RECONNAISSANCE REPORT ON STRUCTURAL DAMAGE IN BAGUIO BY THE JULY 16, 1990 LUZON EARTHQUAKE

by:
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INTRODUCTION

On July 16, 1990, 4:26 p.m. local time, a devastating earthquake struck Central Luzon. Luzon is the biggest island of the Philippines and is located in the northern part of the archipelago. The earthquake had a magnitude of 7.8 in the Richter scale with an epicenter 15.664° N and 121.247° E near Cabanatuan City. News of the collapse of a college building in Cabanatuan trapping hundreds of students and the collapse of a major hotel in Baguio City trapping hundreds of local and foreign tourists gave a preview of devastation caused by this earthquake. As the death toll increases day by day, the Philippine media dubbed this earthquake as the "Killer Quake". This disaster was indeed regrettable. But for the first author, being a Filipino graduate student in earthquake engineering, it was a good chance to appreciate the importance of his studies.

The authors joined the reconnaissance team of the Japan Society of Civil Engineers (JSCE) to survey damages due to the earthquake. The Architectural Institute of Japan (AIJ) was also sending an investigation team about two weeks before the JSCE team. The AIJ team is comprised mainly of structural engineers whose main objective is to study the many structural collapse of buildings due to the earthquake. The first author was able to join this team.

This report is intended to document some observations of damaged buildings gathered from the field investigation in Baguio City with the survey team of AIJ from August 6 to 8, 1990 and the Baguio team of JSCE from August 17 to 20, 1990. Due to the limited time available for the investigation, the data gathered are incomplete and may be inconclusive.

BAGUIO CITY

Baguio city is a mountain resort about 200 kilometers north of Manila. Because of its cooler temperature, it is a favorite summer destination of both local and foreign tourists. Baguio city earned the term "Summer Capital of the Philippines". This explains the existence of numerous hotels in the city.

Baguio city is situated along the Cordillera mountain range. This being the case, the local topography is very hilly. There are only three main roads connecting the city with the lowlands to the west and south and one main road towards the mountain range (Figure 1). These roads

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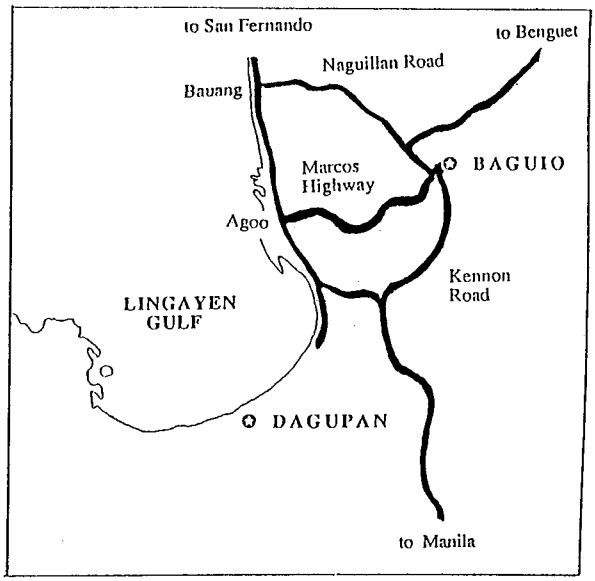


Figure 1 Map showing roads to Baguio city

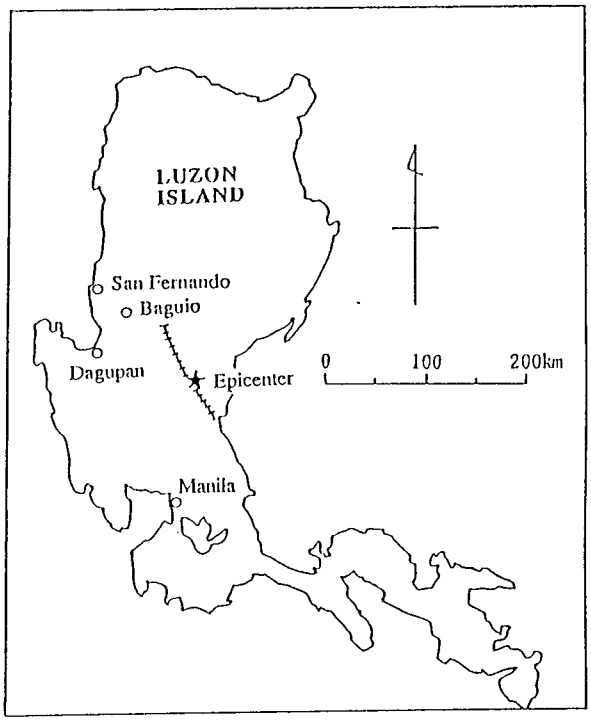


Figure 2 Epicenter of the July 16, 1990 earthquake and apparent surface fault

were cut from the mountainside making them difficult to pass through. They are also very susceptible to landslides and rockslides. In fact, during the earthquake, Baguio city was completely isolated because the roads were blocked by landslides and rockslides (Photos 1 and 2). The airport's only runway was also damaged. These hampered the transport of rescue equipment to the area. Figure 2 shows a map of Luzon with the earthquake epicenter and apparent activated fault line.

Photo 1 Kennon road blocked by rockslides

Photo 2 Failure of road foundation on Marcos Highway

GENERAL IMPRESSION OF DAMAGE IN BAGUIO

The city was generally orderly and peaceful just three weeks after the tremor. Although the city was not completely destroyed, it was the most affected city of the whole country. There were spectacular collapse of buildings but these are not widespread in the city. Figure 3 shows the locations of damaged buildings in Baguio which we have surveyed.

There may be several factors which relate the damaged structures to each other. The height of the structure which is in turn correlated to the natural period of the structure may have played a significant part. The local topography on which the structure was built must also be studied. It is common for structures in Baguio to be built in sloping ground as natural flat ground is rare. Several buildings surveyed have a kind of irregular configuration or plan (e.g., large overhangs, abrupt change in storey stiffness/rigidity, and large dissymmetry of the torsional rigidity). Table 1 shows a comparison of these factors and damage from the buildings discussed here. From this table, it shows that most of the severely damaged buildings were built on sloping ground and/or has a special configuration. Table 2 shows the percentage of damaged buildings from three limited areas of Baguio with respect to the number of stories. This table shows that buildings with 5 stories and higher has a high percentage of severe damage or collapse, especially for buildings higher than 6 stories. Figure 4 shows these relationships in graphical form. This may be an indication that the frequency of ground motion was close to the natural frequencies of these buildings.

