Earthquake Engineering
Research Institute

EERI

Reconnaissance Report

MINDANAO, PHILIPPINES EARTHQUAKE

August 17, 1976

The EERI Reconnaissance Team

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PREFACE

An Earthquake Engineering Research Institute reconnaissance team was appointed by President Henry J. Degenkolb on August 18, 1976 to assess the engineering aspects of the earthquake that occurred on the island of Mindanao in the Philippines on August 17, 1976. The EERI team consisted of James L. Stratta, team leader; Ted J. Canon, C. Martin Duke, and Lawrence G. Selna.* They were joined by two investigators from Canada, W.K. Tso and S.M. Uzumeri. These six departed San Francisco on August 21. A few days later EERI sent J. Eugene Haas to examine the socio-economic aspects, and the United States Geological Survey (USGS) sent Robert E. Wallace to reconnoiter the scientific aspects of the earthquake. The original four team members arrived back at San Francisco on August 30.

This report, then, is the work of the original four investigators, augmented by notes on seismicity by David J. Leeds and social science observations by J. Eugene Haas, as well as extracts from the preliminary report prepared by the Philippine National Geophysical and Astronomical Service (PAGASA) under the direction of Roman L. Kintanar, Administrator.

The present report is somewhat more comprehensive than the usual reconnaissance report. Because the amount and type of damage did not appear to warrant such detailed analyses as were made in some past major earthquakes, the team concluded in the field that it could and should make an investigation and report of sufficient scope to document the earthquake in an engineering sense and to "calibrate" it relative to recent destructive United States and Latin America quakes. President Degenkolb was cabled from Manila to this effect on August 23, after the team had met with knowledgeable Philippine engineers.

Effective results could not be obtained by EERI teams investigating foreign earthquakes without the aid of local jurisdictions. The team wishes to express its appreciation to all who aided it, with special mention of the following:

* <u>Affiliations</u>

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S.M. Uzumeri, Toronto University, Toronto
Robert E. Wallace, U.S. Geological Survey, Menlo Park

1) The Philippine Civil and Structural Engineering Associations, who greeted the team in Manila, briefed it on the damage, and arranged for Philippine Army assistance.

2) The Philippine Army, especially Colonel Castro, Commander of Region XII, who personally escorted the team on a helicopter flight over the tsunami areas and the areas damaged by shaking. Lt. Colonel Navera generously coordinated all aspects of the team's work and living accommodations. Colonel Gatmaitan, who was in charge of the Quirino Bridge repair, personally escorted the EERI team through the bridge problems.

3) The Cotabato City Civil Authorities - Mayor Juan J. Ty, City Attorney Ramon Della Fuente, and City Engineer Teodulo A. Ladub, who responded to requests for information with full cooperation and dispatch.

It would be impossible to name all of the Filipinos who aided in the study, but to each one the team extends its heartfelt thanks.

Financial support of the EERI team's travel costs was provided by the National Science Foundation.

