THE LUZON, PHILIPPINES EARTHQUAKE OF 16 JULY 1990

A FIELD REPORT BY EEFIT

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SUMMARY

On 16th July 1990, a magnitude 7.8 earthquake struck central Luzon, the largest and most developed of the Philippine Islands. The human consequences were severe; at least 1200 people were killed, a further 2,700 injured and 120,000 were made homeless. The earthquake gave rise to extensive soil liquefaction and there was a surface fault break 100km long with horizontal movements of up to 6m. The widespread damage to the infrastructure resulted in effects on the national economy which are still being felt. This damage included the collapse of modern, reinforced concrete multistorey buildings in the mountain resort of Baguio and the failure of a number of major road bridges and blockage of national highways.

This report records the findings of three engineers from EEFIT, the UK earthquake investigation team, who visited the affected region soon after the earthquake. The report sets out the team's conclusions and recommendations, which are summarised as follows.

1) The causes of life threatening failure in the buildings studied by EEFIT appeared in all cases to be due to well understood deficiencies in design and construction.

2) No major deficiencies in local or international codes of engineering practice were revealed by the earthquake. The most urgent need is therefore not to improve the codes themselves, but to improve understanding of them and to ensure that they are enforced. Recommendations are made for ensuring code enforcement.

3) Liquefaction (temporary loss of the strength of sandy soils due to ground vibration) played a major part in the disruption of the road network, which was one of the most serious consequences of the earthquake. The centre of Dagupan City was also devastated because of liquefaction. Many areas of the Philippines have a high liquefaction potential, and currently available information on how to identify such areas should be made more widely available. Further international effort is required to develop existing ideas of how to counter the adverse effects of liquefaction.

4) Unusual amplification of ground motions may have occurred in Baguio. Instrumentation should be installed in and around Baguio to record future ground tremors, which would help the study of these unusual effects.

5) The general lack of instrumentation to record ground motion occurring in the earthquake has hampered efforts to learn from the event. Existing requirements in the Philippines should be enforced to ensure that, in future, such instrumentation is installed in major new buildings. It would then be available for measuring ground shaking in future great earthquakes which will occur in this highly seismic region.

6) The general lack of damage in Manila in the 1990 earthquake is no guarantee of good performance in future earthquakes, because it is likely that the 1990 intensity of shaking will be considerably exceeded in the lifetime of the current building stock.

◄ *Baguio miners engaged in rescue work.*

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1.0 INTRODUCTION

1.1 Background to the Field Mission

On 16th July 1990, a major earthquake struck the centre of Luzon, the largest and most developed island in the Philippines. The official statistics (1) indicate that 1200 people died, a further 1000 are reported missing, 2700 people were injured and 120,000 were rendered homeless. The earthquake caused widespread damage to engineered and non-engineered structures and gave rise to both extensive liquefaction and a major surface fault break.

This report summarises the findings of an EEFIT team which visited the Philippines soon after the earthquake. The EEFIT team consisted of Edmund Booth (Ove Arup & Partners, London), Adrian Chandler (University College London) and Philip Wong (Ove Arup & Partners, Hong Kong). The stated objectives of the team were as follows.

a) To study the effects of the earthquake and particularly to observe the response of engineered structures.

b) To gather information towards improving methods of earthquake resistant design and construction.

c) To share lessons from the earthquake as widely as possible.

d) To collaborate where possible with other organisations studying the earthquake.

The team arrived in the Philippines on 31st July and left on 10th August 1990. A detailed itinerary is given in Appendix A. During that time, the team had useful discussions with many people, including the following.

- Mr Engracio de Gracia, President of the Association of Structural Engineers of the Philippines;
- Francisco Pascual, Director, Bureau of Design, Department of Public Works and Highways;
- Dr Salvador Reyes, Professor of Civil Engineering, University of the Philippines;
- Mr Julio Sabit of the Philippines Institute for Volcanology and Seismology;
- Mr Ian Gill, Information Officer, Asian Development Bank, Manila;
- Dr David Hopkins and Mr Win Clark of the New Zealand Society for Earthquake Engineering Reconnaissance Team;
- Dr Robert Pearce and Dr John Bicknell of the US Geological Survey, Menlo Park, California.

In a subsequent visit to the Philippines in November 1990, Andrew Coburn (Cambridge Architectural Research Ltd) toured the epicentral area as part of an expert mission for the United Nations Centre for Human Settlements (Habitat). He visited the towns of Baguio, Dagupan and Agoo. The full report of this UN mission has been published (1). Dr Coburn has contributed Section 11 (Performance of Non-Engineered Buildings) and Section 15 (Economic Losses and Consequences) to the present report in addition to his general editorial assistance.

1.2 Authors of this Report

Edmund Booth, MA, MICE, MIStructE, acted as leader of the EEFIT team and general editor of this report. He is a founder member of EEFIT, for whom he has led three previous field missions, and is chairman (1990 - 1992) of the Society for Earthquake and Civil Engineering Dynamics (SECED), the British national section of the International and European Associations for Earthquake Engineering. Mr Booth works as a structural engineer for Ove Arup & Partners in London, where he is their designated specialist on earthquake engineering.

Adrian Chandler, PhD, MICE, is a lecturer in structural engineering at University College, London and specialises in research on the torsional response of earthquake loaded structures. He has undertaken two previous earthquake field missions for EEFIT (Loma Prieta, California 1989 and Newcastle, Australia 1989).

Philip Wong, BE(Hons), ME, MIStructE, MICE, is a structural engineer with Ove Arup & Partners in Hong Kong, where he takes a special interest in earthquake resistant design. He prepared his master of engineering thesis at the University of Canterbury, New Zealand on the earthquake resistance of reinforced concrete frames, working under Professors Priestley and Park.

Andrew Coburn, MA, DipArch, PhD, is a director of Cambridge Architectural Research. He is an architect who specialises in earthquake reconstruction, risk modelling and risk reduction programmes. He has undertaken numerous studies for the UN and national governments, and has published many papers in the field of earthquake risk. He has carried previous earthquake field investigations in Turkey, Iran and Italy.

1.3 Background to EEFIT

EEFIT (Earthquake Engineering Field Investigation Team) is a group of British earthquake engineers, architects and scientists who seek to collaborate with colleagues in earthquake prone countries in the task of improving the seismic resistance of both traditional and engineered structures.

The principal activity of EEFIT is conducting field investigations following major damaging earthquakes, and reporting to the local and international engineering community on the performance of civil engineering and building structures under seismic loading. A preliminary reconnaissance mission is carried out within a few days of an earthquake and detailed survey or follow-up visits are then arranged as appropriate.

EEFIT was formed in 1982 as a joint venture between universities and industry. It has the support of the Institution of Civil Engineers through its associated society SECED (the British National Section of the International Association for Earthquake Engineering), and of the Institution of Structural Engineers. It is advised by a number of British engineers experienced in the field of earthquake engineering. Funding for its missions has come from the Science and Engineering Research Council, and other research and industrial sources.

EEFIT has investigated earthquakes in Liege (1983), Chile (1985), Mexico (1985), San Salvador (1986), Loma Prieta, California (1989), Newcastle, Australia (1989), Romania (1990), Iran (1990), Philippines (1990) and Sicily (1990). EEFIT reports are available or in preparation for all these events and can be obtained from the secretary of EEFIT at the address on the back cover.

2.0 METHODOLOGY

The team had relatively limited resources of time and personnel. It was decided that the best use of these resources was to carry out a visual survey of a representative selection of the most affected areas. Accordingly, 2 days of briefing and preparations were spent in Manila, followed by a 4 day field trip through the epicentral region, followed by 3 days of debriefing, talks and discussions in Manila.

Because the team had the use of a helicopter for 1½ days, it was possible to visit a representative number of the damaged areas. Visual inspections of the noteworthy sites, careful photography, note and sketch taking, and discussions with people familiar with the sites, often through interpreters, formed the main survey techniques. A limited quantified damage survey was also undertaken in Baguio. These methods, when put together with discussion with other investigators and study of other investigation reports, enabled a broad picture of the earthquake to be pieced together and its unusual or noteworthy features to be identified.

A detailed itinerary is given in Appendix A and an equipment list is given in Appendix B.

3.0 THE EARTHQUAKE AFFECTED ZONE

3.1 General setting

Figure 3.1 shows the Philippine Islands in their south-east Asian setting and Figure 3.2 shows the central area of the main Philippine island of Luzon affected by the earthquake. The principal features of this central area are now described.

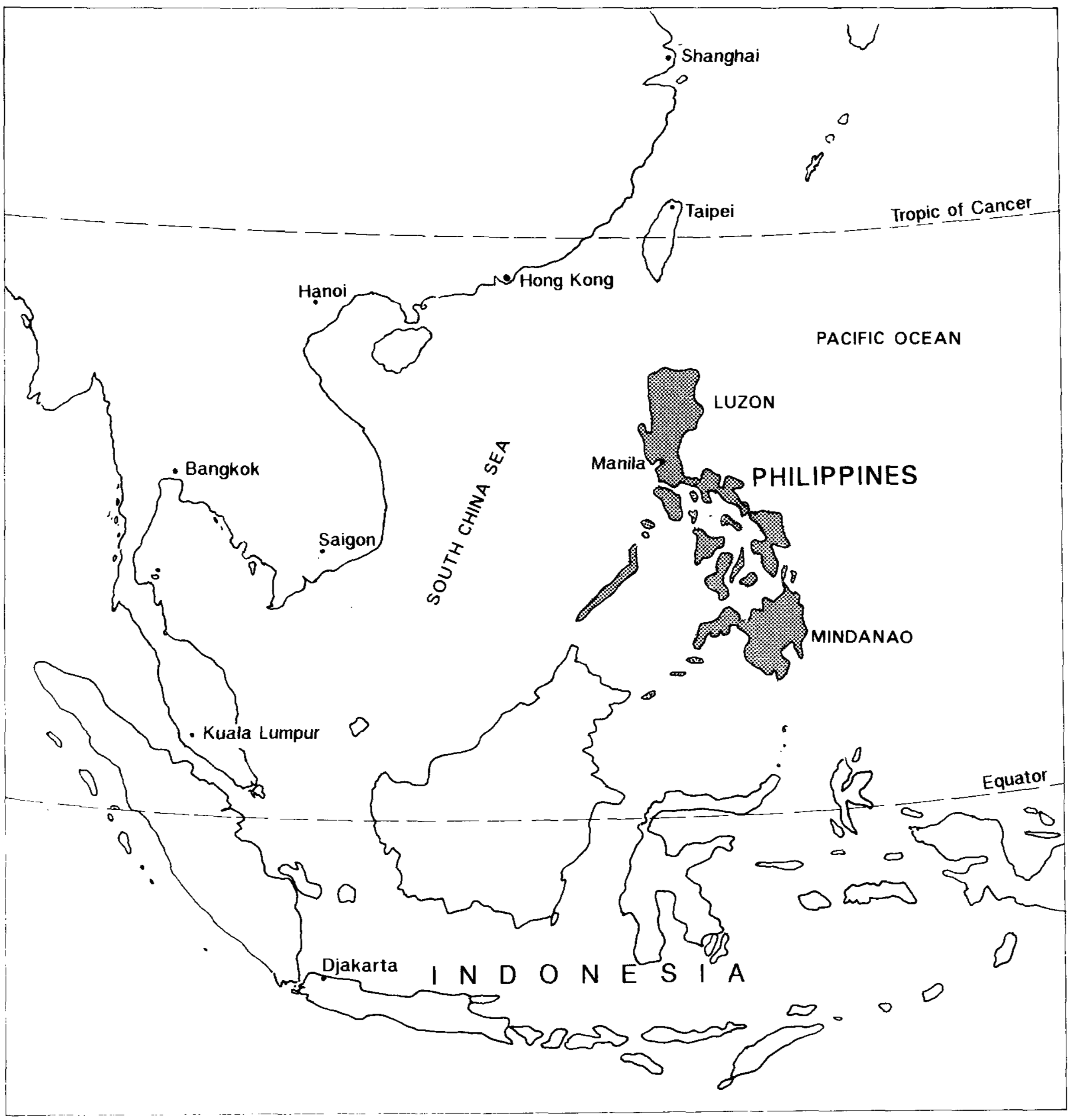


Figure 3.1 The Philippine islands in their south east Asian setting

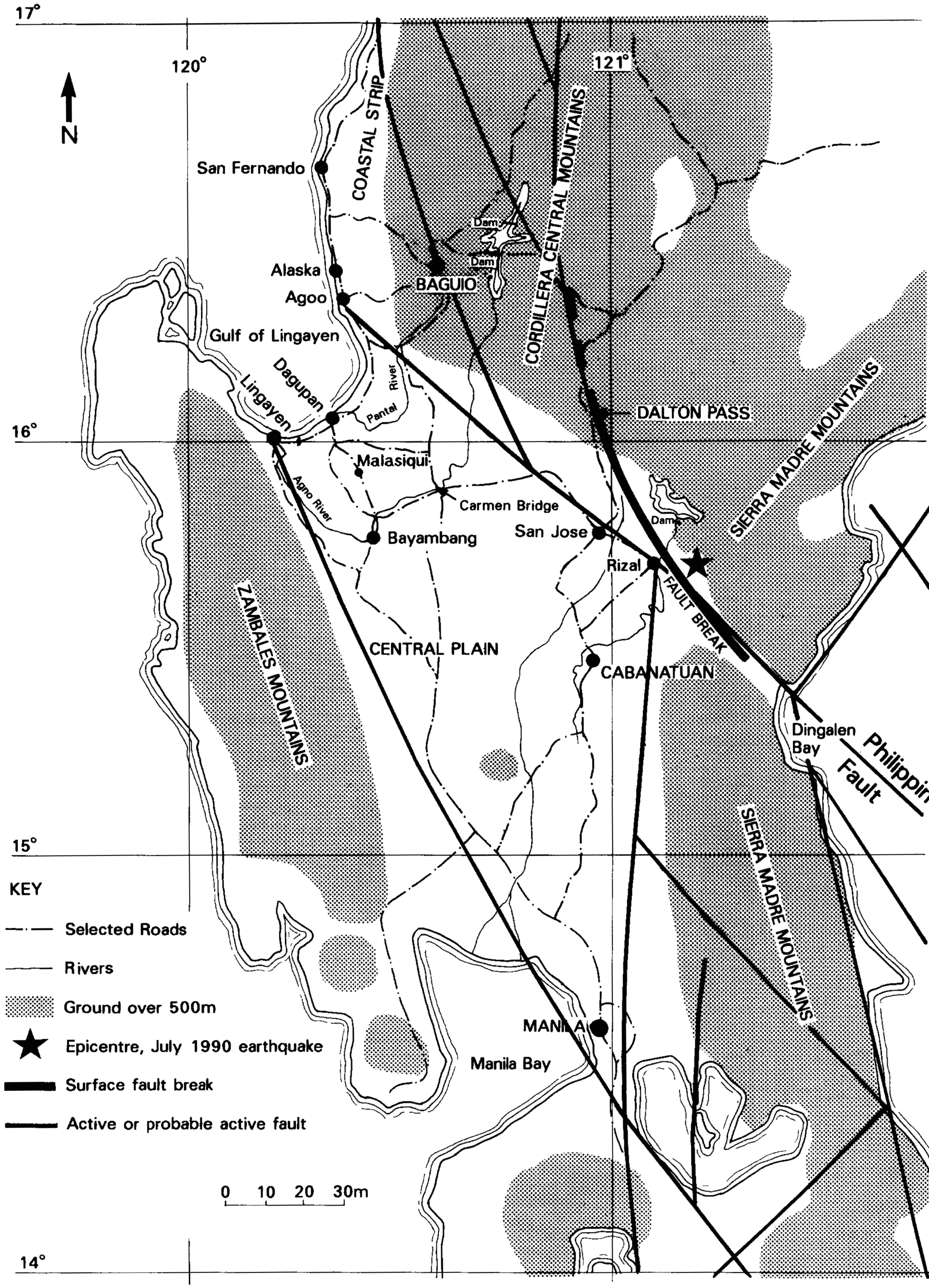


Figure 3.2 Geographical features of central Luzon.

3.2 The Central Plain

A Central Plain extends northwards from Manila, covering an area approximately 150km by 60km. This area is very flat and is generally less than 30m above sea level. There are isolated volcanic outcrops on this plain, one rising to 1000m in a horizontal distance of 3km. The plain is bounded to the south by a ring of volcanoes, some of which have been active within recorded history, and by Manila Bay. The western edge is bounded by the Zambales mountains and the eastern edge by the Sierra Madre mountains. The north eastern edge of the plain is bounded by the Cordillera Central mountains. The north western edge is bounded by the Gulf of Lingayen.

A number of rivers rise in the southern part of the Cordillera Central mountains and flow south into the central plain. Those to the east flow south into Manila Bay, while those to the west flow into the Gulf of Lingayen, forming deltas at their mouths. The small gradients in the plain would be expected to be associated with low flow speeds.

The Central Plain is extensively farmed with paddy fields. There is a major conurbation around Manila, which has a population of around 10 million and has well developed commercial and industrial facilities. Elsewhere on the Central Plain, the largest city of Cabanatuan has a population of about 80,000. The plain is predominantly rural with a population density of around 250 people per square kilometre.

There is a well developed infrastructure of paved roads, which generally appear quite well maintained. The rural roads are typically paved in concrete. A rail network used to extend from Manila to the north of the plain; it has generally been abandoned, except around Manila.

3.3 The Sierra Madre Mountains

These extend along the entire eastern coast of Luzon north of Manila. They are steep and reach a height of up to 3000m. Few roads penetrate the area which is sparsely populated. A notable feature is the rift extending north west from Dingalen Bay, which follows the line of the Philippines Fault, and which was the south eastern end of the fault which moved in the July 1990 earthquake.

3.4 The Cordillera Central Mountains

These extend 400km northwards from the Central Plain to the northern end of Luzon. The mountains have steep slopes, rising up to 3000m, and they are generally sparsely populated. The main central highway through Luzon crosses the mountains at their southern end through the Dalton Pass, following the line of the Philippines fault. The main town in the south of the mountains is Baguio, which was one of the worst affected cities and is further described in Section 5.1. Before the earthquake, Baguio had an airport and 4 main road links to the major highway system.

3.5 Western Coastal Strip

This lies between the Cordillera Central mountains and the west coast. It consists of flat, farmed areas and hills rising up to 300m. The main western highway runs along this coastal strip. The town of Agoo and the port of San Fernando, each with populations around 20,000, are the main centres at the southern end of the strip, which was the portion of this area affected by the July 1990 earthquake.

4.0 SEISMOLOGICAL ASPECTS

4.1 Tectonic setting

The Philippine Islands lie in a complex tectonic environment caused by the interaction of the Eurasian and Philippine plates (Figures 4.1 and 4.2). Major earthquakes and fault zones are shown in Figures 4.3 and 4.4. The average earthquake recurrence relationship for the Philippines, based on instrumental data this century, is shown in Figure 4.5, and is compared with other areas of the world. It can be seen that the Philippines is a highly seismic area, by world standards, comparable to California and Japan.

A further introduction to Philippine seismology is given in the Philippine Institute for Volcanology and Seismology's (Philvocs) excellent booklet 'Earthquake and Tsunami' (2).

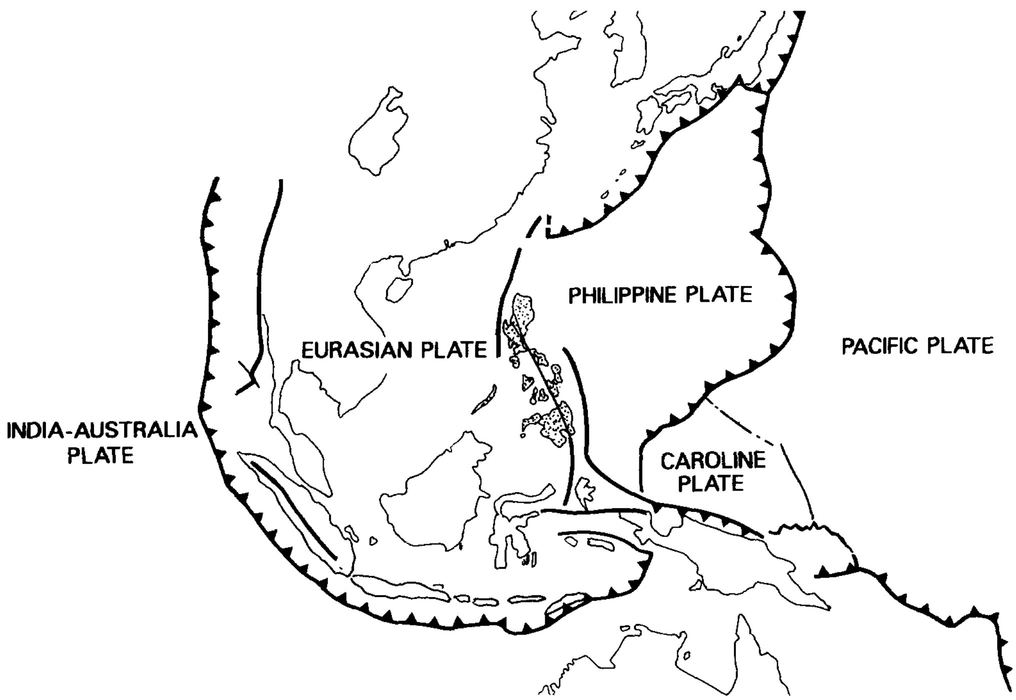


Figure 4.1 Tectonic map of south eastern Asia.
(Based on National Geographic Magazine, August 1985)

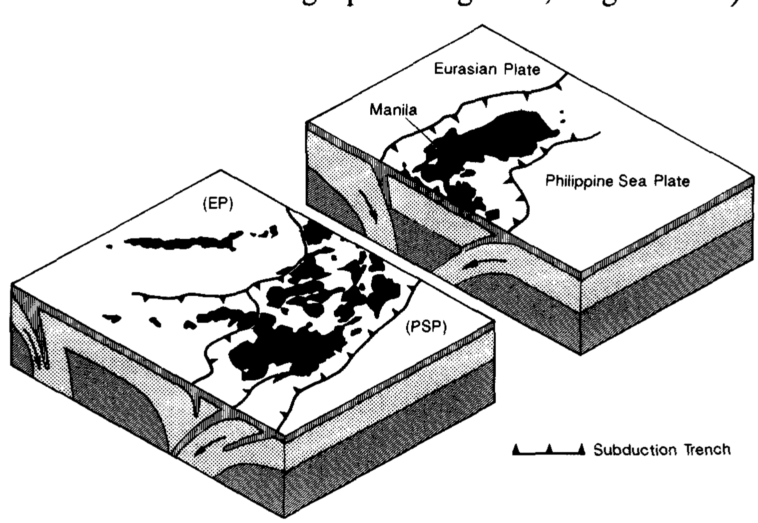


Figure 4.2 Subduction zones in the Philippines regions (after Philvocs, 2)

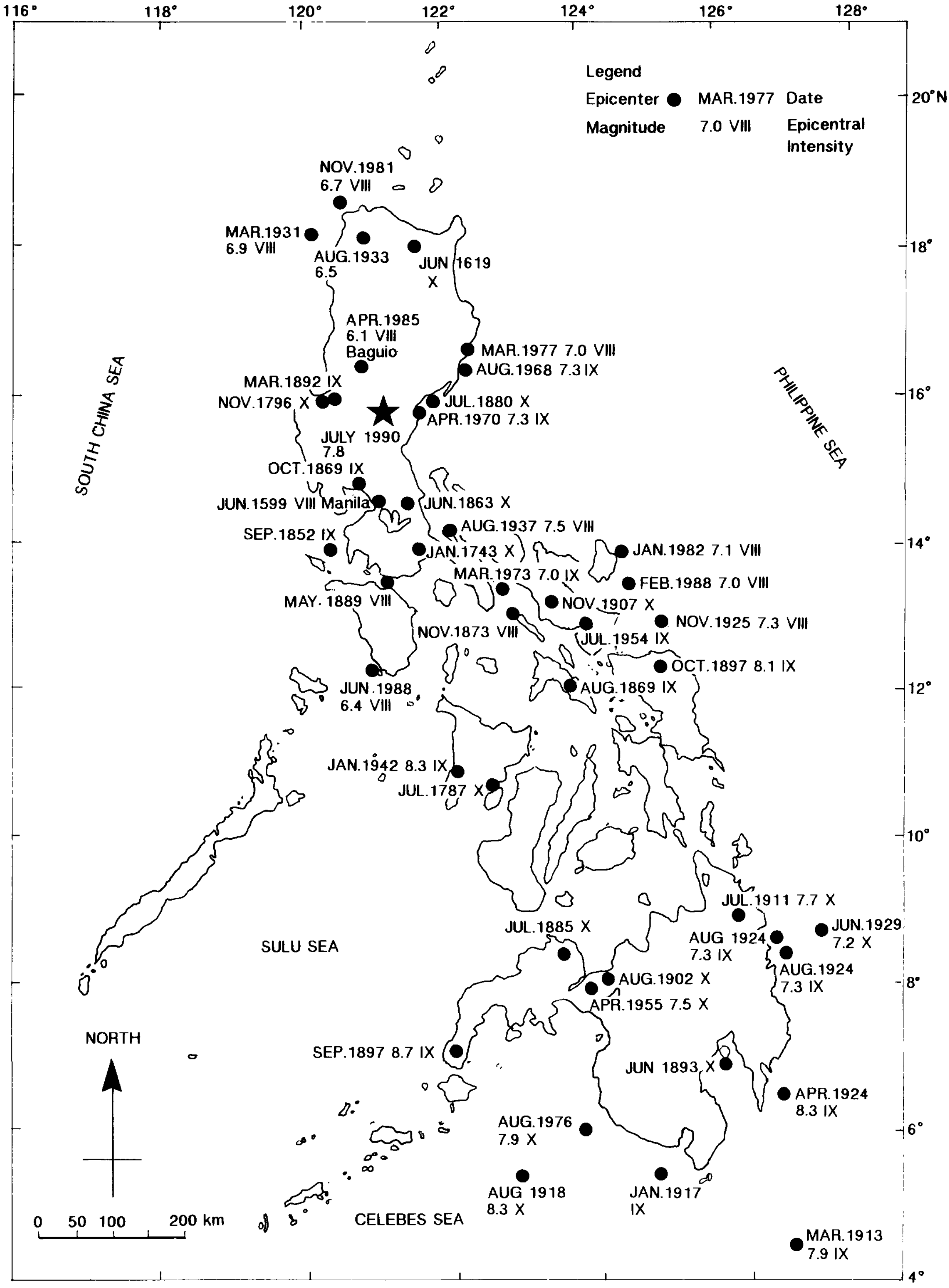


Figure 4.3 Distribution of Strong and Major Earthquakes (M>6) in the Philippines, 1599-1990 (after Philvocs, 2)