The Director of the Philippine Volcanology and Seismology (Philvocs), Dr. Raymundo Punongbayan, has stated that Baguio was the

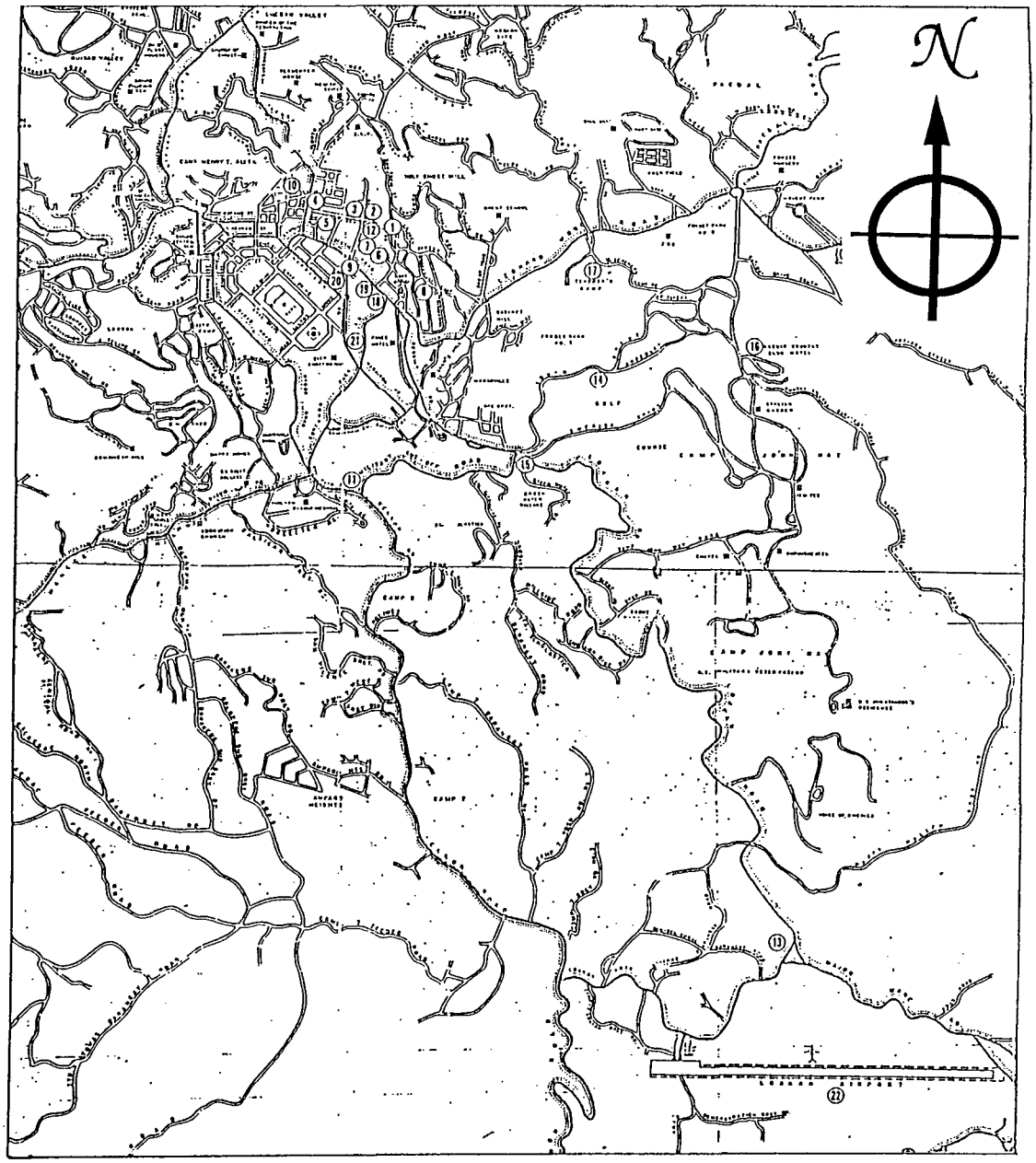


Figure 3 Location of surveyed buildings in Baguio
(numbers correspond to buildings in Table 1)

Table 1 Summary of observations of surveyed buildings in Baguio

	Building	Stories[1]	Sloping Ground	Special Configuration [2]	Damage[3]
1.	Golden Bake Shop	5 (1)	O	O	Severe
2.	FRB Hotel	5	O	O	Collapse
3.	University of Baguio				
	Commerce Bldg.	8 (1)	O	O	Collapse
	Engineering Bldg.	4 ?	X	X	Moderate
4.	Royal Inn	4	X	O	Collapse
5.	Aurora Theater	2	O	-	Collapse
6.	Baguio Cathedral	1	X	O	Moderate
7.	Little Angel's Nursery School	4	X	X	Slight
8.	S&L building	4 (4)	O	X	Severe
9.	Skyworld Condominium	9 (1)	O	O	Severe
10.	Hilltop Hotel	7	O	-	Collapse
11.	Baguio Medical Center	4	X	O	Slight
12.	St. Louis University High School				
	Girl's Campus	3,4	X	X	Slight
	Boy's Campus	3 (3)	O	X	Slight
13.	Baguio EPZA North Bldg.	3	X	X	Severe
	South Bldg.	3	X	X	Collapse
14.	Hyatt Terraces Hotel				
	Terrace Bldg.	7	X	O	Collapse
	East Bldg.	8	X	X	Severe
	West Bldg.	7	X	X	Moderate
	South Bldg.	7	X	X	Moderate
	Tower Bldg.	11 (1)	X	O	Collapse
15.	Hotel Nevada	4 (1)	X	X	Collapse
16.	Baguio Country Club				
	Rice & Ozaeta Annex	6 (2)	X	O	Collapse
	Swiss Chalet	3	X	X	Moderate
17.	Quezon Hall at Teacher's Camp	2	X	X	Moderate
18.	Siesta Inn	4 (2)	O	X	Severe
19.	Cafe Amapola	2	O	X	Severe
20.	Baguio Park Hotel	9	X	-	Collapse
21.	Baguio Colleges Foundation	6 (2)	O	O	Collapse
22.	Baguio (Loakan) Airport				
	Control Tower	5	X	O	Moderate
	Terminal Building	1	X	X	Moderate

[1] Number of stories above ground reckoned from front entrance (stories below)

[2] Examples : Large overhangs, abrupt change in storey stiffness, large dissymmetry of torsional rigidity, etc.

[3]

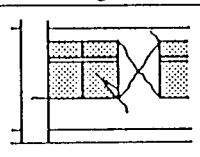
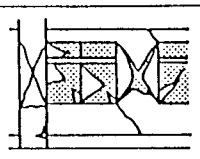
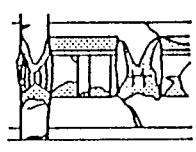
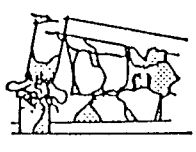
Slight	Moderate	Severe	Collapse
			

Table 2 Percentage of damage with respect to number of stories (data from Nomura, Ref. 2)

No. of Stories	Negligible to Slight		Moderate		Severe to Collapse		Total
	No.	(%)	No.	(%)	No.	(%)	
1	7	88	1	13	0	0	8
2	37	76	8	16	4	8	49
3	47	89	6	11	0	0	53
4	33	80	2	5	6	15	41
5	14	58	4	17	6	25	24
6	3	75	0	0	1	25	4
7	0	0	1	33	2	67	3
8	2	40	1	20	2	40	5
9	0	0	0	0	3	100	3
Total	143	75	23	13	24	13	190

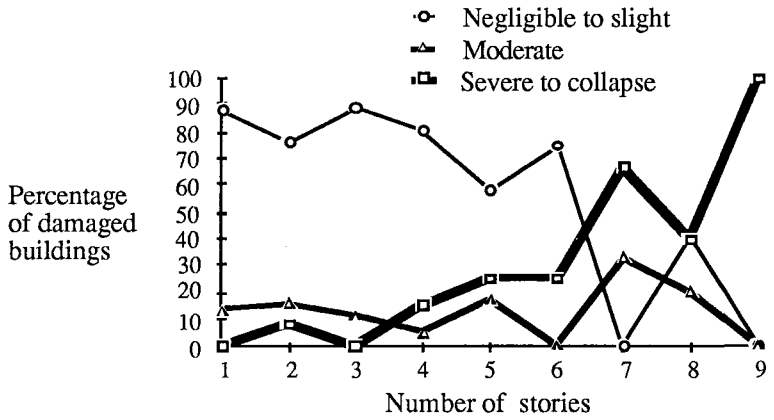


Figure 4 Relation of number of stories to percentage of damage

worst hit area because there was a second earthquake with an epicenter 30 km from Baguio and with a magnitude of 7.6 in the Richter Scale (Ref. 6). This information, however, has not been confirmed yet. There was also a big earthquake that hit Baguio last 1985. This earthquake, which had a magnitude of 6.0 and epicenter at 16.5°N, 120.9°E (Ref. 7), may have significantly weakened some of the structures. The Hilltop Hotel was reported to have been condemned due to damages sustained from this earthquake. Table 3 shows a historical list of large earthquakes in Northern Luzon.

