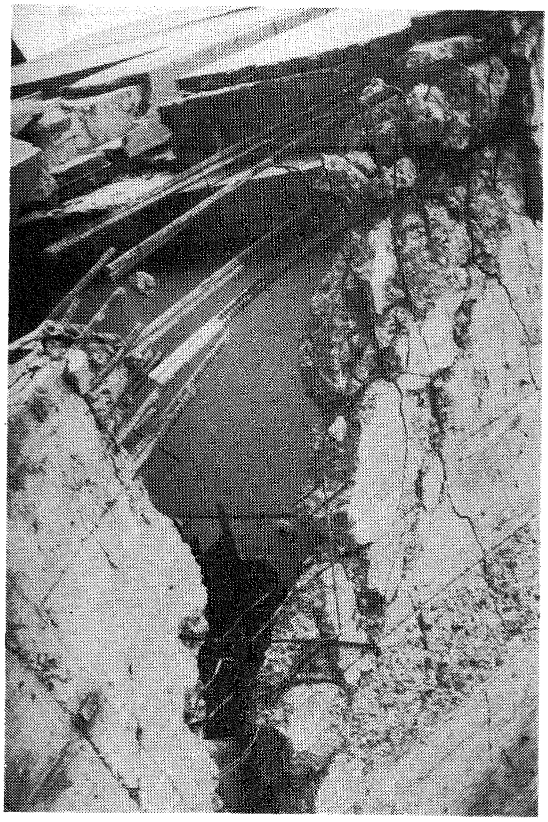

Figure C1.5: *Tower block, Hyatt Terraces Hotel, Baguio; note light, widely spaced, ties and longitudinal bars spliced at one point*

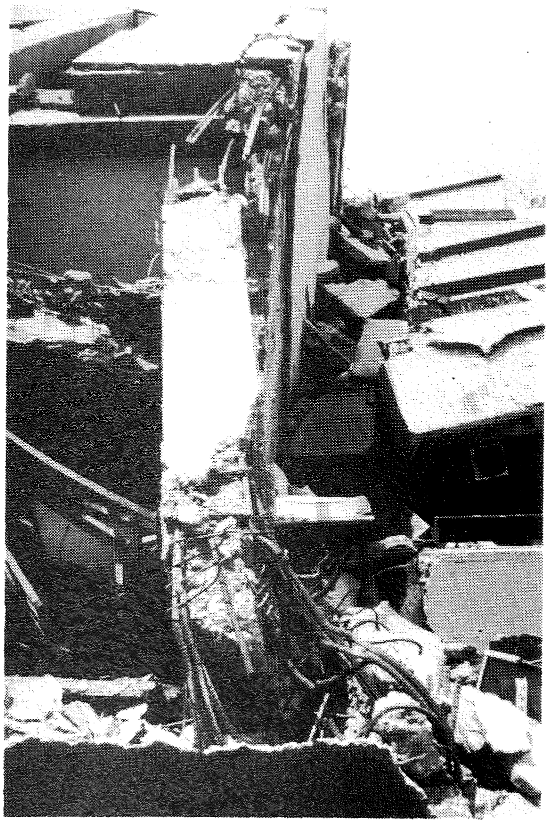

Figure C1.6: *Tower block, Hyatt Terraces Hotel, Baguio; torsion/tension splice failure of column element at end of shear wall*

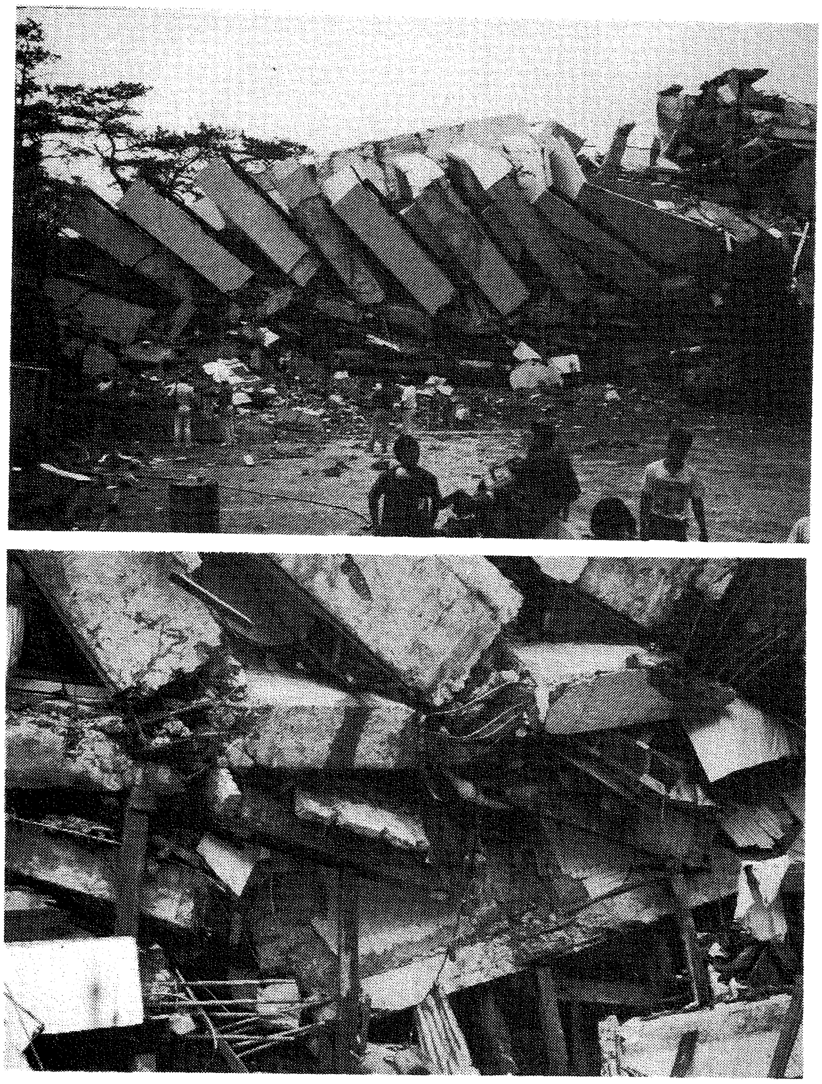

Figure C1.7: *(top) Tower block, Hyatt Terraces Hotel, Baguio. The heavy balcony elements have collapsed back on themselves during impact due to failure of the joint with the column (now lying horizontal)*

(bottom) Tower block, Hyatt Terraces Hotel, Baguio. Close-up of balcony/column joint failure and torsional failure of shear wall (lower left rising to right)

CASE STUDY NO. 2

NATIONAL POWER CORPORATION BUILDING
QUEZON CITY, METRO MANILA

Principal Features

The head office of the National Power Corporation is housed in a modern 3-storey building, approximately 2 years old. The building form is 'L' shaped in plan, with each wing 93.9 metres by 25.6 metres on the column grid, linked by a short, 3-span bridge structure at first floor level only. The structure is a reinforced concrete two-way frame, with columns on a 8.534 metre module in each direction (12 transverse rows of columns with 4 longitudinal rows). The facade at ground level is set within the column line, whereas the first floor facade is set on the column line and the third floor cantilevered 4 metres beyond. At roof level a bulky reinforced concrete sunscreen projects beyond the flat roof line. Refer Figure C2.1 and C2.2. During construction the design of the sunscreen was altered to reduce its weight. The longitudinal and transverse roof beams are post-stressed. The corners of the roof and sunscreen are supported by diagonal reinforced concrete beams which frame over the corner column to the second column back of the inner column row. Columns are 630mm square, supporting longitudinal and transverse beam 450mm deep by 630mm wide, haunched by 400mm into the columns. The roof beams are a uniform depth of 850mm where they cantilever beyond the perimeter columns.

Each column is reinforced longitudinally with a D32 bar in each corner and a D20 in the centre of each face. (4-D32 plus 4-D20 total). Tie reinforcing at mid height of the columns consists of 2-D10 @ 150crs, enclosing each vertical bar in a right angle bend. It was not determined if ties were closely spaced adjacent to the beams. Tie laps were 90° hooks around corner bars, with the tails in the cover concrete.

Earthquake Performance

Two areas of the building were damaged by the earthquake. They were:

(i) Cracking of non-separated concrete block masonry partition walls.

(ii) Sliding movement along a construction joint at mid height of 4 columns in the third floor space, at the end of one wing adjacent to the link bridge. Refer Figure C2.3.

Cracking of the masonry partitions occurred at the mortar construction joints to columns and slab soffits. In one area a crack had opened up at the base of a wall. This was considered to be due to the relatively light cast in-situ floor separating from the stiff wall spanning between columns.

The mid height construction joint in the columns showed signs of construction rubbish (sawdust, tie wire, nails) cast in. High shears would have been developed due to horizontal inertia of the heavy sunscreen during the earthquake, in conjunction with column shear generated by the cantilever moment from the beam supporting the sunscreen gravity load.