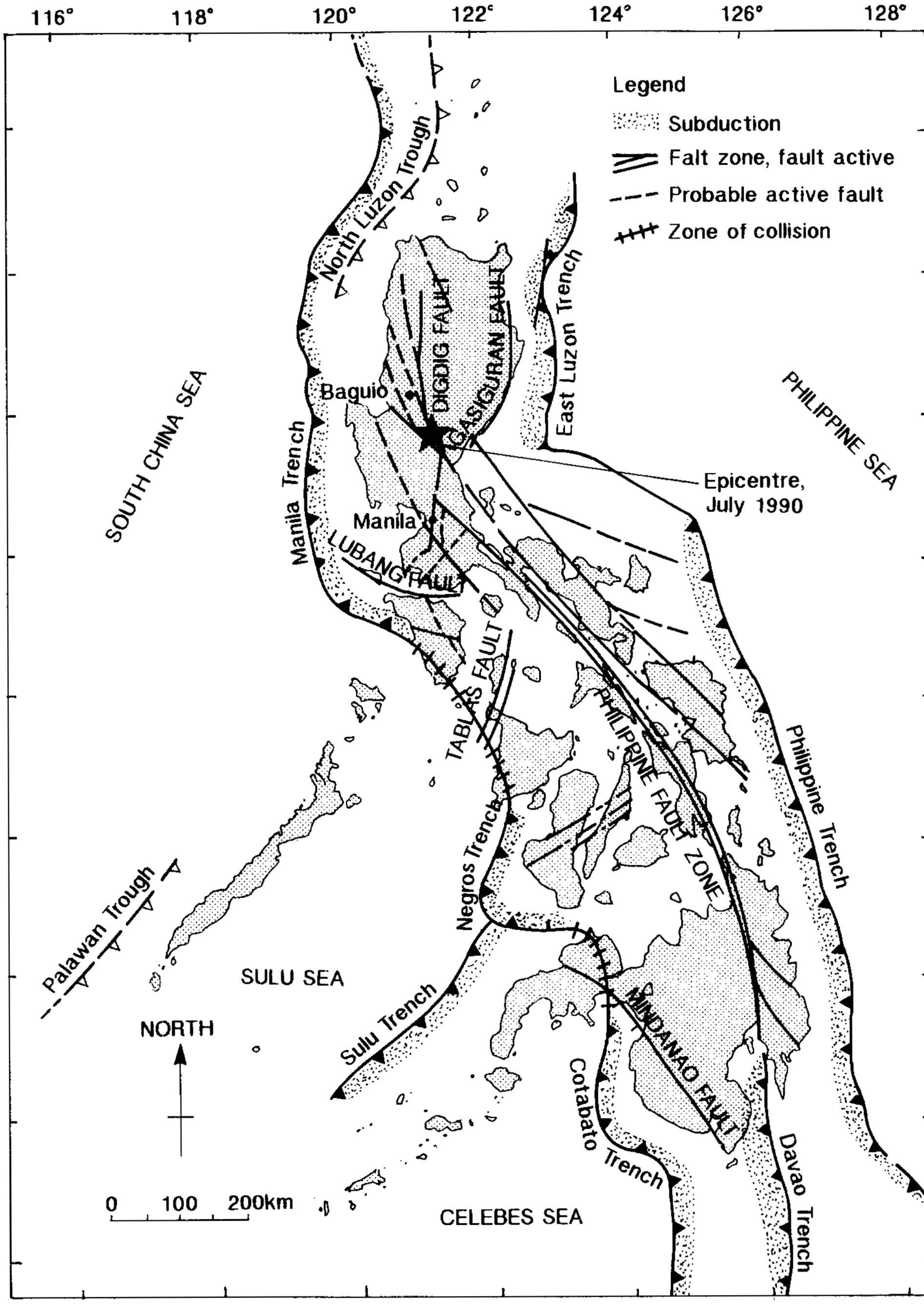
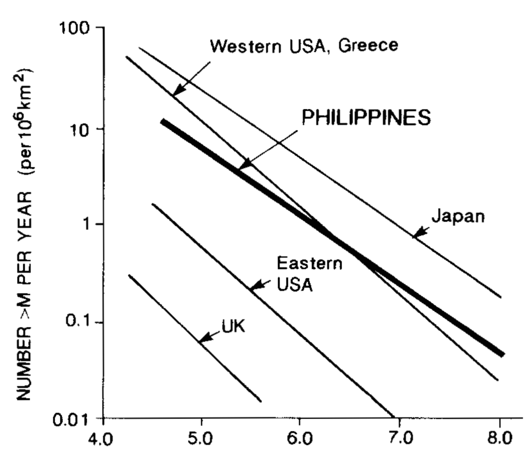


Figure 4.4 Distribution of potential earthquake generating faults in the Philippines (from Philvocs, 2)

Figure 4.5 Earthquake recurrence in the Philippines, compared with other areas (from Booth et al, 25)



4.2 Earthquake of 16 July 1990

4.2.1 Instrumental data

The earthquake occurred at 16:26 local time (07:26 UTC time) on Monday 16th July 1990. Its epicentre was on the Philippines fault, east of Cabanatuan (Figure 4.6), at a depth of 25km. The US Geological Survey (USGS) has given a preliminary magnitude of M_{sz} = 7.8. USGS gives the seismic moment as 8.0 x 10^{20} N-m, corresponding to a moment magnitude of 7.9. The focal mechanism is moderately well controlled and corresponds to strike-slip faulting with a moderate reverse component. Of the two fault plane solutions, the preferred one is a fairly steeply dipping nodal plane striking 167° east of north, corresponding to the evidence of the surface fault break. The location of the centroid moment tensor solution from Harvard, USA is also shown on Figure 4.6. This provides an estimate of the centre of energy release of the event.

Some sources (3) have reported that the main event to the south was followed about 2 minutes later by a second event at the northern end of the fault break, some 30km to the east of Baguio, although it appears that there is no definitive instrumental evidence for this. An earthquake of this size over such a long fault break would be expected to rupture at a number of distinct points.

4.2.2 Surface faulting

A north west trending surface fault break at least 100km long was recorded; at the time of writing, its northern extent had not been mapped. Left lateral movements of up to 6m combined with vertical movements of up to 1m, upthrow being on the east side, were recorded at the surface. These would be expected to correspond to much larger sub-surface displacements. The length and size of movement of the surface fault break are particularly notable.

The fault that moved during the earthquake is expressed very clearly in the surface geology and topography, and therefore would be expected to have moved many times in geological history. The tectonic setting supports this. It can be seen from Figure 4.3 that the most recent earthquake with $M>6.5$ along this region of the fault occurred at least 50 years ago. A major earthquake occurring where it did was therefore no surprise.

4.2.3 Aftershocks

A series of aftershocks was recorded, as shown in Figure 4.6 and listed in Table 4.1 based on USGS data. The largest was magnitude 6. This is quite usual for an earthquake of this size.

4.2.4 Strong motion record

As far as is known, no strong motion instruments were triggered by the main earthquake. A number of instruments were brought into the area about a week later, but the EEFIT team did not have access to data from these at the time of writing.

4.2.5 Tsunami

There were no reports of any significant tsunami.

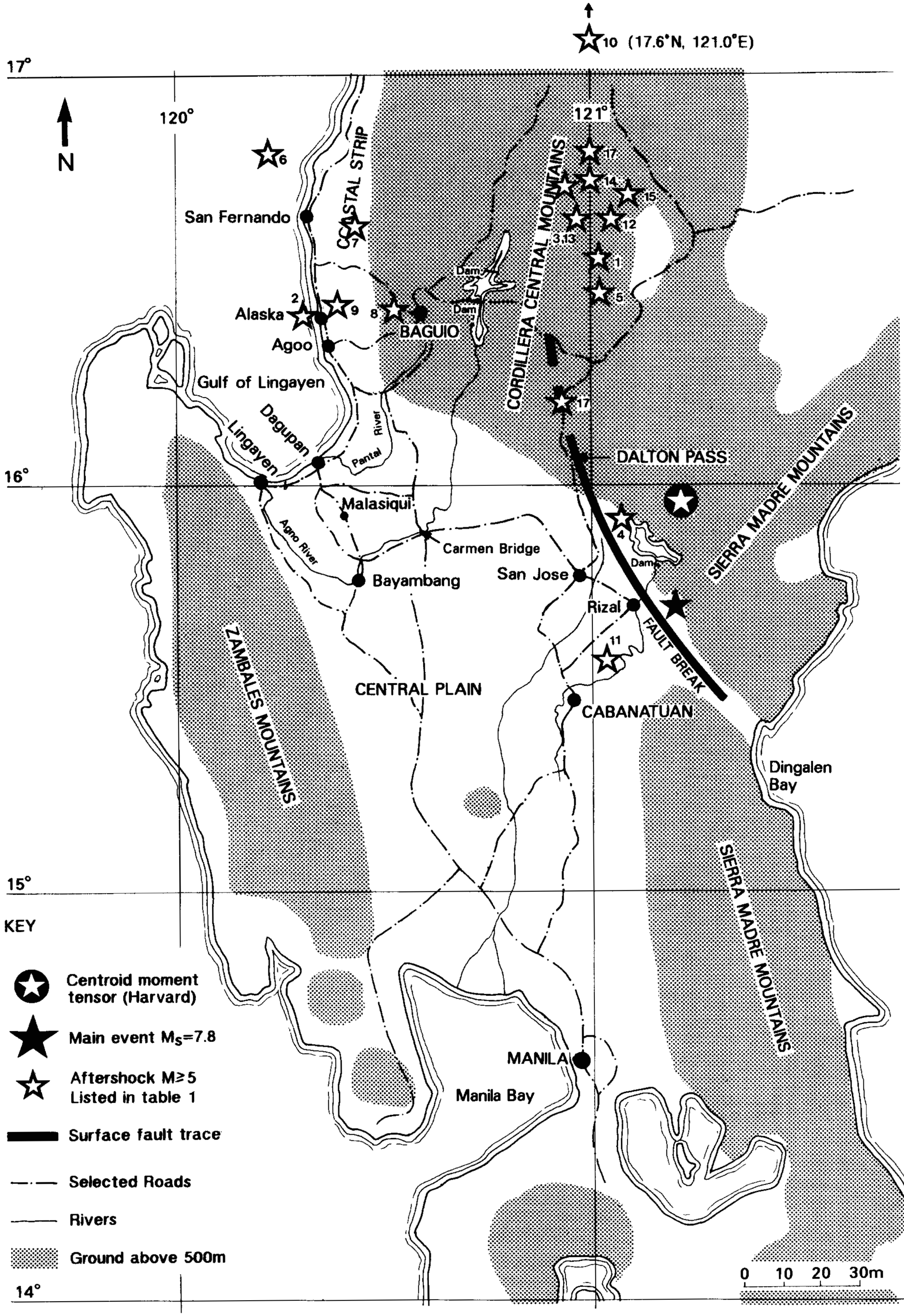


Figure 4.6 Detailed location of July 1990 earthquake, fault break and aftershocks (from USGS data)

Aftershock No. (see Fig 4.6)	Magnitude M_b	Time after main event		
1	5.1		1hr	24mins
2	5.8		2hrs	03mins
3	5.1		2hrs	58mins
4	5.5		5hrs	36mins
5	5.6		6hrs	05mins
6	5.5		7hrs	38mins
7	5.5		8hrs	53mins
8	5.1		12hrs	19mins
9	5.2		12hrs	50mins
10	5.3		13hrs	05mins
11	5.8	1day	10hrs	40mins
12	6.0	1day	13hrs	48mins
13	5.0	1day	15hrs	20mins
14	5.0	1day	18hrs	09mins
15	5.3	1day	18hrs	30mins
16	6.0	2days	0hr	34mins
17	5.5	2days	?hrs	?hrs
Main event: M_s = 7.8 at 16hrs 26mins 35.5secs local time, (07:26 UTC) on 16 July 1990				

TABLE 4.1

Aftershocks ≥ M=5 occurring
within 2½ days of the Main Event
(based on USGS data)

5.0 STRUCTURAL EFFECTS OF STRONG GROUND MOTION

5.1 Baguio

5.1.1 Introduction

Baguio is situated about 270 km north of Manila in the Cordillera Central mountains (Figure 3.2). It is a major mining area, with several gold and copper mines in current operation and is also a centre for light industry. Baguio is a popular vacation resort, primarily because of its setting and altitude, being over 1500m above sea level. The city has a permanent population of about 200,000, supplemented by a large transient student and tourist population.

Figure 5.1 shows a general view of Baguio, which is surrounded by very hilly terrain. Figure 5.2 shows the street plan of the central part of the city, and Figure 5.3 gives a map of the major roads in the approaches to the city. Plotted onto Figures 5.2 and 5.3 are the locations of the photographs taken in Baguio City and surrounding areas which are referred to in this report.

The city was cut off by landslides from the rest of Luzon for three days following the earthquake (see Section 7.1), which severely hampered the rescue and relief operations in the immediate aftermath of the disaster. As a result of the prominent role which Baguio plays in the tourist economy of the Philippines, together with the fact that most of the better hotels were severely damaged in the earthquake, the Philippines government has estimated that there will be a 15 to 20 per cent drop in tourist revenue for the country in 1991. Before the earthquake, the city of Baguio hosted 90,000 tourists on an average day, and 120,000 a day during the peak season.

Baguio is thought to be at least 30 km from the main fault break although the location of the northern part of the fault is not precisely known. Also Baguio may have been closer to the source of aftershocks (Figure 4.6), which were strongly felt and were significant contributors to the widespread structural damage in the city.

Figure 5.1

Aerial view of Baguio showing topography

5.1.2 Summary of Structural Damage

The earthquake of 16 July 1990 caused severe structural damage to at least 20 modern engineered buildings in Baguio, and resulted in the collapse of a number of reinforced concrete buildings of 4 to 10 storeys in height built within the last 20 years. The collapsed buildings, which were mainly hotel and educational establishments, were founded on weathered rock, often on steep slopes. The percentage of affected buildings of under 4 storeys in height was much lower.

The results of an indicative but non-comprehensive survey carried out by EEFIT is shown in Table 5.1 and illustrates the relatively high proportion of damage in buildings of four storeys or more. It is based on a fairly cursory external inspection in the central part of Baguio. In the survey area, the percentage of low buildings with damage other than minor appeared to be less than 5% compared with the 40% shown for taller buildings in Table 5.1.

Level of Damage	Minor or not Observable	Major Damage	Partial or Total Collapse
Number of Buildings	26 (60%)	10 (25%)	6 (15%)

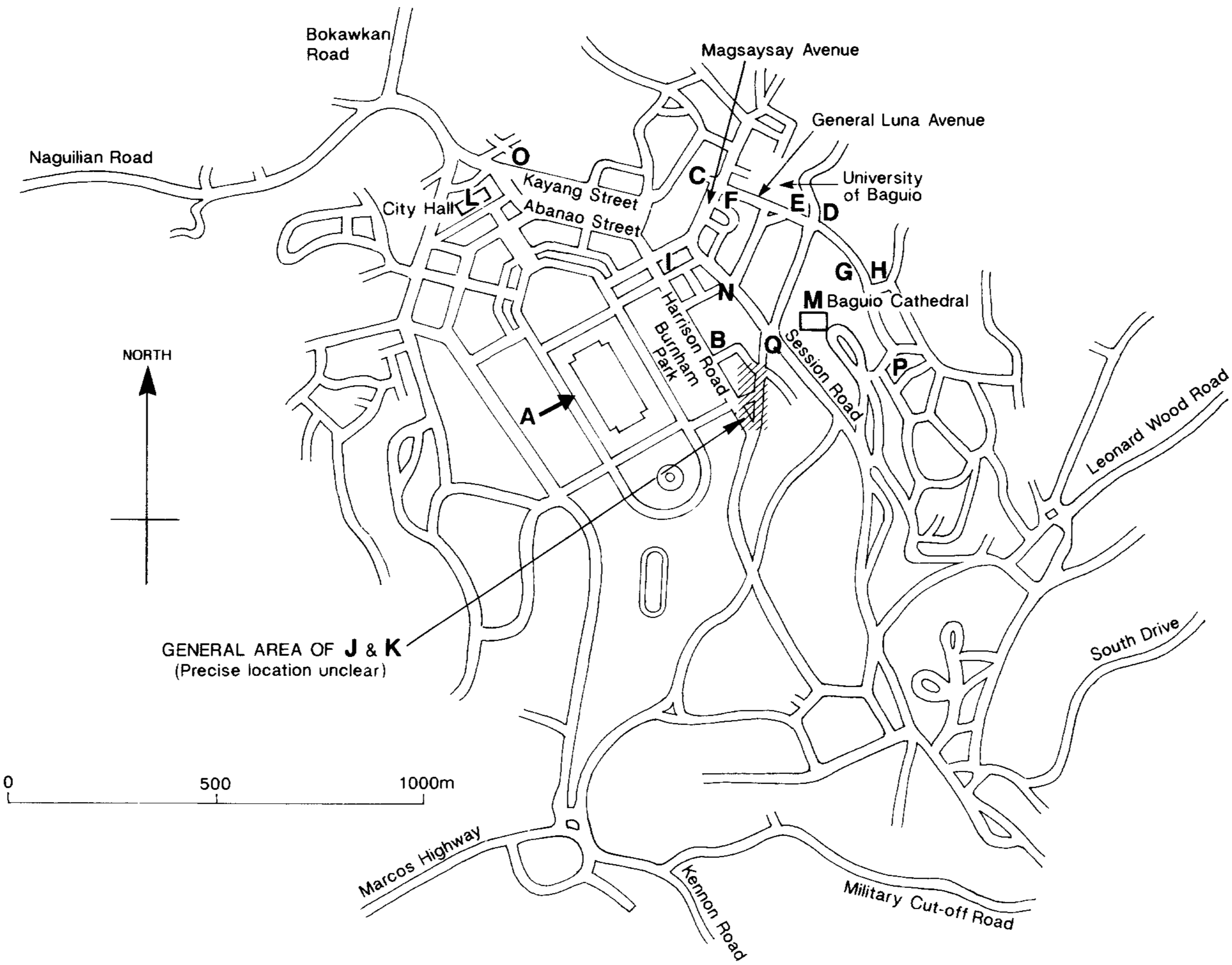
TABLE 5.1

Rough survey of damage in buildings of 4 storeys or more in Central Baguio

Throughout Baguio and the other centres visited, the vast majority of engineered structures consisted of reinforced concrete moment-resisting frames, usually with blockwork infill. Newer structures occasionally included concrete shear walls. Steel frame buildings were not encountered in Baguio and are rarely found elsewhere in the Philippines.

5.1.3 Design Regulations

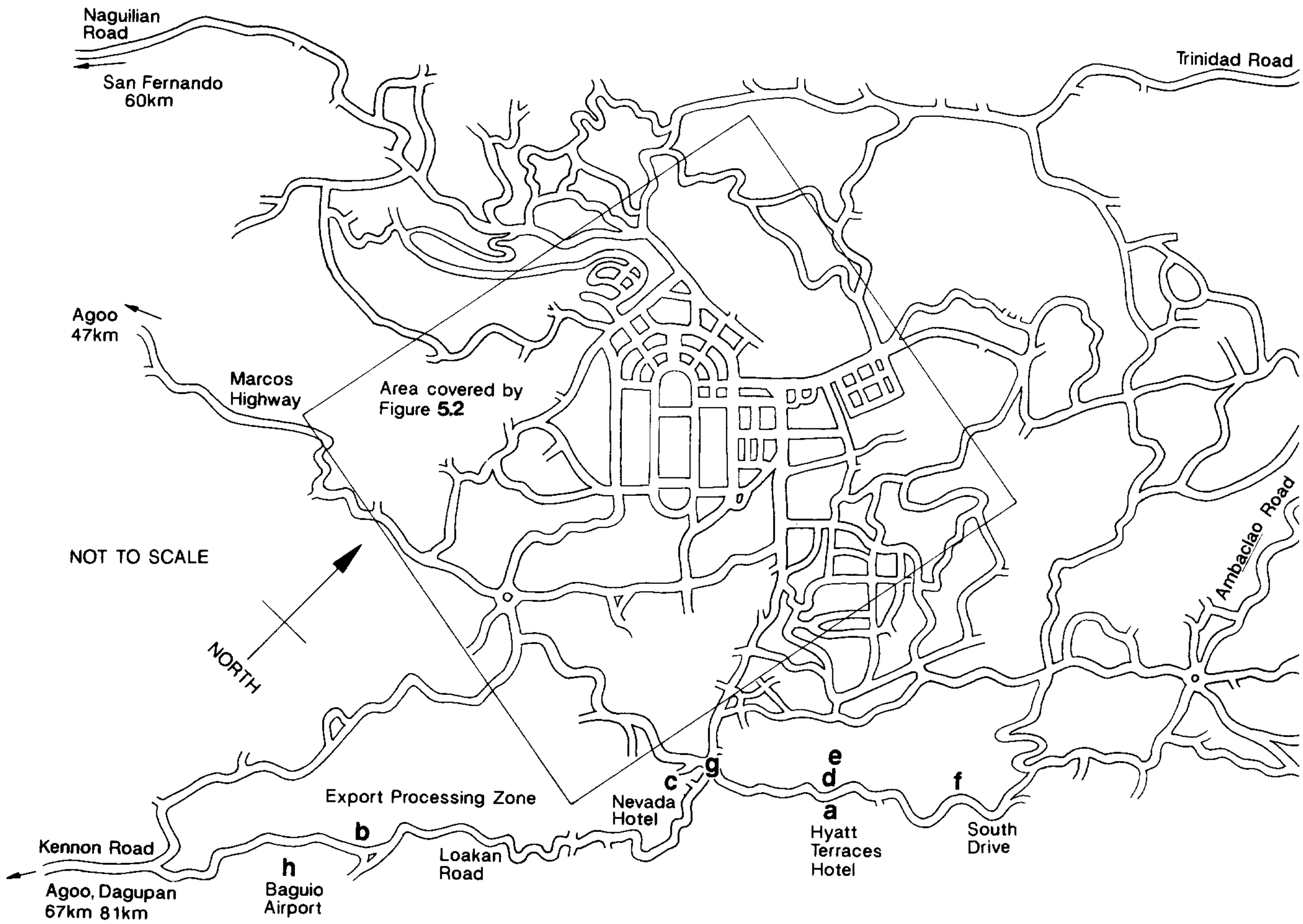
As discussed in Section 12, building regulations in the Philippines are based on US practice including the UBC (4). The evidence gathered by EEFIT, and reported below, suggests that the earthquake resistant design of many of the worst affected buildings in Baguio and elsewhere in the region of earthquake damage did not conform to current US requirements. However, practice in earthquake resistant design has developed rapidly in the last 20 years, and this does not necessarily imply that the damaged buildings did not comply with regulations and practice current at the time of design and construction.



Key to building locations

Fig 5.1	A	Fig 5.32	I
Fig 5.16 - 5.17	B	Fig 5.33	J
Fig 5.18	C	Fig 5.34	K
Fig 5.21 - 5.22	D	Fig 5.35	L
Fig 5.24 - 5.25	E	Fig 5.36	M
Fig 5.28	F	Fig 5.39	N
Fig 5.29	G	Fig 5.40	O
Fig 5.30 - 5.31	H	Fig 5.41 - 5.42	P
		Fig 5.47	Q

Figure 5.2 Street plan of central Baguio



Key to building locations

Fig 5.4 - 5.15	a
Fig 5.19 - 5.20	b
Fig 5.23	c
Fig 5.26 - 5.27	b
Fig 5.37	d
Fig 5.38	e
Fig 5.43	f
Fig 5.44	g
Fig 5.46	a
Fig 7.2	h

Figure 5.3 Outskirts of Baguio

5.1.4 The Hyatt Terraces Hotel

A notable failure in Baguio was that of the Hyatt Terraces Hotel and Aparthotel, which overlooks the centre of the city from near the ridge of a hill to the east. This failure caused a large number of fatalities. Figure 5.4 shows a sketch plan and section (not based on engineering drawings) and Figures 5.5 and 5.6 show aerial views of the Aparthotel and C-shaped main Hotel.

