Chapter 3

EARTHQUAKE EFFECTS TO URBAN AREAS AND LAND INSTABILITIES

Although, the extent of earthquake damage to public infrastructure and facilities such as national, provincial and local transportation systems, flood control, irrigation and water supply systems, ports and others, was far more the largest of all sectors (about 50% of the estimated losses), an extreme concentration of earthquake damage to residential and school buildings,hospitals and other public buildings, local transportation,lifelines and communication system has been experienced in the largest populated urban areas such as Baguio, Dagupan, Agoo and Cabanatuan. Only in the three major cities of Baguio, Dagupan Cabanatuan of the earthquake affected five regions of CAR, Region I, II and III, and NCR, the number of casualties is about 45% of total, affected population is 25.1% (322.995 in respect to total affected population of 1.255.248), with collapsed and damaged residential facilities of about 20% of the total number of damaged houses.

It has been demonstrated once more, like in the other recent catastrophic earthquakes in the world, that with further concentration of the population and material goods in the earthquake prone urban areas seismic and other natural hazard risk is rapidly increased, unless consistent and continuous measures and activities are undertaken for protection of these urban areas from the expected natural hazards.

In order to illustrate concentrated effects of the 16 July 1990 Luzon earthquake in urban areas two cities have been selected for this purpose: Baguio City with dominant earthquake damage and failure due to vibrational effects of the earthquake ground motions, and Dagupan City exposed to extensive earthquake damage and failure of buildings and infrastructure facilities caused by intensive liquefaction as dominant land instability induced by the earthquake ground motions on a distance of about 60 kilometers from the causative fault.

3.1. Dominant Earthquake Effects in Baguio City

Baguio district displays features of young geological and geomorphological development. The district is an uplifted terrain being dissected by streams occupied by deep gorges and V-shaped valleys. Baguio city is located on high elevation plateau where it contributes to the city as the summer capital of the country. The city occupies elevations between 1000 and 1500 meters, with central plateau position surrounded by hills and wide valleys at immediate vicinities, deep gorges - incised valleys - steep ridges at the southern city limits and karsted rolling topography at north and west-southwest position of the city.

The Baguio district lies on the southern portion of the tectonically active Cordillera Mountain system which has been dissected by the splays of the Philippine Fault (Fig. 2.3, 2.5, 2.11 and2.13). The Cordillera is flanked in the east by the Cagayan Valley Basin and Carabaldo mountain range at the southeast portion. The Cordillera constitute an arc terrain with western subduction zone located at the west facing Manila Trench and back arc basin occupied by the Cagayan Valley Basin. The mountain system is dotted by quaternary inactive volcanoes (Fig. 2.2)which may have contributed strongly to the physiographic development of the region. The Central Cordillera is cut by the northwest to north-northwest branches of the Philippine Fault in which prominent branch is Digdig Fault, located east of Banquet, passing through Nueva Vizcaya. The 16 July 1990 earthquake with the main shock epicenter near Cabanatuan City had triggered tectonic displacements along the Philippine Fault. Much of the earthquake energy appears to have been absorbed by the fault branches in the Cordillera region, among which prominent Digdig Fault branch had moved along strike for about 6 meters (Fig. 2.9) and the clustering of the after-shock epicenters at La Union - Banquet - Nueva Viscaya area (Fig. 2.11), signify to the seismic activity of the Philippine Fault branches, causing continuously intensive earthquake ground motions in the Baguio district.

The earthquake of 16 July 1990 caused the largest concentration of casualties, damage and failure of buildings and infrastructure facilities in Baguio city area. About 38% of all casualties due to he earthquake are found in Baguio city and 20.9% of the total affected populations, with total or partial damage of more than10.000 houses. Out of the 202 larger buildings for which detail earthquake damage classification was performed (DENR-MGB Task Force, JSCE, 1990) it has been found that 71.6% of the total number of more significant school buildings, hospitals, hotels and other commercial and public buildings were left out of use with total collapse of about 26% of these classified stock of important buildings (Table 3.1-1). Most pronounced failure and damage was associated with hotels and commercial buildings (Table3.1-1), where more than 50% of 63 major buildings (Fig. 3.1)failed in most dramatic mode of pancake failure, ground floor failure, or experienced damage beyond repair, making with 44.4%of moderate to heavy damaged buildings 95.2% out of permanent or temporary use of the total stock of most important buildings for the tourist industry in the Baguio City.

Described dramatic damage and failure of the hotels and commercial buildings and somewhat less pronounced, but still heavydamages observed to the schools, hospitals, public and residential buildings is the result of strong earthquake shaking with maximum estimated peak ground acceleration of

30 - 40%g (JSCE and Midorikawa, 1990), and partially to pronounced landslides and subsidence triggered by the earthquake (Fig. 3.2) as well as to extremely low earthquake resistance of modern reinforced concrete4 - 11 storeys structural systems, which is dominated by the following major reasons:

Structural system: Almost all of collapsed or severely damaged buildings were composed as pure framed structures, with many walls inside the buildings made of unreinforced masonry, heavy floor structures with deep lintle beams (Photos 3.2, 3.3, 3.4, 3.8). All failures are associated with large lateral deformations and plastic hinges formed in the columns of the reinforced concrete frame structures.

Ductility and confinement: In the case of reinforced concrete framed structures, ductility of each member, columns and beams and their connection zones must be maintained. However, lack of development length of main reinforcement and/or imperfect connections are reducing the total ductility of the entire structure. Volumetric ratio of column hoops has been found very small, causing low confinement and buckling of main reinforcement in the collapsed columns.