Conclusions/Comments

The cause of damage appeared to be:

- Inadequate separation of stiff infill partitions from the flexible seismic frame.
- Inadequate quality control of construction to ensure boxing was cleaned out before casting concrete.
- Lack of appreciation at the early design stage of the dynamic effect (horizontally and vertically) of a large mass set at a high level in a relatively light frame building.

Reinstatement

- Separate all masonry partitions from the seismic frame.
- Clean out and grout up column construction joints.
- Check dynamic analysis of building to ensure adequate strength under design earthquake intensity loading.
- Check and ensure all potential hinge zones are adequately confined.

Lessons

- The importance of conceptual design to avoid potential difficulties with future structural design detailing, or with inadequate performance of the building during moderate earthquake events.
- Quality control of construction to ensure the design performance can be achieved.

Figure C2.1: NPC Building, Quezon City - east wing

Figure C2.2: NPC Building, Quezon City; bridge structure to east wing

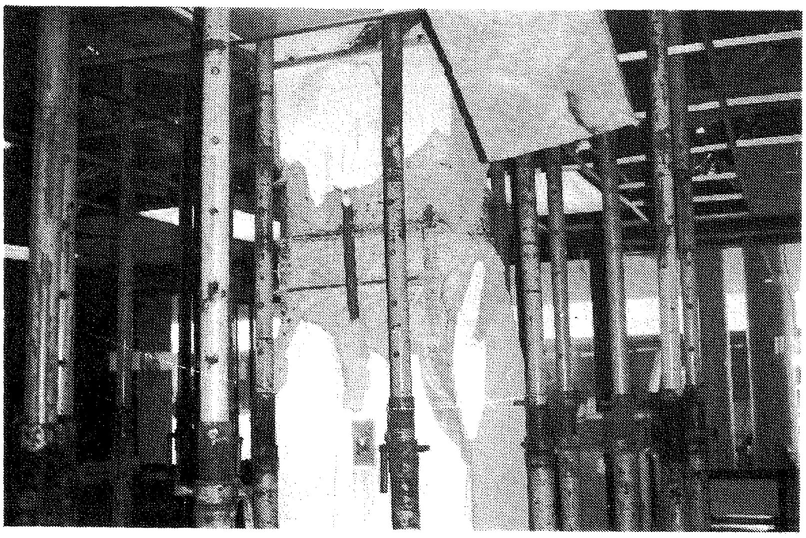

Figure C2.3: NPC Building, Quezon City, 3rd level; shear failure of column at mid height construction joint

CASE STUDY NO. 3

CHURCH AT MUNOZ, NEAR SAN JOSE. (CHURCH OF JESUS CHRIST OF THE LATTER-DAY SAINTS)

Principal Features

Two single storey portal frame buildings with courtyard in between (Figure C3.1 and C3.2).
One is the main meeting/worship area with few partitions, the other for administration/small meetings.

Portals - reinforced concrete to near hip level, with steel roof members.
Walls - exposed aggregate panels.
End walls - concrete with stone veneer.
Lightweight roof - asbestos cement sheet.

Free-standing reinforced concrete spire with stone veneer.

Extensive exposed aggregate paving between and around both buildings with steps down to lower ground near stream at rear.

Foundations to buildings are on grade, with either hardfill or short piles. Paving on grade only.

An unusual feature was the heavy barge boards and fascias of reinforced concrete. These Church buildings are built to a standard pattern used world-wide, with local adaptations to suit construction practices.

Earthquake Performance

This building and the surrounding site was clearly shaken strongly. Damage was spectacular but confined to certain areas. Principal damage included:

- Collapse of a barge board at the front, but not at the rear.
- Spalling of untied veneer from the base of the spire which was said to have swayed 30°.
- Settlement of a slab at the rear of the Church by 20mm, accompanied by bowing out of the rear reinforced concrete wall.
- Spalling of concrete cover at base of portals.
- Minor cracking of partition walls at junctions.
- Settlement and cracking of paving and stairs.
- Collapse of a timber canopy in the chapel due to the lack of engineering connections.
- Buildings did not settle.
- Sideways movement of the second building (approximately 20mm) towards the stream.

Refer Figures C3.3 and C3.4.

The custodian said the earthquake shaking lasted 45 seconds or more, and was very strong. Munoz is 15km from the fault break.

Conclusions/Comments

The causes of the damage appeared to be:

- Inadequate connections of the end walls, to longitudinal walls
- Inadequate connections of the front barge board. There were no connections between it and the roof purlins, suggesting that the member pulled away from the roof line, increasing the moment on the supporting cantilever, and causing that to fail. (Moment capacity at the base of the cantilever was small as can be seen from the photographs).
- Liquefaction of material under the paving and stairs, causing settlement.

Reinstatement

Overall damage to the buildings was not extensive and these would be readily repaired. Replacement of barge boards with lightweight material is clearly advisable. Paving and stairs would require reconstruction with more extensive hardfill.

Lessons/Questions

These buildings were well built and designed for owners with international experience. The nature and extent of damage demonstrated the ability of earthquakes to find the weak spots. The complex does not require full replacement but repairs will be costly. Many similar buildings in New Zealand could suffer this sort of damage for much the same reasons - lack of attention to some key details, either in design or construction.

With proper connections at these points, the buildings would have suffered little damage.

The weakness of the foundation material was apparently recognised in the building foundations, except at the rear where the ground falls away.

The extensive damage to paving, stairs and an ornamental pond is evidence of the cost of non-building damage which can result from ground movement.