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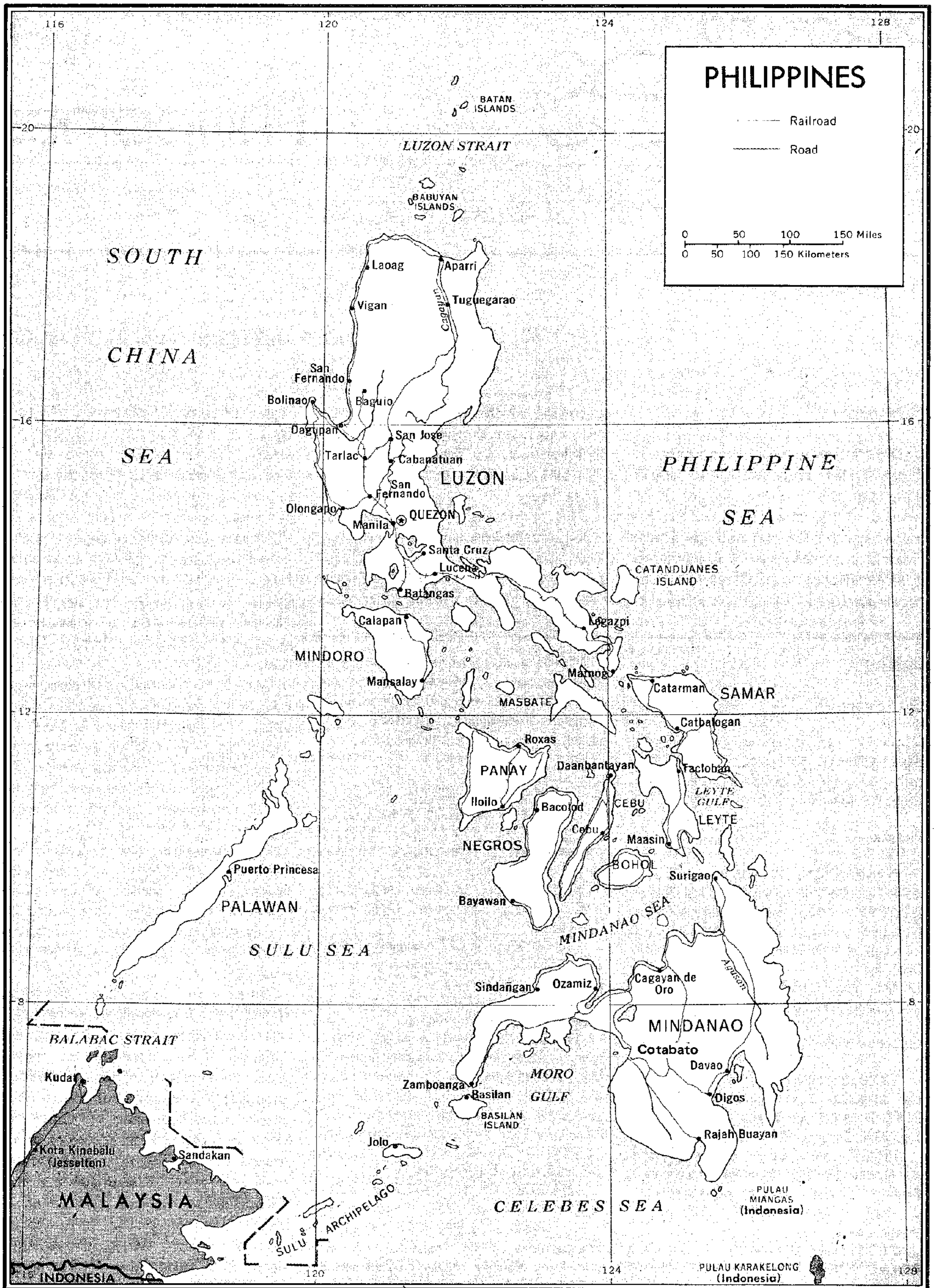

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I. INTRODUCTION

A major earthquake occurred in Mindanao in the Philippine Islands on August 17, 1976. A map of the Philippines (see frontispiece) shows that the island of Mindanao lies at the southernmost tip of the island group, some 500 miles south of Manila.

Seismological reports of the main shock develop a refinement of the epicenter location with additional data. The most complete report to date is the USGS "Earthquake Data Report" (EDR 21-76, Apr 15, 1977, pp. 11-14), in which 231 observations are summarized, as follows:

UTC (GMT) time	Aug 16 1976 16:11:07.30 ±0.07 sec
Local (120° EMT) time	Aug 17 1976 00:11:07.30 ±0.07 sec
Latitude	6.262°N ±1.78 km
Longitude	124.023°E ±2.12 km
Depth of focus	33.0 km (normal)
Magnitude	
MB	6.4 (46 observations)
MSZ	7.9 (8 observations)
MS-BRK	7.9
MS-PAS	7.7

The Philippine National Geophysical and Astronomical Service (PAGASA) records show strong, remarkably recorded surface waves, indicating that the depth of focus was rather shallow. The depth, therefore, may be somewhat shallower than the "controlled" depth given in the EDR cited above. The PAGASA preliminary origin time is given as 16:11:44.2, some 33 seconds later than the EDR time. This difference is attributed to the USGS interpretation of a foreshock preceding the main event. The location of the epicenter is offshore in the Moro Gulf approximately 100 km south of Cotabato City and about 12 km west of Cadiz Point. The entire Mindanao region is shown in Figure 1.

The PAGASA determination places the epicenter farther out into the gulf. The earthquake was felt as far north as the Visayas Islands and the southeastern tip of Luzon, and as far south as Borneo.

Foreshocks

Approximately a month before the major earthquake of August 17, 1976, two tremors were reported felt in Zamboanga City, near the epicentral area of the main shock. These preliminary tremors were not recorded at the Geophysical Observatory in Quezon City nor in any of its field stations. Analysis of seismic records for August prior to the earthquake showed that six tremors were recorded that had epicenters within the same area as the main shock. This brought to eight the total number of tremors which may be considered as foreshocks of the Moro Gulf