Deformability capacity: Most of the structures are designed as earthquake resistant controlling only load bearing capacity for rather low shear base coefficient in the range of 5 - 10%. No deformability capacity was controlled for these extremely flexible structural systems.

Unbalanced structural systems: There were many over-hang cantilever elements at upper floors. The unbalanced structures cause abrupt change of rigidity between stories, causing failure of one or two specific floors and progressive collapse of the entire building.

Average damaging effects to the entire stock of buildings could give completely different impression if more systematic damage classification is performed. An example of damage classification based on the data collected for the commercial district of Baguio City by the Japanese field inspection teams (AIJ, 1990) is presented in Table 3.1-2. Out of the considered 190 buildings in the blocks around Session Road it has been found that only 7.4% collapsed and 17.4% experienced moderate to heavy damage, making only 24.8% of total number of buildings not for immediate use. These are dominantly old masonry structures (Photo 4.33) which did not experienced significant structural damage.

Very intensive damage and failure dominantly due to unfavourable soil conditions and inconsistent earthquake resistant design has been observed on the industrial facilities in the Expert Processing Zone in Baguio City (Photo 3.7 and 3.8), where three floor twin industrial buildings, of about 20.000 square meters floor area each, collapsed and the second one was damaged. Similar failures of the industrial and other modern buildings have been observed in the other recent large scale earthquakes in the Philippines (Photo

4.38), thus confirming rather spread inadequate earthquake resistant conceptual design and construction practice in the Philippines, which creates, like in other parts in the world, increase of highly vulnerable structural systems and consequently rapid increase of seismic risk.

Lifelines in Baguio City such as water supply, sewage and electric power system, suffered severe damage. Baguio Water District suffered severe damage to the water sources and pipeline system. However, the city authorities has worked efficiently to restore the water supply system and 75% of services were in order one month after the earthquake. The new sewage treatment plant had no damage, several breaks were found in the sewage pipelines, but in general earthquake damage to the sewage system was rather limited. However, existing leakages and insufficient capacity of old pipes are representing more severe problem. The electric power supply system performed rather well after the earthquake, early restoration is mainly attributed to the insignificant damage of substations and transmission lines

Transportation system: of highways and roads to Baguio City experienced very intensive damage caused by landslides and rockfalls along the sections of Kennon Road, Marcos Highway, Nagulian Road and Halsema Road, remaining closed for a longer period of time, thus creating serious difficulties in the immediate assistance to Baguio City after the earthquake. Additionally, Baguio airport has been damaged as well. The runway and the apron were damaged due to differential settlement and landslide, terminal buildings experienced repairable structural and nonstructural damage. With adequate and careful repair and strengthening design and construction, these buildings could be retrofitted to proper earthquake resistant conditions.

Summarizing the dominant effects of the Luzon Earthquake of 16 July 1990 in Baguio City it could be concluded that most of the highrise buildings of modern 5 - 11 storeys reinforced-concrete structures collapsed in most unfavourable modes of failure exhibiting misconceptual earthquake resistance design typical "one line of defense" of low ductility frame structural systems. Failure of most of these buildings was the main reason for 385 deaths and 1102 injuries representing the largest concentration 38.1% of human casualties out of total in this earthquake. In average, Baguio City experienced significant damage to the residential, schools, hospitals, public and in particular commercial and industrial buildings.

Infrastructure facilities of transportation facilities (highways, roads, bridges and airport facilities) suffered very high damage causing additional penalties to the economy of the country for a larger period than those estimated as direct physical losses.

Lifelines such as water supply, sewage and electric power systems suffered significant damage, which were efficiently restored within relatively short period of time by the impressive work organized by the government authorities. However, it is important to recognize that detail earthquake damage statistics is most important to be established in order to create earthquake damage data base for establishment of hazard related vulnerability functions for buildings by structural types and infrastructure facilities.

It is recommended urgent elaboration of preliminary seismic land capability map which should be a synthesis map of the expected vibrational effects, land instabilities (land slides, rockfalls, subsidence, etc.) and earthquake damage potential of the existing elements at risk (buildings by structural types, lifelines, transportation, power and communication systems) for a return period of 200 years. This seismic land capability map should be based on engineering geology, hydrogeology and geotechnical maps with particular identification of slope ranges and their expected instabilities for the determined levels of the earthquake ground motions by performing of detail seismic zoning of the entire urban area and vulnerability analysis of the existing elements at risk, as well as strong motion instrumentation.

Earthquake damaged buildings should be repaired and strengthened based on the requirements given in an emergency interim building code and corresponding guidelines for implementation of the emergency code. Seismic land capability map and emergency interim building code will serve immediate needs for establishment of the economically justified acceptable seismic risk level based on the criteria developed in accordance with the economic capacity of the Republic of Philippines, and rationalization of the reconstruction programme in the earthquake affected region. Developed technology, methods and techniques could be later extended to other earthquake prone areas in the country and other natural hazards to which Philippines are exposed very frequently.