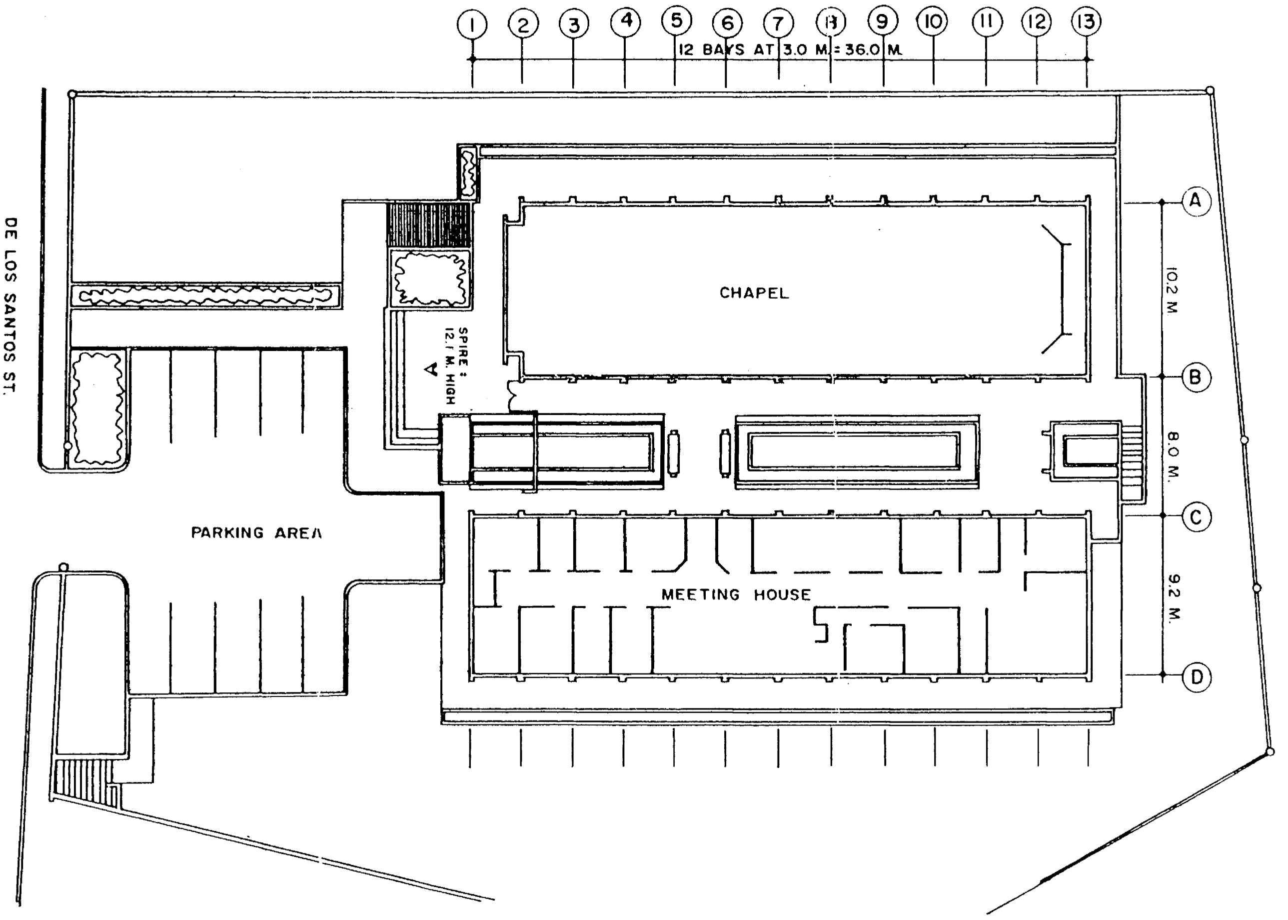

Figure C3.1: Church at Munoz; floor plan

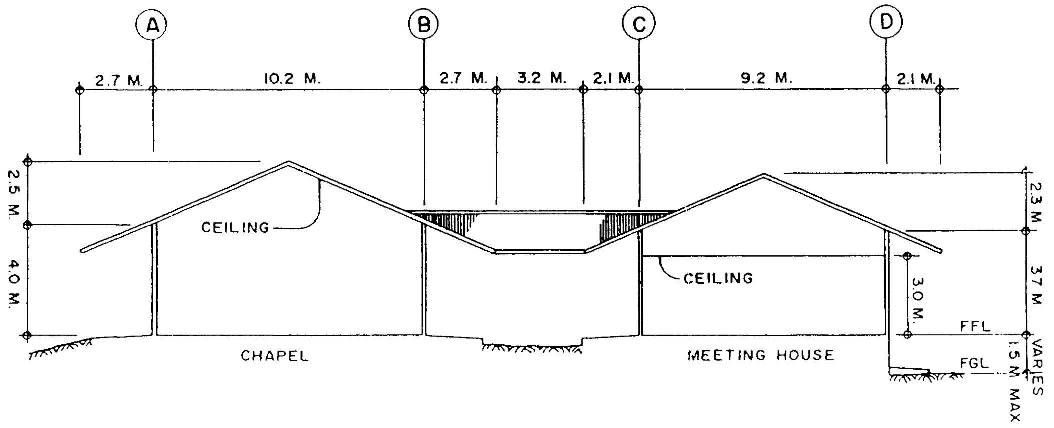

Figure C3.2: Church at Munoz; transverse section

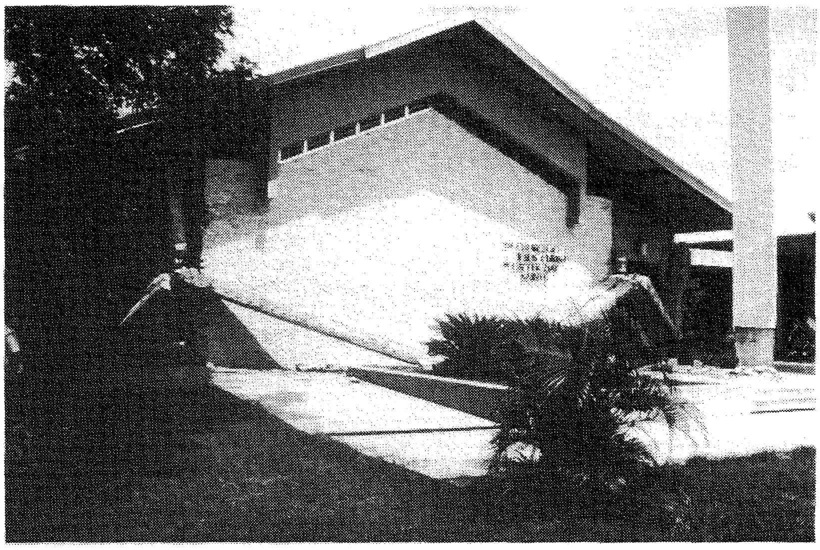

Figure C3.3: Church at Munoz; collapse of reinforced concrete barge board

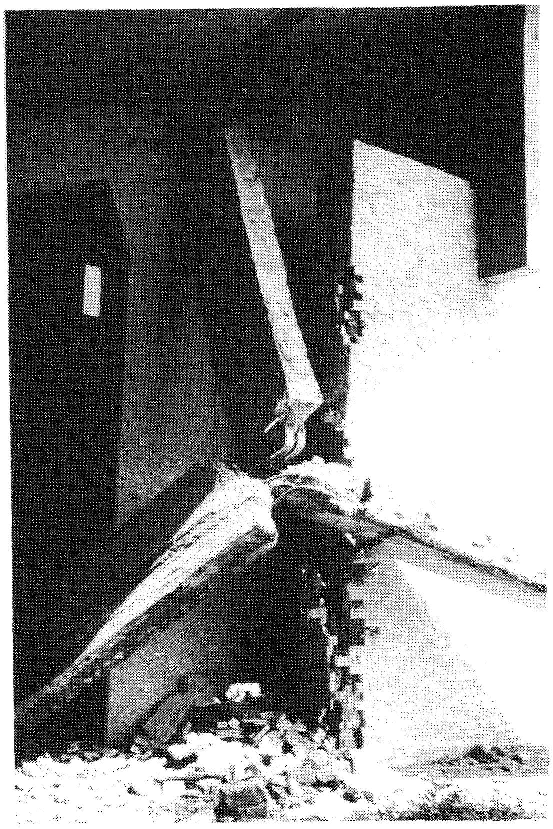

Figure C3.4: Church at Munoz; collapse of reinforced concrete barge board with its supporting cantilever beams

CASE STUDY NO. 4

AMBUKLAO HYDROELECTRIC PLANT

Description

The Ambuklao Hydroelectric Plant is located in the mountains some 35km north-east of Baguio. It was commissioned in 1956 and is capable of generating 75mW. The plant comprises a 129m high zoned rockfill dam, a chute spillway, an underground powerhouse, low level outlet works and electrical switchyard. The layout is shown on Figure C4.1 and the dam cross-section and material grain size curves are shown on Figure C4.2. Engineering consultants for the project were Harza Engineering (USA) and civil works were undertaken by Guy F Atkinson (USA).

The dam is a zoned structure consisting of a central earthfill core and rockfill shoulders. At the time of design, there was little precedence for vertical core dams of this size. It represents one of the early examples of large compacted rockfill dams of this type. The upstream shoulder was placed in 600mm lifts and compacted by 50-ton rubber-tyred rollers and sluicing. The impervious core was placed and compacted in 450mm thick layers by the same 50-ton rubber tyred rollers. The downstream shoulder was placed by end-dumping in approximately 9-27m lifts and sluicing. Details of design and performance are summarised by Fucik and Edbrooke, [9].

Earthquake Performance

The dam is located approximately 15km west of the northern extent of inferred fault rupture on the Digdig fault. It is estimated that peak horizontal ground accelerations of the order of .3-.4g may have been generated at the site, and accelerations at the crest of the dam could have been higher than 1g. The level of shaking at crest level was certainly very high as evidenced by failure to some low, squat weakly cemented rockfill walls. At the time of the earthquake the reservoir was close to the maximum operating level.

The effects of the earthquake are summarised below:

1. Settlement occurred along the dam crest. At the interface with the concrete spillway, settlements of about .4m were noticeable (Figure C4.3). Settlement of about .75m occurred on the upstream side of the crest, although it was partially associated with slumping of the upstream shoulder. A transverse crack developed at the interface of fill on the right abutment.

2. Shallow slumping of the upstream shoulder which resulted in intermittent longitudinal cracks along most of the crest (which had been infilled by the time of our visit), and on the upstream shoulder.

3. Tilting and separation along construction joints in the spillway wing wall (Figure C4.4). This movement is believed to be caused by slumping in the upstream shoulder of the dam.

4. Increased seepage flows, although at the time of our visit detailed information was not available.

5. Sloshing of water within the reservoir after the earthquake with wave heights of up to 1m.

6. Underwater slumping of silt in the reservoir which entered the power intake tunnel and blocked the turbines. This was creating problems in closure of gates to the tailrace tunnel which were necessary to enable remedial works to be undertaken.

7. A number of mainly shallow landslides in to the reservoir including many trees. This will compound the existing siltation problems at the dam.

8. Rockslides blocked the outlet of a low level scour pipe, which was originally a diversion tunnel.

9. Rockslides including boulders (up to 2m diameter) caused some damage to substation equipment.

10. Numerous landslides resulted in closure of the only access road to the site from Baguio. It will take many months to reopen this road and so the only access to the site is by helicopter.

11. Landslides carried away one small transmission tower and undermined the foundations of a large important tower.

Comments

The dam itself performed well considering the level of shaking to which it was subjected. The magnitude of settlement and slumping observed is not unexpected. Slumping only appeared to have occurred on the upstream shoulder where the material was saturated. The effect of slumping on the spillway wing wall serves as a warning of the consequences of such movement on dams. We are unaware of the design details and consequences of the movement on the structural integrity of the spillway.