Table 3 Historical List of Big Earthquakes in Northern Luzon

Date	Information
1619 November 30 ; 12:00	Cagayan, Isabela; 18.2°N, 121.6°E ; Intensity 9 (Rossi-Forrel)
1796 November 05 ; 14:00	Pangasinan; 16°N, 119.3°E
1880 July 18 ; 12:40	Casiguran-Baler; 16°N, 121.9°E
1931 March 19 ; 14:26	18°20'N, 120°10'E ; 50 km from the coast ; Intensity 8-9 (MMI)
1968 August 2 ; 16:19	Casiguran, Aurora ; 16°5'N, 122°3'E; Magnitude 7.3 ; Intensity 8 (RF) (342 dead, 600 injured) ; Ruby Tower collapsed in Manila
1970 April 07 ; 13:34	Baler, Quezon ; 15°8'N, 121°7'E; Magnitude 7.3 ; Intensity 7 (RF) ; (15 dead, 200 injured)
1983 August 17 ; 20:18	Ilocos Norte ; 18°33'N, 121°27'E ; Magnitude 6.7; Intensity 8 (RF) (7 dead)

(Sources : Reference 4, 6 and 7)

CHARACTERISTICS OF DAMAGE

The modes of failure of structures in Baguio are typical for structures which were not sufficiently designed for the forces imposed unto it. This will lead to the question of whether the earthquake forces exceeded the design earthquake force or if the methods of design and/or construction were not according to specifications.

The following modes of failure were observed from the damaged structures in Baguio :

1) Soft-first storey It is common in the Philippines to use the ground floor of a multi-storey building for commercial purposes like a store or restaurant to increase the utility of the property. In such a case, the ground floor will usually have a longer unsupported length for the columns. There will also be a tendency to have more and larger windows, while the upper stories will have mostly reinforced concrete hollow blocks (CHB) for exterior and interior walls. This abrupt change in the storey stiffness will cause the first storey to have a larger drift than the rest. The result would be the formation of plastic hinges at the maximum moment sections of these columns (Figure 5). The damaged buildings which experienced this kind of failure mode are the FRB Hotel, Royal Inn, Nevada Hotel, and Cafe Amapola.

2) Shear failure of columns Due to the large horizontal forces brought about by earthquakes, columns (especially the lowest ones) experience large and cyclic shear stresses. If the shear stress goes beyond the capacity of the column, then diagonal cracking will initiate near the center of the column. Because of the cyclic reversal of the stress, this results in the characteristic X-cracks (Figure 6). Examples of damaged buildings are the S&L Building and Quezon Hall in Teacher's Camp.

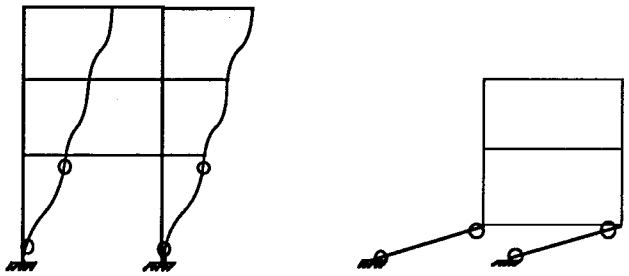


Figure 5 Soft First Storey Failure

Infill walls that are not continuous from bottom to top contribute the shear stress by the so called short-column effect. These low infill walls make the lower part of the column more rigid. Thus when the storey experiences drift, the "short" column will experience more induced shear stresses. Examples of buildings with this type of failure are the Skyworld and Baguio Country Club.

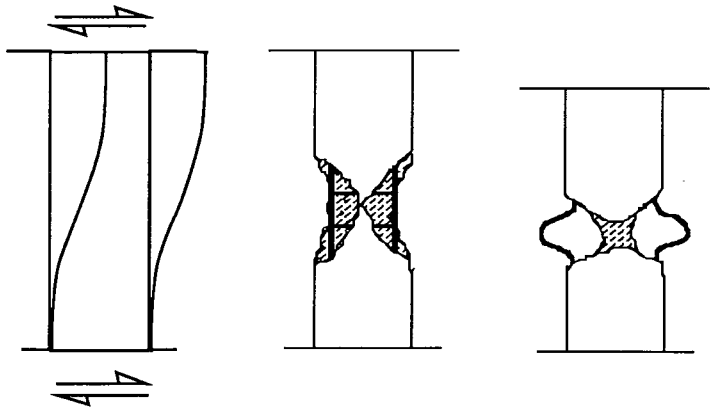


Figure 6 Shear failure of columns

3) Shear failure /cracking of walls In a similar way as with columns, walls that are fixed to the structural elements suffer from large shear stresses. In the Philippines, the most common type of partition is the reinforced CHB. These walls are usually connected to the columns and the upper and lower beams through the use of reinforcement bar studs. Since these walls were not designed to carry significant shear loads, they

are usually the first one to crack and fall off (Figure 7). This type of failure is very common with the damaged buildings in Baguio.

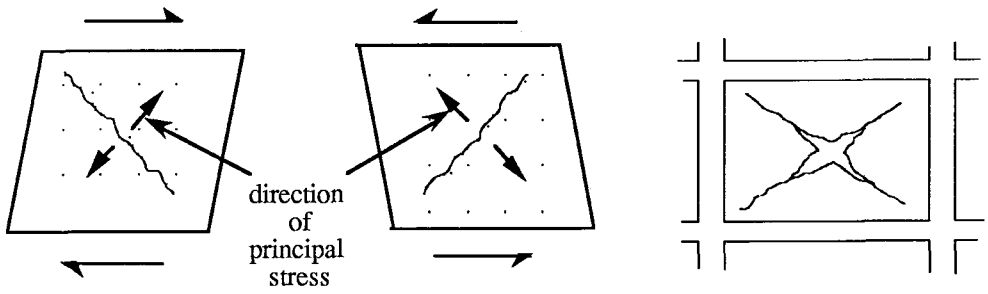
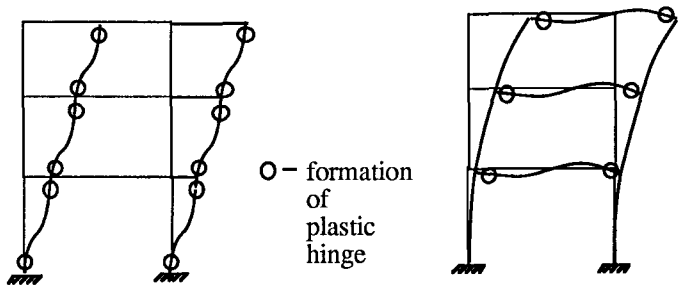


Figure 7 Shear damage of walls

4) "Pancake" collapse This kind of collapse is characterized by the failure of all columns in a storey, or in some cases, all stories (Figure 8). Due to this "total" collapse, a lot of casualties result. This type of collapse can be avoided if the strong-column, weak-beam concept was applied. Buildings which suffered this type of failure are the Baguio Park Hotel and the Hyatt Hotel's Tower Building.



weak column, strong beam
(collapse)

strong column, weak beam
(no collapse)

Figure 8 Mechanism of "Pancake" collapse

5) Torsional Shear Failure This type of failure is mainly due to the unsymmetrical torsional rigidity of the building. If the center of mass and the center of rigidity has a large eccentricity, then the lateral force will have a torsional moment about the center of rigidity. This will impart a larger shear forces at some of the columns in the storey (Figure 9) . This will also tend to twist the storey from the floors below. An example of this is the University of Baguio College of Commerce and the Golden Bake Shop.