Table 3.1-1

SUMMARY PRESENTATION OF DAMAGED BUILDINGS IN BAGUIO CITY, DUE TO LUZON EARTHQUAKE OF 16 JULY 1990 (Source: DENR-MGB Task Force, August 8, 1990)

Category of Usage	Damage Category: 1&2 Slight	Damage Category: 3&4 Moderate & Heavy	Damage Category: 5 Severe	No. of Bldgs out of Use (3-5)	Total no. of Bldgs (1-5)	Description of Damage Categories
SB	**1. School Buildings:**					**Damage Categories Petrovski, J., 1983:** 1. None - green 2. Slight - green 3. Moderate - yellow 4. Heavy - yellow 5. Severe - red (See Appendix III) **Comments:** ◦ Most of the presented earthquake damaged buildings are r.c. frame structures. ◦ Typical mode of failure observed in pancake total collapse or lost ground or upper floor. ◦ Main reason of damage and failure is misconceptual earthquake resistant design with one line of defence, no shear walls.
	24 37.5%	33 51.6%	7 10.9%	40 62.5%	64 100%	
HB	**2. Health Buildings:**					
	4 33.3%	6 50%	2 16.7%	8 66.7%	12 100%	
PB	**3. Public Buildings:**					
	5 26.3%	13 68.4%	1 5.3%	14 73.7%	19 100%	
HCB	**4. Hotels and Other Commercial Buildings:**					
	3 4.8%	28 44.4%	32 50.8%	60 95.2%	63 100%	
RB	**5. Residential Buildings:**					
	11 36.7%	11 36.7%	8 26.6%	19 63.3%	30 100%	
Total no. of Bldgs	47	93	52	145	202	
% of Total	23.3%	46.0%	25.7%	71.7%	100%	

Buildings damage classification made by J. Petrovski based on damage description given in the Report of DENR-MGB Task Force as made by the City Engineer of Baguio.

Table 3.1-2
AVERAGE DAMAGING EFFECTS TO THE BUILDINGS IN THE COMMERCIAL DISTRICT OF BAGUIO CITY DUE TO THE EARTHQUAKE OF 16 JULY 1990
(based on data from AIJ, 1990)

No. of Storeys	Damage Category 1&2 Slight	Damage Category 3&4 Medium & Severe	Damage Category 5&6 Partial or Complete Collapse	No. of Bldgs out of Use (3-6)	Total no. of Bldgs	Description of Damage Categories
1	7	1	0	1	8	**AIJ Damage Categories:** 1. No or slight damage 2. Small damaged 3. Medium damaged 4. Severely damaged 5. Partially collapsed 6. Completely collapsed **Comments:** ∘ Earthquake shaking intensity estimated 30-40%g. ∘ Relatively low no. of severely damaged and collapsed bldgs. ∘ Low influence of landslides on bldgs. failure.
2	37	10	2	12	48	
3	47	6	0	6	53	
4	33	3	5	8	41	
5	14	8	2	10	24	
6	3	1	0	1	4	
7	9	1	2	3	3	
8	2	2	1	3	5	
9	0	1	2	3	3	
Total:	143	33	14	47	190	
% of Total:	75.2%	17.4%	7.4%	24.8%	100%	Collapsed and demolished 7.4% of total no. of bldgs. in the district.

Damage classification is made by field teams of AIJ. Selected 3 groups of buildings: along Session Rd down right side from Siesta In. transverse Aurrora Thecter and St.Louis Girl's School; along Gov. Pack Rd. and Session Rd. down left side from Baguio Colleges Foundation to third transverse street; along Arano St., Magsaysay Ave., Assumption and Harrison Rd., above Burnham Park.