Landslides into the reservoir will compound the existing siltation problems at Ambuklao. Most of the reservoir catchment has had the natural forest removed and the existing secondary vegetation makes the land more prone to landsliding. With hazards such as earthquakes and the annual monsoon rains, management of the reservoir catchment is very important.

At the time of our visit the damage caused by silt entering the intake tunnel had not been assessed, but it could be considerable. Any large components required for repair cannot be transported to the site until the road is reopened which could take months.

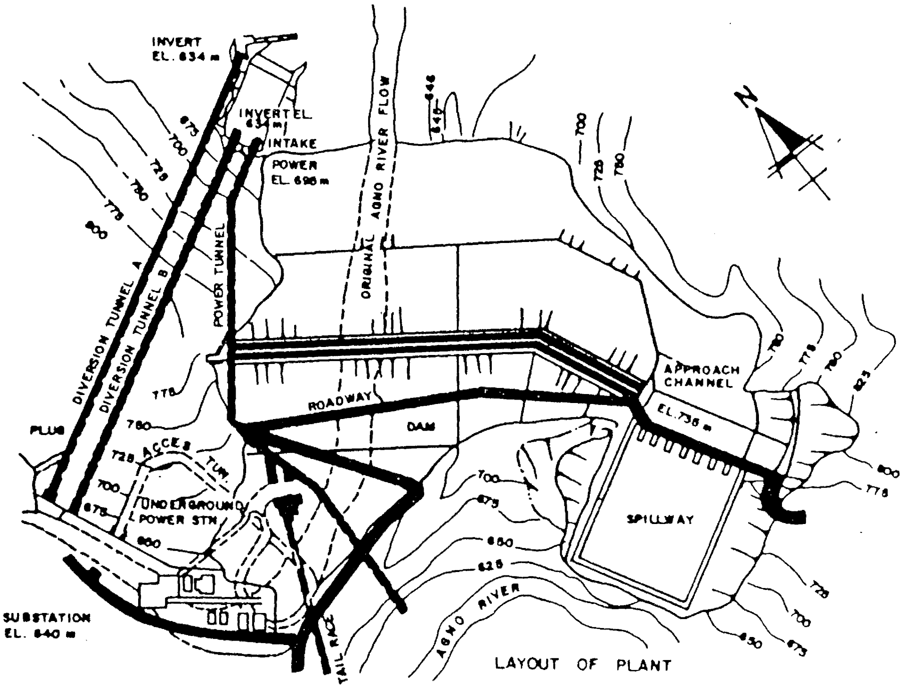

Figure C4.1: *Ambuklao Hydroelectric Plant - layout*

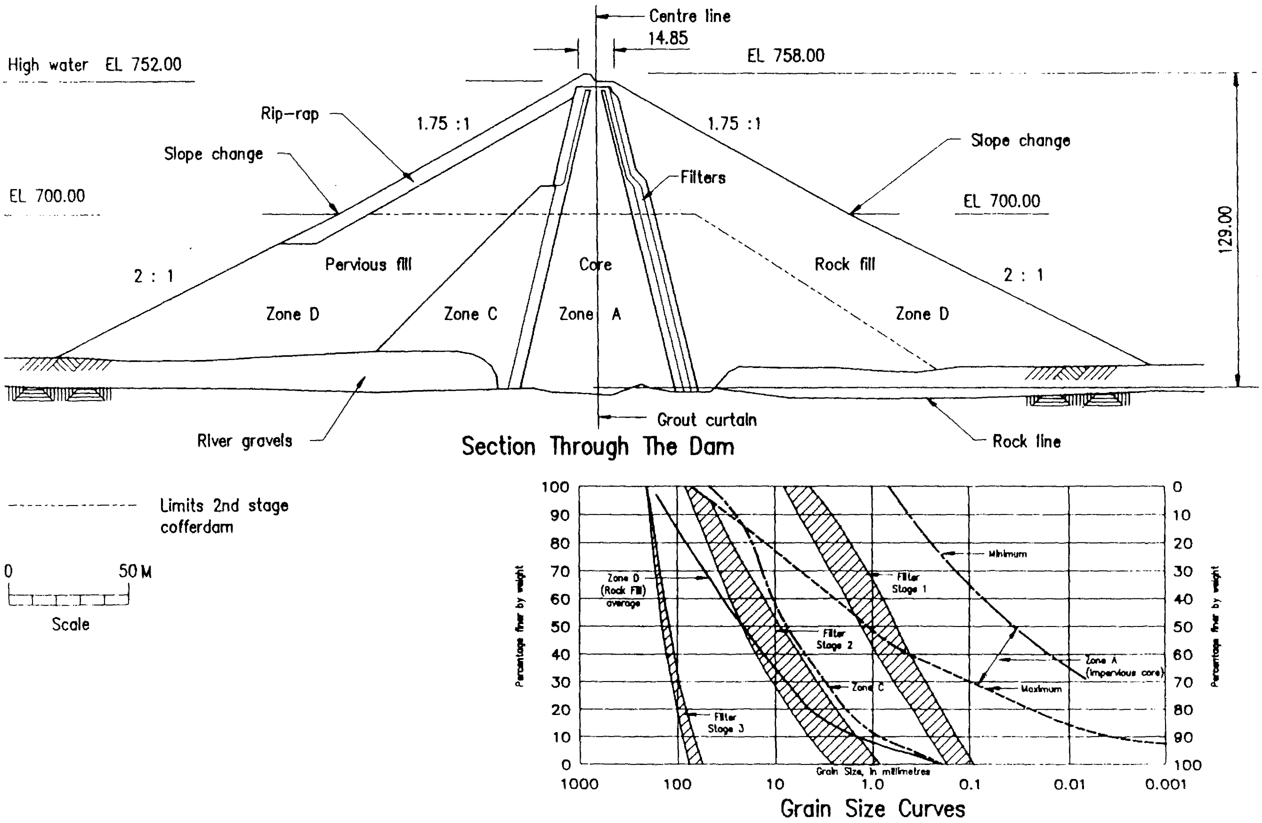

Figure C4.2: *Ambuklao Hydroelectric Plant - typical section and embankment grain size curves*

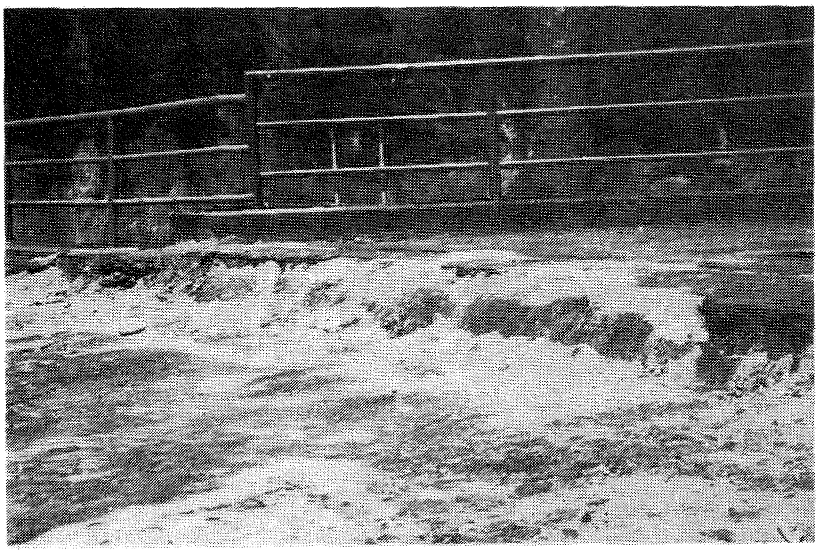

Figure C4.3: *Ambuklao Hydroelectric Plant - settlement of rockfill embankment adjacent to spillway*

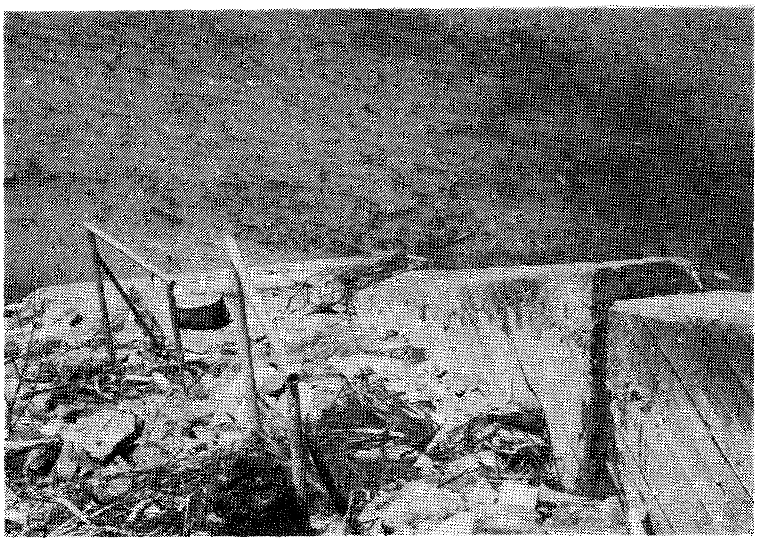

Figure C4.4: *Ambuklao Hydroelectric Plant - tilting and separation of spillway wing wall segments due to settlement of rockfill dam*

CASE STUDY NO. 5

MONTEPINOS APARTMENTS, BAGUIO

Principal Features

Eleven storey reinforced concrete frame with infill block walls. Three separate towers linked together form the 75 apartment complex. (Refer Figure C5.1). Better than average quality construction. Thick stone veneer to front wall adjacent to entry. Well distributed and extensive wall elements. Glazing in the plane of the structural elements.