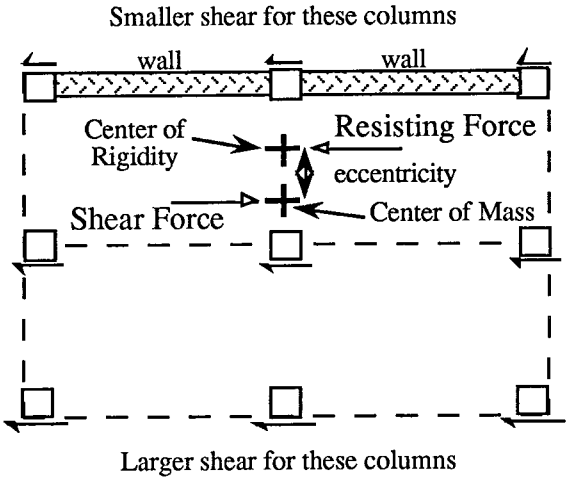


Figure 9 Torsion due to eccentricity of centers of mass and rigidity

6) Detailing Inadequacies It has been well known that for structures to withstand the cyclic lateral earthquake forces, special detailing specifications must be followed. The special detailing is needed to ensure the ductile behavior of joints and to provide for the reversal of forces during earthquakes. Examples of these observed in Baguio were : very small tie reinforcements with wide spacing for large columns with bundled, large diameter main bars; non- reinforced beam column joints and in some cases, improper placement of extension bars from beams; lap splices for main bars were not staggered; 90 degree hooks were used for shear reinforcements; etc.

Some of the damaged buildings have combinations of the failure modes discussed above. The failure modes and damages observed for each building will be discussed in the next chapter. Due to time constraints, not all damaged buildings in Baguio were surveyed. Some buildings with slight damage are also discussed.

DESCRIPTION OF DAMAGES

1) Golden Bake Shop (Luna Road)

This is a 5-storey reinforced concrete building with one basement. The building is of new construction with interior finishing left to be done. The plan of this building is unique in the sense that the width at the front is longer than the width at the back. This gives the building a trapezoidal shape. Also, the top three floors are cantilevered by about 2 to 3 meters in front (Photo 3).

There are large diagonal and X-cracks on architectural columns (walls so designed to look like massive circular columns). The plaster of exterior walls have spalled (Photo 4). And some of the third floor columns

failed in shear. Concrete of the columns spalled at mid-height and the exposed longitudinal reinforcing bars have buckled. The rest of the columns seem to be undamaged, though.

Photo 3 Facade of Golden Bake Shop showing large overhang

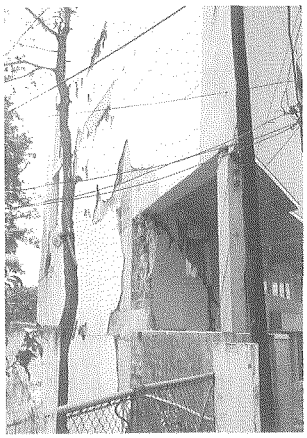


Photo 4 Side view of Golden Bake Shop showing triangular plan

2) FRB Hotel (Luna Road at the corner of Assumption Road)

This is a 5-storey, reinforced concrete frame structure. The first 2 stories have a regular rectangular shape while the top 3 floors have a circular shape. The building uses both circular columns and rectangular tied columns. The first two floors were being used by commercial establishments (Photo 5).

Numerous columns on the first floor failed in bending, developing plastic hinges on both ends of the column. Due to the formation of the plastic hinge, the top four floors swayed and moved backward about 2 to 3 meters (Photo 6). Several columns experienced buckling after the concrete cover has spalled. The beams and girders of this building were observed to be larger than the columns resulting in a strong beam, weak column effect.

According to a witness inside the building during the tremor, she felt two distinct ground motions separated by a few minutes. The building collapsed during the second tremor.

3) University of Baguio (Assumption Road at the corner of Luna Road)

The campus of the University of Baguio is made up of three main buildings. These are the Commerce building, gymnasium, and the Engineering building. The Commerce building consists mostly of classrooms but has space for commercial establishments on the ground floor fronting Luna Road. It should be noted that the Commerce building

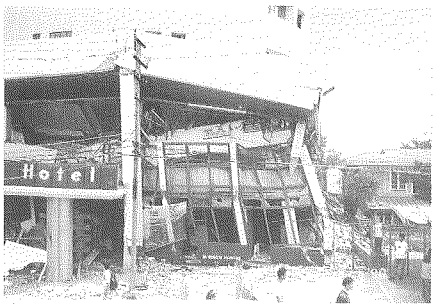


Photo 5 View of FRB Hotel from Luna road

Photo 6 Side view of FRB Hotel showing the displacement of a circular column

was built on a sloping ground. The Commerce building and gymnasium are connected by a catwalk on the fourth storey, while the Engineering building is connected to the gymnasium building.

The Commerce building suffered the heavier damage with the complete collapse of the fifth floor. Rotational movement of the upper four stories relative to the lower stories can be observed from Luna Road (Photos 7 and 8). The rotational rigidity of the building is not symmetric. One side of the building is mostly made up of walls. The north side of this building suffered progressive collapse of the columns, starting from the fifth storey to the top (Photo 9). Photo 10 shows shear punching failure of a column on the first floor.

The Engineering building did not experience any collapse but there are severe damage to structural members (Photo 11). One interior wall completely fell down in one piece. Cracks on non-structural walls can be observed near the junction of the wall with the upper beam (Photo 12). Large horizontal cracks can also be observed on the wall lintel beams.

Spalling of concrete occurred in some beam-column joints in the gymnasium building. Use of different materials in mixing concrete can be seen in the different color and texture of one column with the adjacent beam.

4) Royal Inn (104 Magsaysay Avenue)

This is a 4-storey reinforced concrete building with a penthouse. This hotel was classified by the Department of Tourism as a standard class hotel. The building has a regular and almost square plan. The relative stiffness of the first two floors cannot be ascertained because of the collapse.

The first two stories of the building collapsed due to the failure of the columns. The rest of the structure does not seem to have any structural damage. The top floors moved about 1 meter to the North-northeast.

It is probable that the first storey was a soft storey and that the second storey collapsed due to the impact of the building when the first storey collapsed (Photos 13 and 14).