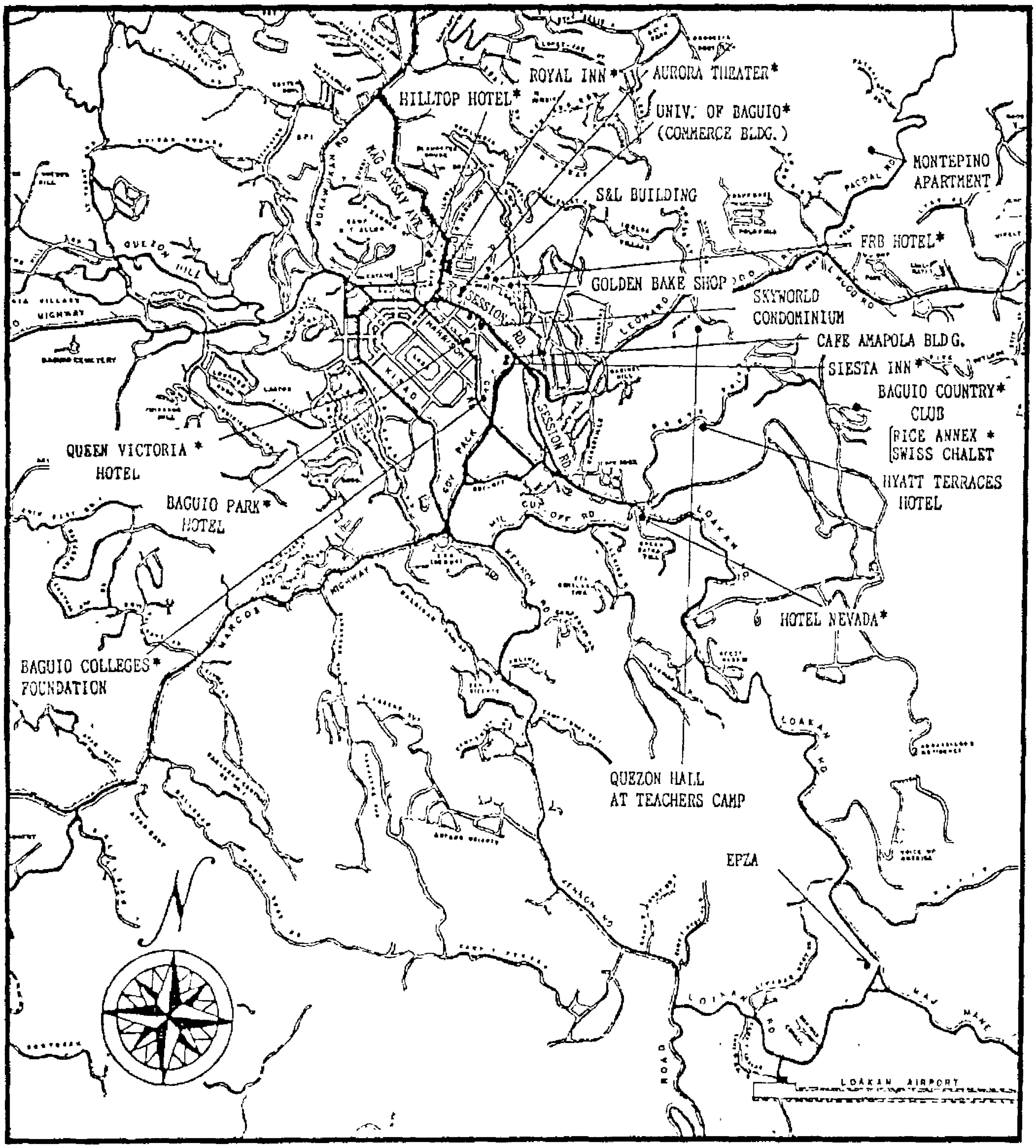

Fig. 3.1 Distribution of modern collapsed (*) or heavily damaged buildings in Baguio City due to the earthquake (from 4, Architectural Institute of Japan; 10 October 1990).

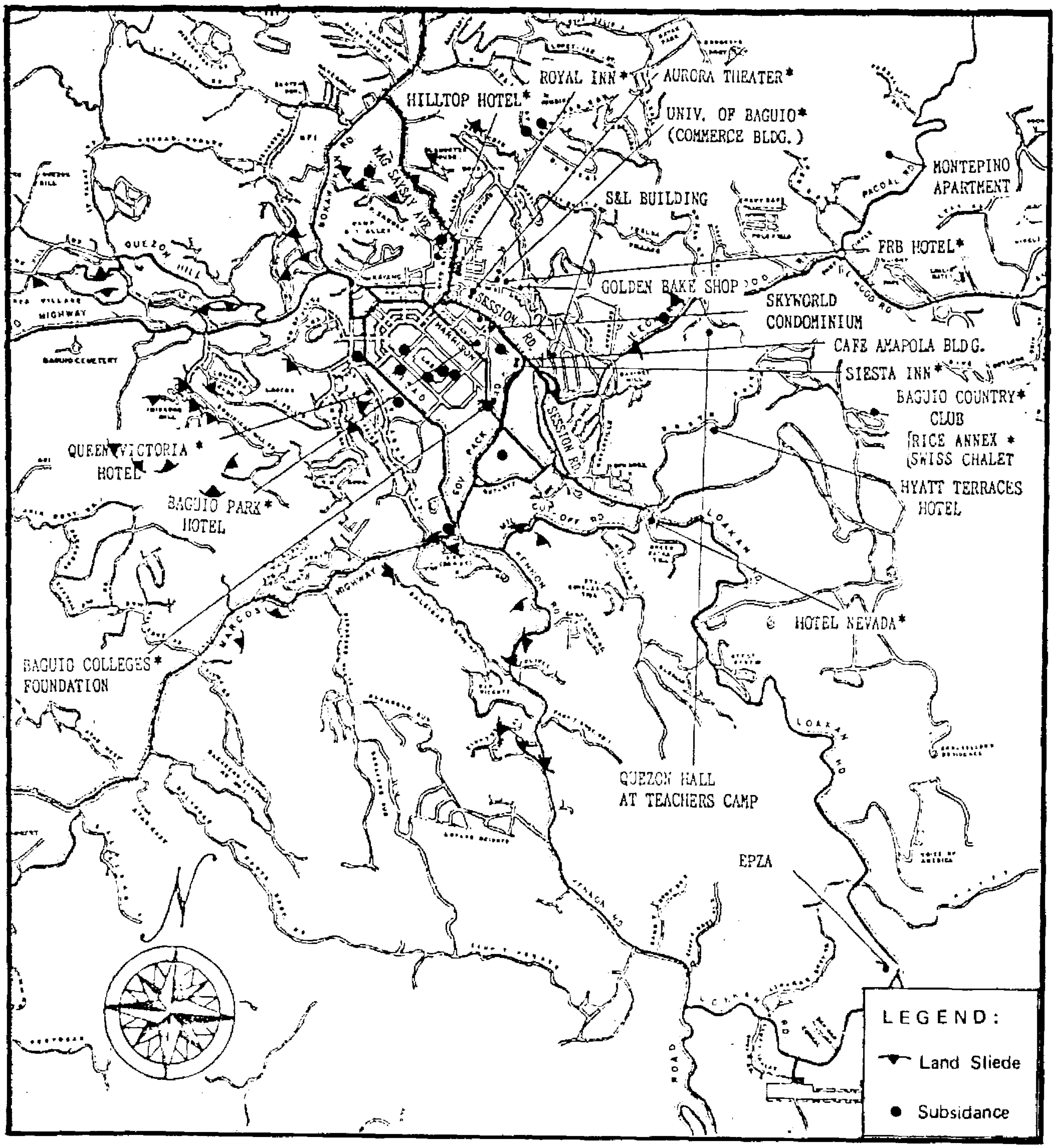

Fig. 3.2 Distribution of sites in Baguio City with observed pronounced land instabilities: landslides; subsidince (from 1, DENR - NGB Task Force, August 8, 1990).