Foundations: Not known. Probably raft or piles. Ground falls away steeply at the rear.

Earthquake Performance

On first sight appears undamaged. Closer inspection revealed:

- Extensive loss of veneer from wall at entry. Refer Figure C5.2.
- Windows broken due to structural movement. Refer Figure C5.3.
- Cracked block wall panels. Refer Figure C5.4.

- Failure of one block due to block infill falling out with consequent rupture of columns, causing significant tilt.

Occupants stayed inside the building because they could see the veneer falling.
The whole complex had been evacuated. Many owners were not in Baguio at the time of the earthquake.

The interior of the building was not inspected.

Reinstatement

Apart from the tilted section, reinstatement would be straightforward but costly. Strengthening of selected walls may be necessary. For the tilted block, reinstatement will depend on the condition of the remainder, and whether it could withstand any efforts to restore it to vertical.

Lessons/Conclusions

Foundation conditions are unknown and may have played a part in causing damage. However, there is little doubt that failure of the block infill brought about the most serious structural damage.

Had the walls been of even reasonable reinforced concrete, this building would have survived without significant damage. This building highlights more than any other the need to consider block infill as structure and design accordingly. Such action in the first place would not have added greatly to the cost, but would have greatly increased its earthquake resistance. On the other hand, the fate of this building could have been very different if the earthquake shaking had been more intense and/or lasted longer.

This building is outwardly like a number in New Zealand. The main difference is that in New Zealand, what look like structural walls generally are.

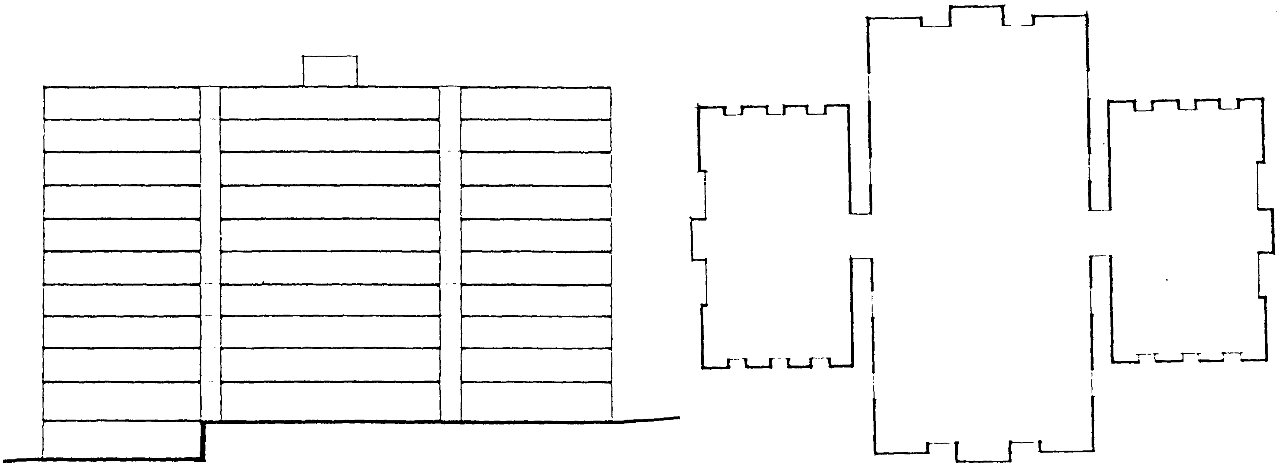

Figure C5.1: Montepinos Apartments, Baguio

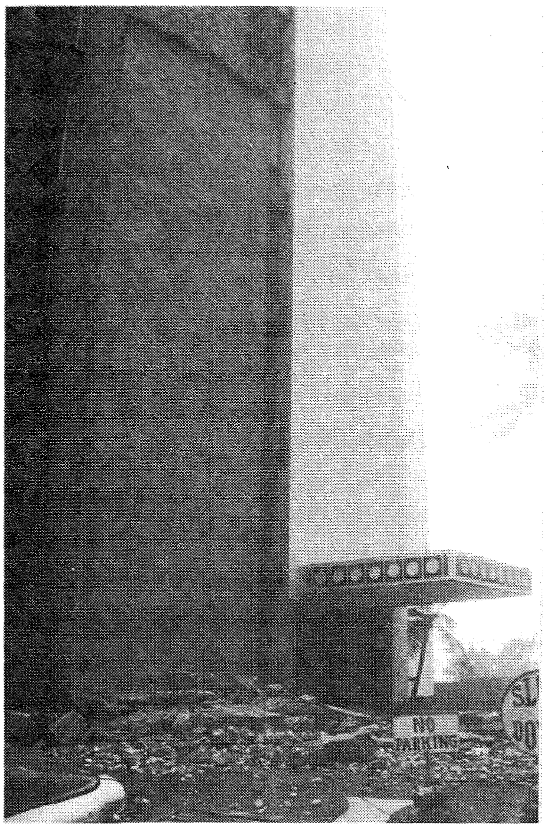

Figure C5.2: *Montepinos Apartments, Baguio; occupants did not run outside this building during the earthquake - they could see the large blocks of masonry falling from this feature wall*

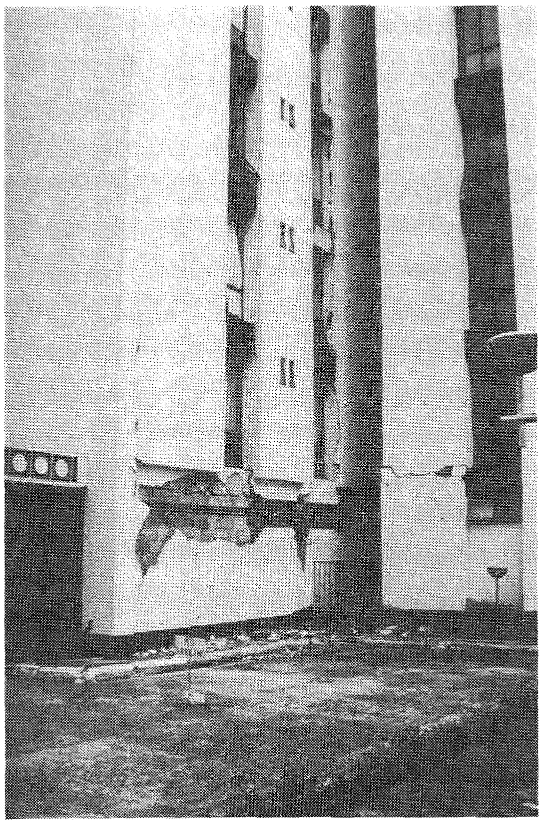

Figure C5.3: *Montepinos Apartments, Baguio; windows broken due to structural movement*

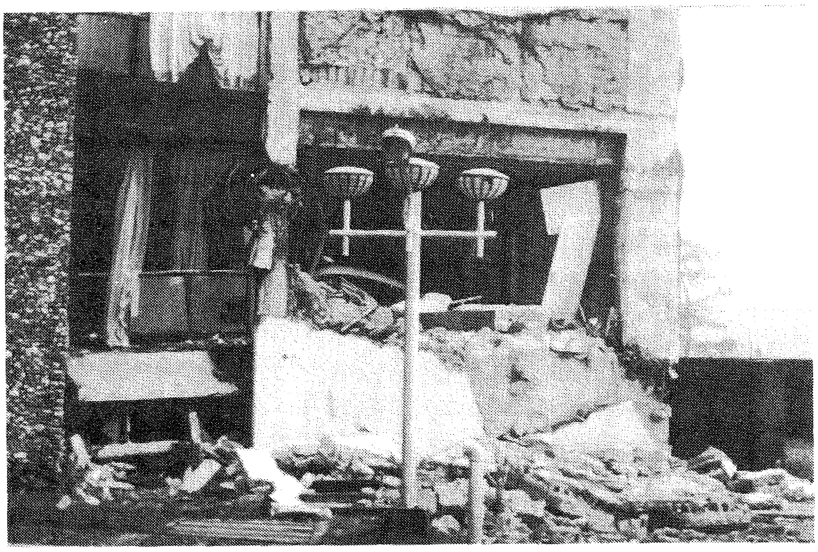

Figure C5.4: *Montepinos Apartments, Baguio; failure of infill block panels and adjacent columns*

CASE STUDY NO. 6

CARMEN BRIDGE

Description

The 650m long Carmen Bridge carries the MacArthur Highway across the Agno River, in the central plains of Pangasinan province. The MacArthur Highway is the main access route north of Manila to La Union and Benguet Provinces. The bridge site is located on deltaic deposits from the Central Cordillera.