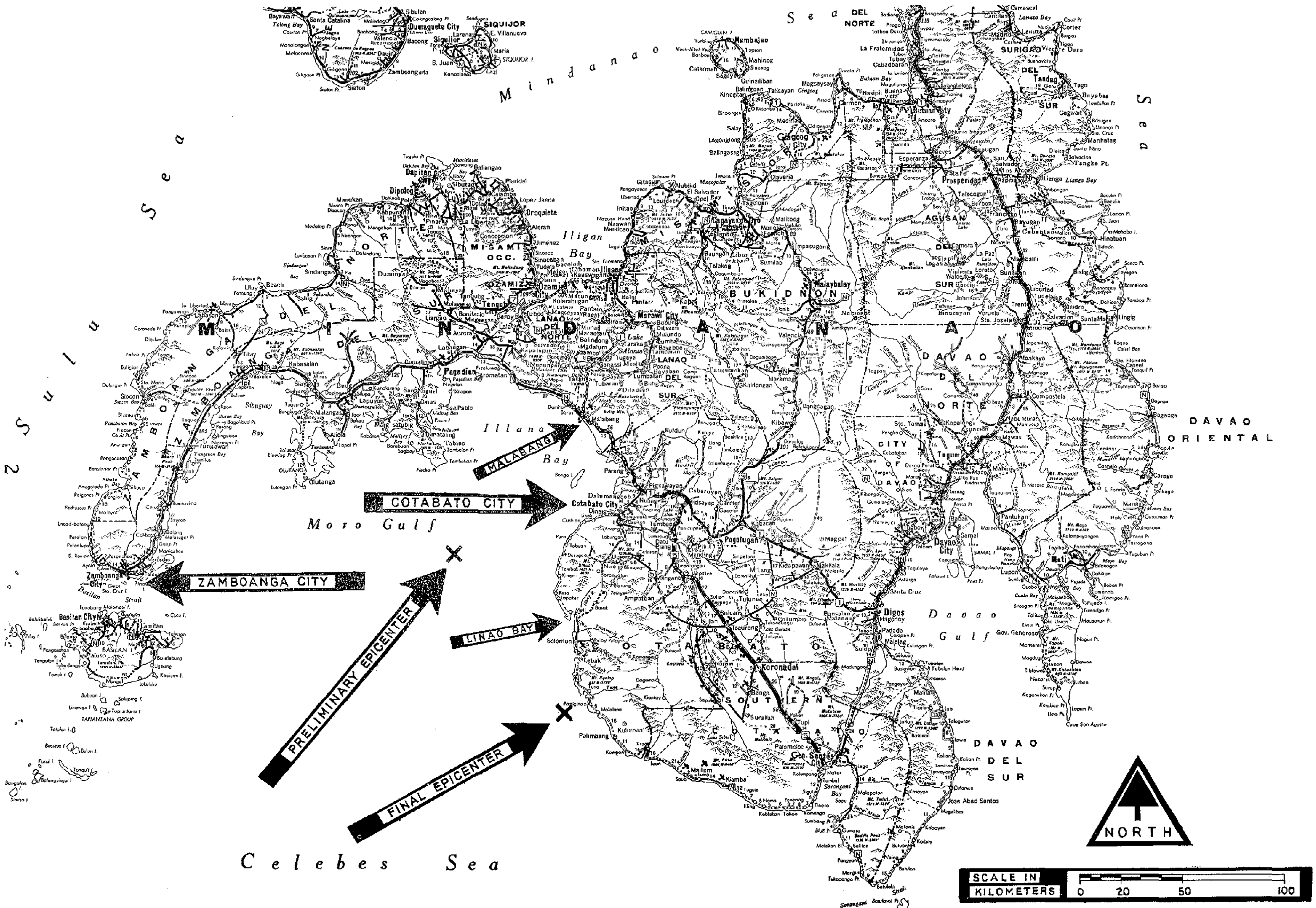

Figure 1. Mindanao Region

earthquake. Three of the eight events were felt with Rossi-Forel intensities of II through IV (see Table 1).

Aftershocks

Approximately 70 aftershocks were recorded on the PAGASA seismic network through August 29, some 40 of which were felt with Rossi-Forel intensities as high as VI. Some of these aftershocks were quite local in character and not recorded at any of PAGASA's seismic stations. The largest aftershock to date had a magnitude of 6.8 and occurred at 04:19.29.6 GMT on August 17, 1976 (12:19.29.6 EMT).

Monitoring of aftershocks at Cotabato City was instituted by the Commission on Volcanology of the Philippine Islands, using a three-component Hosaka seismograph with drum speed 6 cm/min and a one-component Kinemetrics Ranger seismometer. The instruments were placed in the Army officers' mess hall, located on the very firm decayed limestone of Colina Hill. Alejandro Oanes, a mining engineer with the Commission, reported 1148 aftershocks recorded between 1934 hours on August 18, 1976 and 0645 on August 26, 1976, Philippines time, giving an average of 143 aftershocks per day. Of these, 12 were perceptible to people, with intensities on the Rossi-Forel scale varying from I to III. There were no strong motion accelerographs or seismoscopes in the affected area.