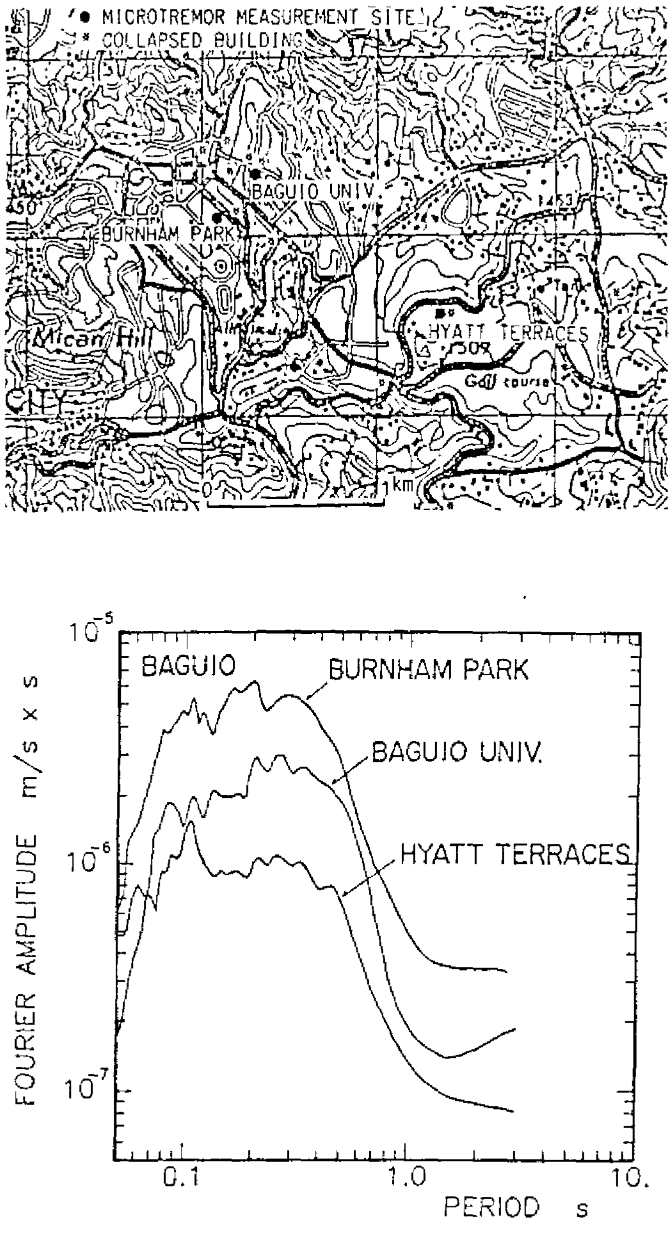

Fig. 3.3 Comparison of Fourier Spectra of microtremors measured at the sites of Burnham Park, Baguio University and Hyatt Terraces Hotel in Baguio City (from Midorikawa, S., 1990).

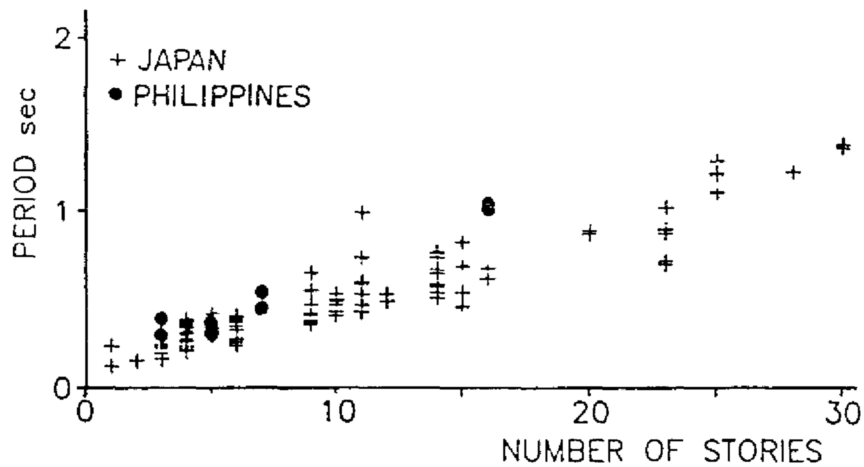

Fig. 3.4 Measured first mode period of vibration of the selected hotel buildings in Cabanatuan, Dagupan, Baguio, and Manila; and relationship of period of vibration with number of storeys of the measured buildings in Philippines and compared with similar height buildings in Japan (from Midorikawa, S., 1990).

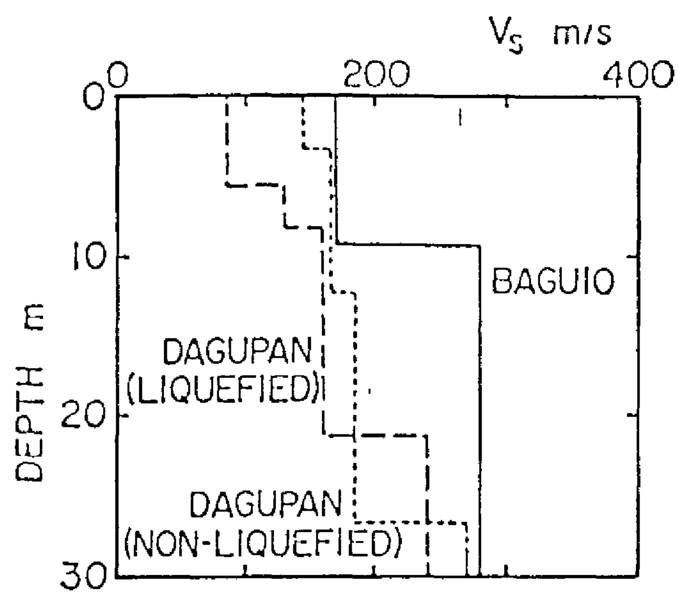

Fig. 3.5 Shear wave velocity profiles in Baguio and Dagupan as measured by AIJ (Japan) field mission (from Midorikawa, S., 1990).