The bridge structure is made up of thirteen standard 50-metre spans of simply supported steel trusses with a concrete deck. The 1920-30's rivetted fabrication used rolled 'I' sections extensively to form the side truss bottom chords, diagonals and top bracing. Bowed top chords were fabricated from plated, back-to-back rolled steel channels.

The concrete deck was supported on rolled 'I' sections spanning between the truss bottom chords. Each truss is supported on a roller at one end and a pin bearing at the other, sealed on the reinforced concrete abutments or piers. No longitudinal tying between spans is provided. The abutments and piers are in turn supported on timber piles.

The river channel occupies the four northern spans (200 metres), whereas the remaining nine spans cross a broad flood plain. The first pier from the northern abutment had settled at some time prior to the July 1990 earthquake. Remedial work had been carried out with a large bored pile placed up and down stream of the original pier, and cast integrally with a reinforced concrete jacked around the pier.

Earthquake Performance

Refer Figure C6.1.

The trusses supported by the strengthened northern pier had come off their pin and rocker bearings, but were still supported by the broad pier cap. At the southern end, two trusses had slid off their supporting abutment and pier to rest on the floodplain. The sixth truss from the southern end had come off its southern rocker bearing allowing that end to rest on the floodplain. Considerable damage had occurred to the truss steel work, particularly where the truss had slid forward over the pier so that the pier had broken up through the bottom chord and deck.

Large rotations of the four southern piers had occurred, either towards or away from the river as shown in Figure 6.1. The fifth pier had also rotated away from the river, but not to the same degree. Around the piers that had rotated, the fine sandy flood plain material had settled noticeably for a distance of about 600mm out from the pier face.

The bridge was still usable to pedestrian traffic, with wooden ladders provided to enable pedestrians to negotiate between the different levels of the bridge deck and walkways on the flood plain.

Conclusions/Comments

It would appear that liquefaction had a major part to play in this bridge collapse. Lateral spreading may have had some effect, but this was not obvious because the flood plain is relatively flat. Failure may have been initiated by out of phase oscillations of liquefied blocks of soil and the bridge structure, which led to inadequately anchored spans dropping off the southern piers and abutment. The large rotations of bridge piers may have been due to failed connections of pier to piles or shallow pile depth.

Reinstatement

New piers could be built in line with, and downstream of the existing piers. These piers could consist of piles ith sufficient depth to bear below any liquefiable soil layer. The ten mainly undamaged spans could be pushed across, one at a time, on to the new piers. Three new spans could be built to replace those destroyed. The whole structure could then be linked to resist future earthquake action while still allowing thermal movement.

Lessons/Conclusions

The collapse of these bridge spans show the need to consider at the design stage:

- Bearing depth for piles to penetrate potentially liquefiable layers.
- Horizontal spreading potential of soils through which foundation piles or piers penetrate.
- Longitudinal continuity of the bridge structure to resist lateral movement or loss of support.
- Viable mechanisms for the bridge structure to absorb energy introduced by ground shaking during an earthquake.

An area of fruitful investigation would be the development of cost effective methods of strengthening existing bridge structures against earthquake attack.