Acceleration

Although no strong motion instruments were in the epicentral area, peak acceleration can be calculated using any of several formulas based on epicentral distance and magnitude. The range of values of peak acceleration derived from these formulas is 0.08 to 0.18 g. Little purpose would be achieved by detailing the formulas here. Moreover, the epicenter is not necessarily the closest point of energy release to the area of interest. Although the formulas used to determine these values did not incorporate soil factors, soil conditions should be considered at the site of damage. The roughness of the calculation is illustrated by the spread of results. Intensities varied from Rossi-Forel V to VII in Mindanao and Sulu.

Macroseismic Reports

An isoseismal map using Rossi-Forel intensities is shown in Figure 2. A summary of PAGASA field reports is provided in Table 2.

The damaging effects of the earthquake and tsunami which followed were distributed over an area extending as far as Zamboanga City on the west, Davao City on the east, and Pagadian City on the north. A statistical evaluation of the damage and its causes and distribution is afforded by Table 3, the data for which were furnished by PAGASA and the Regional Disaster Coordination Centers. Data from the centers show that, outside of Cotabato City, 80% of the casualties were caused by the tsunami. In addition, 39,850 persons are listed as homeless, 10% of whom were from Cotabato City. Of the 6900 houses damaged, 1300 were in Cotabato City.

TABLE 1. ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES (ADAPTED)

I. HARDLY PERCEPTIBLE SHOCK: Felt only by an experienced observer under favorable conditions.

II. EXTREMELY FEEBLE SHOCK: Felt by small number of persons at rest.

III. VERY FEEBLE SHOCK: Felt by several persons at rest. Duration and direction may be perceptible. Sometimes dizziness and nausea are experienced.

IV. FEEBLE SHOCK: Felt generally indoors, outdoors by a few. Hanging objects swing slightly. Cracking of frames of houses.

V. SHOCK OF MODERATE INTENSITY. Felt generally by everyone. Hanging objects swing freely. Overturn of tall vases and unstable objects. Light sleepers awaken.

VI. FAIRLY STRONG SHOCK. General awakening of those asleep. Some frightened persons leave their houses. Stopping of pendulum clocks. Oscillation of hanging lamps. Slight damage in very old or poorly built structures, old walls, etc. Some landslides from hills and steep banks. Cracks in road surfaces.

VII. STRONG SHOCK: Overturn of movable objects. General alarm, all run outdoors. Damage slight in well-built houses, considerable in old or poorly built structures, old walls, etc. Some landslides from hills and steep banks. Cracks in road surfaces.

VIII. VERY STRONG SHOCK. People panicky. Trees shaken strongly. Changes in flow of spring and wells. Sand and mud ejected from fissures in soft ground. Small landslides. Slides in river banks.

IX. EXTREMELY STRONG SHCOK: Panic general. Partial or total destruction of some buildings. Fissures in ground. Landslides and rock falls.