3.2. Dominant Earthquake Effects in Dagupan City

Land instabilities dominated by intensive liquefaction, la: spreading and subsidence induced by the Luzon Earthquake c 16 July 1990 affected wide- spread area of the Centra Plains from Tarlac to the Gulf of Luigayen (Fig. 3.6). Soil liquefaction caused extensive damage to the reinforced concrete and light weight timber houses, damage to roads, bridges, embankment, fishponds and other facilities, out of which the largest concentration of damage has been observed in Dagupan City. Considerable damage to wooden houses also occurred in several towns along the Lingayen Gulf and in the Central Plains. Some of the villages facing the Lingayen Gulf were totally submerged below sea level due to considerable settlements of the ground.

Dagupan City extends over the delta of several rivers which flow into he Lingayen Gulf with an area of about 44 square kilometers. The city has a population of about 110.000. The altitude of the city is only about one meter, and the water table is very shallow. Fifty eight percent of the total area of the city is for fishponds or rivers, 27% for cultivated lands, and only 15% for commercial and residential areas. Thus, commercial district of Dagupan is surrounded by fishponds and rivers.

Figures 3.7 and 3.10 are presenting commercial district of Dagupan City which is bisected by the Pantal River. The figure indicates the approximate zone in which buildings and houses were severely damaged as a result of bearing failure due to liquefaction of its foundation soil. Most of the commercial buildings are concentrated in the area from Burgos Avenue to Del Pilar Street and from Fernandez Avenue to Perez Blvd. By and large, ground sliding or lateral spreading occurred on both sides of the river, making structural damage within the area much worse. The slide which occurred on the right side of the river extended 150 m wide by 300 m long area causing extensive damage to over ten reinforced concrete buildings. Magsaysay bridge on Perez Blvd. over Pantal River with seven spans collapsed due to lateral movement and bearing failure of the piers. The river at the bridge site has been narrowed due to lateral spreading of both side banks of the river. The lateral displacement on the left side of the river appears significantly larger than that on the right side. Thus, at least 5 piers from the left side tilted toward the right. Many wooden houses near the river were found to be submerged.

Over 80% buildings on the left side of the river suffered extensive damage, with buildings on and in the west of Galvan Street from Jovellaros Street to Gomez Street remaining intact. Much of the buildings on Perez Blvd. and me buildings on Fernandez Street settled and tilted considerably, whereas settlement and tilting of the buildings on Fernandez Avenue appeared generally smaller. However, damage to superstructure was significant in many buildings on this avenue. Several reinforced concrete buildings distributed within wooden houses in the south of Perez Blvd. suffered extensive settlement and tilting. Wooden houses in this ar-- were also badly damaged. The ground surface along San Jc Street appeared to have settled as much as 50 cm, due extensive soil liquefaction.

The damage to reinforced concrete buildings on the right side of the river was almost restricted within the sliding zone. Relative settlements of the structures to the ground surface appeared moderate except several buildings near the river. Many wooden structures including two schools were significantly damaged in the south of Perez Blvd. The playgrounds of these schools were largely covered by ejected black fine sand. Many wooden houses on the sliding zone became submerged. Uplifts and breaks of buried light-weight utilities such as tanks in automobile service stations, sewage tanks, and water and sewer pipes, and resulting pavement damage were seen everywhere within the affected area. Many telegraph poles tilted considerably due to foundation bearing failure.

Geotechnical conditions: Most of the area exposed to liquefaction in Dagupan City is considered as artificial fills or alluvial deposits of river delta underlaid by clay and gravel deposits below 15 to 20 meters (Figure 3.8). Artificial fills were built over fishponds or swampy lands with fine sand deposits several tens of years before the earthquake. After the earthquake DPWH and Mayer office of Dagupan conducted limited field investigations in the most earthquake affected areas in the city by performance of standard penetration tests (SPT) at 16 sites (Figure 3.7). The surface layer to a depth 5 to 10 meters is a loose to medium dense sand in the affected area, while clay or dense sand is dominant from the ground surface in the nonliquefied areas. Thus, the fills and loose alluvial deposits are considered to have liquefied at the depths of 5 to 10 meters. The SPT tests results (Fig. 3.8) indicate that liquefied layers are fine to silty sands with a main grain size from about 0.1 to 0.2 mm and with a finest content to 30% (after Takimatsu, K., 1990).

Liquefaction potential at each SPT test site has been estimated by Tokimatsu, K. (9) using SPT based correlation proposed by Tokimatsu and Yoshimi (1983) and Seed et al. (1985). The current SPT practice in the Philippines, however, uses different test procedures from those in Japan and USA, which raises questions about consistency of the SPT N - values for evaluation of liquefaction potential in the Philippines.