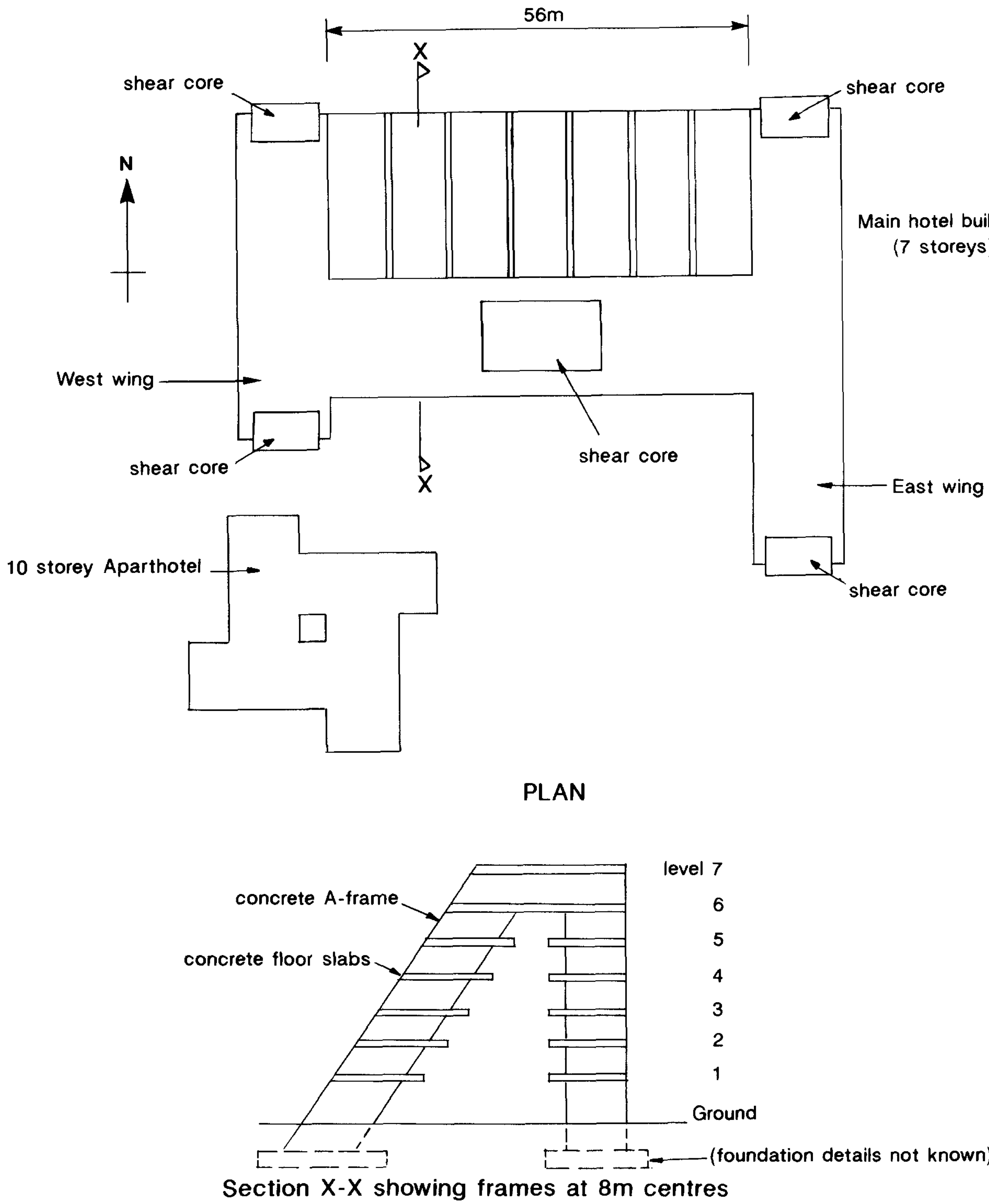


Figure 5.4 Sketch (not to scale) of Hyatt Terraces Hotel, Baguio

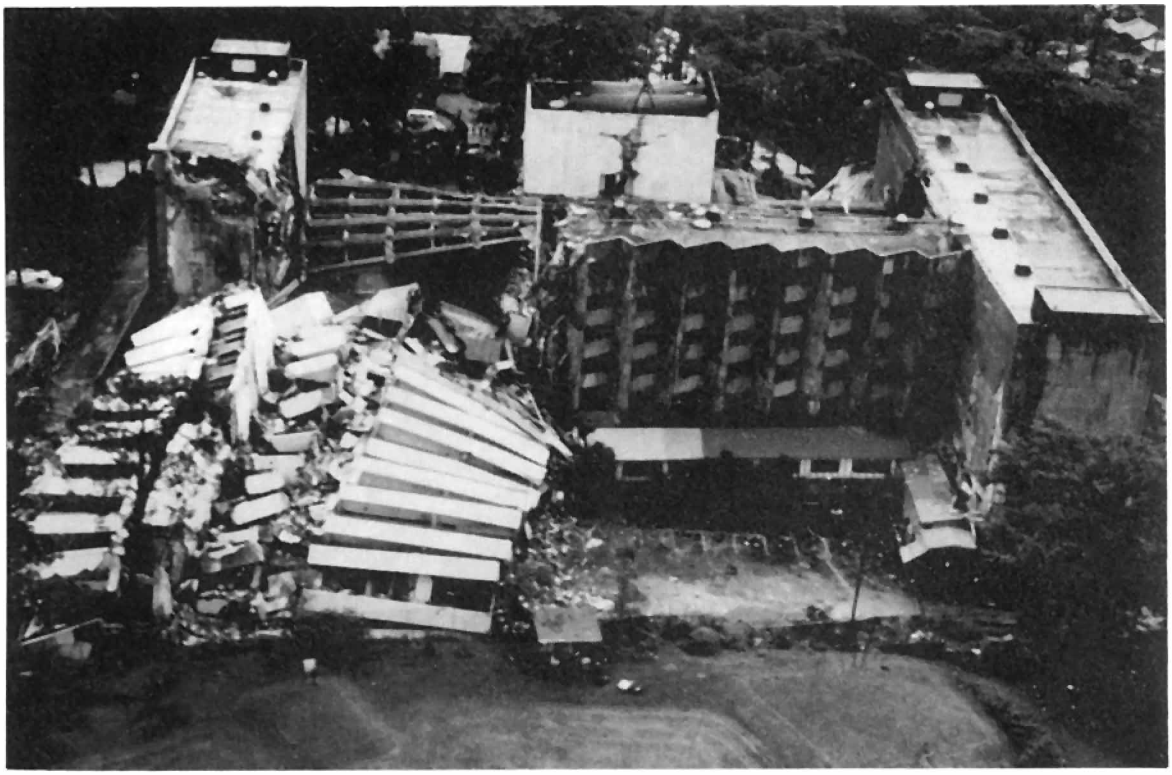


Figure 5.5 Hyatt Terraces Hotel from the air, looking north

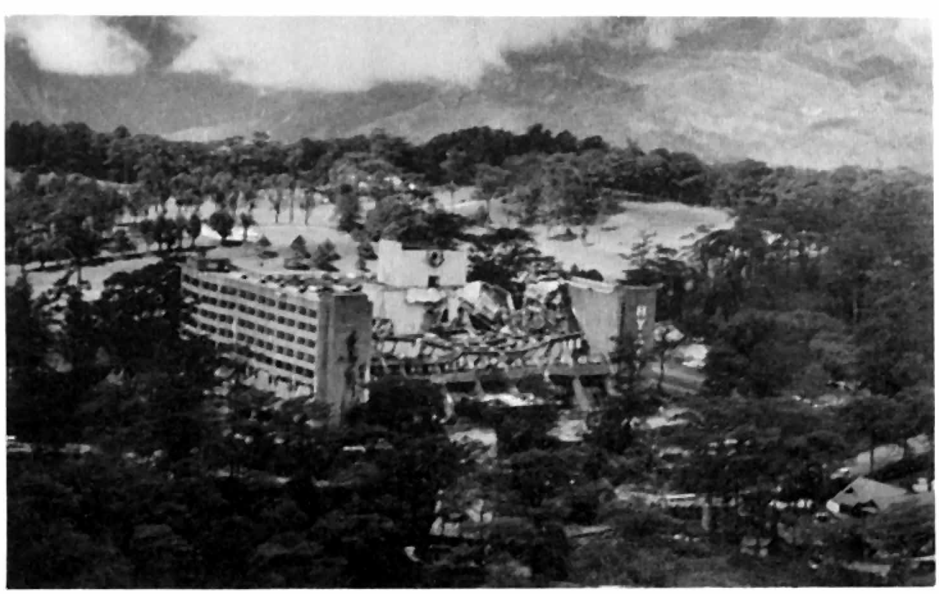


Figure 5.6 Hyatt Terraces Hotel from the air, looking south

Figure 5.7

Hyatt Terraces Hotel, Baguio: Aparthotel

Figure 5.8

Miners digging for bodies in Aparthotel

Figure 5.9

Hyatt Terraces Hotel, Baguio: shear wall details in Aparthotel

a) Hyatt Terraces Aparthotel

The Aparthotel (Figure 5.7) is understood to have collapsed in the first shock to be felt in Baguio, falling onto the western side of the main Hotel. It is understood that the Aparthotel consisted of 4 rectangular blocks connected in plan and grouped around a core (Figure 5.4). The date of construction of the Aparthotel is not known; it is thought to have been built after the main hotel, which dates from 1975.

The close-up in Figure 5.8 shows local volunteer miners digging for bodies, more than two weeks after the earthquake. A man trapped in the collapsed building for 17 days after the earthquake was rescued alive on 2nd August, the day before EEFIT visited Baguio City. Figure 5.9 shows the Aparthotel from the south, with a failed shear wall. Failure in the columns on the side closest to the main hotel possibly initiated the collapse, but the exact cause of failure was uncertain. In Figure 5.9 reinforcement details in the Aparthotel can be seen. The concrete was apparently reasonable, with 40-50mm pebble aggregate. The main reinforcement consisted of 32mm deformed bars, some of which were rusty. There were 10mm diameter links (transverse reinforcement) at approximately 250mm centres, which had apparently failed to give sufficient confinement to prevent buckling of the longitudinal bars.

b) Hyatt Terraces Main Hotel

The outline form of the main Hotel can be seen in Figure 5.4, though exact details are not known. The central portion consisted of 6 concrete shear walls in the form of large A frames, creating a central atrium. A concrete access core was located in the middle of this central section and did not collapse; it can be seen projecting in Figures 5.5 and 5.6. The central portion was flanked at each end by wings, apparently with shear walls at their southern and northern ends and infill blockwork frames in between. The Hotel is understood to have been built in 1975.

A shock occurring between 30 minutes and 2 hours (accounts differ) after the event causing the collapse of the Aparthotel, is understood to have triggered the main collapse of the Hotel which was in the sloping front. Referring to Table 4.1 and Figure 4.6, this may have been aftershock no 2 of magnitude 5.8, which is recorded as occurring close to Baguio 2 hours 03 minutes after the main event. The accuracy of location, however, may not be reliable.

The collapse was probably initiated by weakening of the reinforced concrete A-frames due to collapse of the Aparthotel onto the rear of the main building. Failure of the A-frames occurred generally along construction joints on the sloping legs (Figure 5.10), where there was little vertical (tension) or confining (horizontal) reinforcement. The entire upper portion of the sloping, front face of the hotel collapsed. The upper portion of the vertical, rear face collapsed where it was impacted by the Aparthotel.

Figure 5.10 Failure of A-frame along construction joint, main hotel

The west face of the east wing of the Hotel is shown in Figure 5.11. The damage in this part of the building was less severe than elsewhere, but there was compression buckling failure of the columns at second floor level on both sides of the building (Figures 5.12 and 5.13). This appears to have been as a result of the external infill walls above level 2 acting as a shear wall and concentrating ductility demand in the short columns at ground floor level (Figures 5.13 and 5.14). Reinforced concrete shear walls in both the east and west wings of the main hotel building were apparently provided to resist forces in the east-west direction. Figure 5.11 shows the end wall in the east wing. These walls appeared to be without damage, but were rare examples of this form of construction in Baguio City.

The side wall of the west wing, shown in Figure 5.15 had considerable damage to inadequately reinforced masonry infill, particularly at the second storey level. The major structural damage in the west wing wall resulted from impact of the aparthotel.

c) Previous damage to the Hotel

It is understood that the Hotel suffered damage in 1985 after the M= 6.1 earthquake which was located near Baguio (Figure 4.3). This caused cracking in the concrete floors and some non-structural damage. Settlement damage was also noted. The hotel was closed for 7 months for repairs and subsequently reopened, following a satisfactory structural inspection report.

Figure 5.11

West face of East Wing,
Hyatt Terraces Main Hotel

Figure 5.12

Compression failure in columns
(detail of Figure 5.11)

Figure 5.13

Failure of short columns
East side of East Wing,
Hyatt Terraces
Main Hotel

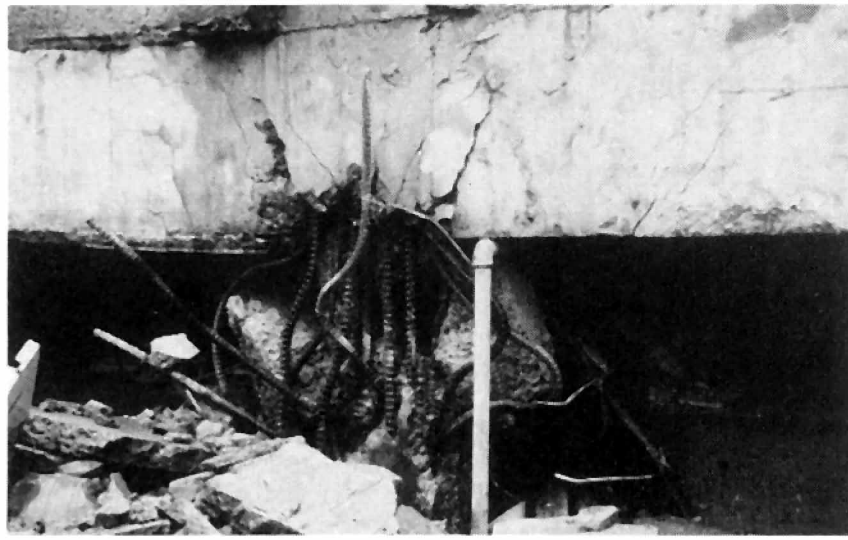
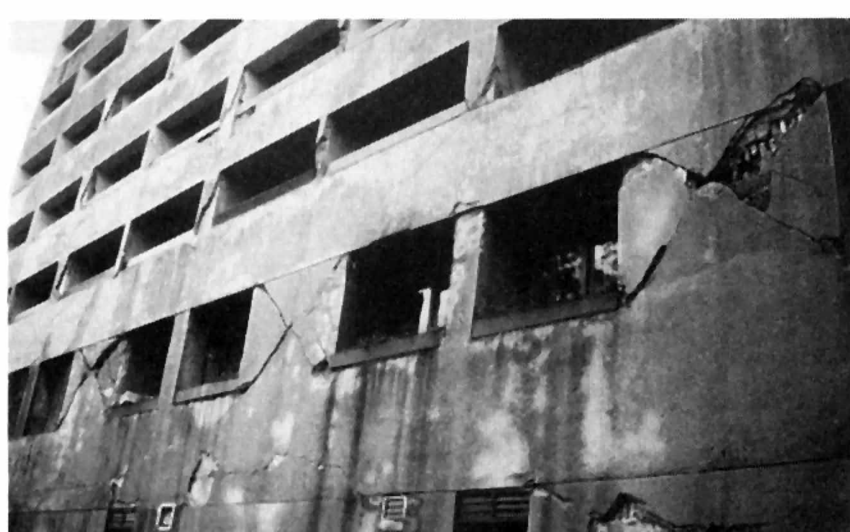


Figure 5.14

Car park under East
Wing, Hyatt Terraces
Main Hotel

Figure 5.15

Side wall of West Wing
Hyatt Terraces
Main Hotel



5.1.5 Reinforced Concrete Frame Buildings

Several other modern reinforced concrete frame buildings in Baguio City suffered total or partial collapse, as described in Sections 5.1.5(a) and (b). Other forms of structural damage not leading to collapse are described in Section 5.1.5 (c).

a) Total Collapse

The Baguio Park Hotel (Figure 5.16) was a seven-storey reinforced concrete frame building, where only part of the first storey had survived, the rest having collapsed. Neighbouring buildings of up to five storeys were very close but suffered no apparent damage, apart from local impact damage to the building on the northwestern side (Figure 5.17).

Figure 5.16

Baguio Park Hotel

Figure 5.17

Impact damage caused by collapse of Baguio Park Hotel

The Hilltop Hotel (Figure 5.18) was another example of a modern reinforced concrete frame building which suffered total "pancake" collapse. This nine-storey hotel in central Baguio close to the Market was condemned and abandoned following significant damage in a previous earthquake in 1985, but not subsequently demolished. The building was apparently built originally with only six or seven storeys and was subsequently extended.

The Baguio Export Processing Zone is an industrial park near the airport (Figure 5.19), which includes warehouses and light manufacturing operations. Within the export zone, five large, concrete frame buildings collapsed, reportedly trapping several hundred workers. One collapsed building, the 3-storey reinforced concrete Arax factory contained plastic resin, which caught fire on the day following the earthquake (to the right in Figure 5.19). This building suffered a pancake collapse at the time of the earthquake (Figure 5.20).

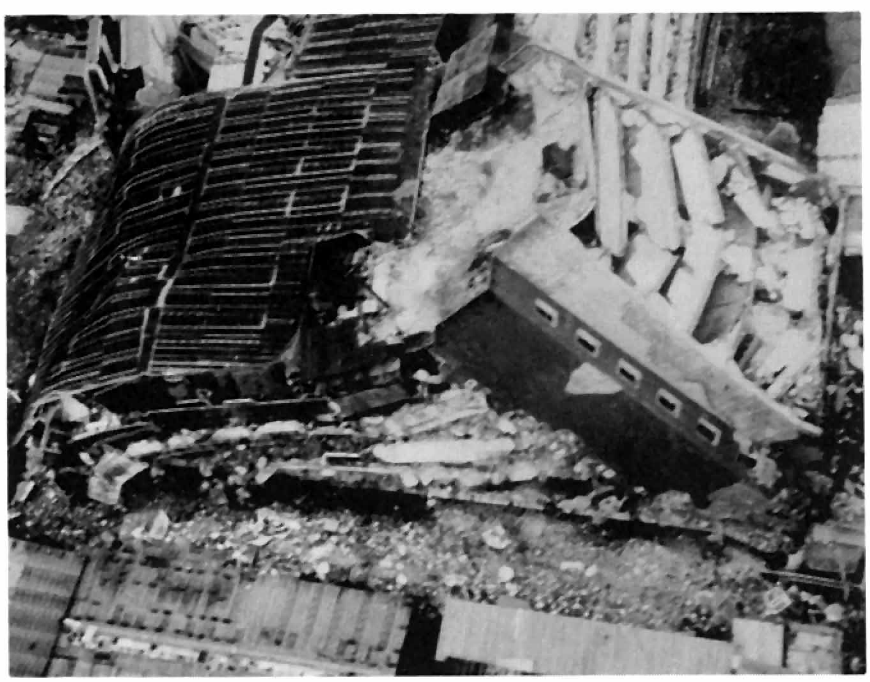


Figure 5.18 Aerial view of Hilltop Hotel,Baguio

Figure 5.19 Aerial view of Baguio Export Processing Zone

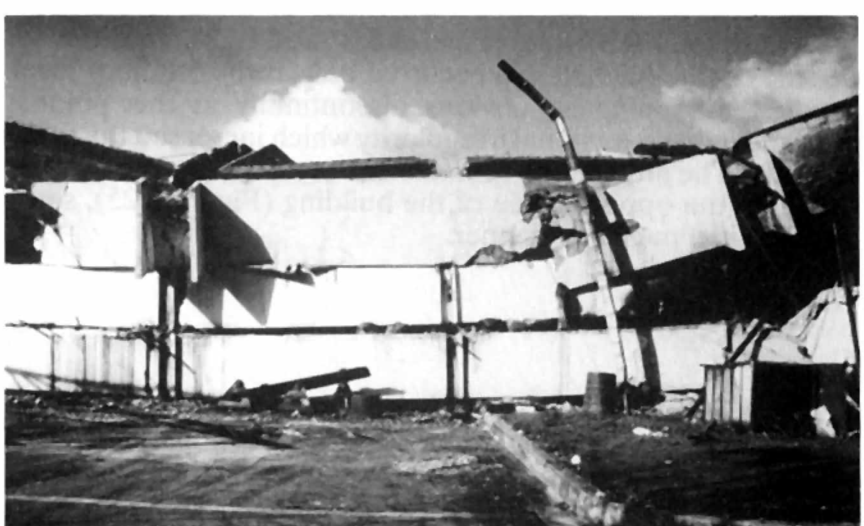


Figure 5.20 Baguio Export Processing Zone: Arax factory

b) Soft Storey Failures

Several cases were observed in Baguio where soft (weak) storeys had failed, causing the storeys above (which in many cases had remained substantially intact) to sit down on the collapsed structure. The failure commonly occurred in the lowest storey (Figure 5.23, for example), which in many buildings had facades which were weak in shear due to functional requirements such as shops, stores, lobbies or garages. The lowest storey is also commonly taller than the upper floors and frequently the infill walls and parapet upstands on upper floors concentrate the ductility demand at the lowest level. Combining these factors with the fact that generally the greatest seismic loadings are generated at the lower levels of a building, means that such buildings are very vulnerable to earthquake damage. The damage caused to such buildings in Baguio was also accentuated by a lack of adequate ductile detailing.

Three examples of soft storey collapses are illustrated in Figures 5.21 to 5.25. The FRB Hotel (Figure 5.21) is a reinforced concrete structure where the lower two storeys (rectangular in plan) had collapsed due to weak columns in the lower storeys (Figure 5.22). The collapsed lower floors supported an additional four-storey cylindrical tower structure which was apparently undamaged.

The Nevada Hotel suffered partial collapse. In this case also it was the lowest storey which had failed (Figure 5.23). The front of the Hotel is a newer, 5-storey building which separated from the older, 7-storey section to the rear and collapsed onto the garage and lobby area of the ground floor. This failure triggered a partial collapse of the lightweight corrugated iron roof in the rear structure.

A smaller reinforced concrete frame building adjacent to the Nevada Hotel also suffered a soft storey collapse at first floor level. Failure in this case was initiated due to the inability of the column tops to sustain the plastic rotations imposed by the large lateral deflections.

A notable example of soft-storey collapse in a multi-storey reinforced concrete frame structure is shown in Figures 5.24 and 5.25, taken from opposite sides of the building. This is a nine-storey reinforced concrete frame building with block infill, built around 1980, and forms part of the University of Baguio. It is adjacent to the FRB Hotel (Figures 5.21 and 5.22). In this case, the failure on one side of the building had occurred only at the 5th floor level (Figure 5.24), despite there being no obvious discontinuity at this point. The building appeared to have torsional irregularity which increased the forces on the frame elements. The infill panels remained intact above and below the failure (Figure 5.24). On the opposite side of the building (Figure 5.25), several storeys had collapsed in a pancake manner.

Figure 5.21

FRB Hotel, Baguio from General Luna Avenue

Figure 5.22

FRB Hotel, Baguio showing soft storey collapse

Figure 5.23

Nevada Hotel, Baguio

Figure 5.24 University of Baguio from south showing 5th floor collapse

Figure 5.25 University of Baguio from north

c) Other Recorded Damage

A building opposite to the Arax factory in the Baguio Export Processing Zone (to the left in Figure 5.19), which was the same height and of similar construction, suffered column failure where the infill blockwork stopped short of the beam soffit (Figure 5.26). The confining steel (Figure 5.27) apparently prevented a catastrophic collapse, though the building was said to be propped inside. Another notable feature of these two buildings is that the collapsed Arax factory was built on filled ground created when the natural slope was levelled, whereas the second building, which did not collapse, was built on the cut side.

Figure 5.26

Column failure in building opposite Arax factory, Baguio

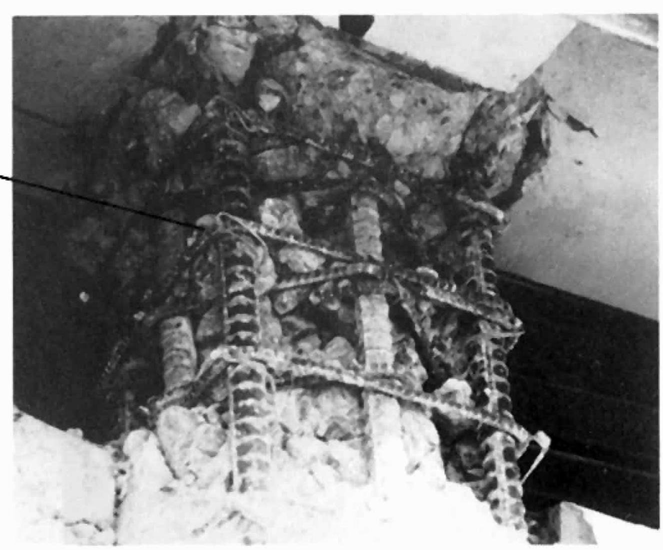


Figure 5.27

Detail of Fig 5.26

A commercial reinforced concrete building in the centre of Baguio showed severe cracking in a corner column (Figure 5.28). Further south up General Luna Avenue, the 5-storey St. Louis University Elementary High School (Figure 5.29) had some cracked glass and infill masonry.