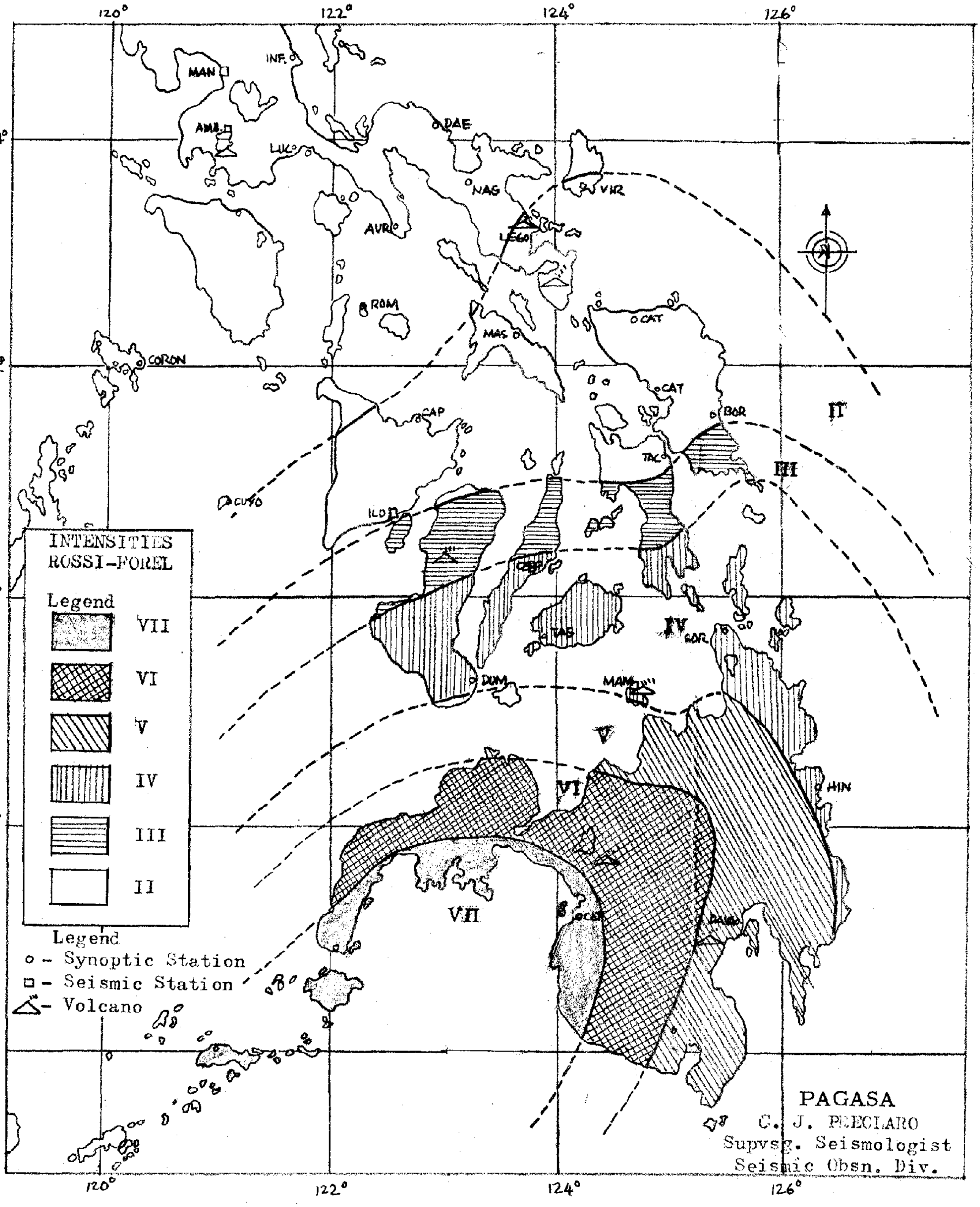

Figure 2. Isoseismal Map of August 17, 1976 Earthquake

TABLE 2. SUMMARY OF PAGASA FIELD REPORTS ON MAIN SHOCK GROUND MOTION

Place	Intensity (Rossi-Forel)	Duration of Felt Motion, sec	Direction of Felt Motion
Cotabato City	VII	Undetermined	Undetermined
Jolo, Sulu	VII	30	N-S
Zamboanga City	VII	30	E-W
Basilan City	VI	Undetermined	Undetermined
Pagadian City	VI	Undetermined	Undetermined
Dipolog City	VI	37	NW-SE
Malaybalay, Bukidnon	VI	8	NW-SE
Cagayan de Oro City	V	40	NE-SW
Davao City	V	25	Undetermined
Gen. Santos City	V	27	NNE-SSW
Dumaguete City	IV	23	N-S
Hinatuan, Surigao del Sur	IV	20	ENE-WSW
Tagbilaran, Bohol	IV	8	N-S
Cebu City	IV	Undetermined	Undetermined
Surigao, Surigao del Norte	IV	Undetermined	Undetermined
Roxas City	II	18	Undetermined
Iloilo City	II	3	Undetermined
Tacloban City	II	Undetermined	Undetermined
Legaspi City	II	27	Undetermined
Palo, Leyte	II	Undetermined	Undetermined
Catbalogan, Samar	II	Undetermined	Undetermined

By the August 23, 1976 arrival date of the EERI team, only 7 days after the main shock of the earthquake, effective civil and military relief organizations had completed much of the immediate relief work.

The team concentrated its investigation on Cotabato City, 7.2°N latitude and 124.2°E longitude, on the shore of Illana Bay on the Island of Mindanao. This city of approximately 70,000 population was the only area that suffered substantial damage to fairly modern facilities. Most of the affected buildings were constructed in the 1960's. After analysis of the damage, the team assigned the following intensities on the Modified Mercalli scale to Cotabato City:

Low-lying land (main part of the city)	VIII
Colina Hill and high land to the south	V

Table 4 provides a correlation of Rossi-Forel and Modified Mercalli intensities.

TABLE 3. CASUALTIES AND NUMBER OF PERSONS RENDERED HOMELESS

Affected Areas	Casualties									Homeless Families
	Dead			Missing			Injured			
	EQ*	TS*	Total	EQ	TS	Total	EQ	TS	Total	
Region IX										
Zamboanga City			153			15			151	97
Zamboanga del Sur			563			521			4,110	818
Zamboanga del Norte			-			-			-	-
Pagadian City			418			29			2,500	3,980
Basilan City			30			6			10	129
Sulu			89			107			15	25
Region XII										
Lanao del Norte			80			162			2	1,488
Lanao del Sur			561			89			273	879
Maguindanao			1,198			429			645	2,761
Sultan Kudarat			305			51			106	1,081
North Cotabato			-			-			1	50
Cotabato City	110	57	167	0	93	93	422	21	443	879
Total			3, 564			1,502			8,256	12,183

*EQ = earthquake; TS = tsunami.