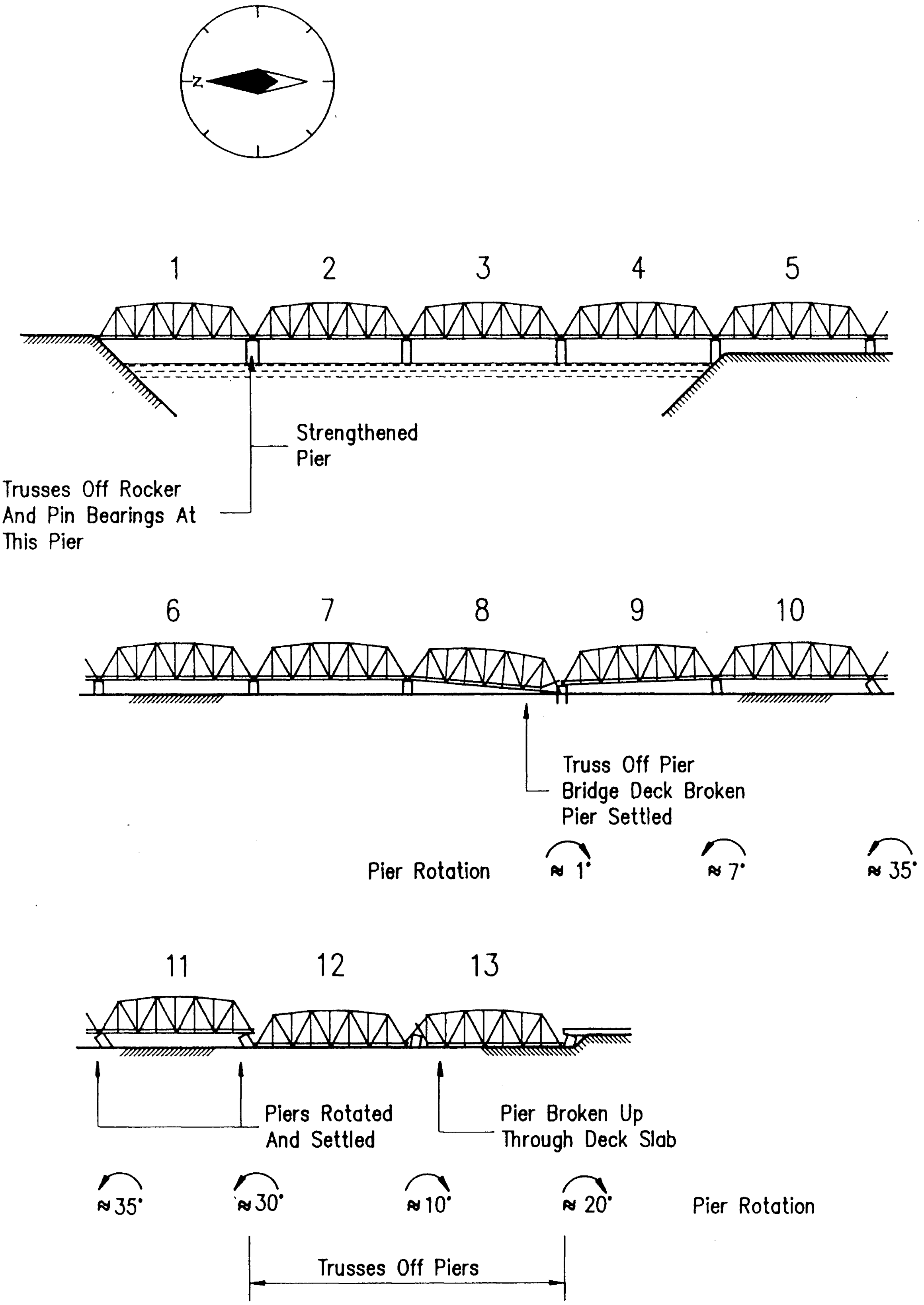

Figure C6.1: *Carmen Bridge*

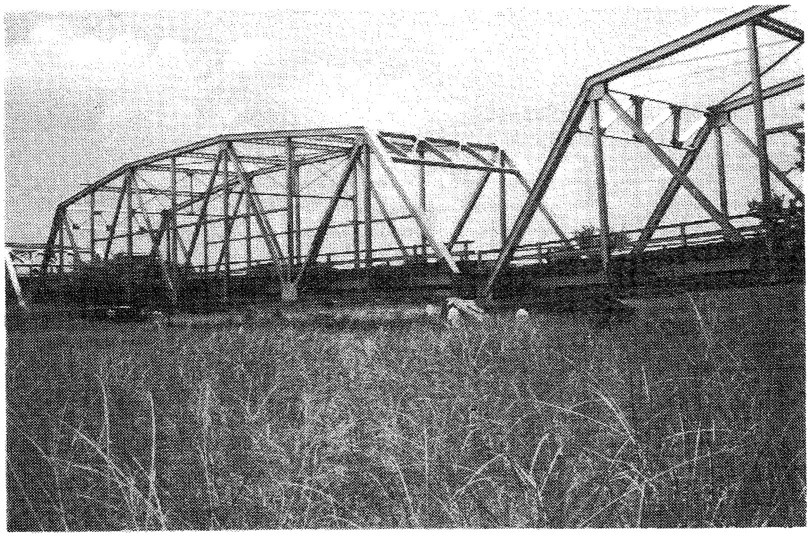

Figure C6.2: Carmen Bridge; truss span no. 11 viewed towards the southwest

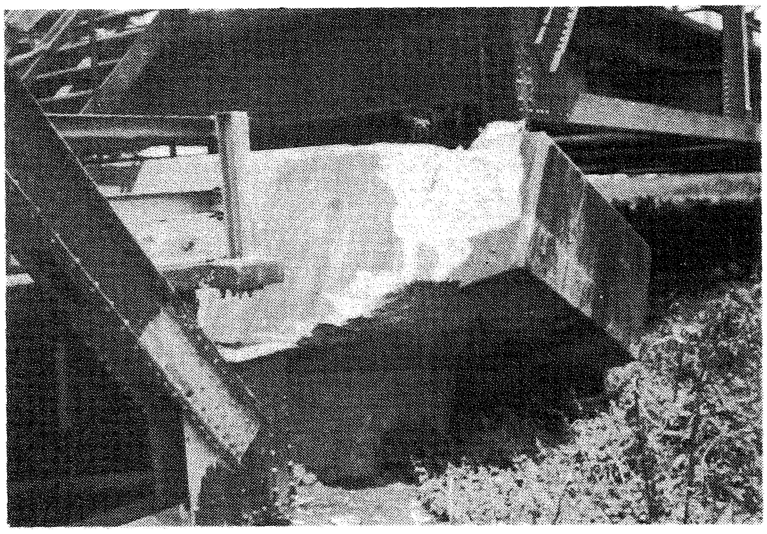

Figure C6.3: Carmen Bridge; liquefaction at pier between spans 11 and 12 viewed towards the northwest

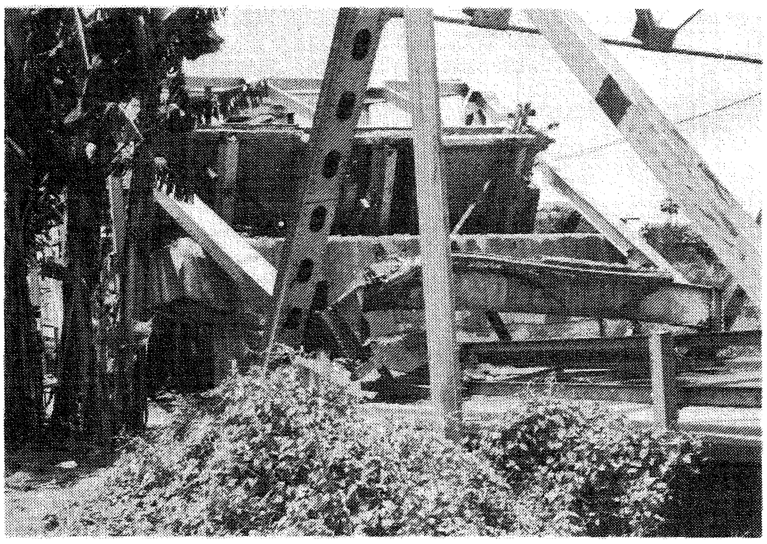

Figure C6.4: Carmen Bridge; pier between spans 12 and 13. Pier has broken up through bottom chord and deck of span 13 which has folded up - view towards the southwest

CASE STUDY NO. 7

MAGSAYSAY BRIDGE, DAGUPAN CITY

Principal Features

Maysaysay Bridge in Dagupan City carried one of the main commercial thoroughfares, Perez Boulevard, across a channel of the Agno river delta. The bridge was seven spans of varying length. The four eastern spans, over the river channel, had a cast in-situ reinforced concrete deck supported on four welded steel girders per span. The girders were themselves supported on reinforced concrete piers and the eastern abutment. The remaining three shorter spans to the western abutment were cast in-situ, reinforced concrete beams (three per span) and deck supported on concrete piers and abutment. Post and beam deck guard-rails, 900mm high, were in reinforced concrete. No longitudinal continuity was provided between spans. It is understood that the driven piles supporting the abutments and piers may have been hardwood timber.

The concrete bridge beams had a convex curved steel plate cast into their end lower surface to be supported by a flat steel plate cast into the pier head. Steel pin and rocker bearings were provided to support the steel girders off their piers.

Earthquake Performance

Two of the piers supporting steel girder spans had rotated and settled below river water level, taking the ends of the simply supported spans with them. The pier between (in the middle of the river channel) had rotated only 15° without significant settlement. The steel girders, supported by this pier were still attached via their pin bearings.

At the western end, the abutment and three concrete beams spans had moved horizontally towards the river channel by approximately 2.5 metres. The two landward piers had moved laterally with the bridge beams and rotated 12°. At the third pier from the western abutment, the bridge beams had slid over the pier common with the first steel girder span support, without significant movement or rotation of the pier. This steel girder span had fallen away into the river, completely below water level. Refer Figures C7.1 and C7.2.

Lateral movement of the silty sand riverbank material had not only carried the abutment towards the river channel, but also continued to slump away, building up in large mounds behind the first two piers from the western end.

There were indications that the eastern bank had slumped towards the river channel, but not to the same degree as the western bridge abutment. Horizontal movement at the eastern end of the bridge was difficult to determine as the first eastern pier had settled below river level and the deck structure slid under the next western span. This suggests that this eastern pier had rotated in the same sense as the western piers: the pier cap towards the east. Refer Figure C7.3. (View taken from eastern abutment towards the west).

At deck level, considerable pounding between spans was evident where the walkway and guard-rail concrete had sheared off horizontally from the main deck.

Conclusions/Comments

The bridge site is approximately 70km from the adjacent fault rupture. A second, similar bridge in Dagupan, 100 metres downstream, had no apparent damage, although minor slumping of the adjacent river banks had occurred.

Liquefaction is considered to be the primary cause of bridge failure. Two of the three pier/pile structures in the river channel lost support so that settlement and rotation took place into the liquefied material. The third pier in the river channel (between the other two) rotated but did not settle. Lateral spread of the riverbank carried the western abutment towards the river channel without significant settlement. This lateral movement carried the two adjacent piers with the bridge deck towards the river, with build up of material behind the piers. At the third pier in the edge of the river, lateral movement or rotation was not as great, but the first steel span fell away and the concrete beams slid over the top of the pier. It is not clear whether the steel girder span pulled away from its western end pier support as the river channel piers failed, or the spans were pushed off as lateral spread forced the concrete beam spans forward. Damage to the concrete bridge deck interface at this common pier was not as great as at other span junctions that could be observed.

Reinstatement

This bridge will require complete replacement with a structure that is founded below the liquefiable material, but can allow lateral spread of the riverbanks without destroying the bridge.

Lessons/Conclusions

The collapse of these bridge spans show the need to consider at the design stage:

- Bearing depth for piles to penetrate potentially liquefiable layers.
- Horizontal spread potential of soils through which foundation piles or piers penetrate.
- Longitudinal continuity of the bridge structure to resist lateral movement or loss of support.
- Viable mechanism for the bridge structure to absorb energy introduced by ground shaking during an earthquake.

An area of fruitful investigation would be the development of cost effective methods of strengthening existing bridge structures against earthquake attack.

Figure C7.1: Dagupan City, Magaysay Bridge on Perez Blvd.; collapse of bridge spans due to liquefaction and lateral spread of river bank

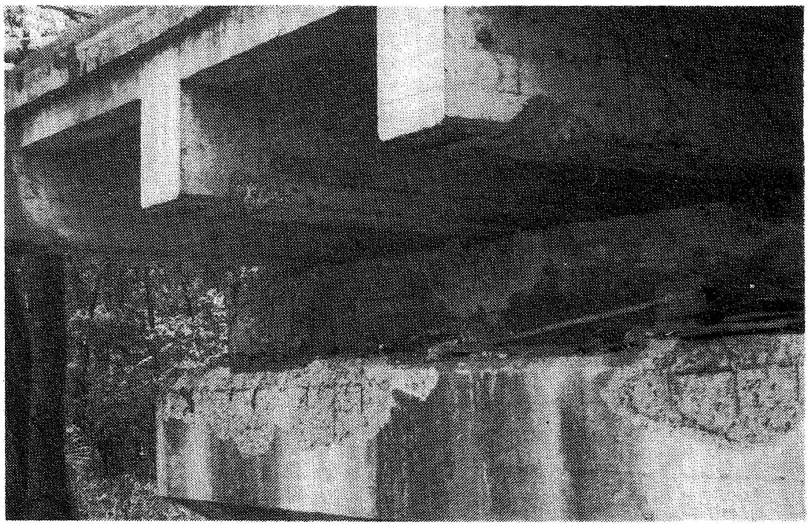

Figure C7.2: Dagupan City; common pier to support steel girder and concrete beams