A 5-storey reinforced concrete frame building on a narrow corner site (Figure 5.30) was highly irregular both in plan and vertical form, having a deep cantilever at second floor level. This building had suffered severe cracking in a corner column (Figure 5.31).

A building under construction in the centre of Baguio (Figure 5.32) showed no sign of damage in the prestressed, post-tensioned concrete cantilever beams projecting about 2 m at the first floor level, but there was severe cracking in the beams at the second floor level.

There were several other examples in Baguio City of taller, modern reinforced concrete frame buildings which showed external signs of moderate to severe damage. Figures 5.33 and 5.34 show two typical examples, though neither was inspected internally by EEFIT.

Figure 5.28

Corner building
in Baguio

Figure 5.29

St Louis University
Elementary High School, Baguio

Figure 5.30

Building with
cantilevered front, Baguio

Figure 5.31

Detail of Figure 5.30

Figure 5.32 First floor of building with prestressed beams, Baguio

Figure 5.33 Damage to multistorey r.c. building, Baguio

Figure 5.34 Damage to triangular multistorey r.c. building, Baguio

5.1.6 Masonry Buildings

Baguio City Hall, which is an imposing 2-3 storey masonry building on the top of a hill (Figure 5.35) showed no sign of damage, and was operating normally two weeks after the earthquake.

Minor non-structural damage was observed in Baguio Cathedral (Figure 5.36). This massive masonry building showed some cracking in the decorative parapets, but otherwise survived the earthquake undamaged.

Low rise non-engineered masonry buildings generally appeared to have survived with only minor cracking and the only failures noted were associated with landslips (section 5.1.9). There were no signs of piles of debris from, for example, collapsed ceilings which are often seen in earthquake stricken zones.

Figure 5.35

City Hall, Baguio

Figure 5.36

Baguio Cathedral

5.1.7 Steel Frame and Timber Frame Buildings

There were very few steel framed buildings in the affected region, and none were identified in Baguio City.

A timber framed building immediately below the Hyatt Terraces Hotel (Figure 5.37) was occupied and suffered only minor damage. However, another timber building just below this, with one side supported on the steep slope and the other by timber columns (Figure 5.38) showed severe damage to these base support columns. The building was considered unsafe for occupation.

Figure 5.37

Timber framed building below Hyatt Terraces Hotel, Baguio

Figure 5.38

Unstable timber framed building below Hyatt Terraces Hotel, Baguio

Severe damage to supporting columns

5.1.8 Non-StructuralDamage

Tiles had been dislodged from the roof of a shopping centre (Figure 5.39), but there was apparently little other damage.

The roof mounted tank at Baguio police station had failed, but there were no other signs of damage. Interestingly, the long cantilevered entrance canopy (Figure 5.40) survived intact, and there was also no observable damage to the fire station situated in Kayang Street opposite the police station. 1 and 2-storey commercial buildings on the same street also appeared undamaged.

The Church of Jesus Christ of the Latter Day Saints (Figure 5.41) is a solid 2-storey reinforced concrete building built in 1987. There was no structural damage, but minor superficial damage was observed in the cladding and suspended light fittings at one end of the structure (Figure 5.42).

A number of houses near the Hyatt Terraces Hotel with tall chimney stacks showed minor cracking or partial collapse (Figure 5.43).

Bronze sculptures were also toppled from their mountings (Figure 5.44).

Figure 5.39 Roof of shopping centre, Baguio showing dislodged tiles

Figure 5.40

Baguio Police Station: cantilevered entrance canopy

Figure 5.41

Church of Jesus Christ of the Latter Day Saints, Baguio

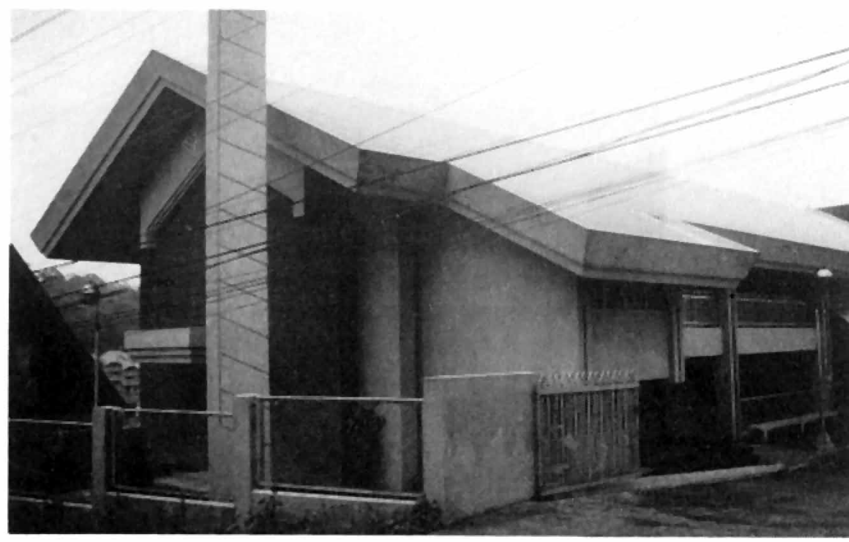


Figure 5.42

Interior of 5.41, showing minor internal damage

Figure 5.43 Partial collapse of chimney stack in house, Baguio

Figure 5.44 Toppled bronze sculptures near Nevada Hotel,Baguio

5.1.9 Influence of Soil Conditions and Slope Failures

Another possible contributor to the poor performance of buildings in Baguio were the slope failures observed throughout the hilly terrain of Baguio (where in many cases the slopes had been levelled by cut-and-fill). This was the case for the ground around the Nevada Hotel, (Figure 5.45), where differential settlements of several centimetres, observed near to a retaining wall, may have contributed to the ground floor collapse. This did not however appear to be the primary cause of collapse.

Slopes weakened by heavy rainfalls immediately prior to the earthquake had also failed, such as those shown in Figures 5.46 and 5.47, photographed adjacent to the Hyatt Terraces Hotel and Baguio Cathedral, respectively. Other apparently vulnerable slopes, such as that in Kayang Street (Figure 5.2), remained intact during the earthquake.

The results of the damage survey carried out in Baguio by the EEFIT team strongly suggest that the building damage was in almost every case caused to the superstructure as a direct result of ground shaking, and was not associated with ground failures, unlike the cases of liquefaction-induced failure observed in Dagupan and elsewhere (see Section 6).

Figure 5.45 Ground settlement near Nevada Hotel, Baguio

Figure 5.46 Failed slope near Hyatt Terraces Hotel, Baguio

Figure 5.47 Failed slope near Baguio Cathedral

5.2 Agoo

Agoo lies on the main highway running along the western coastal strip of northern Luzon (Figure 3.2). It is situated on flat ground about 2 km inland. A minor river runs along the northern boundary of the town.

The town has an estimated 20,000 inhabitants. Most of the buildings are one or two storeys. The only tall structure, which had some damage but was still standing, was the cathedral, a building at least 50 years old and possibly much older.

There was extensive damage to the low rise buildings and it appeared that a much greater percentage had been seriously damaged than was the case for low rise buildings in Baguio. The buildings affected included simple concrete structures of poor quality, masonry buildings, and single storey steel frame classrooms with masonry infill walls (Figures 5.48 to 5.50). The cathedral referred to above had suffered some damage and another church building opposite had collapsed. There were a number of bus shelters, with a lightly anchored surface pad foundation, all of which had toppled over (Figure 5.51). It should be borne in mind that these shelters will have survived severe, possibly typhoon winds and so their lateral strength, although low, was certainly not negligible.

There were no signs of liquefaction or foundation failure in the town, although extensive signs of liquefaction were seen within a few kilometres. The bridge over the river just to the north of the town appeared undamaged although, as reported in section 6.2, the EEFIT team examined a bridge a few kilometres to the north which was affected by large settlements probably associated with liquefaction.

Figure 5.48 Don Marcos Center, Agoo: damage to steel frame classroom

Figure 5.49

Agoo town centre:
2 storey r.c.
soft storey building

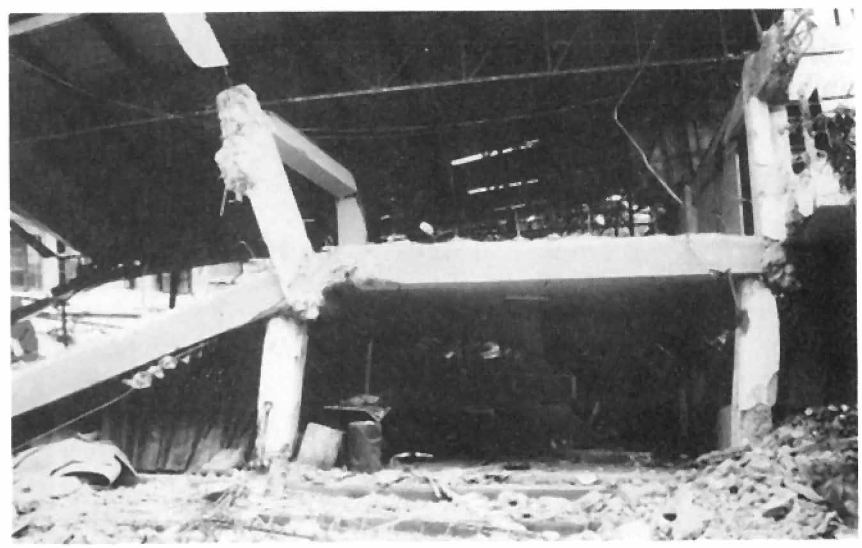


Figure 5.50

Agoo town centre:
collapse of 2 storey
r.c. frame building

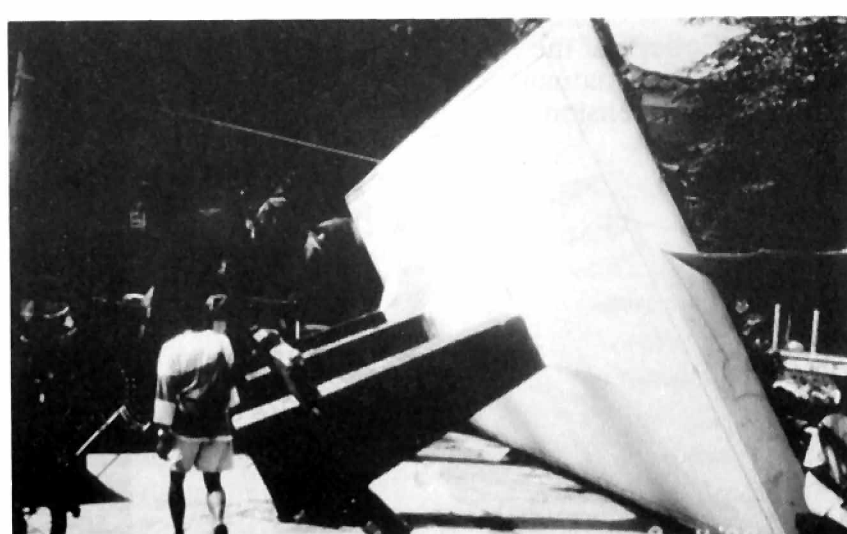


Figure 5.51

Agoo: bus shelter

5.3 Structural Damage in Cabanatuan

Cabanatuan is a sizeable town of around 80,000 inhabitants on a very flat area in the central plain (Figure 3.2). The major buildings appear of reasonable standard and are mainly three storeys high or less. The main buildings are single or two storey houses, shops or workshops of reasonable quality, mainly in masonry.

There was one catastrophic collapse in the town of a 6 storey reinforced concrete frame building. This was part of the Christian College of the Philippines. It is reported that the upper storeys were added after the original construction. When the EEFIT team examined the building, it had been partially demolished as part of the search and rescue operation (Figure 5.52). Surrounding concrete frame buildings of similar height which formed part of the College appeared completely undamaged. They also had provision made for extension (Figure 5.53). The library building of the Central Luzon State University was also reported to have suffered partial collapse (3).

Figure 5.52

Christian College of the Philippines, Cabanatuan

Figure 5.53

Christian College of the Philippines, Cabanatuan: provision for extension

There were few other signs of damage, let alone collapse, elsewhere in the town which appeared to be busy and operating normally. A comprehensive tour of the town was not undertaken, but the worst damage observed, apart from at the College, was in a two storey corner building with evident torsional eccentricity. Minor damage was also noticed in the pinnacle of a church (Figure 5.54). These were very isolated instances, however, and there was no sign of the piles of rubbish on pavements from fallen ceilings and broken partitions often seen in earthquake zones when there are few other signs of damage.

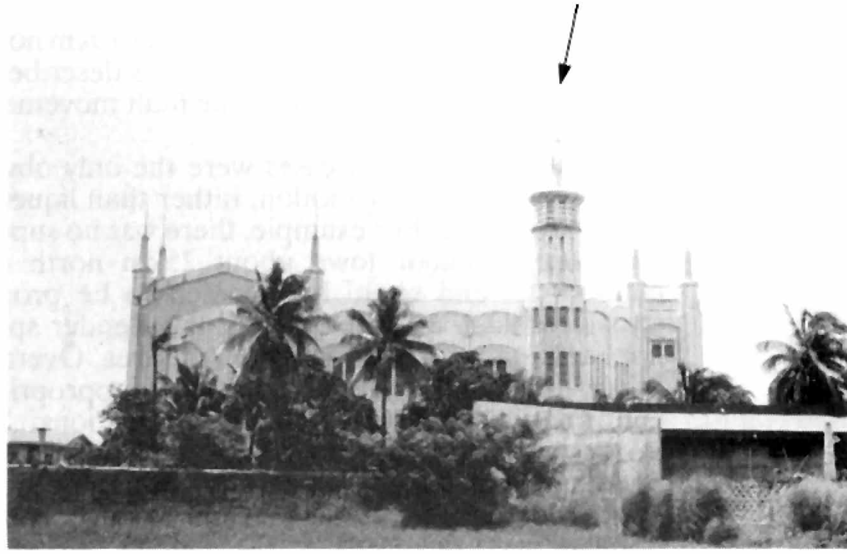


Figure 5.54

Church at Cabanatuan with minor damage to pinnacle

Figure 5.55

School at Malasiqui

5.4 Structural damage in other locations in the northern Central Plain

The most significant instances of structural damage caused by strong ground motion that were inspected by the EEFIT team have been described in the previous sections. Elsewhere on the route taken by the team across the north of the Central Plain (Appendix A), there was little evidence of damage, though some isolated instances of severe damage were noted, as discussed below.

A single storey school building at Malasiqui, which is about 25km south of Dagupan, had damage in the short concrete columns which raised the floor some 0.3m above ground level (Figure 5.55). The damage was worst in the corner column. What appeared to be liquefaction ejected sand could be seen by the school building, but the damage appeared to have been caused by shaking rather than settlement. A number of other similar buildings were passed, but without signs of damage.

A three storey house at Umingan, a village about 50km north of Cabanatuan, had suffered a soft storey collapse. A 5m tall barn had suffered some damage to its concrete columns in a village about 10km north of Cabanatuan. There was also strong motion damage in Rizal, as described in Section 8.1, although the main damage there was due to the fault movement.

These and a few other cases were the only obvious signs seen by EEFIT of damage due to strong motion, rather than liquefaction induced settlement or fault movements. For example, there was no superficial evidence of damage in San Jose, a major town about 25km north of Cabanatuan, and normal commercial and social life seemed to be proceeding there. Long period structures such as water towers and slender spires on church buildings also appeared undamaged throughout the area. Overall, a damage intensity of about VI on the MSK scale would appear appropriate, though this would need confirmation by more extensive observations. This compares with an MSK intensity in Baguio of around VIII in taller buildings and about VI to VII in low buildings. The population density of this area is around 200 to 300 people per square kilometre, so the lack of damage cannot be attributed to sparse population density.

5.5 Manila

The July 1990 earthquake was very strongly felt in Manila (see Appendix D). However, the only damage of any kind that the EEFIT team saw during their 5 days spent in the metropolitan area was to San Agustin cathedral, as described below, and the lack of damage was confirmed during discussions with local engineers.

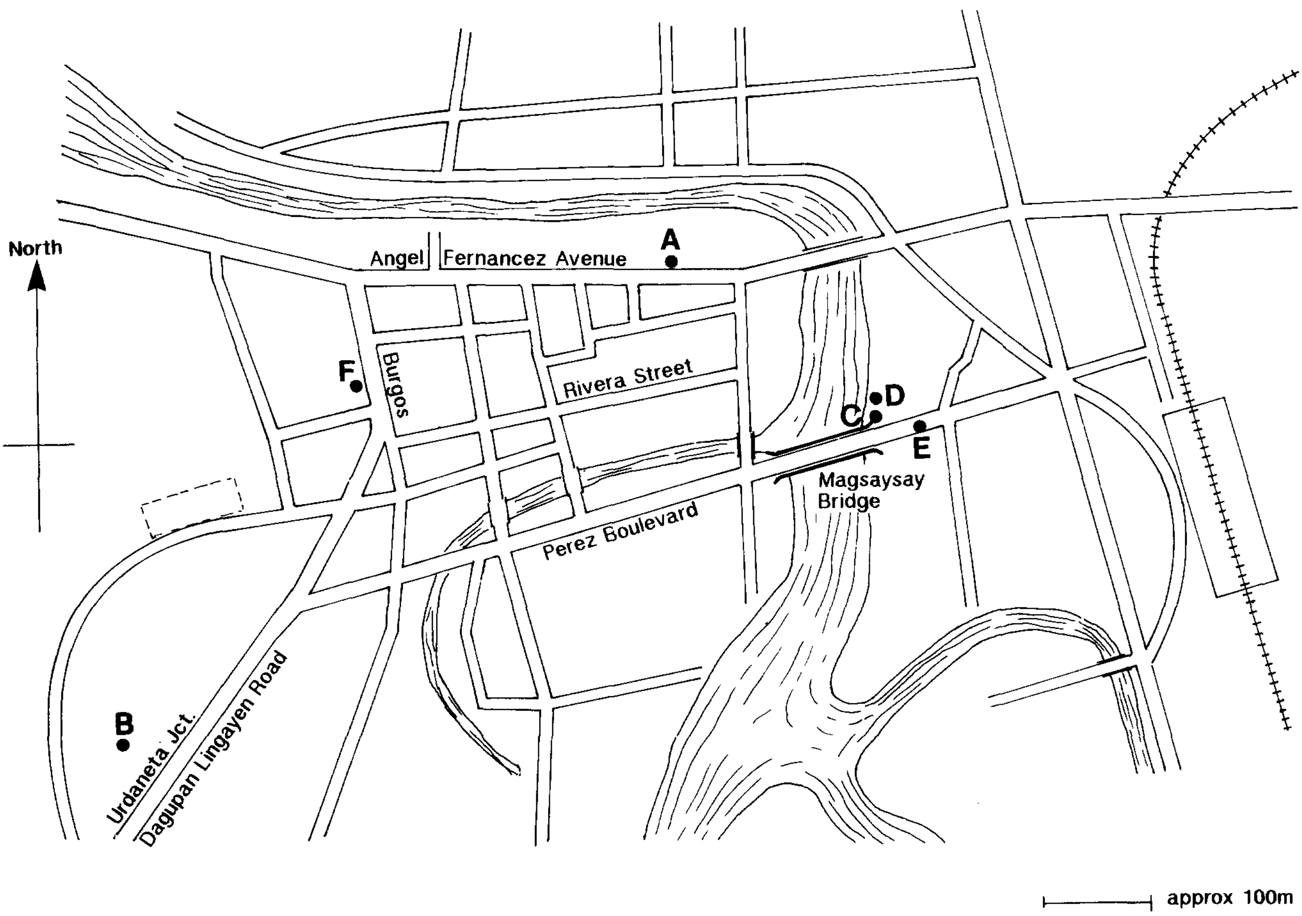
Despite this apparent absence of damage, it appears that some damage was experienced by a number of school buildings in Manila, which were reported to have been closed because of earthquake damage. The EEFIT team also visited San Agustin cathedral, which dates from 1587 and is one of the oldest buildings in the country. It is a traditional church building of massive masonry construction which has been damaged by a series of earthquakes in the last 3 centuries. It is founded on poor ground and has undergone settlement. In the July 1990 earthquake, about ten metres of the perimeter wall to the cathedral compound (not part of the main building), which was in very poor condition, collapsed. More seriously, some cracks in a building about 10m tall, which had formed in previous earthquakes and been repaired, had again opened up and left that part of the building in an apparently dangerous condition. Damage to the rest of the cathedral appeared minor, and the buildings were open and performing normal offices.

6.0 LIQUEFACTION

6.1 Liquefaction Effects in Dagupan

6.1.1 General

Dagupan is situated about 180km north of Manila, on the Gulf of Lingayen (Figure 3.2). The city has a population of 120,000. Dagupan serves one of the north-south routes of Luzon, the Romulo Highway, via two main bridges crossing the River Pantal through its town centre. Central Dagupan has developed on a river delta of alluvial and loose sand deposits, reportedly by filling in flooded areas extended from the fertile lowland of the Central Plains. Figure 6.1 shows a map of central Dagupan and locates some of the buildings described in this section. Angel Fernandez Avenue and Perez Boulevard are the two main streets through the downtown area.



Key to building locations

Fig 6.6	A	Fig 6.11	D
Fig 6.8	B	Fig 6.12	C
Fig 6.9	C & D	Fig 6.13	E
Fig 6.10	C	Fig 6.14	F

Figure 6.1 Map of Central Dagupan

The 1990 earthquake caused liquefaction in many places along the Lingayen Gulf and the Central Plain and was particularly severe in Dagupan. As described below, many buildings were affected, but there was equally serious damage to the road network. The two major roads through the town were flooded and the road base had failed (Figure 6.2); many minor roads in the area between were also affected. In addition, the Magsaysay Bridge, one of two crossings of the Pantal River collapsed as described in section 6.3.3. Many areas were flooded, both along the river banks (see Figure 6.3) and elsewhere.

Figure 6.2

Evidence of liquefaction on Dagupan main street

Figure 6.3

Flooding on the banks of River Pantal, Dagupan.

6.1.2 Effects on building structures

Many buildings in the central business district settled and tilted (some by up to 1.5m) following bearing failure (see Figures 6.4 and 6.5). The major commercial area along the two main streets of Perez and Angel Fernandez Boulevards was particularly affected.

The susceptible buildings were generally reinforced concrete frame structures two to four storeys high. Structural damage was normally not severe, however; this was probably because the superstructure became decoupled from the forcing motions once ground softening and liquefaction were initiated during the earthquake.

Uneven settlement caused a three storey apartment building to tilt bodily. Had it not been for a neighbouring store, it might have toppled over (see Figure 6.6). Localised foundation failure caused a two-storey shoe emporium to settle on one side and the front facade suffered shear damage (see Figure 6.7). A brief survey of the campus of the Lyceum NW (a large, private educational establishment) revealed widespread flooding up to 400mm deep from groundwater saturated with fine sand. The 25m by 6m ground bearing floor in one of the buildings had arched upwards by 200mm centrally. A three-storey building on the campus hammered against its neighbouring four-storey building and then tilted (see Figure 6.8) dislodging its internal staircase from the brickwork partition. This shows signs of possible first shaking before softening and liquefaction set in.

Figure 6.4 Foundation failure of building in Dagupan

Figure 6.5

Foundation failure of building in Dagupan

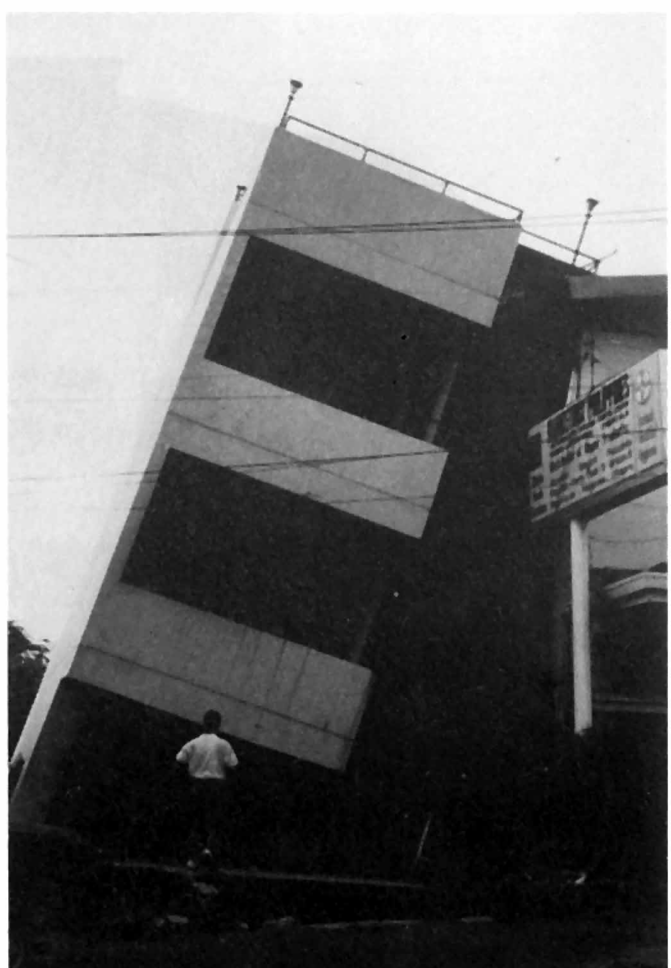


Figure 6.6

Tilted building in Dagupan

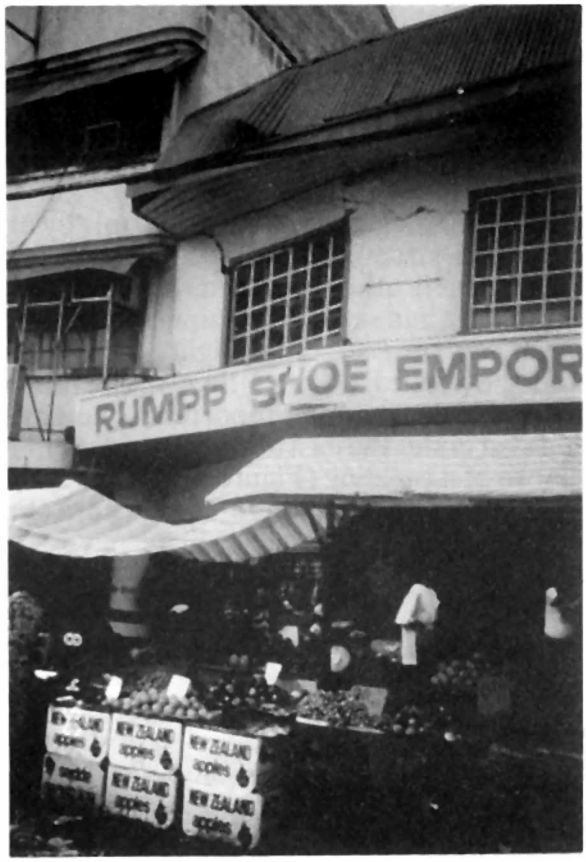


Figure 6.7

Building settlement in Dagupan

Figure 6.8

Buffeting damage in Dagupan

Two major buildings (Figure 6.9) which suffered severe settlement were located near the east bank of the Pantal River, immediately downstream of the failed Magsaysay Bridge (section 6.3.3). One building, the STI building, was 3 storeys tall; the other, the AsiaCareer building, was 5 storeys and had a light roof mounted radio mast. Both buildings were reinforced concrete frame structures and were reported to have strip foundations of unspecified depth.