TABLE 4. CORRELATION OF INTENSITY SCALES

Rossi-Forel 1873	Modified Mercalli 1931
I	I
I-II	II
III	III
IV-V	IV
V-VI	V
VI-VII	VI
VIII-	VII
VIII+ -IX	VIII
IX+	IX
X	X-XII

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2. SITE CONDITIONS AND SOIL EFFECTS

Most of the older part of Cotabato City is at an elevation only slightly above sea level. The general level of the city had been raised 1 m by means of filling. This part of the city lies on deep, very young deltaic deposits. Engineer Augusto Chio reported that a boring carried to over 90 m in this area did not reach firm material.

A general feeling for the subsurface materials of the low-lying area is provided in Table 5, which shows simplified driller's logs of a number of wells recently drilled for water supply purposes. The wells are located southwesterly of the Notre Dame University Campus, shown as Buildings 1, 2, 3, and 4 in Figure 3. A list of buildings, whose locations are shown in Figure 3, is given in Table 6. The data were provided by Manuel D. Magdael and Lauro S. Gecosala, Sr. of the Office of the City Engineer. Immediately to the south of the city proper is a weathered limestone rise called Colina Hill, approximately 55 m high, which accommodated the Army Headquarters.

TABLE 5. SIMPLIFIED LOGS OF WATER WELLS

Well	Depth to Bottom, m	Material Penetrated
Roales	32	Sandy clay
Orotouste Rosal	20	Cemented sand, then coarse sand
Orotouste Ugaligan	22	(Material not reported)
Motor Pool	23	Sandy clay, then sand rock, then adobe rock
Ilang-Ilang St.	27	Adobe clay, then sand rock, then coarse sand
Gutierrez-Sampaquita	19	Clay,. then rock, then coarse sand
Gen. Luna Pump	39	Clay, then sand, then blue sandy clay
Lutheran Pump	36	Clay, then limestone, then red sand rock, then coarse sand