Photo 7 View from Luna road of University of Baguio Commerce building

Photo 8 Rotation of the upper four stories of U.B. Commerce building

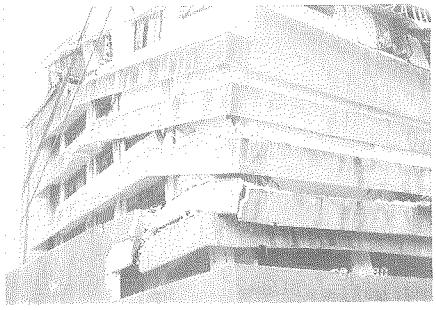


Photo 9 Progressive collapse from the fifth floor and higher of the U.B. Commerce building

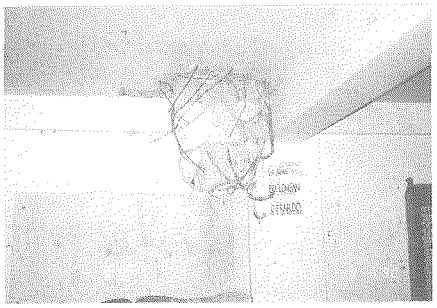


Photo 10 Punching shear failure at the basement of the Commerce building

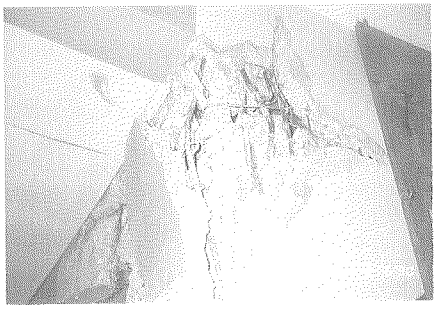


Photo 11 Failure of beam column joint at University of Baguio Engineering building

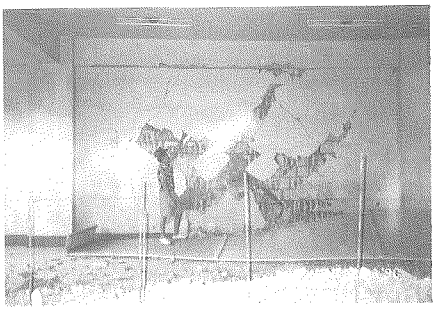


Photo 12 Shear cracks on CHB wall of U.B. Engineering building

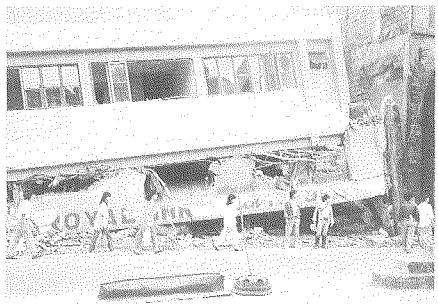


Photo 13 View from public market of Royal Inn

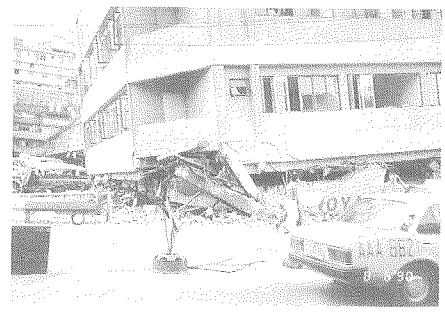


Photo 14 The Royal Inn building moved about 2 meters to the left

5) Aurora Theater

This is a two-storey reinforced concrete structure with one basement. This structure was completely collapsed (Photo 15). At the time of the survey, the configuration of the structure cannot be imagined anymore. The structure is quite old and had undergone many additions and alterations.

Upon inspection of the rubble, however, the following were observed. The longitudinal bars and tie bars for the rectangular columns used were plain round bars. The concrete has a light brown color. Also, the aggregates used were of different sizes. The aggregates were not ordinary gravel taken from rivers, but more likely taken from the mountainside (Photo 16).

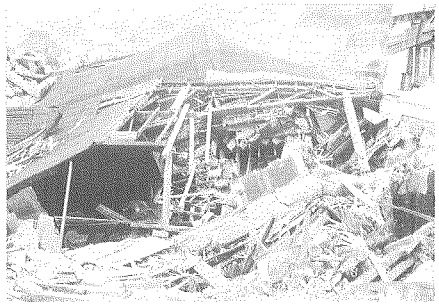


Photo 15 The completely collapsed structure of Aurora Theater

Photo 16 RC columns from Aurora Theater showing reinforcements and concrete with light brown color

6) Baguio Cathedral

The Baguio cathedral is an old church built on top of a hill. According to the priest in charge, the cathedral has undergone several modifications due to damage from past earthquakes. Two types of columns were observed. Unreinforced, gravity type columns are used to support the arches which in turn support the roof. Reinforced concrete columns are used to support balconies/mezzanine to accommodate more people.

Damage to the exterior is slight with small cracks on the walls. One of two tower roofs was leaning to the southwest direction. The retaining wall supporting the ground failed (Photo 17) and cracks parallel to the failure can be seen on the ground.

The columns supporting the reinforced concrete framed balcony at the back of the church suffered shear failure, exposing the reinforcement (Photo 18). The RC columns of the balcony on the side suffered only cracks on the plaster at the construction joint. One of the gravity columns supporting the arches twisted with respect to its base (Photo 19). And cracks appeared on the arches.

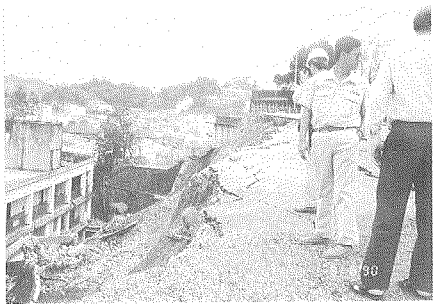


Photo 17 Failure of retaining wall of Baguio Cathedral

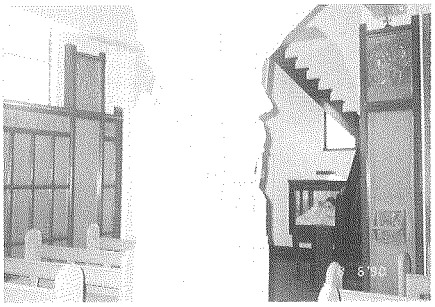


Photo 18 Shear failure of column supporting balcony at Baguio Cathedral

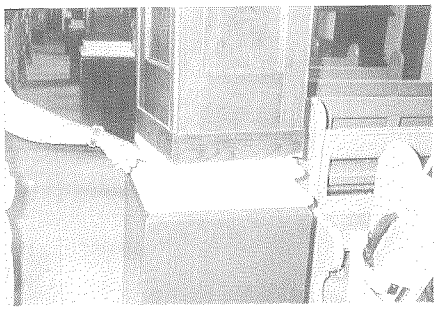


Photo 19 Twisting of gravity type column in Baguio cathedral

Photo 20 Crushing of concrete at stairs support of Little Angel's Nursery School

7) Little Angel's Nursery School

This is a four storey reinforced concrete building managed by the priests of the Baguio Cathedral.

The building suffered cracking on the exterior wall and infill walls. The reinforced concrete stairs suffered crushing at the supports (Photo 20) and in one case, completely collapsed.

8) S & L Building

This is a reinforced concrete building with four stories above and four stories below the front ground level. The natural ground line is sloping steeply from the front of the building to the back. The ground around the building subsided about 1 to 3 meters (Photo 21). There are some slight cracking on the exterior walls.

The most serious damage, however, can be found on the lowest basement. Here, almost all the columns suffered severe shear failure. The reinforcements buckled and the top portion of the column shifted (Photo 22). Note that small diameter ties with wide spacing were used.