The 3 storey STI building had settled uniformly by at least 2m (Figure 6.10). It had suffered some structural damage to some of its external columns, but appeared undamaged otherwise from an external inspection. The 5 storey AsiaCareer building had settled by a similar amount, carrying down one end of an adjacent single storey building (Figure 6.11) and had also tilted by about 5 degrees from the vertical. Other than the settlement, there was no sign of structural damage, nor was any reported. The river bank in front of the STI building (and also under the east abutment of the Magsaysay Bridge) had failed, causing collapse of a building (Figure 6.12). Part of the concrete road near the STI building suffered a settlement of about 1.5m (Figure 6.13).

Figure 6.9

STI and AsiaCareer buildings, Dagupan

Figure 6.10

Settlement of front (south side) of STI building, Dagupan

Figure 6.11

Settlement of AsiaCareer building, viewed from the north

Figure 6.12

Failure of river bank in front of STI building and Magsaysay Bridge, Dagupan

Figure 6.13

Road failure near STI building and Magsaysay Bridge, Dagupan.

An old masonry church building in the west of the town had part of its roof dislodged (Figure 6.14). Although there was some evidence of liquefaction in areas close to this church, it was not as severe as in the centre of the city and ground shaking seemed to be the source of damage. A recent eight-storey reinforced concrete building opposite the church suffered very little structural damage, although it was reportedly flooded at the basement.

Dagupan City suffered heavy financial loss because of the settled buildings. Many activities could only carry on by using standby generators and pumps and the local people had to pile the liquefied sand onto the sides of the streets to clear the way for traffic. Damage to the central business district severely hampered the economy and structure of the city. This highlights yet again the importance of taking proper account of the nature of the foundation soils in seismic areas. Much planning is needed to rebuild or even to relocate the city.

Figure 6.14 Roof failure of masonry church building, Dagupan

6.2 Coastal Areas Near Agoo

Agoo is one of the main population centres on the west coast of Luzon (see Sections 3.5 and 5.2). The coastal region around Agoo consists of flat ground on river deltas and it is extensively used for agriculture, with the focus on milkfish and rice cultivation.

The 1990 earthquake caused large areas of the low lying coastal area around Agoo to liquefy and settle. Houses built along the coast, rice fields and milkfish ponds were flooded with sea water (Figure 6.15). Although as reported in section 5.2, there was no indication of liquefaction in Agoo, the banks of a river immediately to the north had moved (Figure 6.16), although the adjacent bridge was undamaged. A bridge about 2km north of Agoo had undergone a large foundation movement (Section 6.3.2).

Figure 6.15

Flooding of coastal areas near Agoo

Figure 6.16

Spreading of river bank just outside Agoo

The EEFIT team also visited Alaska, a small village to the northwest of Agoo on very low ground near the mouth of a large river. Figure 6.17 shows the mouth of a similar river about 20km further south; the large sand bar should be particularly noted. It was reported that Alaska was built on similar sand deposits.

The village itself had been almost totally destroyed by the earthquake, with some thirty houses along the line of the palm trees in Figure 6.18 collapsing. Inland from the village, there were extensive signs of liquefaction, with many liquefaction blowholes (Figure 6.19) and ejected fine black sand. The villagers reported that water spurted from these blowholes to a height of about 1m high during the earthquake; the ejected water was said to be hot. The ground inland from the village had settled by at least 1m, allowing seawater to flood in and spoil paddy fields and fishfarms.

Figure 6.17 Mouth of river between Agoo and Dagupan

Figure 6.18 Remains of the village of Alaska

Figure 6.19 Liquefaction blowhole near Alaska

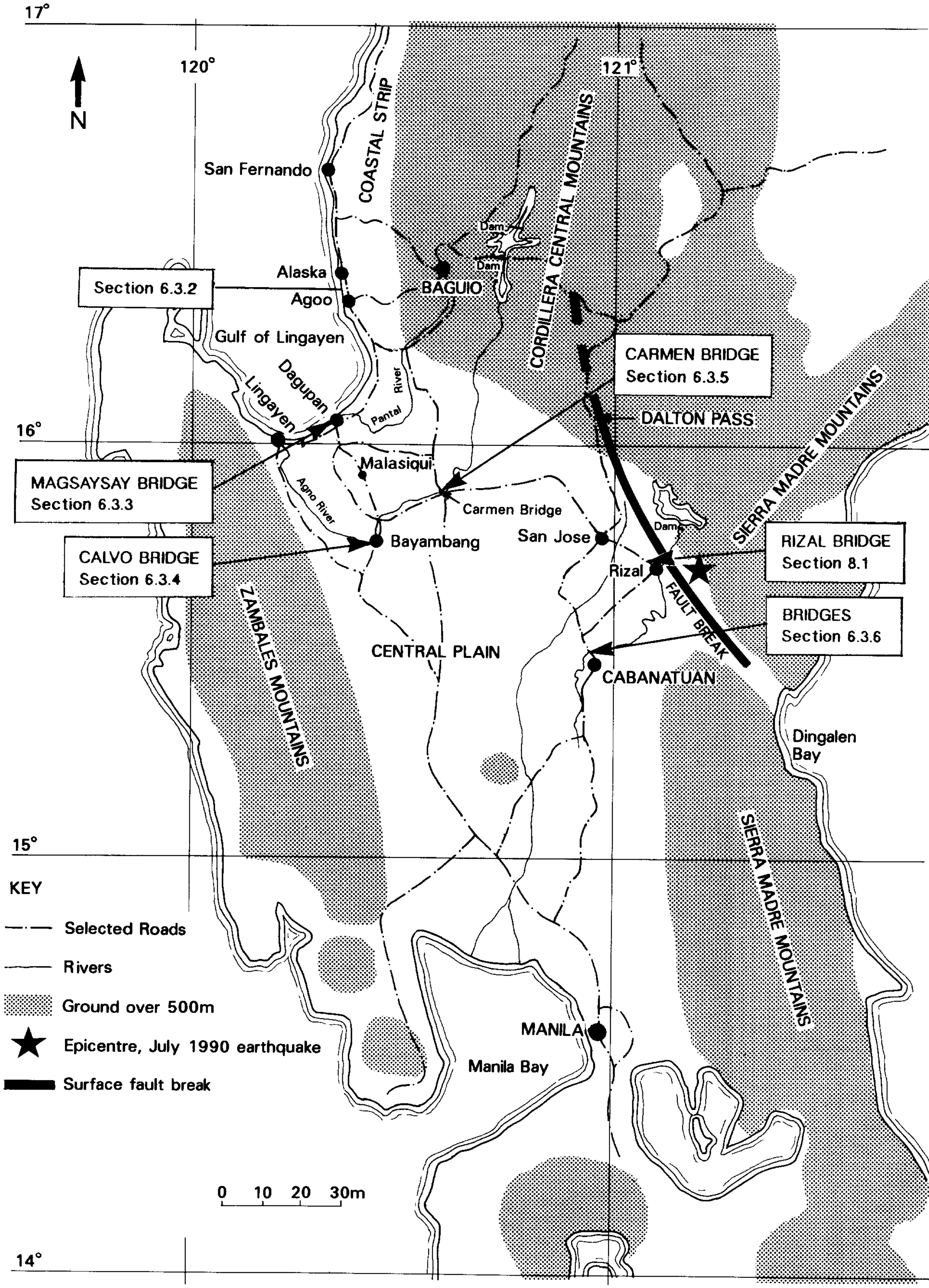


Figure 6.20 Location of bridges inspected by EEFIT team

6.3 Bridges

6.3.1 Introduction

The Ministry of Public Buildings and Works, Manila produced a preliminary estimate 2 weeks after the earthquake that 14 bridges needed repairs in excess of 1 million Filipino pesos (US$40,000) and a further ten in excess of 0.1 million pesos (US$4,000). The total estimated repair cost at that time was about 90 million pesos (US$4 million). Of the seven bridges with serious damage that the EEFIT team inspected, there was only one case (a bridge at Rizal, described in Section 8.1) where the damage was not caused by gross foundation movement probably or certainly due to liquefaction. The bridge at Rizal collapsed because it was straddling a fault line that had a relative movement of 3 metres. In no case was damage observed which had been caused directly by ground vibration. Thus, there was no sign of shear or bending failures in deck support structures or of distress or large movements on deck bearings in cases where the supporting structure had not itself undergone a large movement or settlement. The damage descriptions in the Ministry list of bridges referred to above confirms that damage was predominantly due to gross foundation movements.

The bridges inspected by the EEFIT team which suffered from liquefaction induced failure are located on Figure 6.20 and are now briefly described. The economic impact of the failures in affecting the road network was one of the most significant features of the earthquake, as discussed further in Section 10.1.

6.3.2 Bridge between Agoo and San Fernando

This concrete road bridge spanned a small river about 2 km north of Agoo and carried the main highway on the Agoo/San Fernando road. It had a single river span of about 7m and two short abutment spans. The bases of both piers, which were about 2m high, had moved in towards the centre of the river by about ½ metre (Figure 6.21). Temporary wooden shoring had been installed to support the deck and the bridge was open to traffic. It formed part of the only land link from Manila to Baguio open after the earthquake.

Figure 6.21

Bridge between Agoo and San Fernando

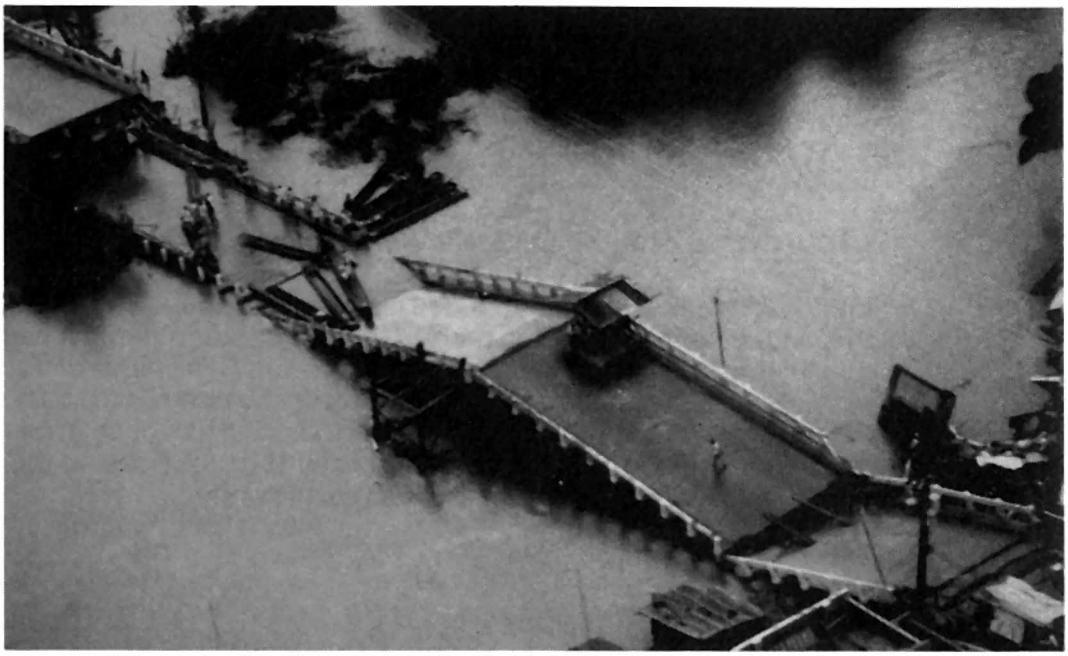
6.3.3 Magsaysay Bridge, Dagupan

This is one of the two major road bridges about ½km apart in Dagupan which cross the River Pantal (Figure 6.1). The Magsaysay Bridge has 5 river spans of about 20m and two abutment spans (Figures 6.22 to 6.24). The piers are reinforced concrete supporting four concrete beams at the west end and four steel beams at the east end, which in turn support a concrete deck carrying a 7m wide carriageway. Each span is simply supported.

Figure 6.24 shows a sketch of the bridge. The easternmost pier appeared to have moved about 1½ metres towards the centre of the river and the adjacent river pier failed, causing loss of the abutment span. A river pier also suffered a gross foundation movement.

The second major bridge crossing in Dagupan was apparently undamaged and was open to unrestricted traffic.

West abutment



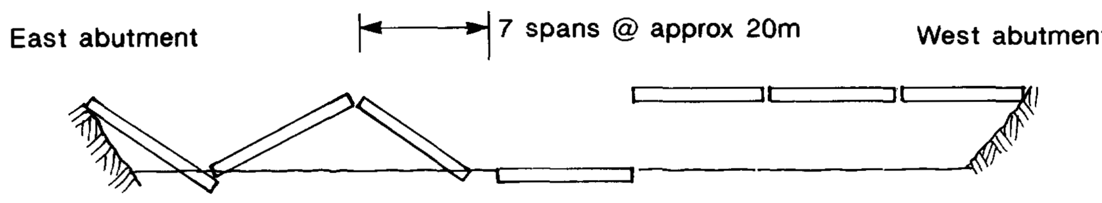
East abutment

Figure 6.22

Magsaysay bridge, Dagupan

Figure 6.23

Magsaysay bridge, East Abutment



Sketch section along bridge, showing collapsed spans

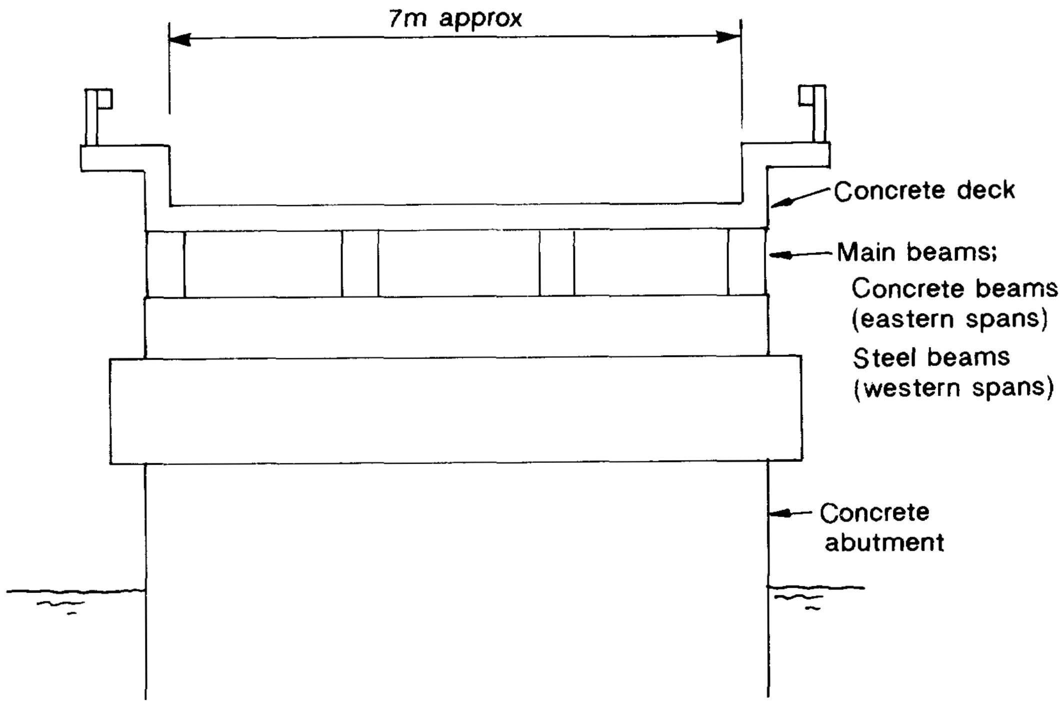


Figure 6.24 Sketch of Magsaysay bridge, Dagupan

6.3.4 Calvo Bridge, Bayambang

This road bridge crosses the River Agno at Bayambang. It has four main river spans of about 40m length and a shorter end span across the eastern river bank (Figures 6.25 to 6.27). The two river piers and two main abutments are of concrete and support rivetted plate girder steel trusses with bolted end connections. Each span is simply supported, with a simple steel rocker bearing at one end and a steel sliding bearing at the other. One of the trusses has a plate with the inscription 'USA, 1950'. At the time of the EEFIT inspection, the bridge appeared to have been recently painted with a metallic paint and had apparently been well maintained.

The main damage was caused by a substantial rotation of the main east abutment, which had moved about 1.5 metres toward the river, causing the short end span to come off its bearings (Figure 6.27). There was an associated minor slip of material around the east abutment (Figure 6.26) and fine black sand could be seen, evidence that liquefaction had taken place.

There appeared to be no damage to the river piers or the west abutment, although the stone facing to the west abutment bank had cracked slightly and there were signs of liquefaction blown sand. There was no sign of any distress at the bearings, except on the east abutment which had suffered a gross movement. Nor was there any sign of distress other than associated with the abutment movement.

The loss of support to the east end span had created a metre of so vertical step in the road, which had been bridged by a Bailey span. A notice was placed stating 'Weak bridge - Load Limit 10 tons' and single file traffic was being allowed across the bridge.

Figure 6.25

General view of
Calvo Bridge, Bayambang

Figure 6.26

East abutment of
Calvo Bridge, Bayambang

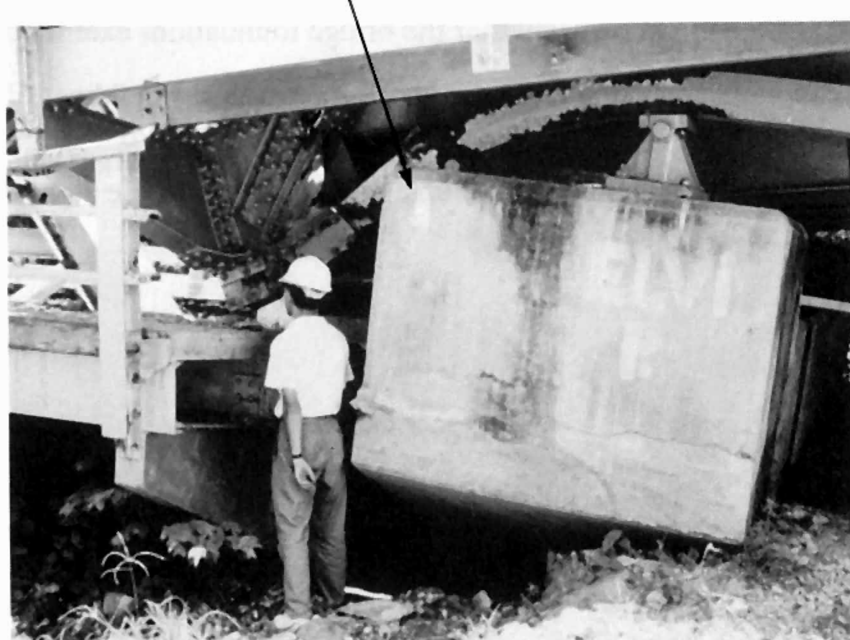


Figure 6.27

Movement of east
abutment, Calvo Bridge

6.3.5 Carmen Bridge, Villasis

This major bridge crosses the Agno river at point about 25km upstream from the Calvo bridge, and carries the main road link from Manila to the north west coast of Luzon. The bridge is of similar construction to the Calvo Bridge, with rivetted plate girder trusses on simple steel bearings supported by concrete piers. There are 13 simply supported spans; five spans to the north cross the river and the eight southern spans cross a flood plain (Figure 6.28).

Several of the spans crossing the flood plain had undergone gross foundation movements, causing the associated decks to come off their bearings (Figures 6.29 and 6.30). The first pier had sunk and rotated through about 5° along the axis of the bridge, the second pier had sunk and rotated in the same direction to become almost horizontal and the third pier had sunk at least a metre. Other piers in the flood plain had suffered similar movements. There appeared to be no signs of distress in the river spans.

The southern end of the bridge was impassable to vehicular traffic, although there was a constant stream of pedestrians. Light vehicles were able to cross the river using the bridge up to about half way along the bridge. Piling was in progress at a site on the south bank about 200m upstream from the Carmen bridge, which appeared to be for a temporary or permanent replacement crossing.

Piles of fine black sand could be seen in a number of places near the bridge on the flood plain; these were interpreted as having come from liquefaction blows. About 50gms of this sand was taken back to the UK and a grading analysis was performed. The results are shown in Figure 6.31 and compared with the grading limits for most liquefiable soils given by Tsuchida (5). It can be seen that the sample falls within these grading limits, except for the finest particle sizes. The sand may not have been truly representative of the grading present in the layers before liquefaction occurred, since certain particle sizes may have been more easily ejected in a sand blow than others. However, the grading supports the other evidence that the bridge foundation movements were associated with liquefaction of the supporting soils. The Japan Society of Civil Engineers report (6) has published cone penetration test results for four sites at the bridge, showing bands of material of negligible strength at depths up to 2½m. It is not known whether the bridge foundations extended to a greater or lesser depth.

A small village of one and two storey buildings of non-engineered construction exists at the southern end of the bridge. There was no sign of earthquake damage in this village, or in the slightly larger village of Rosales which lies about 3 km upstream on a main tributary of the Agno river.