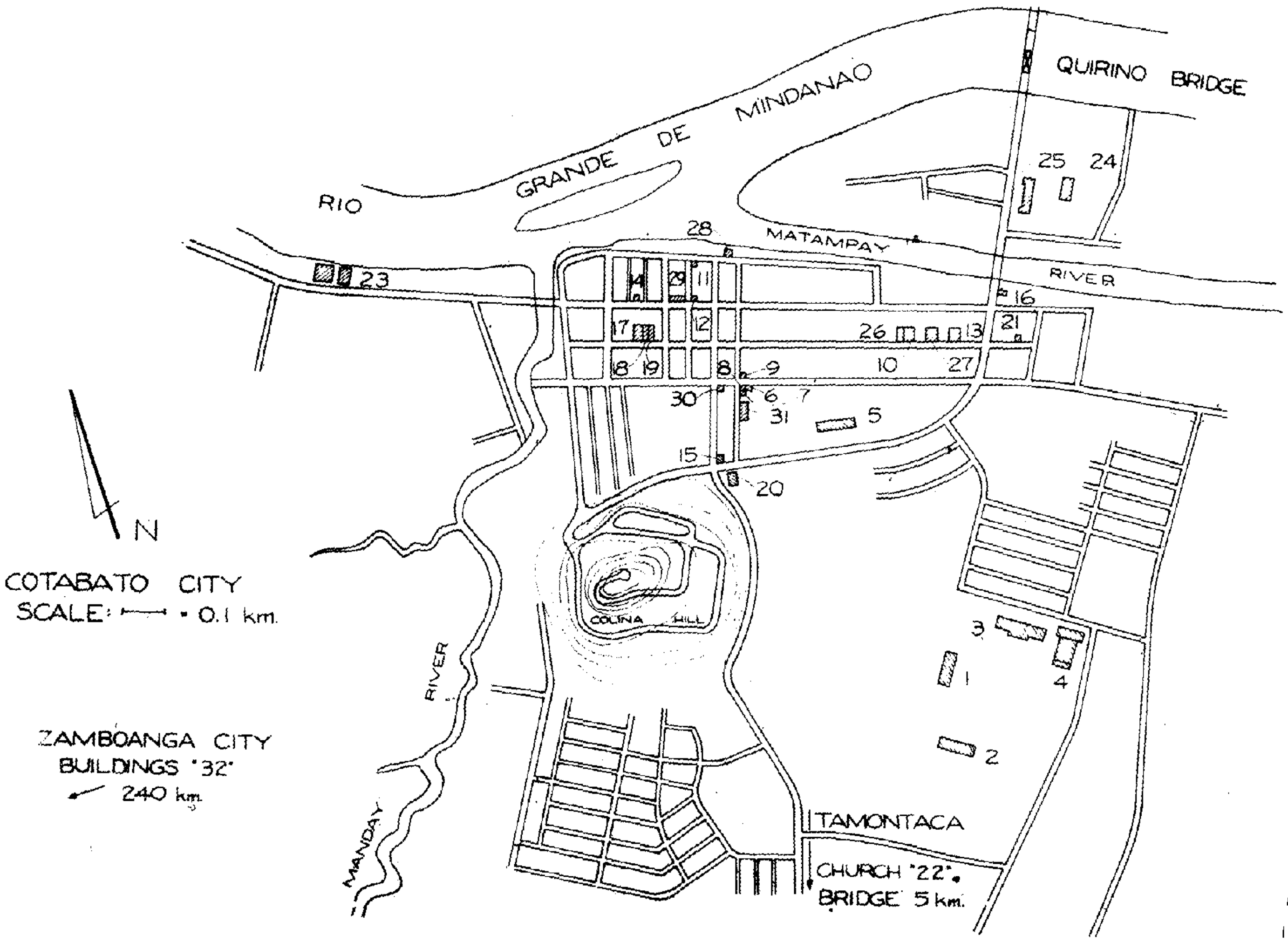

Figure 3. Cotabato City
(numbers refer to Table 6)

TABLE 6. BUILDINGS INVESTIGATED
(Refer to Figure 3)

No.	Name	No.	Name
1	Notre Dame University Residence Hall	16	Melbourne Hotel
2	Notre Dame University Technical School	17	Imperial Hotel #2
3	Notre Dame University Administration Building	18	Rita Theater
4	Notre Dame University Auditorium and Science Building	19	Imperial Hotel #1
5	Harvardian College	20	Immaculate Conception Church
6	Amicus Building	21	Melineen Building; Grain and Rice Sales
7	Sagittarius Hotel	22	Tamontaka Church
8	D'Max Restaurant	23	Waterfront Warehouses
9	First Gift and Book Store	24	Cotabato Chinese School Gymnasium
10	Sultan Hotel	25	Cotabato Chinese School Administration Building
11	New Society Hotel	26	Cotabato Movie Theater
12	LCT Hardware and Auto Supply	27	Boston Bakery Building
13	Cotabato Auto Supply	28	Cotabato Fire Station
14	South Seas Trading Building	29	Francel Theater
15	Tison Building	30	Tan Bo Building
		31	Dawns Hotel

Through the courtesy of the Philippine Army unit, on August 24 the team made a helicopter surveillance tour over the region principally affected by the earthquake. This tour covered the coastal area from Linao Bay on the south to Malabang on the northwest (Figure 1) and extended a limited distance inland. On this flight numerous superficial landslides were observed on the steep slopes of decomposed limestone cliffs, apparently due to the earthquake. Evidence of tsunami wave encroachment was seen at several places, including the destruction of an unreinforced concrete wharf in the vicinity of Balabagan. Near Malabang, team members observed from the helicopter a crack approximately 30 m long and 15 cm wide in the soil on a river delta. The buildings at Malabang, however, could not be sufficiently observed to permit an evaluation of their behavior.

A few other soil movements or failures were seen by team members, but not of a widespread character. Abutment soil cracks were exhibited at the Quirino and

Tamontaka Bridges. Notable ground cracking occurred to the west of the Quirino Bridge on both sides of the Rio Grande. Some of these were 25 cm wide and 1.8 m deep, with as much as 25 cm of settlement on the river side. Both the south and the north sides of the Rio Grande contained wharves and warehouses that showed ground motion and cracking near the bank of the river.

At the Harvardian University the ground was marshy, with the water table at ground surface. Dr. Wallace reported he saw a number of small mud boils there, perhaps 60 to 90 cm across. The Fire Station, a modern structure next to the Rio Grande, settled a few cm on the north, or river side, creating an out-of-plumb condition. The Immaculate Conception Church also exhibited some limited foundation settlement.

Engineering practice in Cotabato City used a 3600 kg/m^2 bearing capacity for spread footings and found pile capacities using the Engineering News formula for the standard 15 to 20 cm timber piles of approximately 4.6 to 7.6 m in length.

The 1973 edition of Earthquake Resistant Regulations, a World List, published by the International Association of Earthquake Engineering, contains a seismic code for the Philippines (pp 328-350) which is designated as "Approved June 23, 1972". The code was not updated in the 1976 supplement to the Regulations. This is essentially the 1970 Uniform Building Code but contains these seismic coefficient Z factors for the Cotabato region, modified for foundation type:

Foundation Type	Z Factor
A. Rock foundation	1.0
B. Intermediate between A and C	1.2
C. Alluvium or poor foundation	1.4

It appears that, except for the Tison Building (see Building 15, Figure 3) this code had not been used for Cotabato City. As a matter of interest, one may look at total lateral force, or base shear, $V = ZKCW$ or $V/W = ZKC$, with

$K = 1.0$

$C = 0.10$

$V/W = 0.14$ g on low-lying land

$V/W = 0.10$ g on Colina Hill

It will be left to the reader to reconcile these design criteria with the intensities, the computed accelerations, and what actually happened.