Photo 21 Ground subsidence of 1 to 3 meters can be observed around the S & L building front entrance

Photo 22 Severe shear failure of columns at the basement of S & L building

9) Skyworld Condominium

This is a nine storey reinforced concrete building with one basement located at the most crowded area of Baguio City. The first two stories were used by commercial establishments while the rest were used as condominium type residences. This building is one of the tallest building in Baguio. The building's plan is unique because it is triangular shaped. The building is also located in sloping ground (Photo 23).

The first floor columns along Session road suffered severe shear failure. Bundled, large diameter longitudinal reinforcements were used together with small diameter ties with wide spacing. The existence of low infill walls also aggravated the situation, producing a short column effect (Photo 24). Numerous diagonal cracks starting from the corner of windows can also be observed.

The six storey Jollibee building across the Skyworld building performed well with no structural damage. Damage was limited to shear cracking of non-structural walls (Photo 25).

Photo 23 View from Session road of Skyworld building

Photo 24 Column with severe shear damage at Skyworld building

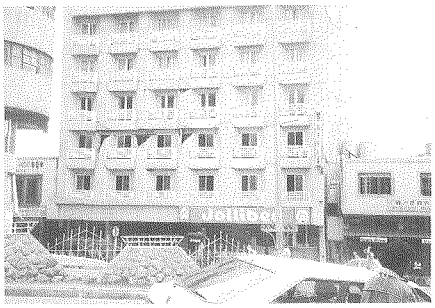


Photo 25 The Jollibee building across the Skyworld building suffered only damage to non-structural walls

10) Hilltop Hotel

This is a seven storey reinforced concrete building located beside the public market. This building completely collapsed. Even the shear wall acted as a cantilever beam and broke near the bottom (Photo 26).

Residents say that this building was damaged during the 1985 earthquake in Baguio and was already condemned before the July 16 earthquake. Photo 27 shows the extension of the reinforcement bars of a beam to the column. Notice that the extension was not placed within the confinement of the column reinforcements.

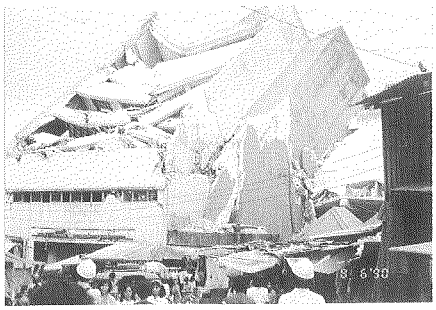


Photo 26 Collapse of Hilltop Hotel

Photo 27 Damaged beam column joint showing beam reinforcement extensions not confined in column cage

11) Baguio Medical Center

This is a four storey reinforced concrete building with a curved facade. At the time of the survey, damaged columns were already repaired. Damage was limited to the spalling of mortar plaster of the columns (Photo 28).

However, one of the interior columns suffered crushing of concrete at the top. This failure was caused by the placement of a drainage pipe inside the column and a Y-joint was placed near the top of the column. This displaced a lot of concrete. Both ends of a column are critical because they have the highest moment when subjected to lateral forces.

12) St. Louis University High School

St. Louis University High School is divided into two campuses; the Girl's High School and the Boy's High School.

The girl's campus is composed of two buildings. In the first building, there was a severe shear cracking on the walls of one corner on the ground floor level. The crack continued to the corner column (Photo 29). There were also limited spalling of mortar plaster which occurred at the construction joints. Limited diagonal cracks on non-structural walls were also observed.

For the second building, limited spalling of concrete occurred. A horizontal crack occurred on top of one column. Photo 30 reveals the use of non-uniform aggregates and the use of mineral rock for coarse aggregates. Horizontal cracking along the boundary of the beam and non-structural wall also occurred.

The laboratory building of the boy's campus suffered very little structural damage. Cracking of infill walls near the vicinity of the lintel beam were observed. Another damage was the spalling of concrete on one spiral column revealing a void at the bottom of the column (Photo 31). The void was due to a construction defect in pouring the concrete on the forms. Another circular column holding a spiral staircase was vibrating as the first author was climbing up the stairs. The reinforcements of this

column is not continuous with the roof beam making it act as a long cantilever beam.

Photo 28 Almost completed repair of Baguio Medical Center

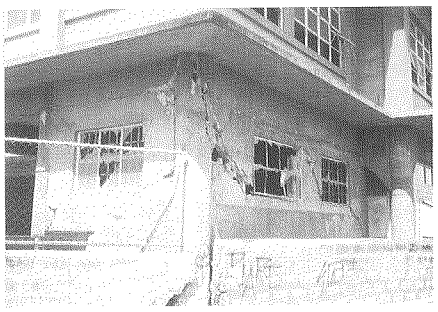


Photo 29 Severe shear cracking of first storey wall in St. Louis University (Girls' Campus)

Photo 30 Mineral rock used as aggregates in St. Louis University (Girls' Campus)

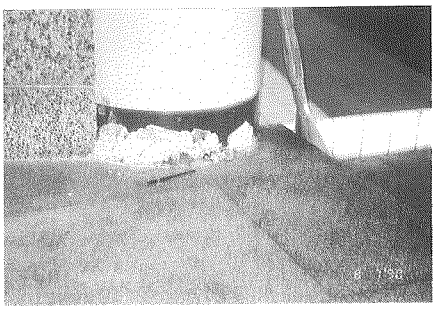


Photo 31 Void at bottom of column in St. Louis University (Boys' Campus)

13) Baguio Export Processing Zone (EPZA)

The export processing zone is comprised of two identical buildings. Both are reinforced concrete and have three stories. The south building completely collapsed and burned soon after killing a lot of people trapped inside (Photo 32). The cause of the fire was not known. The north building was severely damaged but did not collapse (Photo 33). Some columns lost their concrete cover exposing the reinforcements (Photo 34).

The difference in performance of two identical buildings only several meters apart may be attributed to the local ground condition. The north building was reported to have been constructed on a cut while the south building was built on a fill.

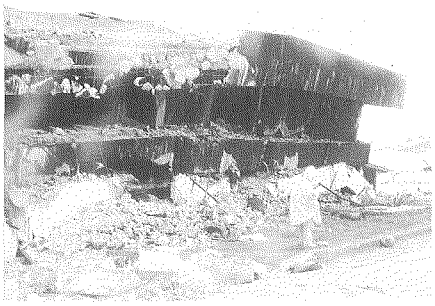


Photo 32 The burnt out Baguio Export Processing Zone (EPZA) South building

Photo 33 Damage to EPZA North building

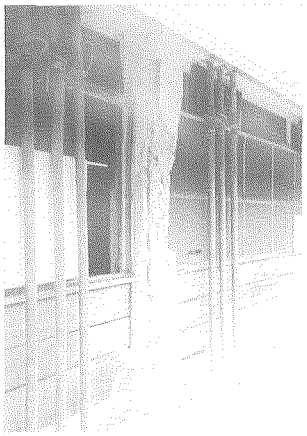


Photo 34 Exposed reinforcements of column in EPZA North building

14) Hyatt Terraces Hotel

The Hyatt Terraces is the biggest hotel in Baguio. It is composed of five buildings constructed close together. These are the Terrace building, West building, East building, South building and the Tower building (Figure 10).