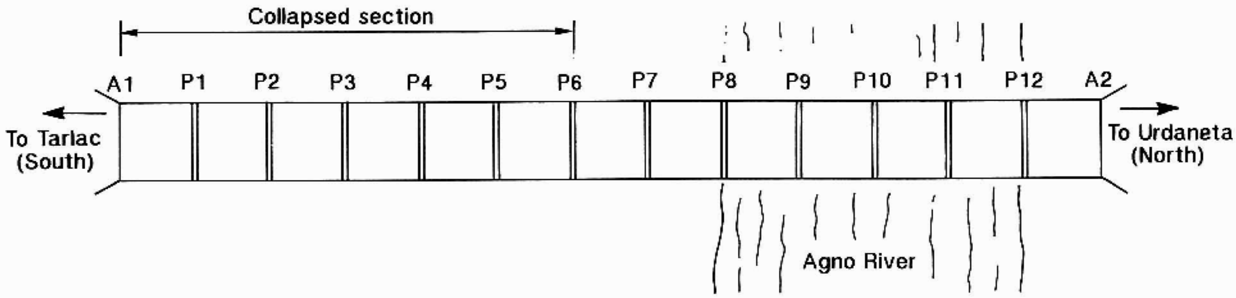


Figure 6.28 Sketch plan of Carmen Bridge

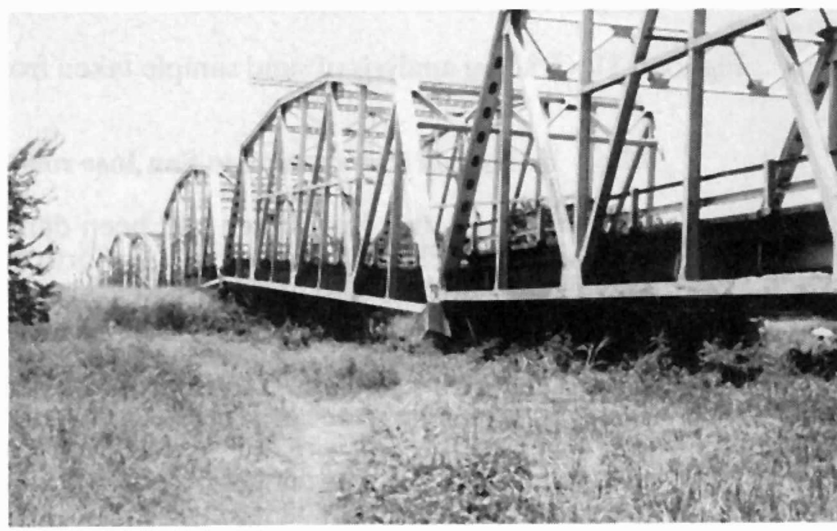


Figure 6.29

Carmen Bridge:
General view

Figure 6.30

Carmen Bridge:
Typical pier failure

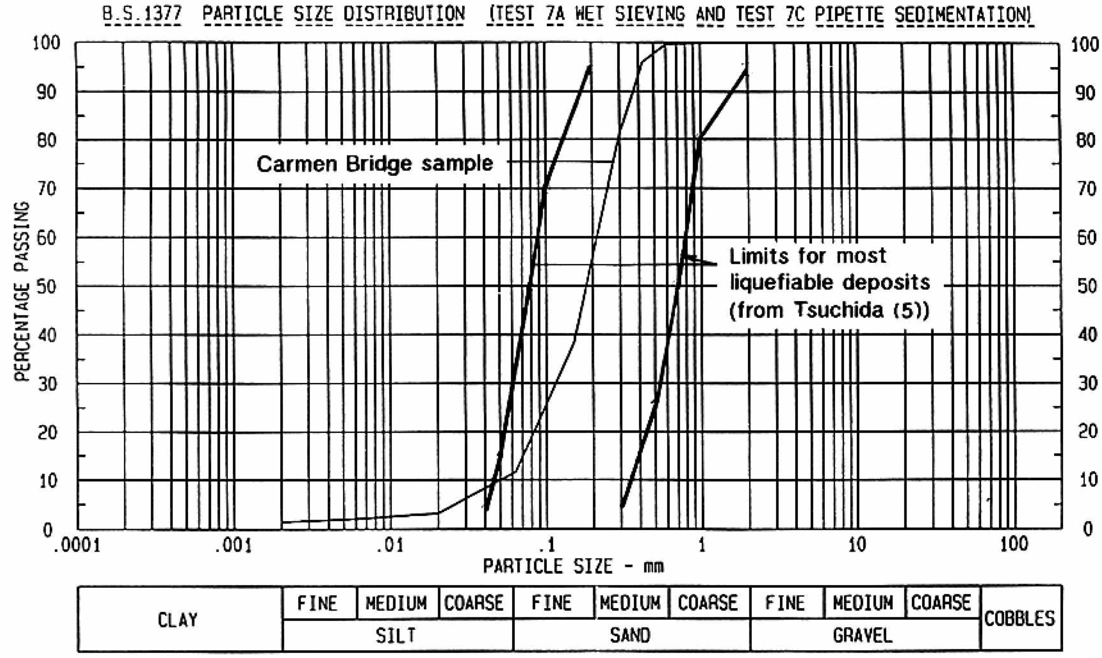


Figure 6.31 Grading analysis of sand sample taken from Carmen Bridge site

6.3.6 Bridges on Cabanatuan to San Jose road

Two bridges on this road which had been damaged by the earthquake were crossed by the EEFIT team. One was north of Talevera and was of similar construction to the Calvo and Carmen bridges described above, with upstand steel girders supported by concrete piers and abutments. It had three spans of approximately 40m each. The southern river pier appeared to have rotated so that the top of the pier had moved about 200mm away from the centre of the river, causing both the decks it supported to come off their bearings. The river span was therefore left with only about 150mm bearing on the edge of the pier and seemed to be in some danger of collapse. The bridge was open to single line traffic and there was a suitable warning posted at either end of the bridge (Figure 6.32). Minor soil movements were observed on the south abutment slopes.

About 5km to the south, a second bridge of similar length but without steel upstand beams was posted as under repair, but was not inspected by the EEFIT team.

Figure 6.32

Warning notice on bridge near Talevera

7.0 SLOPE STABILITY

7.1 Access Roads to Baguio City

Landslides were a major source of economic loss. Tens of thousands of slope failures were triggered by the earthquake, which occurred during the rainy monsoon season. Most of these slides were shallow, affecting only the near-surface soils. However, many deep landslides brought down large volumes of material, and several large rockfalls also occurred. Slides were triggered by the main event and by aftershocks. Some slides also occurred several days later when earthquake-weakened soil slid in a series of heavy rainstorms. It has been estimated that in some places in the Central Cordillera, 10% of the topsoil was lost at the time of the earthquake and a further 30% in the weeks thereafter.

Damage to transportation systems and the disruption to communications as a result of these landslides had a significant impact on the emergency response and recovery from the earthquake. Numerous vehicles were trapped between landslides, for example on the heavily-used Kennon Road, the main access road to Baguio from the southwest. A typical landslide is shown in Figure 7.1.

The loss of roads in mountainous regions and the loss of bridges due to liquefaction isolated Baguio City for three days, and for at least a month after the earthquake only one road was open to the city. This was the Naguilian Road which was restored within three days, but the remaining access roads were closed for several months. Reconstruction in the higher elevations was further hampered as earthquake and rain- weakened slopes continued to fail in the weeks after the earthquake.

Figure 7.1 Landslide on Kennon Road below Baguio

7.2 Baguio Airport

The concrete pavement at Baguio Airport was severely cracked in places, but was re-opened within 48 hours of the earthquake to assist in the evacuation of the injured and homeless. The damage shown in Figure 7.2 is typical, with cracks of about 100mm width together with some smaller vertical movement. Baguio airport is on sloping ground, and the cracks are likely to have been associated with slope stability failure.

Figure 7.2 Damage to concrete pavement, Baguio Airport

7.3 Dalton Pass

The interruption to the transportation systems, described in Section 7.1 above, affected a very wide region serving central and western Luzon. Landslides were the biggest problem, closing all of the major roads through the Central Cordillera mountains. Amongst the most important of these is the road running northwards from Cabanatuan towards the northern part of the province, which crosses the Cordillera at the Dalton Pass (Figure 3.2). This road was closed by several massive slope failures, as shown in Figure 7.3, and was expected to remain impassable for several months.

Figure 7.3 Slope failure in Dalton Pass

7.4 Dams

3 major dams are known to be located in the epicentral area (Figure 3.2), though none were visited by the EEFIT team. They are understood all to be rockfill dams. One dam impounds a large lake 10km north of Rizal, and lies about 5km to the northeast of the fault trace. The two others impound smaller lakes in the mountains about 10km east of Baguio.

Only minor surface movements were reported in the dams and the associated hydroelectric facilities continued to operate after the earthquake.

8.0 EFFECTS OF SURFACE RUPTURE OF FAULT

8.1 Rizal

Rizal is a town of perhaps 10,000 inhabitants lying on the eastern boundary of the Central Plain about 30km northeast of Cabanatuan. The main fault trace passed through the centre of the town. It was northwest-southeast trending, with about 3m of left lateral movement and about 1m of vertical movement, the higher side being to the east. One subsidiary fault trace trending west of southwest was also observed with similar displacements; others are understood to have been mapped by the USGS team.

Buildings on the fault trace were severely affected (Figure 8.1), though remarkably some weak buildings spanning the fault did not collapse (Figure 8.2). Some buildings immediately adjacent to the fault were found to have severe cracking, corresponding to about MSK intensity VI to VII. Rizal Central School had 6 out of about 20 single storey classrooms rendered unfit for use; typically, steel structures supporting light pitched corrugated iron roofs had suffered collapse in their block walls, which were poorly attached to the main frame (Figure 8.3). These buildings were generally within 100m of the subsidiary fault trace noted above, though one collapsed classroom was about 300m distant.

Elsewhere, there was little evidence of damage to buildings and local residents reported that no-one had been killed or seriously injured by the earthquake, though there were a number of minor casualties.

Two single span concrete bridges of about 20m length lie on the road heading northwest out of Rizal. One is about 1km from the town, and crosses the main fault trace. It had been destroyed by the movement on the fault trace (Figures 8.4 and 8.5). Another apparently identical bridge (Figure 8.6) lies on the same road closer to Rizal, about 80m from the fault trace. A close inspection of the bridge revealed no damage, nor any sign of movement at the simple steel to steel movement joint at one end of the bridge deck. The bridge was solidly constructed from in-situ concrete; although there were no obvious defects, the standard of construction judged from concrete finishes and dimensional accuracy was not particularly good. The fault trace passed through a levee separating the river that the bridge crossed from paddy fields. The levee, which was about 3m high, had accommodated the fault movement without collapse (Figure 8.7).

Figure 8.1

Remains of building spanning fault (foreground adjacent to damaged building (rear), Rizal

Figure 8.2

Rizal building spanning fault trace without collapse

Figure 8.3

Damage to poorly attached blockwork walls at Rizal Central School.

Figure 8.4

Rizal: looking NW along fault trace towards collapsed bridge

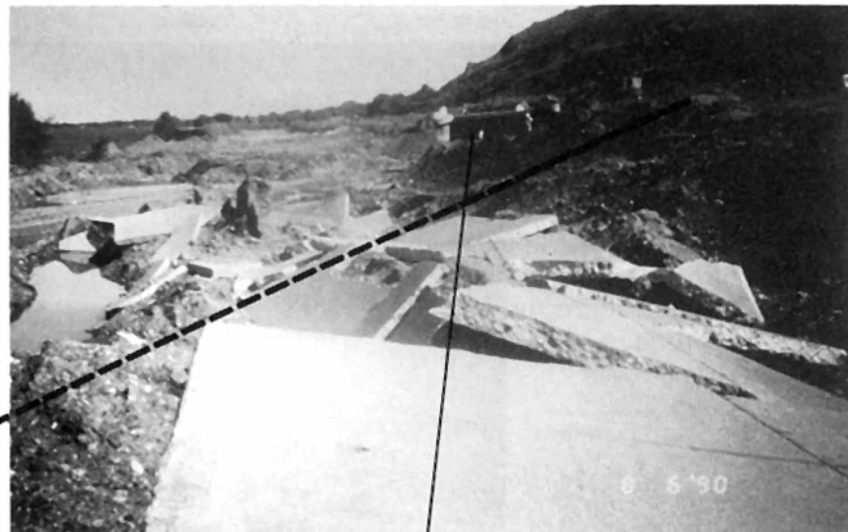


Figure 8.5

Detail of 8.4 showing collapsed bridge

Figure 8.6

Undamaged concrete bridge at Rizal

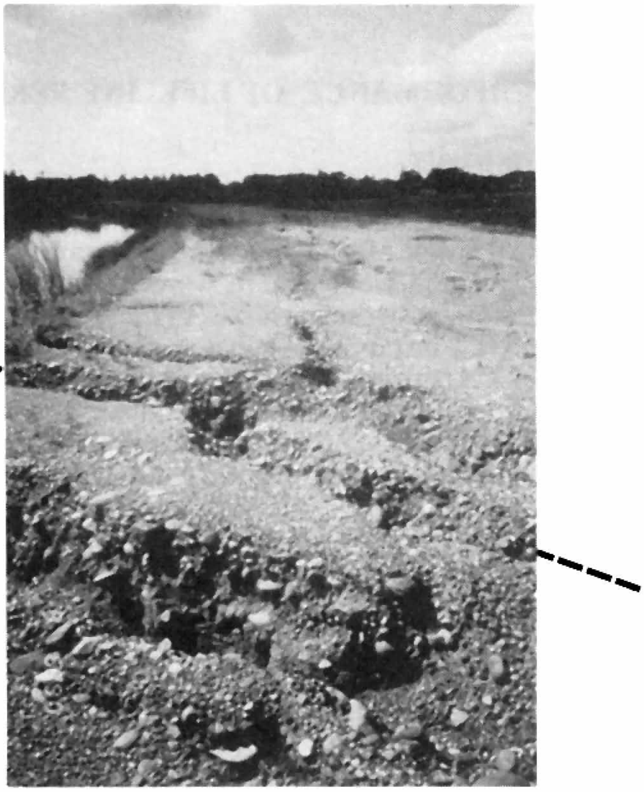


Figure 8.7

Levee near Figure 8.6
bisected by fault trace

8.2 Dalton Pass

The surface fault movement described in Section 8.1 above also affected the road through the Dalton Pass (Figure 8.8). Lateral and vertical displacement of the road surface resulted, of approximately 5 m and 1 m, respectively.

Figure 8.8

Fault movement in road
through Dalton Pass

9.0 PERFORMANCE OF LIFELINE SERVICES

9.1 Electricity

There was electricity supply to all the places visited by the EEFIT team, in the third week after the earthquake, and the system appears to have generally performed well. There were no failures in the hydroelectric stations in the mountains to the northeast of the Central Plain which supply the epicentral area, and few instances of substation failure. EQE (3) report one such major failure at La Trinidad high voltage substation supplying Baguio, which was reinstated within a few days of the earthquake. Elsewhere, the problems were either minor or associated with collapsed buildings. Figure 9.1, taken from the Japan Society of Civil Engineers report (6) shows the time of disconnected supply at various locations.

9.2 Water

Of the places visited by the EEFIT team, Dagupan and Baguio were still affected at the time by some loss of water supply. The large ground movements induced by liquefaction affected both distribution systems and deep wells in Dagupan. Power failures and damage to pumping facilities affected Baguio, with buried pipelines also damaged. Figure 9.1, taken from the Japan Society of Civil Engineers report (6) shows the time of disconnected supply at various locations.

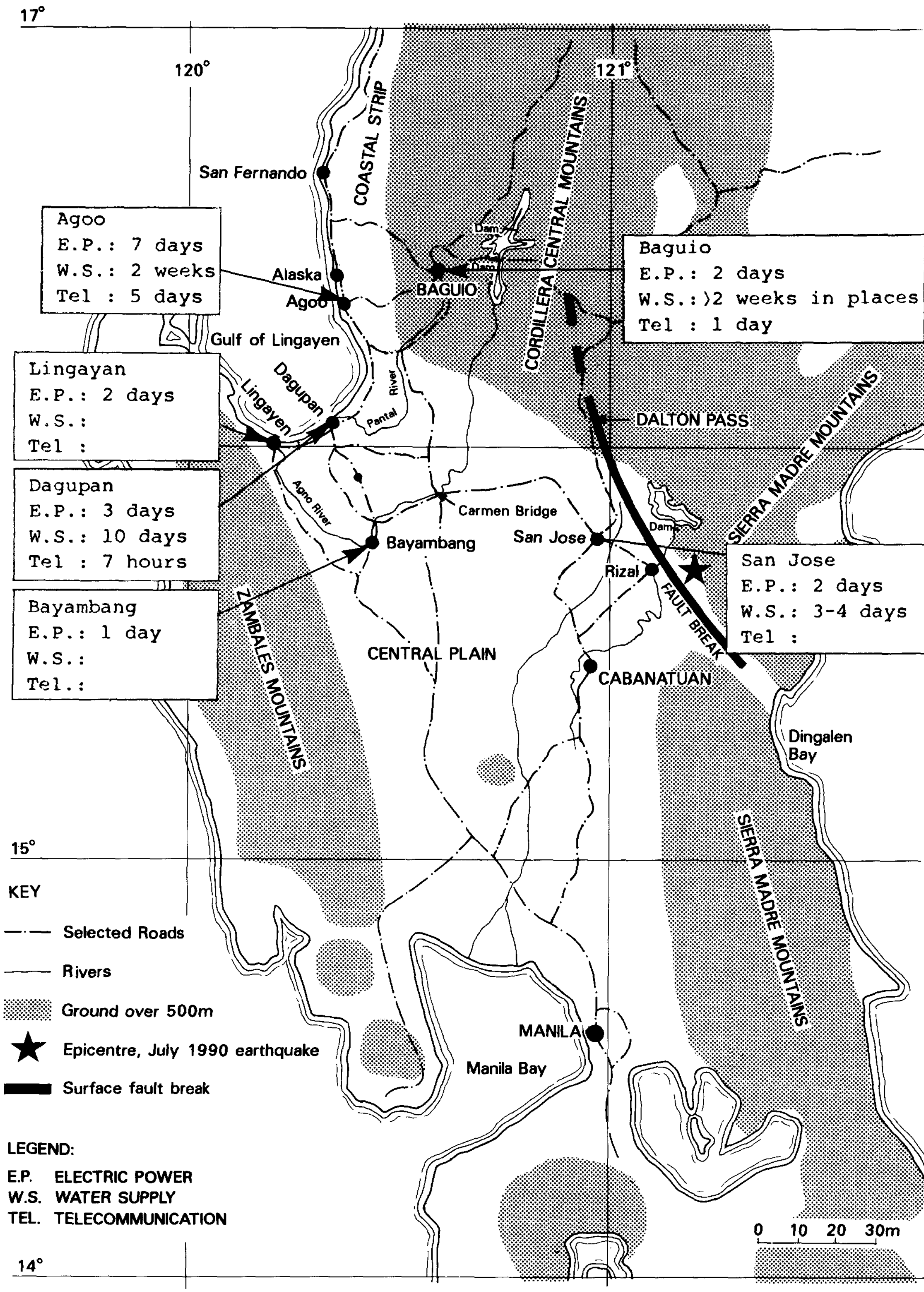


Figure 9.1 Times of disconnected supply of water, electricity and telephone

10.0 PERFORMANCE OF COMMUNICATIONS NETWORKS

10.1 Roads

Disruption to the road network may prove the most serious and long lasting general consequence of the earthquake. Road links which were severely affected included those which linked Manila to the economically important areas at the north of the Central Plain, to the north east coast of Luzon, and to the region north of the Dalton Pass. Baguio was completely cut off to road traffic for three days, and access was severely restricted for many weeks thereafter, hampering reconstruction efforts in the city. Three different causes of roads becoming impassable have already been reported, namely liquefaction induced foundation failure to bridges (Section 6.3), landslide blockage of roads (Sections 7.1 and 7.3) and surface faulting (Sections 8.1 and 8.2). Failure of thin concrete pavements, a common method of constructing primary roads in the area, was also observed due to bearing failure, greatly reducing traffic speeds though not generally rendering the roads impassable.

It should be noted that strong ground motion causing failure of bridge superstructures or failure of bridge bearings was not observed by the EEFIT team and was certainly not a major or even a minor factor in the disruption of the road network. This is in contrast to the situation observed during other earthquakes, particularly in California (refs 7 and 8).

10.2 Air

The only airport apparently affected by the earthquake was at Baguio, which was closed for 2 days, as reported in Section 7.2. However, this was the only significant airport in the epicentral area and became even more crucial after the earthquake because of the loss of road links to Baguio.

10.3 Ports

There was significant structural damage to a wharf at the port of San Fernando on the north east coast of Luzon, but this was not inspected by the EEFIT team. No other reports of damage to port facilities were received.

10.4 Telecommunications

The telephone system appeared to have survived the earthquake well, and all the towns where EEFIT stayed were in telephone contact with Manila at the time of the EEFIT visit. The major problem that EQE reports (3) was the overturning of unsecured racks of batteries, which interrupted dc supplies. Figure 9.1, taken from the Japan Society of Civil Engineers report (6) shows the times of disconnected service at various locations.

11.0 PERFORMANCE OF NON-ENGINEERED BUILDINGS

11.1 Introduction

The majority of building stock in the affected area was not designed by engineers but built directly by individual house owners, professional carpenters or building contractors. These non-engineered structures comprise an estimated 90% of residential buildings and much of the commercial low-rise building stock.

Some 120,000 people were made homeless from a variety of causes, although a breakdown of this figure is not available. Many buildings appear to have been rendered uninhabitable by slope failures, landslides and rockfalls. Some, in the Pangasinan region, were abandoned after liquefaction failures. The numbers of different types of residential structures destroyed by ground shaking have not yet been analysed, but from field observations, the main losses through vibrational failure appear concentrated more in the reinforced concrete housing and informal, shanty-type of structure than in the timber-framed houses that are the predominant building type over most of the earthquake-affected area.

11.2 Timber-Framed Houses

Housing in the region is typically timber framed. The traditional form of house is single storey, elevated off the ground on timber columns and with a pitched roof with a large overhang. The distinctive Philippine roof style has a ventilating half-gable appearing through the hipped roof. Wall materials are light and where possible, pervious to breezes. Damage to timber housing was generally light. Losses did occur from ground failure in areas of major landslides or slope failure, but few houses suffered heavy damage from the vibration effects of ground motion. No cases of a timber-framed building collapsing due to vibration were observed during the field study, even in areas where damage to masonry and other structures indicated that intensities experienced had been high. Timber houses tend to be light, relatively well constructed and ductile enough to survive ground shaking of high intensity without structural collapse. It is likely that higher forces are experienced from the wind loads of strong typhoons which are experienced more frequently in the Philippines.

Older timber-framed houses were noticeably more vulnerable however, with timber rotting and becoming brittle and fixings deteriorating with age. In areas close to the epicentre, joints of older buildings can be seen to have failed, indicated by fallen beams or disconnected posts. Twisted or leaning buildings showed that despite the failure of members and fixings, the structural frame and joints retained sufficient ability to deform without collapse.

11.3 Non-Engineered Reinforced Concrete Buildings

A growing number of houses in the region are reinforced concrete framed structures of two or more storeys. These are built by local contractors, who also design the layout and use rule-of-thumb practices for construction details, assessment of reinforcement needs and other structural considerations. Concrete framed houses cost 5 to 10 times as much per square metre as timber houses and clearly represent rising levels of disposable income and aspirations for modern housing styles. This type of housing generally performed badly in the earthquake by comparison with the timber-framed housing. A number of cases were seen where concrete framed houses had collapsed completely alongside areas of virtually undamaged timber housing. Damage to reinforced concrete structures appeared principally related to poor quality construction techniques and low levels of understanding of the use of reinforced concrete as a structural medium. Inspections of collapsed concrete-framed houses showed poor concrete mixes, under-reinforcement, inappropriate reinforcement placement and very poor compaction of concrete. It is evident that the non-engineered construction sector has had little experience of building in reinforced concrete - most concrete-framed houses date from the mid 1970's or later - and practical expertise has yet to become established. As the number of concrete-framed houses increases with growing affluence and market trends, the earthquake exposure could grow significantly in future in this sector unless the quality of contractor-built reinforced concrete improves.

11.4 Informal Structures

A significant proportion of the housing losses appears to have occurred in the informal housing sectors, although quantitative information is not available to confirm this. Shanty shacks are built on marginal land on the outskirts of most towns in the region.

These are built from whatever is available - sheeting loosely tacked onto framing made from any element that can be found - and tend to be found on the poorest sites; steep slopes, flood plains and other hazardous lands. Their siting generally puts them at higher risk from site-related hazards, but in the two major cities affected by this earthquake, namely Baguio and Dagupan, squatter settlements did not suffer greatly. In Baguio, the ravine sides on which most of the squatter settlements are located were spared serious failures. Informal sectors in other areas are reported to have suffered from ground failures, although no fire outbreaks - a common hazard in informal settlements - were recorded.

12.0 ENGINEERING PRACTICE IN THE PHILIPPINES

12.1 Building Controls

A Building Permit has to be obtained from local government before any new construction can start. To obtain the permit a complete set of structural drawings and calculations are certified by a Registered Engineer and submitted to government by the owner or Architect, together with sets of architectural, mechanical, electrical and sanitary drawings. The Registered Civil Engineer may be qualified in any engineering discipline although there is a move to restrict this by legislation to Structural Engineers. To become registered, engineers sit government licensure exams which cover a broad range of engineering topics and may be sat without any post graduation experience; the exams are normally taken within a year of graduating.

The drawings are then processed by the Government Engineers. The main checks appear to be limited to means of escape and fire protection systems and it is quite uncommon for feedback to be given on structural drawings or calculations, particularly on large projects.

Prior to obtaining an Occupation Permit, both the Registered Engineer responsible for the design and the Registered Engineer responsible for the supervision (normally the contractor and often endorsed by the Project Manager) have to certify that the structure has been built according to the drawings. This is followed by a site inspection by the Government Engineer.

It can be seen that the responsibility for quality in the design process lies principally with the organisation performing the design. There is little active interaction between engineers to reach a consensus on details of design procedures or interpretation of codes, unlike that which occurs in countries with a more rigid approvals system. However both the Philippines Institute of Civil Engineers (PICE) and the Association of Structural Engineers of the Philippines (ASEP) are active in promoting seismic design seminars and lectures. Within the last few years, Design and Construction Reviews by independent consultants, as recommended by SEAOC(9), are becoming more popular, particularly for major projects in Manila.

Large projects normally have a project management team which supervises construction, monitors programming and take cores and steel for testing to the US standard ASTM (American Standard for Testing & Materials) requirements. Taking samples for testing normally follows code recommendations although assessment of test results by a qualified engineer or by the design engineer frequently does not happen.

12.2 Codes of Practice and Design Procedures

The office approach to analysis, design and detailing is heavily influenced by US practice. The National Structural Code of the Philippines (NSCP) copies the 1985 UBC Section 2312 (4) and ACI- 318:83 (10) verbatim. A zone 4 seismic risk is used for the whole of the Philippines; this corresponds to the most seismic zone in the USA. The 1988 UBC and updates of ACI-318 have been used in place of the NSCP for recent major projects in Manila.

Structures are generally analysed with US software such as ETABS and SAP using a response spectrum analysis for the more significant structures.

12.3 Construction Practice

Reinforced concrete is much more common than structural steel which is not produced locally. The most common structural systems are frames up to 10 storeys and dual systems of shear walls and frames above 10 storeys.

Reinforcement in compression elements is commonly butt welded by manual metal arc to minimise wastage. The lack of control and testing carries the danger of a lack of ductility or loss of strength at the splice locations.

Maximum bar sizes in main reinforcement are typically 32mm diameter with a yield strength 410 N/mm^2, although occasionally 36mm bars are used. Bundled bars are very common and vertical elements are typically heavily reinforced, up to 6%. It is still common for smaller bars (used for shear reinforcement) of 20mm diameter or less to have a yield strength of 275 N/mm^2.