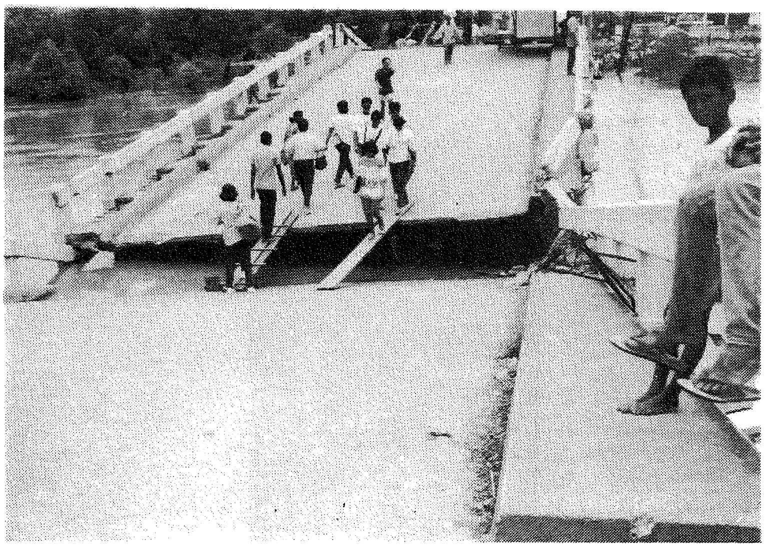

Figure C7.3: Dagupan City; easternmost pier - rotation towards bank

CASE STUDY NO. 8

OIL STORAGE FACILITY - SAN FERNANDO PORT

Description

A bulk storage depot and associated facilities for Caltex Oil near the wharf at San Fernando Port. See plan. This large facility was built within a compound surrounded by bund walls 1.5 metres high. Each tank was founded on a metre high hardfill platform. There is a variety of sizes and diameters of tank, up to 29 metres diameter and typically 14 metres diameter, which were generally two-thirds full at the time.

Earthquake Performance

Generally good. No damage evident to facilities other than the bulk store tanks.

No significant loss of product. Main effect was settlement (50-150mm), lateral movement (up to 150mm) and minor tilting of most tanks. Settlement caused minor slumping at edge of plinth and 400mm lateral spreading of the mounds away from the tank perimeter. This edge settlement induced a dome form in the tank base. Several draw-off pipes were fractured due to lack of provision for settlement.

Flexible pipe couplings are not used due to their poor performance in the hot climate. Some overstressing of pipes occurred but there was no fracture or loss of product. Concrete foundation plinths for pipework were partially overturned in some cases. A gantry between tanks at roof level fell when they moved apart. One lightning conductor fractured at ground level.

Some tanks had been drained and were out of service. Most of the interconnecting pipework was to be replaced due to overstressing in the earthquake. The pipeline to the wharf was being repaired as a result of failure of the pier.

Comments

Tanks would have been designed to API 650 and performed satisfactorily under approximately 0.2g ground acceleration. Edge failure of the supporting plinths may have prevented elephant's foot buckling of the walls by relieving compressive stresses. This failure appeared to be a local bearing failure under the tank wall as a result of cyclic loading.

Relatively minor overstressing of pipes and tank bottoms has caused costly damage and some loss of use of the tanks.

Lessons/Conclusions

These tanks, designed to international standards, performed reasonably well at relatively low ground accelerations. The fact that some damage was sustained indicates that damage in stronger shaking could have rendered this facility unserviceable for a considerable time.

Minor settlements of tanks can result in significant costs of repair and disruption.

Bearing failure of the soils under the edges of the tank could have been avoided if a perimeter beam had been provided.

Plinths for supporting pipework should be designed to resist earthquake loadings and have foundations that can resist overturning.

Outlet pipes from tanks should be protected by recesses in the foundations to prevent them from rupturing due to tank settlement or tilting.

Flexible connections to tanks are preferable.

It is important that bunding to retain spillage from tanks is properly designed, constructed and maintained.

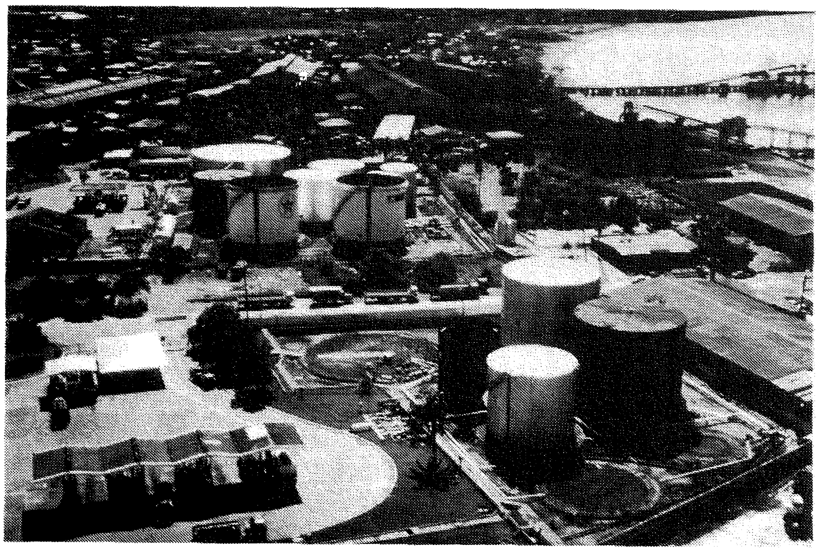

Figure C8.1: San Fernando Oil Depots (Ian Gill, ADB)

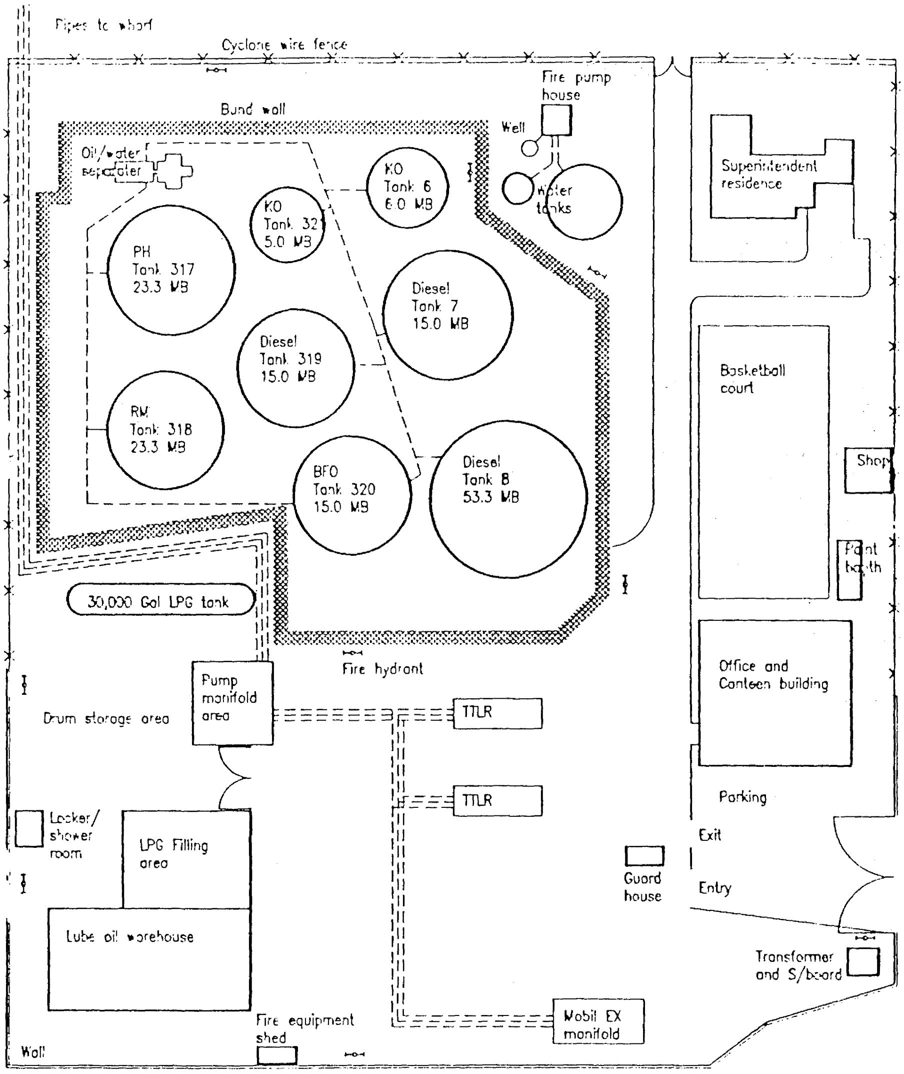

Figure C8.2: *San Fernando Port - Caltex Bulk Depot*

Figure C8.3: *San Fernando Port - Oil Storage Facility. Storage tank settlement caused drainage valve to break because the outlet pipe was restrained by the concrete sump wall. Note the broken valve in the foreground*