The facade of the Terrace building (7 stories) was sloped and fell into the atrium in a south direction. The inclined wall-type columns failed, reinforcements lost their bond and pulled out (Photo 35). The Tower building (11 stories and 1 basement) completely collapsed in the North direction (Photo 36). The East building (8 stories) suffered severe cracking on exterior walls but did not collapse (Photo 37). The South building (7 stories) suffered little damage on the outside. The West building suffered severe shear cracking on the exterior walls. Damage to columns were limited to the spalling of the mortar plaster (Photo 38).

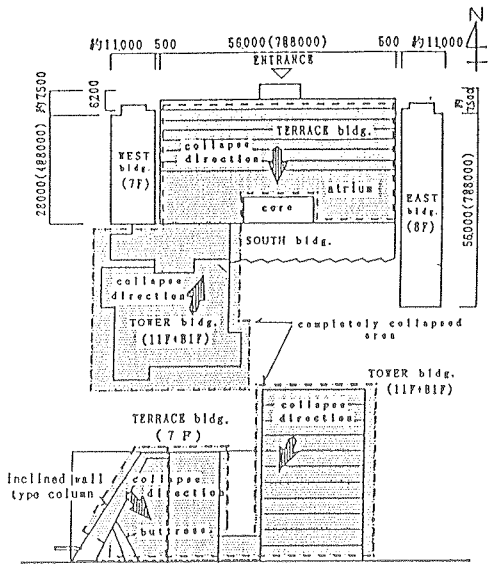


Figure 10 Outline of Hyatt Terraces Hotel (after Nomura)

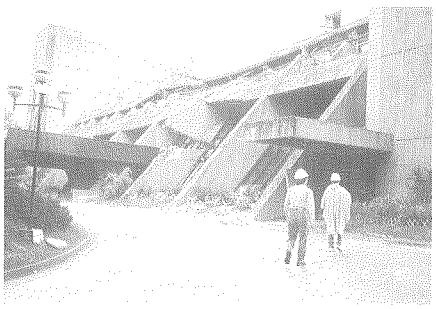


Photo 35 Inclined wall-type columns collapsed into atrium in Hyatt Terraces Hotel's Terrace building

Photo 36 "Pancake" collapse of 11 storey Hyatt Tower building

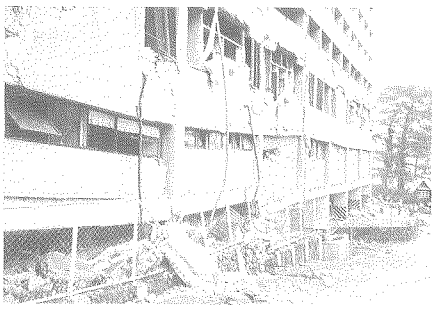


Photo 37 Severe damage on exterior walls of Hyatt's East building

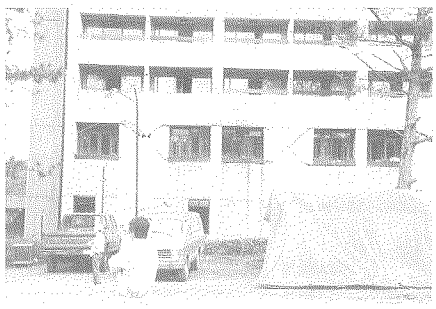


Photo 38 Typical shear cracks on exterior walls of Hyatt's West building

15) Hotel Nevada

This is a four storey reinforced concrete building with one basement. The first two stories of this building completely collapsed killing several people. The collapse is probably of the soft storey type (Photos 39 and 40).

Photo 39 This Nevada Hotel building tilted and the penthouse damaged

Photo 40 Collapse for first two stories of Nevada Hotel building

16) Baguio Country Club

The Baguio Country club consists of several buildings. The seriously damaged ones are the Rice and Ozaeta Annex and the Swiss Chalet. The Rice and Ozaeta Annex is of reinforced concrete construction and has six stories above ground and two basements, while the Swiss Chalet, also reinforced concrete, has 3 stories and 2 basements.

The Rice and Ozaeta Annex's first storey completely collapsed, probably due to a soft storey. The first storey was mainly used as a dining hall (Photo 41). For the Swiss Chalet, the columns suffered shear failure due to the short column effect of the infill walls (Photo 42).

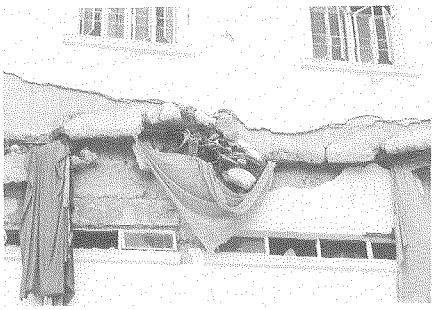


Photo 41 Collapse of first storey (relative to front entrance) of Baguio Country Club's Rice and Ozaeta Annex

Photo 42 "Short" column shear failure at Baguio Country Club's Swiss Chalet

17) Quezon Hall at Teacher's Camp

This is a two storey, reinforced concrete building. There were severe cracking of the first storey walls and spalling of concrete cover of the first storey columns (Photos 43 and 44). One non-structural wall fell down completely (Photo 45). This building was relatively small compared to the other damaged buildings. The main failure mode was in shear for the columns and walls.

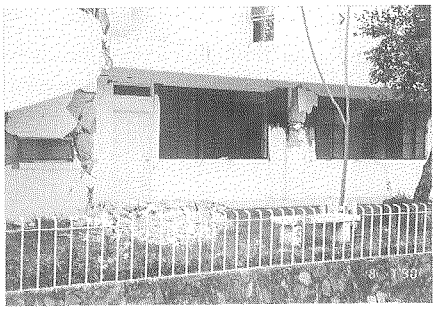


Photo 43 Shear damage to walls and columns in Quezon Hall at Teacher's Camp

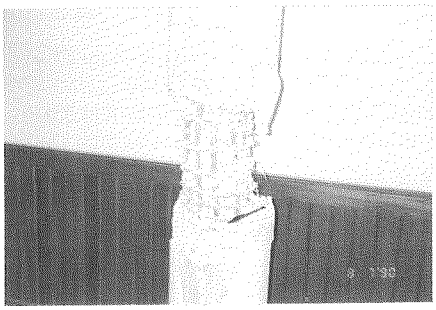


Photo 44 Spalling of concrete cover of round column in Quezon Hall at Teacher's Camp

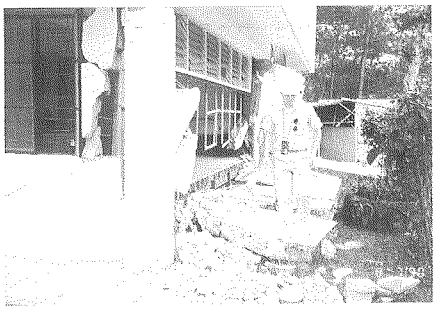


Photo 45 This non-structural wall of Quezon Hall at Teacher's Camp completely fell down .

18) Siesta Inn

This is a reinforced concrete building with four stories above ground and two basement stories. The first storey of this building collapsed, probably as a soft storey (Photo 46).

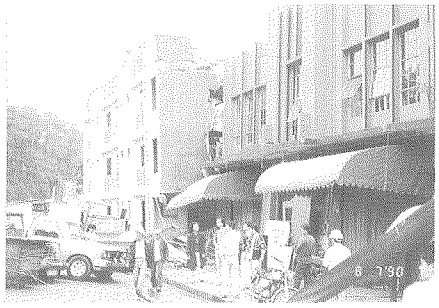


Photo 46 Siesta Inn (left) is leaning forward and is currently being demolished at time this photo was taken (building on the right is Cafe Amapola).