Perimeter infill walls are usually made out of reinforced concrete, up to 200mm thick, with a central mesh reinforcement and built flush to the structural frame. These walls are built after the main frame and a construction joint gap of 0-15mm will normally exist at the connection of the top of the wall to the floor above.

Internal infill partitions are usually made of 150mm hollow block. Walls are reinforced with 16mm bars every 400mm both vertically in a grouted void and horizontally along the bedding planes. These are normally built flush against the structure above and to the structural frame with the 16mm bars extending into the structural element.

External and internal walls will usually have a plastered finish at least 10mm thick and usually nearer 30mm.

The effects of the infill walls on the structural performance is generally not considered by design engineers, although they change the fundamental seismic characteristics such as period. Even if infill walls may change a regular structural system to a 'soft storey' a 'weak column, strong beam' or a highly irregular structure, the infill walls would not normally be shown on the engineers' drawings, neither would they be assessed to limit their detrimental consequences.

Debate on how to deal with infill walls is growing in the Philippines and a number of recent buildings have started to introduce separation gaps between infill walls and the structure. This practice is to be encouraged, provided adequate measures are taken to stop the walls falling out of the frame due to out of plane seismic motions.

12.4 Civil Engineering

Civil engineering works follow basically similar procedures for submission. The authority is the Department of Public Works and Highways which publishes manuals and design guides. Design of civil engineering works is again heavily influenced by US practice. Specifications and publications by the American Association of State Highway and Transportation Officials (AASHTO) are referred to extensively, such as the 'Standard Specifications for Highway Bridges' and the 'Guide Specifications for Seismic Design of Highway Bridges'. These require consideration of the site relationship to active faults, the seismic response of the soils at the site, and the dynamic response characteristics of the total structure. There is no stated requirement to investigate the liquefaction potential of a site, though this is sometimes done.

13.0 DISCUSSION OF STRUCTURAL ASPECTS

13.1 Distribution and amplitude of strong ground motion

Apart from the intense damage at Agoo and Baguio, the structural damage caused by strong motion in the earthquake appeared generally low for an earthquake of magnitude 7.8. Typically, epicentral intensities of VIII to IX might be expected in the epicentral area of such an event (11), but for the Luzon earthquake, this intensity was only experienced in Agoo and in medium rise structures in Baguio. Elsewhere in the epicentral area, the intensity appears to have been VII or less. Thus, in the absence of strong ground motion instruments, it can be concluded that the high frequency motions were apparently smaller than might be expected for similar sized events. More tentatively, the lack of damage to longer period structures in the Central Plain, such as water towers or church spires, suggests that longer period motions were also relatively low, except in Baguio, as noted below. The low intensity adjacent to the fault break at Rizal was particularly striking. This is an unusual feature for a shallow depth event of magnitude 7.8 with a surface fault break of 100km; it would repay further study. Recent work (12) on seismic wave propagation models may shed light on the distribution of strong motion.

There is some evidence from the lack of observed damage to the east or upthrow side of the fault that motions were less intense there. However, the low population density and the difficulty of access to the area, especially after the earthquake, makes this a tentative observation.

The absence of any strong motion instruments in the area to record the earthquake motions will seriously hamper the efforts to draw appropriate conclusions from the event and to improve performance in the next great earthquake which is likely to strike the Philippines in the foreseeable future.

13.2 Structural Damage in Baguio

The scale of damage in Baguio can be attributed to well understood defects in conceptual and detailed design, and in construction. These were particularly the following, which are further discussed by Booth et al (25).

i) Inadequate confining steel and other aspects of poor reinforcement detailing,

ii) Inappropriate structural form, including soft storeys, strong beam/weak column structures and torsional eccentricities.

iii) Inappropriate detailing of blockwork infill leading to unintended soft storeys and torsional eccentricities and to dangerous 'short columns' above the tops of partial height blockwalls.

Although ground settlements were observed around many of the damaged buildings, these were not considered by the EEFIT team to be the primary cause of structural failure in most instances.

It is expected that more comprehensive surveys than that performed by EEFIT will confirm this and will support the conclusion that had the buildings conformed to the current requirements of UBC (4), the scale of the damage would have been very greatly reduced.

Nevertheless, it is also clear that intense motions did occur at Baguio and that they were predominantly of medium to long period, because structures with natural periods in this range were the ones primarily affected. It seems that there may have been some amplification in this frequency range due to local effects at Baguio in a manner usually associated with deep deposits of soft soils. There are few data on the soils at Baguio; they are understood to comprise heavily weathered rock to a depth of between 0m and 50m. The fact that steep slopes exist at Baguio rules out the presence of very soft deposits of muds such as caused long period amplification of motions in Mexico City in 1985 (13) or in San Francisco Bay in 1989 (8). Other reasons for the possible amplification must therefore be sought.

The lack of instruments to record ground motion at Baguio makes it difficult to postulate a solution. It may be speculated that topographical effects played a part, whereby the steep hills in the town acted as local resonators amplifying certain frequencies. Topographical effects have been observed in previous earthquakes and definitively measured in Chile in 1985 (14), where increased motions on the ridge of a hill in Vina del Mar were found. The recent French code AFPS:90 (15) gives advice on ridge effects. In Baguio, the Hyatt Terraces Hotel was near a ridge, but other collapsed buildings were on the sides of slopes (for example, the University of Baguio and FRB Hotel) or near the bottom of slopes (for example, despite its name, the Hilltop Hotel). If topographical effects were influential at Baguio, they appear to have been complex and it is certainly important to study them further, since they have important implications not just for future construction in Baguio, but also in similar mountainous terrain elsewhere. The first step would be to establish a network of strong motion instruments or broad band seismometers in and around Baguio to record response to the minor earthquakes that may be expected in the immediate or near future.

13.3 Structural damage at Agoo

The nature of damage at Agoo was in striking contrast to that at Dagupan. In the latter town, there were extensive signs of liquefaction, as discussed in Section 14.3, which without doubt caused most of the damage by giving rise to foundation movements. In Agoo, there was no sign of liquefaction or foundation movement, despite being on flat (almost certainly alluvial) ground with a high water table, close to areas which had liquefied. Shallow deposits of soil overlying rock, which may well have been present at Agoo, are known to amplify the underlying rock motions by factors up to 5 at short periods (16). It can be postulated that this occurred at Agoo, but that conditions were not such that liquefaction took place. Investigative boreholes at Agoo accompanied by simple site response analyses would help to resolve this.

13.4 Structural damage at Manila

The earthquake was strongly felt in Manila, which lies 100 km from the causative fault, but there was little structural damage. The absence of strong motion instruments does not allow an exact comparison with the design intent of UBC, which is effectively the governing code of practice for earthquakes in the Philippines. However, some comparison can be made with the Zone 4 requirements of UBC, which are intended to result in negligible structural or non-structural damage for 40%g PGA (peak ground acceleration) and survival against collapse in motions 2 to 3 times as large (17).

Eyewitness accounts (Appendix D) suggest an intensity at Manila of V, which would correspond to an acceleration of about 5 to 10%g (18). Ground motion attenuation data from other earthquakes would suggest a peak ground acceleration of around 3% to 5% on stiff soils or rock (19). However, some of Manila is underlain by fairly deep soft soil deposits. The question then arises as to whether these might have been sufficient to increase the motions locally to damaging levels, just as the soft clay underlying Mexico City did during the magnitude 8.1 earthquake of 1985, which was about 300 km from the rupture zone.

A simple site response analysis was performed using the program SIREN (20). The soil properties were taken from real borehole data for two sites in downtown Manila. Site A was on 32m of soft clay, which is around the maximum depth to bedrock in Manila; Site B was on 15m of soft clayey sand. A peak rock acceleration of 5%g was assumed. The requirements of UBC:88 for a soft soil site, type S3, were also calculated for Zone 4, which applies to Manila. In fact, the deeper site would have been classified as the more onerous type S4, for which a site specific soil analysis is required by SEAOC (9).

The results are plotted on Figure 13.1. It can be seen that, even for the most critical frequency, the UBC requirements are three times greater than the calculation motions for the 1990 earthquake at the deep site. The shallower site and the bedrock had a much lower response.

It can be seen that this earthquake was not the most onerous test of buildings in Manila, which suffered much more devastating effects in 1645 and 1863 and will at an unknown but inevitable date in the future be subjected to ground shaking much more intense than in 1990. There are well founded concerns that some of the construction in Manila is of the same inappropriate standard as that of the buildings that collapsed in Baguio; any such substandard Manila buildings would be bound to suffer a similar fate unless appropriate strengthening measures are taken.

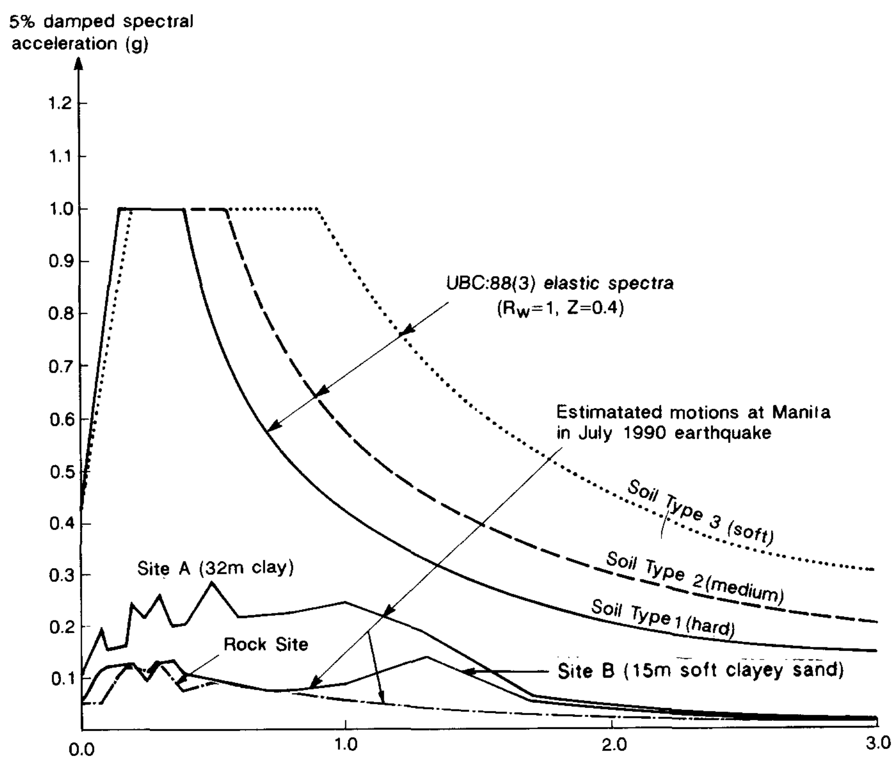


Figure 13.1 Comparison of UBC:88 Spectra
with estimated ground motions at Manila for the July 1990 earthquake
(from Ove Arup & Partners internal report, December 1990)

14.0 DISCUSSION OF GEOTECHNICAL ASPECTS

14.1 General

Except at Baguio and Agoo, the effects of landslides, liquefaction and fault movement caused far more damage than did strong ground motion. This was particularly true for the effect on the road network in the north of the Central Plain and the adjacent mountains. The disruption and damage to the road network was probably the most important economic consequence of the earthquake, although the greatest loss of life is likely to have been caused by collapsing buildings in Baguio and elsewhere.

14.2 Slope stability failure

The dangers of building on unstable slopes in seismic regions are well known and were warned against over 100 years ago by the great Irish seismologist, Robert Mallet (21). The EEFIT team observed a few examples of simple domestic buildings in Baguio which had slid on unstable slopes and were severely damaged. However, the instances of ground movements observed near some of the failed engineered structures in Baguio were not thought by the EEFIT team to be a primary cause of the building collapse.

It is reported (1) that building failure due to landslides also occurred in the mountain villages around Baguio. However, the extent of damage appeared lessened by the fact that slope failures are a frequent occurrence in the mountains, even without earthquakes. The most unstable locations have therefore probably been avoided as a result of previous experience.

The major effect of landslides was in blocking roads. Building roads through mountain terrain such as that of north Luzon will always carry the problem of landslide blockage; in the absence of earthquake, the most cost effective strategy may well be to clear slides as they occur, rather than undertake very expensive countermeasures such as tunnelling or building protective shelters. The additional problem in seismic regions is that a very large number of slips can occur at the same time, as happened in this event, overwhelming the ability of the clearing services to cope at a time of general emergency. Multiplicity of routes is not necessarily a solution; Baguio with its four access roads was still completely cut off to road traffic for 3 days.

The great economic impact of this earthquake on the road network should lead to a review of the strategy for coping with road blockages, particularly for roads of national or strategic importance.

14.3 Liquefaction

14.3.1 Liquefaction potential in the epicentral area

The high erosion rate of the Cordillera Central mountains, the heavy rainfall in the area and the very flat terrain through which the rivers draining the mountains pass on their way to the sea all make for ideal conditions for the deposition of liquefiable soils in the northern Central Plain. Hence, the widespread liquefaction that occurred there was to be expected. Liquefaction occurred up to about 60km from the source zone of the earthquake; Ambraseys (22) reports that liquefaction is generally found at a radius of up to 100km from earthquakes of similar magnitude, so the geographical extent was also predictable.

However, it cannot be assumed that the soils which liquefied in the northern Central Plain will not be liquefied again in the foreseeable future, even if they were densified by this earthquake. This is for three reasons.

i) The high pore water pressures which can cause liquefaction create a situation in which the soil particles in upper soil layers are effectively suspended temporarily in the surrounding pore water, while the underlying layers densify. As these pore water pressures dissipate, the soil particles in the upper layers settle out in what may be a fairly loose state. Therefore, despite the tendency of ground motion to densify soils and hence reduce their potential for liquefaction, it cannot be assumed that the soil layers which liquefied in this event were sufficiently densified to prevent liquefaction from occurring in future earthquakes.

ii) Deposition rates in certain areas, such as river outlets, may be sufficiently high that further liquefiable deposits might build up again within a generation or two.

iii) The distribution of ground motion in this event is not well understood and it is possible that certain areas which did not experience ground motion sufficient to liquefy them in 1990, due to focusing or other local effects, might be more severely shaken by another earthquake in the same general area but with a different precise location and frequency content.

Other areas in the Philippines not affected by the 1990 earthquake also have high liquefaction potential. Liquefaction is therefore bound to continue to be a problem that the Philippines must face in the future. Production of regional maps of liquefaction potential, although requiring considerable effort, could prove a valuable aid to regional development planning.

14.3.2 Liquefaction effects on bridges

The loss of a number of bridges due to liquefaction induced foundation movements was a major factor in the effect of the earthquake on the road network. At least some of the bridges affected were built in the 1950's when the phenomenon was poorly understood. It is now generally possible with the aid of borehole data to predict the likelihood of liquefaction with some confidence (23). It would be advisable to check the condition of bridges founded on alluvial deposits, particularly those of national or strategic importance, where it is not known whether appropriate measures were incorporated into the original design and construction. Remedial measures may be difficult but a planned programme of replacement would usually be preferable to loss of a major bridge during the crisis of a great earthquake. Prevention of large foundation movements due to liquefaction may not be possible in all cases, but other measures may be possible. For example, bearings could be designed to prevent loss of support to bridge decks in the event of large foundation movements, to ensure at least that the bridge is passable to relief traffic, after these movements have occurred. Appropriate statutory measures should also be in place to govern new construction.

14.3.3 Liquefaction effects on housing and services

Other than its effect on the roads, the adverse consequences of liquefaction were threefold.

i) The foundations of many buildings taller than one storey failed.

ii) Significant general settlement of the land occurred, which proved disastrous for low lying areas near the sea and large rivers.

iii) Underground services, particularly water and sewage, were damaged.

Taking these three in turn, the foundation failures in Dagupan illustrate the dangers of building without adequate site investigation and geotechnical design. With such measures, many sites on liquefiable soils can support buildings with a reasonable measure of safety and particularly difficult sites can be identified and, if possible, avoided.

The large general settlements which occurred in this earthquake were a notable feature and serve as a reminder of a further hazard when building in liquefiable areas.

Underground services can be made more earthquake resistant by the use of flexible joints with positive connections; a number of proprietary systems exist. However, services could not be expected to survive where they were connected to buildings which suffered gross foundation movements such as in Dagupan.

14.3.4 Future measures for dealing with liquefiable areas

Green field sites with Dagupan's potential for liquefaction are clearly best avoided for development, if this is possible. It is much harder to decide whether a thriving existing community with a well-developed infrastructure such as Dagupan should be relocated because of its liquefaction problems. In the short term, it may be prudent to prohibit new development in the area unless appropriate liquefaction resistant measures are taken. However, such restrictions are probably best avoided for immediate repair work, in order to revitalise the local economy as quickly as possible. In the longer term, a review of the present liquefaction potential of the soils, structures and underground services in Dagupan should be undertaken. This review should be extended to other towns on the Gulf of Lingayen, including towns such as Lingayen which were not affected in the 1990 earthquake.

14.4 Fault movement

The size and extent of the surface faulting in this earthquake are seldom observed and will make the event remarkable for that fact alone. The effect of the faulting in disrupting the lifeline facilities of roads and bridges was significant and unsurprising. Its lack of effect on the one canal and levee that EEFIT observed it to pass through is notable. Even more noteworthy is the general lack of damaging strong motions near the fault at Rizal. This is in contrast to Californian practice and experience, which is to uprate the potential for strong motion in the vicinity of major faults. These features may result in some re-evaluation of the seismic hazards associated with faults, although some of them are certainly specific to this particular earthquake and will not necessarily apply to other events.

15.0 ECONOMIC LOSSES AND CONSEQUENCES

15.1 Introduction

Property losses to all residential, commercial establishments and agricultural installations is estimated to have exceeded 15 billion pesos (US$500 million), but the estimated cost of reconstruction and associated development will be at least three times that at 50 billion pesos (US$1.5 billion).

Physical damage was generally confined to localised pockets, except in the highland provinces of Benguet and Nueva Vizcaya, where it was extensive. The nation's capital, Manila, although badly shaken, suffered only light damage.

The destruction caused by the earthquake is having serious repercussions on the lives and economic activities of not only the population of the earthquake-affected areas but of Filipinos in general. The disruption of transportation services by the earthquake has had major impact on the Philippine economy. It has choked the flow of goods and supplies for farmers and manufacturers, and cut the agricultural and industrial areas in northern Luzon from their major markets in southern Luzon. As a result, people who barely noticed the seismic event have felt their standard of living decline in its aftermath. The earthquake has increased food prices, unemployment and pressure on the national balance of payments.

The economic losses caused by the earthquake to the production sector far exceeded the cost of repairing the physical damage. The biggest impact of the earthquake came in the form of displaced labour and foregone revenues and opportunities. Labour displacement in industry, trade and tourism has been estimated at 30,000 jobs, a proportion of which may be permanent as a result of reduced economic activities and reduced consumer spending (24).

15.2 Agricultural Losses

In the agricultural sector, destroyed crops, disruption in distribution, displaced labour and losses in production have taken a heavy toll. Rice production, for example, has been permanently reduced by land losses from landslides and erosion, and the non-availability of fertilizer during the planting season due to road failures has reduced this year's yield by an estimated 30%. The damage to irrigation facilities and failures in water supply have caused a decrease in yield of some 12% for about 58,000 hectares of rice lands. Total production losses of around 100,000 metric tons from 97,000 hectares of affected rice lands have resulted in foregone income of 500 million pesos (US$15 million).

Similar losses have been suffered in many other agricultural sub-sectors including vegetable production, fish farming, tobacco production and livestock.

15.3 Effects on Industrial Production

In the industrial sector, destroyed facilities, destroyed distribution networks, and production disruption have been similarly costly. The mining activity in the central Cordillera mountain region constituting nearly 50% of the country's total metallic mineral production, particularly gold, copper and silver extraction is projected to lose about 1.2 billion pesos. Manufacturing industry has been badly affected - most significantly the structural damage sustained in the Baguio City Export Processing Zone - and the concentrations of manufacturing industry in Pangasinan region. Foregone revenues in manufacturing were expected to reach 250 million pesos (US$ 8 million) by the end of 1990.

Tourism revenue is important in localised areas within the earthquake area, particularly Baguio and some of the coastal towns. The impact of the earthquake on future tourism will only become fully apparent in the next tourism season, but estimates are in the millions of pesos.

15.4 Macro Economic Consequences

The earthquake affected four administrative regions (Regions I, II, III and CAR) that between them account for 15% of the domestic economic output of the Philippines and about 32% of the country's total value added in agriculture. The projected impact of the earthquake on the country's output and economy is summarised in Table 15.1. The growth of Gross Domestic Product in 1990 is expected to drop by between 1.2 and 1.5 percentage points from the pre-earthquake forecast of 4.8%. With the tightening of the food supply as a result of transportation bottlenecks between farm and market, the price of food items in Manila increased to an annualised 16.5% in July from an annualised 13.5% inflation rate in June. The food supply has decreased since June and the consumer price index for 1990 is expected to increase from original estimates of 11.7% to 13.4 - 14.0%. The earthquake is also likely to have a significant effect on the balance of payments. Prior to the earthquake, the Philippines was projecting a balance of payments surplus of US$418 million for 1990. This reflected, among other things, substantial debt rescheduling and new financing. After the earthquake the projected surplus is expected to decline by US$73 million. Export growth is expected to lag as a result of the disruption in production activities in Baguio, in the mining production in Benguet and from projected drops in the number of foreign tourists.

	Annual Percentage Growth			
	1989	1990 Estimate		
		Pre-Earthquake Low	Post-Earthquake High	Post Mid East Crisis
Gross National Product	5.1%	4.8%	3.2%	3.6%
Gross Domestic Product	5.6%	4.3%	2.8%	3.1%
Exports	8.3%	7.8%	1.9%	3.3%
Imports	5.1%	9.6%	3.1%	4.9%
Consumer Price Index	10.6%	11.7%	13.4%	14.0%
Unemployment Rate	9.2%	10.0%	11.1%	10.6%

Table 15.1

Macro-Economic Effects of Earthquake of 16 July 1990 on Philippine Economy

16.0 CONCLUSIONS

1. The causes of life threatening failure in the buildings studied by EEFIT appeared in all cases to be due to well understood deficiencies in design and construction (25). In particular, these were:

i) Inadequate provision of confining steel and other defects in reinforcement detailing.

ii) Inappropriate structural forms, particularly soft storeys and plan eccentricities.

iii) Poor detailing of infill blockwork leading to unintended soft storeys and torsional eccentricities and to dangerous 'short columns' above the tops of partial height blockwalls.

2. The defects noted above are well treated in current codes of practice, including the Philippine code NSCP and the US code UBC:88. No major shortcomings in those codes were revealed by the earthquake for the types of building in the earthquake area. The most urgent need is therefore not to improve the codes themselves, but to improve understanding of them and to ensure that they are enforced.

3. These defects are considered to have been the major cause of building damage in Baguio where ground failure appears to have played only a minor role. Nevertheless, it appears that intense, medium to long period motions were present at Baguio and that short period motions were of lower intensity. The reasons for this are not clear and are certainly different from the type of site effects associated with deep soft soils, for example in Mexico City and San Francisco Bay. It may be that the steep topography of the area caused these apparent local amplification effects. This phenomenon is scarcely discussed by current codes of practice and needs study.

4. One of the major effects of the earthquake was disruption to the road network. This was not directly due to the effects of strong ground shaking causing structural damage but to the secondary effects of landslides, liquefaction and fault movement.

5. The extent of liquefaction in the earthquake was predictable and is likely to occur again in the Philippines. The liquefaction resulted in bridge and building failures due to gross foundation movements and also disrupted underground services. Measures to assess liquefaction potential are well established (23); if it is not possible to avoid sites with a liquefaction potential, design measures are beginning to become available to prevent gross foundation movements due to liquefaction or to cope with their consequences, although such measures are still under development. Liquefaction is not directly discussed in current Philippine or US codes.

6. The importance of landslides, liquefaction and fault movements in this event emphasises the need for proper geotechnical advice for major projects in earthquake regions, including the whole of the Philippines.

7. The general lack of damage in Manila in the 1990 earthquake is no guarantee of good performance in future earthquakes, because it is likely that the 1990 intensity of shaking will be considerably exceeded in the lifetime of the current building stock.

8. The apparent low intensity of ground motions around the surface fault break at Rizal was an unexpected feature of the earthquake which would repay further study.

17.0 RECOMMENDATIONS

17.1 General Recommendations for International Action

1. Further research is needed to investigate the possibility that topographical effects amplified medium to long period motions in Baguio. Establishing a network of strong motion instruments or seismometers in and around Baguio would probably yield enough data to help resolve this in the space of a few years. This is necessary to formulate appropriate design advice for inclusion in codes of practice.

2. The consequences of liquefaction during the 1990 earthquake have highlighted the need to make available more widely to engineers in the Philippines and elsewhere the established methods of determining liquefaction potential. An international effort is also needed to develop and disseminate further the techniques to limit the consequences of soil liquefaction.

17.2 Considerations for the Philippines

1. Existing major bridges in alluvial areas of the Philippines, particularly bridges of strategic or national importance, should be checked for their vulnerability to liquefaction; conventional borehole data would be required. This would enable a planned programme of strengthening, replacement and other appropriate measures to take place if found necessary. Checks for liquefaction resistance should be made mandatory for new bridges.

2. A long term review of the risk of liquefaction and the consequential vulnerability of buildings and infrastructure should be conducted for the soils underlying Dagupan and other towns around the Gulf of Lingayen, including Lingayen.