The key factor affecting SPT blowcount is the energy efficiency that is delivered to the SPT rods by the hammer falling from a height of 30 in. (76.4 cm). The safety hammer with 2 wraps of a rope around a pulley, used in the USA, delivers about 60% of theoretical maximum energy to the rods, and the donut hammer with trip monkey method used in Japan delivers about 78% of theoretical maximum energy. It appears common practice in the Philippines to raise and to release the donut hammer by means of a wire rope wrapped several times around a rotating pulley. This method would produce an energy ratio less than those adopted in the USA and Japan. Our preliminary assessments indicate that the energy efficiency delivered to the SPT rods in the Philippine practice would be somewhere between 35 and 50%, which is significantly lower than the values used in the SPT based correlations by Tokimatsu and Yoshimi (1983) and Seed et al. (1985). Thus, the SPT N-values should be corrected in terms of efficient energy (Seed et al., 1985, and Tokimatsu, 1988), before estimating liquefaction potential (after Tokimatsu, K, 1990).

The liquefaction potential was then tentatively estimated assuming an efficient energy ratio of 45% and a maximum horizontal ground acceleration of 20%g. The soils with calculated liquefaction safety factor FL (defined as a ratio of dynamic shear strength, and seismic forces applied to the corresponding soil element) less than unity are considered to have liquefied during the earthquake. Sand layers below the ground water table appear to have liquefied to a depth of about 10 meters in the extensively liquefied zone along the Perez Blvd. (Fig. 3.7, sites 2 and 3), whereas the thickness of the liquefied layers appears generally smaller in the other affected area (sites 4, 5, 11 and 16). This is consistent with the field observation that the structures in Perez Blvd. on the left side of the river settled and tilted considerably compared with the structures in the other affected area. The FL-values in the little or no damaged zone (Fig. 3.7, sites 7, 12, 13, and 15) are generally greater than unity, showing good agreement with the field observation. Thus, the empirical correlation using SPT N-values appears to be able to separate liquefiable from non-liquefiable conditions with a reasonable degree of reliability, if appropriate corrections are made in terms of the energy efficiency delivered to the SPT rods (after Tokimatsu, K, 1990). Cone penetration test results (CPT) indicate also lower shear resistance of the surface sand layers in damaged area and larger values were found at undamaged or slightly damaged area of the city.

Microtremor measurements: To evaluate characteristics of ground motions during earthquakes, a technique of microtremor measurements has been developed by Kanai in Japan and widely implemented in Japan and other countries in the world. Microtremors are ambient vibration of ground excited by natural and artificial disturbances such as wind, sea waves, traffic, and industrial machinery. Kanai discovered that the microtremor at a site reflects its site amplification characteristics strongly: the spectral characteristics of microtremors on soil deposits are similar to those of earthquake motions at the site.

In Dagupan and Baguio, where extensive damage to buildings occurred, microtremor measurements were performed. The measurement system used has a response which is proportional to ground velocity in period of 0.08 to 1 seconds. In Baguio, microtremors were measured at the sites as shown by solid circles in Fig. 3.3, together with the Fourier amplitude spectra for horizontal components at the same three sites in Baguio. The spectral shapes are similar to each other: the spectral amplitude are almost constant in period of 0.1 to 0.4 seconds, and become much smaller in period longer than 0.5 seconds. No predominant peaks are found in the spectra. The amplitude level is, however, different at each site. The difference may be not due to site effects, but due to different level of artificial disturbances which excite microtremors; Burnham park where the amplitude of the microtremors is largest, is just on the center of the city with heavy traffic, and Hyatt Terraces is on calm upland about one kilometer far from the center.

In Dagupan, microtremors were measured at fourteen points as shown by solid circles in Fig. 3.7 (A, B, C., D), selecting areas with extensive soil liquefaction and those with non-liquefied soils due to the earthquake. Based on the micro-tremor analysis recorded in Dagupan, it has been found that horizontal components at site A have a peak at period of 0.3 to 0.4 seconds, and the amplitude level is very small in the period shorter than 0.15 seconds and larger than 0.6 seconds. Comparing the spectra of microtremors in Dagupan at liquefied and nonliquefied sites it has been found that spectra at nonliquefied sites have no sharp peaks, but the spectral amplitudes are larger in the period range of 0.2 to 0.6 seconds. The spectra at liquefied sites, on the contrary, have a sharp peak at period range of 0.3 to 0.4 seconds (after Midorikawa, S, 1990).

Shear wave velocities: It is widely recognized that liquefiable soil layers have very low shear wave velocity. In Dagupan, seismic prospecting using Rayleigh wave have been performed. The results show that layers with low shear wave velocity of 60 to 90 m/s exist near surface at liquefied sites, but not at non-liquefied sites. The shear wave velocity profile at Hyatt Terrace Hotel in Baguio is shown in Fig. 3.5 together with typical shear wave profile in Dagupan. In Baguio, the thickness of soft layers with shear wave velocity lower than 200 m/s is less than 10 meters, while in Dagupan it is more than 20 meters. Based on analysis performed, the difference in the amplification factors in Baguio and Dagupan is small for the periods shorter than 0.3 seconds, but the amplification in Dagupan is twice larger than that in Baguio in the longer period range. Thus, the amplification of ground motions in Baguio is considered as small for longer-period motion. Since the seismic response of collapsed buildings in Baguio would be strongly related to ground motions with period longer than 0.5 seconds, it is difficult to interpret site effects on ground motions as the major cause of collapse of high-rise buildings in Baguio (after Midorikawa, S, 1990).