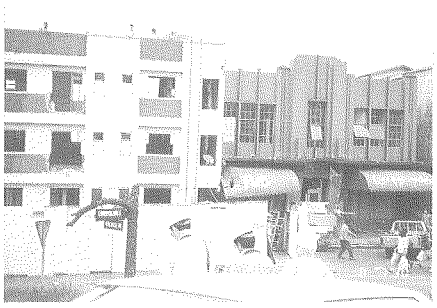


Photo 47 Plastic hinge formation of first floor column of Cafe Amapola (building on left is Siesta Inn)

19) Cafe Amapola

This reinforced concrete building has two stories above ground and used as a pub/restaurant. The first storey columns suffered bending moment failure causing the second storey to have a permanent drift (Photo 47). It is also possible that the building next to it, the Siesta Inn, pounded against this structure.

20) Baguio Park Hotel

Baguio Park Hotel is a reinforced concrete frame structure with nine stories. This building completely collapsed in a pancake type while buildings next to it did not suffer serious structural damage. Photo 48 shows view from Harrison road. The damage to the building on the left was probably caused by the debris from the hotel. Due to the collapse of the building, the configuration cannot be determined during the field investigation. Photo 49 shows the view from the back.

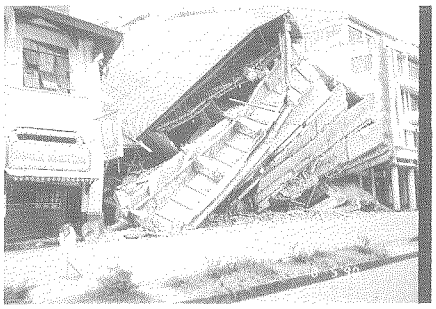


Photo 48 The collapsed Baguio Park Hotel (building on the left was damaged by debris from the collapsed hotel)

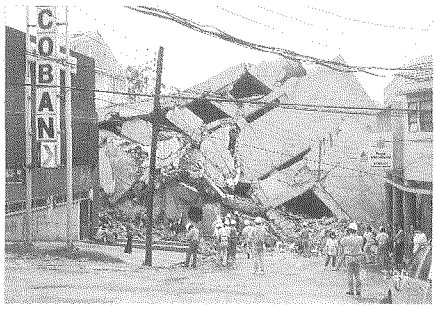


Photo 49 View of Baguio Park Hotel from the back

21) Baguio Colleges Foundation

This is a reinforced concrete building with 6 stories and 2 basements. Photo 50 shows the third storey (reckoned from the front entrance) completely collapsed. It was reported that the upper four stories were added by extension works. Photo 51 shows another building of the Baguio Colleges Foundation. This building which is next to the collapsed building is only slightly damaged.

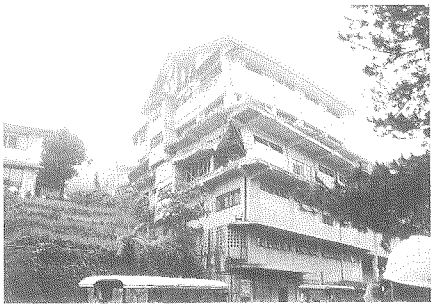


Photo 50 Collapse of third storey of Baguio Colleges Foundation (note hilly terrain of site)

Photo 51 Slightly damaged building of Baguio Colleges Foundation next to collapsed building

22) Baguio (Loakan) Airport

The Baguio (Loakan) airport is located in the southeast suburb of the city near the EPZA. The airport was closed after the earthquake due to an extensive crack that developed in the runway (Photo 52) and to severe structural damage to the control tower.

The control tower is a five-storey reinforced concrete building. The roof of the building fell down to the ground and overturned (Photo 53). The steel columns supporting the reinforced concrete roof look too thin to resist horizontal forces. Many shear cracks developed in the first to fourth stories of the control tower building (Photo 54).

The terminal building, a one-storey reinforced concrete building, had also non-trivial damage. Large shear cracks (Photo 55) were observed in its columns. Since a large permanent displacement which caused the cracks in the runway was observed at the site, the damage to the terminal building may also be related to the ground deformation.

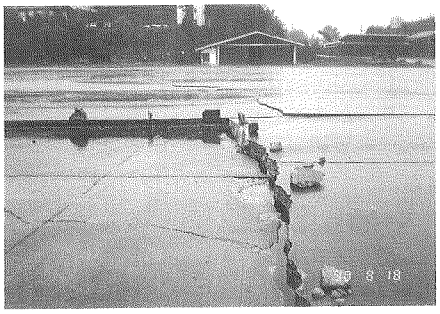


Photo 52 Extensive crack in runway of Baguio (Loakan) Airport

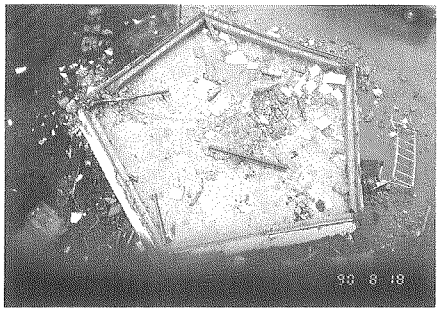


Photo 53 RC roof of Control Tower

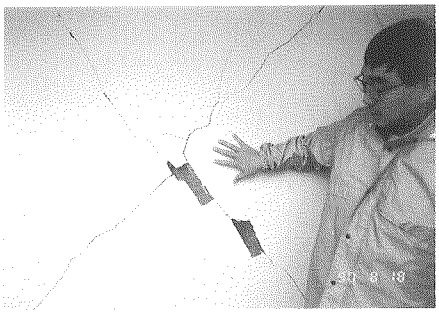


Photo 54 Shear cracks of walls of Control Tower

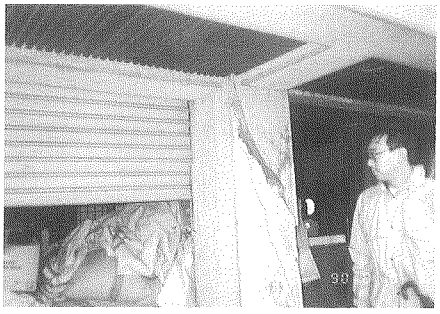


Photo 55 Large shear cracks on column of Terminal building

CONCLUDING REMARKS

The building damages in Baguio were found to be typical for structures which were not designed for the forces imposed unto it. Among these are ; 1) soft-first storey failure; 2) shear failure of columns; 3) shear failure/cracking of walls; 4) "pancake" collapse; 5) torsional shear failure; and 6) failure due to detailing inadequacies.

This does not mean that all structures which suffered damages were improperly designed. The method of construction or the materials may be at fault. The seismic loads experienced by the structures may have exceeded those specified by the current building code. Because of this, it is imperative that strong motion seismographs be installed in the Baguio area to help engineers better understand the devastating effects of this earthquake. There may be other factors not taken into account by the building code, like the effect of constructing in sloping ground and the effect/properties of seismic waves on a hilly region like Baguio. In this sense it is ideal if several instruments can be installed in the ground and

in buildings to establish some correlations on the damage experienced in Baguio.

Another observation is the dispersed distribution of the damaged structures. Most houses were not seriously damaged. Some were damaged by the failure of their foundations. It seems that certain types of structures were susceptible to damage. Especially for Baguio's hilly terrain, unorthodox construction are often used.

It is most certain that additional research in these areas are needed.

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