3. The vulnerability of the trunk road network to blockage by landslides in mountainous regions of the Philippines should be assessed and appropriate measures taken.

4. A more general network of instruments to record strong motion in future earthquakes should be installed in the Philippines, since it would prove invaluable for the learning process from the earthquakes that will inevitably strike the Philippines in coming years. The present recommendation in the Philippine code to install accelerometers in buildings over 14 storeys has previously not been followed. Measures are also required to ensure that accelerometers, once installed, are regularly maintained.

5. Borehole data should be obtained for a few sites in Agoo and more extensively in Baguio and Dagupan, both for studying the 1990 earthquake and also for assisting with the planning of new developments in those towns.

6. In Manila, consideration should be given to the following:

   - Investigations should be conducted and subsequently publicised of the liquefaction potential of loose soil sites in Manila, particularly on reclaimed land.

   - Public buildings which were damaged by the earthquake should be used to open up debate on the strengthening of earthquake damaged and other potentially vulnerable buildings.

7. The UBC (4) requirement for a specially qualified inspector who reports to the designer to provide continuous inspection of the construction of concrete moment resisting frames should be implemented. The SEAOC [9] recommendation for independent 'peer' reviews of design and construction in seismic areas should also be adopted as standard practice for major projects.

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25. Booth E.D., Pappin J.W. and Scott D.M. Engineering for earthquakes in the Philippines. Ove Arup & Partners, Hong Kong, 1990.

APPENDIX A: Itineraryof the EEFIT team

Figure A1 shows the route taken by the EEFIT team.

Tuesday 31 July 1990

Team arrives in Manila.

Wednesday 1st August

Discussions in Manila with various parties, including Philippine Institute of Volcanology and Seismology, First Pacific Land (Phils) Inc and New Zealand investigation team. Preparation for field trip

Thursday 2nd August

Further discussions in Manila, including with Bureau of Design, Department of Public Works and Highways, local architects and engineers, Information department of Asian Development Bank, Professor Reyes of the University of the Philippines. Further preparations for the field trip.

Friday 3rd August

Start of field trip. By Ayala Corporation helicopter to Baguio. Arrived Baguio 9:00am. Entire day until dusk spent inspecting buildings in Baguio. Night spent in Baguio.

Saturday 4th August

First part of morning spent inspecting Nevada Hotel and Baguio Export Zone. Brief meeting with Dr Newhall of US Geological Survey. By Ayala Corporation helicopter to Agoo arriving 9.00am. Inspection of Agoo by foot and thence by pedicab to Alaska. Return to Agoo, and left by helicopter for Dagupan arriving soon after 1.00pm. Received by representatives of Dagupan Lions Club; inspection of town. Night spent at Dagupan.

Sunday 5th August

Transferred to Toyota landcruiser and did further brief tour of Dagupan. By road via Malasiqui, Bayambang, Carmen, San Jose to Cabanatuan inspecting damaged bridge sites etc en route. Spent night at Cabanatuan where discussions were held with Drs Pearce and Bicknell of US Geological Survey.

Monday 6th August

By road to Rizal. Arrived 8.00am and spent 3 hours touring the town. Returned to Manila by road via Cabanatuan.

Tuesday 7th August

Various presentations to groups in Manila on the findings of the EEFIT team. Discussions with Professor Reyes of University of Philippines and Dr Hopkins and Mr Clark of the New Zealand team.

Wednesday 8th August

Visit to San Agustin Cathedral, Manila to inspect damage. Afternoon free.

Thursday 9th August

Discussion with Mr de Gracia, Association of Structural Engineers of the Philippines. Team flew out of Manila in the afternoon.

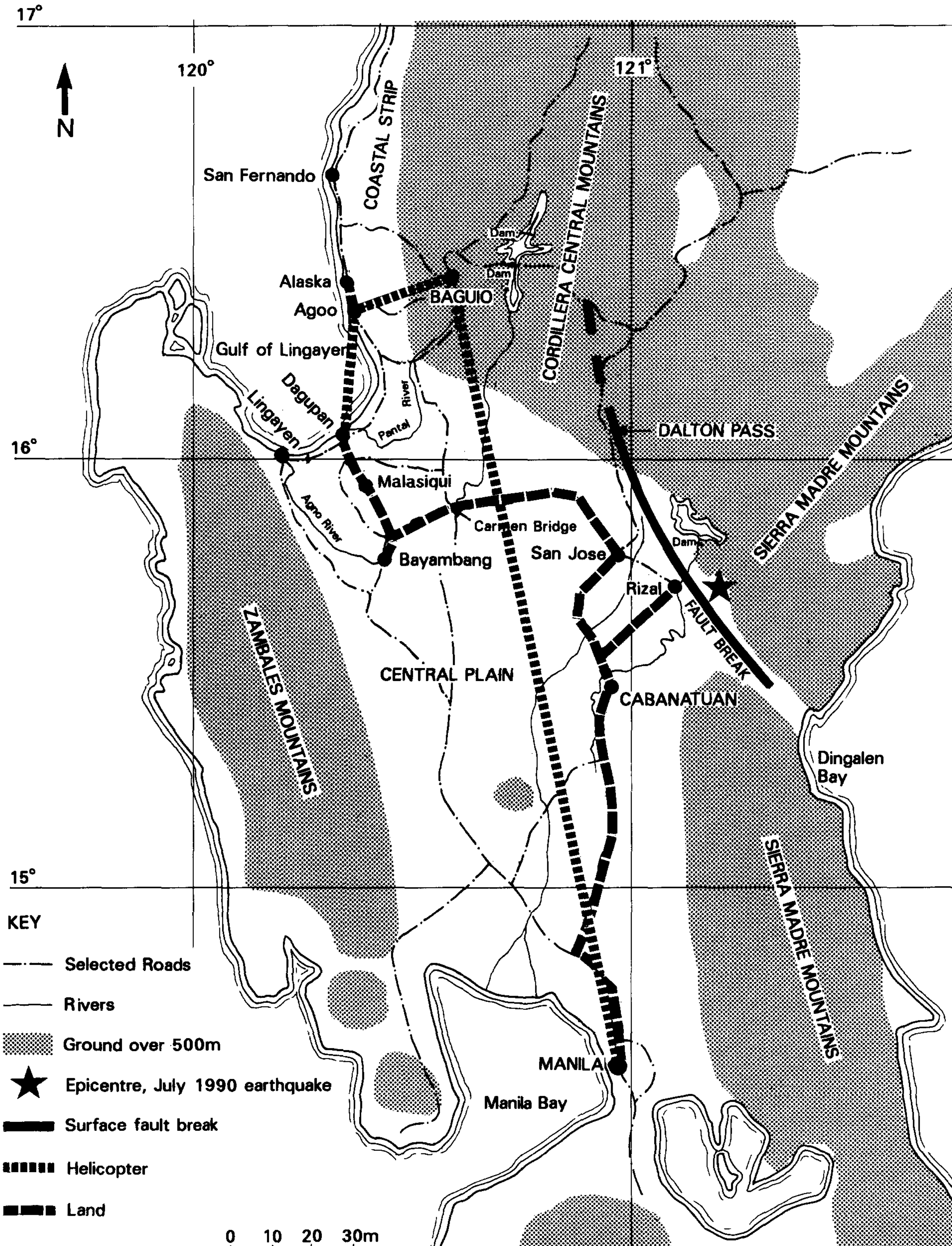

Figure A1 Route taken by EEFIT team

APPENDIX B: Equipment listof EEFIT team

The following proved generally adequate, given the objectives of the team, which were to carry out a non-specialised primarily visual survey, and given the terrain, and the fact that many facilities of normal urban life were available, and that normal life and communications were still continuing without severe disruption in most places.

General

- Notebooks, pencils, erasers
- Two 35mm SLR cameras with 35/105 zooms
- One automatic compact camera with flash
- Ten rolls of 36 exposure Kodak gold 100 ASA colour slide film per person, plus two rolls of colour print film. (NB: black and white print film can also be useful for high quality b&w prints for reports etc.)
- 7 x 20 Binoculars
- Pocket tape recorder for note taking
- Penknife
- Small screwdriver
- Small adjustable spanner
- Miniature hacksaw
- 3m tape
- Small spirit level
- Pocket compass
- 1:500,000 air survey maps
- Hard hats
- Flashlight
- 40 single A4 sheets, explaining the basis of EEFIT and the personnel and objectives of the mission. These were in English, the official language which is widely spoken.

Medical

NB: these notes may be of use for basic first aid needs, but of course are no substitute for proper medical advice related to a particular destination.

- Soluble aspirin packs
- Throat lozenges
- Individually wrapped adhesive dressings
- 'Dettol' (dichloroxylenol) antiseptic solution for external use
- Glucose tablets, as emergency rations
- Malaria prophylactic tablets
- Hand and arm bands impregnated with insect repellant. (These were in fact not used, but are light and of low volume and could have been useful if insects had been prevalent).
- Diarrhoea tablets. Immodium proved the most effective treatment.
- 3 sachets of rehydrating salts per person (more would have been preferable).
- Water bottle (NB: for this climate, a 1 litre bottle per person would have been ideal).
- Water sterilising tablets. (NB: bottled water was fairly readily available. We were drinking about 2 litres per person per day in transit. The tablets are said not to be completely reliable; the MASTA water filter, available from the London School of Hygiene and Tropical Medicine, is probably preferable).
- One MASTA emergency medical kit per person, which includes dried blood plasma.

APPENDIX C: Catalogue of slides taken by EEFIT team

Copies of any of these slides and of the photos reproduced in this report are available, at cost, by application to EEFIT (address on back cover).

HYATT TERRACE HOTEL & APARTEL, BAGUIO, 3 AUGUST 1990

HT1-7	From the air.
HT8-37	From the ground.
HT8-9	West wing and apartel, from west. Note core of sloping central section of hotel projecting at back.
HT10	West wing, from west.
HT11-14	Apartel, from west. Note miners digging for bodies.
HT15-16	Apartel from south, showing shear wall. It is understood that the apartel consisted of 4 rectangular blocks in plan grouped around a core.
HT17-18	Column details in apartel. 32mm deformed bar; note some of it is rusty. 10mm diameter links approx. at 250mm centres approx.
HT19	Looking north to eastern half of central section of hotel, which has survived. Note central core behind. Apartel is to left of photo.
HT20-22	Looking east to east wing of hotel. One column has buckled at about 2nd floor level.
HT23-24	East face of east wing of hotel. Note sheets used to escape from hotel.
HT25-26	Buckled column on east face of east wing. Location probably is opposite buckled column of HT20-22.
HT27-29	North end of east wing. Some ground movement has occurred.
HT30-31	Front of central portion of hotel. Note that central core remains standing.
HT32-33	Failure of A-frame in central portion. Note failure appears to be on a construction joint.
HT34	Junction of central portion and west wing, from front.
HT35	Tented encampment, to west of hotel.
HT36	Wooden building immediately below (north of) the Hyatt. Only minor non-structural damage was sustained.
HT37	Second wooden building below first, on steep slope with front supported by columns, back sitting on slope. The building was said to be unsafe.

BAGUIO, 3-4TH AUGUST 1990

B1-4	Baguio airport. Note damage to concrete pavement.
B5-13	Baguio from the air.
B13-17	Baguio Park hotel, NE of Burnham Park. 7 storey r.c. building; 1st storey apparently survived. Neighbouring buildings up to 5 storeys are very close but suffered no apparent damage, apart from local impact damage to building on west side (B17).

B18-19	Tents in Burnham Park and near town hall. We saw at least 3 tented encampments using inadequate makeshift tents.
B20-22	Building under construction on corner of Magsaysay Avenue and Harrison Road with prestressed post-tensioned concrete cantilever beams projecting about 2m. There was no sign of distress in the cantilevers but there was severe cracking at 2nd floor level.
B23-24	Shopping centre opposite above. Tiles were dislodged from the roof by the earthquake but there was apparently little other damage.
B25	Abanao Street. About 7% slope. Low rise concrete frame/masonry infill shops, with no separation. Few visible signs of damage; about 10% have minor to moderate superficial cracks. No piles of rubbish from collapsed ceilings, etc., to be seen outside.
B26	Town Hall, an imposing 2-3 storey masonry building on top of a hill with no sign of any kind of damage. It was fully occupied.
B27-28	Baguio police station. Entrance canopy survived, roof mounted tank has failed. No other signs of damage.
B29	Unstable looking slope on Kayang Street which had not moved in earthquake. 1 and 2 storey shops on the street had been little affected by the earthquake.
B30-33	Hilltop hotel - total collapse of approx. 6 storey r.c. building.
B34-50	Buildings on Gen Luna Avenue.
B34-36	Building on corner of Magsaysay Avenue and Gen Luna. Severe cracking in corner column.
B37	FRB Hotel and University of Baguio, from the air.
B38-40	University of Baguio. 9 storey r.c. frame building with block infill, about 10 years old. 5th floor collapsed; there was no obvious discontinuity at this point.
B41-45	FRB Hotel. R.C. structure with rectangular lower 2 storeys which had collapsed under upper cylindrical 4 storeys which appeared to have survived.
B46	St. Louis University Elementary High School. 5 storey building with some cracked glass and infill masonry but no other apparent sign of distress.
B47-50	5 storey r.c. building opposite previous, with deep cantilever at second floor level. Severe damage.
B51-52	Church of Jesus Christ of the Latter Day Saints. Solid 2 storey r.c. building 3 years old. Minor superficial damage to cladding and suspended light fittings at one end; otherwise, no damage.
B53-58	Buildings to be identified.
B59-60	Damage to chimney pot in residential house above Hyatt Terraces Hotel. Other similar house showed generally minor damage.
B61-69	Hotel Nevada. 4 storey structure in front, in which the ground floor had collapsed and a 6 storey structure behind, probably connected, which suffered a partial collapse of the lightweight corrugated iron roof.
B70	There was a retaining wall to the right of the hotel, and the ground had moved a few centimetres. However, this did not appear to be the primary cause of collapse. An adjacent 3 storey building had suffered damage in its soft storey.
B71	Baguio Export Production Zone.
B72-76	Arax factory, in the production zone. 3 storey r.c. building with pancake collapse. Fire had broken out a few days after the earthquake.

B77-80 Possibly similar building opposite. This was said to be on a shallow cut, while the Arax building was on shallow fill. This building suffered column failure where the infill blockwork stopped short of the beam soffit. The confining steel appears to have prevented catastrophe, though the building was said to be propped inside.

B81 Our transport in Baguio (a jeepney).

B82 Helicopter at Baguio airport.

B83-90 Flight down 'Kennon Road' valley out of Baguio, 4 August 1990. The road was blocked by many landslips.

B91 Map of Baguio. City of 200,000 with a large student population. Height is 5000ft, on steep slopes of heavily weathered rock. Understood to be undermined by copper and gold workings. Unusually, these conditions appear to have given rise to amplified long period motions which were particularly damaging to medium rise buildings, many of which collapsed. The damage was in almost every case in the superstructure, and was not associated with foundation failure (unlikely the cases of liquefaction induced failure elsewhere).

AGOO, 4 AUGUST 1990

AG1-3 Approaching Agoo. Note very low lying territory, barely above sea level.

AG4-6 Overflying Agoo.

AG7-8 Landing at Don Marcos college.

AG9-11 Single storey classrooms at Don Marcos college. 150 x 60 x 2½ Z section columns supporting c.i. roof with infill precast concrete panels.

AG12 Damage to 2 storey building on Don Marcos campus.

AG13 Undamaged wooden structure with soft storey.

AG14 Soft storey concrete building, near collapse.

AG15-16 Severe damage to r.c. framed structure.

AG17 Ruins of old cathedral, said to have been destroyed by earthquake.

AG18 Newer cathedral, also said to have been damaged.

AG19 Our transport to Alaska (pedicab).

AG20-22 Bridge about 2km north of Agoo. Piers had both moved inwards; temporary wooden shoring had been installed.

AG23 Sand boil in Santa Rosario W, about 3km from Alaska.

AG24-25 Fish and prawn farm, Santa Rosario. Note sand boils to right of picture.

AG26 Ditto. Note proximity of mountains.

AG27 Alaska. This was a village of 400 families, on the mouth of the river. The land was said to have been formed by silting. All the single storey houses were said to have been destroyed by the earthquake; in addition, the land sank, flooding the village and adjacent paddy fields with salt water. The settlement was said to be 1m, though it was not clear how this had been measured. Note that a two storey masonry building is still standing, to left of picture.

AG28 Looking towards Alaska, which was behind the row of palm trees. A few stakes, said to be the remains of the houses, could be seen.

AG29 Mouth of river seen on flight from Agoo to Dagupan, showing silting.

AG30 Flooded land, seen on flight from Agoo to Dagupan. The flooding was caused by settlement following the earthquake.

AG31-32 Electricity substation on main road N of Agoo. The power was supplied by the hydroelectric station E of Baguio. Power failed during the earthquake and was now resupplied to parts of Agoo, though not Santa Rosario. Water supplies also failed; Agoo was reconnected after 3 days.

DAGUPAN, 4TH-5TH AUGUST, 1990

DA1-3 Approach to Dagupan. Note low lying terrain.

DA4 Landing spot at Northwestern Lyceum. Note sand blow on playing field.

DA5-7 3 storey building on Perez Boulevard between Gomezand Rizal Streets which was tilted 15°.

DA8 3 storey building on corner of Gomez St and Perez Boulevard which had sunk substantially.

DA9 Nearby by filling station where tanks had floated to surface. These had now been excavated.

DA10 Building which appears to have settled.

DA11-12 Tilted buildings on Perez Boulevard or A.D. Fernandez Avenue.

DA13 Asiacareer offices: 3 storey and 5 storey buildings immediately east of collapsed Magsaysay bridge on Perez Boulevard. 3 storey building settled substantially; 5 storey building had also tilted. 5 storey building had 20m high mast supported on roof.

DA14 Detail of above, showing building destroyed by land slide on river bank.

DA15 Asiacareer offices: in front of 3 storey building on Perez Blvd looking north. Note settlement.

DA16-18 Asiacareer offices, 5 storey buildings looking south. Note single storey building in front has been dragged down.

DA19 Blown sand outside previous.

DA20-22 Building seen to the left of slide DA16, under construction with no sign of settlement but some signs of distress.

DA23 Collapsed Magsaysay Bridge. Asiacareer offices (out of sight) are to right of picture just on the far side of the bridge. North is top of picture.

DA24-25 On collapsed bridge, looking west (away from Asiacareer building).

DA26 Northwestern Lyceum. Standing in building which appeared to have settled - ground floor slab had lifted relative to walls and there was ponding at this level.

DA27-28 Pounding damage between buildings at Northwestern Lyceum.

DA29-30 Damaged cathedral, caused by strong motion. No signs of settlement or liquefaction.

DA31 Major building opposite above. No sign of settlement. Damage was said to be minor, although the basement had flooded.

DA32-36 Streets in Dagupan. Note water and widespread blown sand.

DAGUPAN-CABANATUAN, 5TH AUGUST 1990

D-C1-3	School building at Malasiqui. Undercroft columns are damaged, particularly at corners. Some evidence of liquefaction in front. Minor isolated signs of damage in the town. We saw a number of other schools of this type, mainly undamaged.
D-C4-14	Bridge over River Agno at Bayambang.
D-C4-7	On east bank of river, with river to right. Bridge has 4 main spans of 40m, with a fifth shorter landspan on east side. Abutment at east end of main spans has rotated and short span has lost its bearing.
D-C8	On east bank. Evidence of slide and possible liquefaction.
D-C9	Under east abutment; river is to left.
D-C10	Short end span, which has lost its bearing. Notice says "Weak bridge load limit 10 tons".
D-C11	East river pier. No sign of distress.
D-C12-13	On west bank. Possible signs of liquefaction but none of settlement or distress in either west abutment or west river pier.
D-C14	Plaque on bridge: USA, 1950. Construction is rivetted steel upstand girder. Each span pinned at one end, sliding at other with simple steel bearing.
D-C15	An old river bridge (disused) about 1km upstream had one pier on east bank rotated through 20° or so.
D-C16-24	Carmen Bridge over River Agno. Very similar construction to that at Bayambang. About 11 spans of 40m. The southern spans pass over a flood plan; the first pier has rotated 5°, the second is almost horizontal and the third has sunk at least a metre. The corresponding decks have been dislodged. The bridge is impassable to wheeled traffic. The northern spans over the river appeared not to have moved.
D-C23	One of a number of sand blows, indicating liquefaction.
D-C24	Piling in progress for a replacement crossing. The river spans appear completely undamaged. The small village of Carmen to the south of the bridge appears undamaged.
D-C25	Bridge between Talavera and Calipahan on San Jose-Cabanatuan road. 3 span bridge of similar construction to previous bridges. Southernmost of 2 river piers has shifted about 200mm south, pushing both piers off their bearings. River span is bearing about 150mm from edge of pier. Bridge is restricted to single line traffic. Preparation works for alternative crossing evident.
D-C26-32	Christian College of the Philippines, Cabanatuan (6th August 1990). 6 storey reinforced concrete frame building, which had completely collapsed. 300mm square columns at base. Much reinforcement in evidence. The building was said to have originally been 2 storey.
D-C30-31	Surrounding buildings were completely undamaged. One has provision for extension.
D-C32	An unsupported wall is left standing - why did it not collapse completely?
D-C33	Pinnacle on a church in Cabanatuan which has rotated; no other sign of damage. This was the only church of this type, of which we saw a number, which appeared damaged. Elsewhere in Cabanatuan, we saw damage (but no collapse) to one corner eccentric, soft storey building but few other signs of damage in this large, busy town.
D-C34-35	Our transport for this part of the trip.

RIZAL, 6TH AUGUST 1990

R1-4	Concrete plant, about 20km S of Rizal. Bracing appeared to have buckled.
R5-6	1km south of Rizal. The town is on the edge of the Manila plain, with hills immediately to the north east.
R7	NW trending main fault line, with 3m left lateral slip, and 1m vertical throw.
R8	Looking along same line.
R9-11	En echelon fault trending SW.
R12	Building on line of main fault, totally destroyed. Adjacent building (background) had some quite significant cracks but was still lived in.
R13	Building standing astride the fault line, damaged but still upright.
R14-21	Rizal Central School.
R15	Undamaged modern block single storey building.
R16	1930's wooden building, severely damaged. About 200m from fault.
R17	Single storey classroom; block cladding collapsed. About 500m from fault.
R18	End block wall had fallen away; parents replaced it with timber stud wall.
R19	More damaged classroom walls (100m from fault break).
R20-21	Building very close to fault break with poorly restrained block wall.
R22-24	Single span 30m long concrete bridge on line of fault break which was totally destroyed. Fault break runs at about 30° to line of bridge, from far left hand side to near right hand side.
R25	An apparently identical bridge, about 1km away and 70m from the fault break appeared completely undamaged.
R26	Fault break 70m from bridge, R25, passing through bank to irrigation river. The bank, although cracked, did not fail.

APPENDIX D: An eyewitness account of the 16 July 1990 earthquake

Thomas Larmour (Ove Arup & Partners, Hong Kong)

Earthquakes, in complete contrast to the typhoons which regularly hit the Philippines, arrive without warning. The tremor which killed more than 1000 people in the Philippines on Monday 16 July 1990 found me sitting in a site meeting in Ayala Avenue, Manila. True to form, our one-storey wooden site hut creaked a little, and it felt as if someone was driving us away, and then slamming on the brakes. The power (and our much needed air conditioning) went down immediately. Within seconds (10 or 20) we had all rushed out, which felt rather like running down the corridor of a train when it goes over the points. Outside we watched two large office buildings sway and eventually touch. They had been built very close together and the separation of only a few inches had been blocked in. The blocks crumbled as the buildings first hit at mid-height (the second mode?) and then again at parapet level. 30 or 40 seconds had then elapsed.

A building still under construction and topped by a tower crane seemed to be twisting; the tower crane, sticking out of a lift shaft and swaying in sympathy was also driven by its concrete counterweight, causing the jib to slew and bounce; was it picking anything up at the time? 50 or 60 seconds had now elapsed.

Telephone wires danced about between their poles, people scrambled down fire escapes and for some reason motorists started sounding their horns. We were in the reinforcement bending section of the site and a bunch of waggling Y16s indicated that the tremor continued; 70 seconds elapsed before the motion ceased.

Within minutes we felt the first aftershock; after two or three stiff jolts, all fell still. The entire event had lasted less than a few minutes with the most serious damage occurring within 20 seconds.

At this stage we knew nothing of the tragedies elsewhere. Telephone and power were knocked out and someone with a radio had no news either. Manila's traffic jams are world-famous and one look outside suggested that waiting or walking was the only answer. I walked to the Peninsula Hotel. There was some rubble in the streets, but no obvious signs of collapse.

The lobby of the Peninsula Hotel was packed, all of the guests having been evacuated from their rooms. A series of announcements followed; the earthquake had registered more than seven on the Richter Scale; Baguio City was thought to have sustained damage; Manila airport was open, but runways were still under inspection, (never mind because traffic couldn't allow you to get there anyhow); power out, phones down, bottled water recommended and lifts definitely out of bounds.

Within a few hours all had returned to a semblance of normality in Manila and the news of the destruction in Baguio started to filter through. There are four routes up through Luzon and all were rendered impassable with landslides blocking the upper sections and bridges knocked off their bearings. Power, drainage, telephones, water supply and local airports were badly damaged.

Earthquake engineering (for me) used to be something about ETABS, codes, symmetry and awkward details; it still will be, but tempered by having seen the incredible forces and extreme displacements that these things generate without any warning whatsoever.