Ambient vibration tests of buildings: To investigate vibration characteristics of buildings in Philippines, ambient vibration tests were performed for reinforced concrete buildings in Baguio, Dagupan, Cabanatuan, and Manila. The ambient vibrations were measured at the top of the buildings, and the natural period of vibration and damping were determined by spectral analysis of the ambient vibration. No damage was observed for the buildings at Dagupan and Manila. Only minor cracks were found on infill walls in the buildings at Cabanatuan and Baguio. Fig. 3.4 shows the relation of period of translational vibration with number of stories. Data for reinforced concrete buildings in Japan are also plotted by cross. The relation for buildings in Philippines is almost the same as that for buildings in Japan; the period in second is approximately one fifteenth of number of stories. This means that the collapsed four to eleven storied buildings in Baguio would have the natural period of 0.3 to 0.8 seconds in small amplitude level. During strong shaking, however, buildings may show non-linear behaviour and the natural period may be much longer than that in small amplitude level. The data for Japanese buildings showed that the period becomes abruptly longer when the response acceleration at the top of the building exceeds 20%g (after Midorikawa, S, 1990). This could be valid in particular for most of the 4 - 11 storey buildings exhibiting failure in Baguio City which could be strongly related with earthquake ground motions with dominant period longer than 0.5 seconds as well as prevailing flexible structural systems of reinforced concrete frame buildings after contribution of the infill walls to the stiffness of the entire structure is gone due to initial cracking.

Several dynamic properties of soils like liquefaction potential, microtremors, shear wave velocity and dominant period of soil media as well as dynamic properties of buildings, have been summarized and presented as determined for the specific conditions in the Philippines, mainly in Baguio and Dagupan City. The purpose is to demonstrate their importance for understanding earthquake phenomena and its effects on dynamic behaviour of soils and structures considering in particular that these are first set of data collected in the Philippines.

Earthquake damaged buildings: The Luzon Earthquake of 16 July 1990 caused large concentration of damage and failure of buildings and infrastructure facilities dominantly due to induced intensive liquefaction of surface soil layers mainly in the commercial district of Dagupan City. Based on the report of NEDA (November 1990) and the data obtained from the Mayor office of Dagupan City, more than 40% of total population of the city was affected by the earthquake (44.166) leaving with total or partial damage 7.448 houses, making 7.3% of the total number of houses damaged in the entire affected area. Out of 77 school buildings 39% were out of use (Table 3.2-1 and Fig.3.12), 27 public buildings, 6 hospitals and other social buildings were damaged (Fig. 3.13). Out of 120 commercial buildings in the downtown are of Dagupan City 75% rendered out of use, experiencing large settlements and tilting (Table 3.2-1, and Fig. 3.10). Damage data on the commercial buildings are summarized and presented in Fig. 3.11. About 90% of the buildings are 2 to 4 story reinforced concrete frame structures with shallow foundation. It appeared that very few buildings in Dagupan City had pile foundation (Photo 3.17) and that no considerations were made in the foundation design to mitigate liquefaction hazard. About 50% of the buildings are tilted more than one degree, and more than 15% experienced 50 to 100 cm of settlement. Significant settlements and tilting were observed at the corner buildings (Photo 3.12), in buildings without adjacent buildings on one or both sides, and in buildings surrounded by light weight structures (Photo 3.14).

Wooden houses experienced damage as well, usually associated with differential settlements (Photo 3.16), large settlements, or differential lateral movement of their foundation. Many wooden houses in the extensive liquefaction area and in the sliding area were submerged due to subsidence of the sites and lateral spreading of the ground.

Relatively new constructed buildings that have continuous foundation or mat foundation appear that have settled or tilted with their superstructure remaining intact or with little damage. For these tilted buildings, possibility of lifting them up should be explored using methods and techniques implemented after Niigata, Japan 1964 earthquake if there is an economic justification found comparing the cost of lifting up with that for demolition and new construction.

Lifelines and transportation system: Dagupan City suffered severe damage due to liquefaction and lateral spreading of the ground. About 4 kilometers of the city center bussed main lines were heavily damaged and out of use before temporary repair was provided (Fig. 3.14). Water District was severely damaged, 6 of total 17 pumping stations were out of use and 12.5 kilometers of 150 and 100mm water transmission lines were damaged. Sewage system made of concrete pipes was filled with sand and experienced large deformations requiring replacement in the major sewage lines like in Hernandez Avenue (Photo 4.22 and 4.23).

Summarizing the dominant effects of the Luzon Earthquake of 16 July 1990 in Dagupan City it could be concluded that for rather low peak ground accelerations (18 to 20%g) extensive liquefaction of soils was triggered causing major damage to buildings, structures, transportation and lifeline systems. Considering that Dagupan City and the Central Plains between Tarlac and Lingayan could be exposed frequently to the earthquakes of MM intensity VIII to IX degrees (Fig. 2.6) from closer earthquake source zones than that of 16 July 1990, it should be expected occurrence of intensive liquefaction on the wider areas assuming that maximum acceleration levels will be significantly higher. Largest part of observed damage in Dagupan City resulted simply from the lack of engineering consideration for mitigation of the liquefaction hazard. In order to avoid similar conditions in the future earthquakes, the following basic recommendations should be implemented as soon as possible:

▪**Urgent elaboration of preliminary seismic land capability map** as described in Chapter 3.1 for Baguio City and in Chapter 7; and,

▪**Urgent elaboration of emergency interim building code** with guidelinesfor repair and strengthening of earthquake damaged buildings , as described in Chapter 3.1 and Chapter 7.