Differences in damage level on Colina Hill and on the low-lying land of the city proper were pronounced. The former may be summarized by the essentially complete absence of damage to the Army facilities, the water tank, the power and light facility, and the telephone headquarters. However, on the hill there were none of the typical reinforced concrete buildings that failed frequently on the low-lying land. The lowlands siting condition applies essentially everywhere else and corresponds with a monopoly on damage, but it should be emphasized that the prevailing non-earthquake resistive reinforced concrete construction was found only on the lowlands.

This general damage distribution has been exhibited many times in past earthquakes where damage on saturated soil of low strength and density can be compared with damage on very firm ground of high strength and density. The contrast is seldom pronounced when the range of soil involved goes only from intermediate to firm without the presence of soil of such very low density and strength such as that in Cotabato City.

In the absence of borings penetrating to bedrock, with associated soil properties including shear wave velocity, and in the absence of strong motion accelerograms on Colina Hill and central city sites (or anywhere for that matter), one can only speculate as to the cause of the apparent amplification of surface ground motion on the low-lying land. It seems probable that the effect was one of amplification rather than liquefaction, since the team found only a few evidences of the movement of foundations of buildings. However, it is also possible to attribute the effect discussed to the lurching or horizontal landsliding of pockets of the lowest strength foundation soil.

3. DAMAGE TO LIFELINES

Cotabato City is served by the following lifelines:

Transportation

- Streets and highways
- Bridges
- Harbor and waterways
- Airport

Water

- Water supply
  - River source
  - Wells
  - Distribution
- Water for fire fighting
- Sewage

Communication

- Telephone
- Radio
- Mail
- Newspaper

Energy

- Electric power
- Gasoline and diesel fuel
- Bottled gas

Transportation

The streets in the city appear in outline form in Figure 3. They were essentially cleared of rubble by August 27. Longitudinal buckling occurred opposite the Harvardian College and on the pavement of the highway to the airport, and was promptly corrected. No earthquake-caused problems with the airport were uncovered by the team. As discussed in the previous section, several wharves on the Rio Grande experienced settlement or vibrational damage. Damage to the wharf near Balabagan was mentioned.

Of the several highway bridges serving Cotabato City, at least three experienced damage. The EERI team members evaluated the damage to two of them; their findings are presented in the discussion of bridges (Section 8). Briefly, the Quirino Bridge dropped one of four steel truss spans into the Rio Grande; this was being replaced by a Bailey bridge which was scheduled to be operative August 29. Two concrete box girder bridge decks (Tamontaka and Esteros south of Cotabato City) shifted on their piers but remained in use.

Communication

The local Cotabato City telephone system serves 1000 single lines and ties to the Philippine Long Distance Telephone Company. According to spokeswoman Mrs. Florentine A. Bacar, and confirmed by the team, there was no seismic damage to the "internal" system, located on Colina Hill, which contains the local switch gear and emergency power. The switch racks were well secured to the walls of the two-story wood building.

On the outside system, cables fell over approximately 2 km of its length, and they broke at many of the damaged buildings. Damage to poles and lines was experienced mainly in three areas of poor foundation soil: the northern part of the downtown section, the vicinity of the Notre Dame University, and the Malagapas and Esteros villages south of Cotabato City.

While the local system headquarters was never inoperative, the long distance system was out for approximately 3 hours after the earthquake. The latter contained microwave towers in Cotabato City and at Upi Muro, 36 km away, where a large battery fell, causing the 3 hour outage. As of August 27, it was still difficult to reach Zamboanga City from Cotabato City, partly due to the tieing up of circuits for Army and relief work.

Three or four radio stations were operating when the EERI team arrived. The Mindanao Cross, a weekly newspaper in Cotabato City, published an 8 page issue August 28. A TV station was operating in Zamboanga City on August 26.

Water

The principal water supply to Cotabato City is provided by an intake from the Dimapatoy River, 16 km away. The intake elevation is 116 m. This involves a diversion dam 1.5 m high. Local storage is provided in a 750,000 liter concrete tank on Colina Hill, with water elevation up to 53.7 m. The tank appeared to be in good condition. The transmission line consists of 5.5 km of 20 cm pipe followed by 10.5 km of 26 cm centrifugal cast iron (CCI) bell and spigot pressure pipe. An earlier 13 cm pipe had been abandoned.

The bell and spigot joints broke at many places where the line crossed the Tamontaka River on the bridge near the airport and for a few km to the north. The 26 cm pipe sheared off where it went from the bridge deck into the north abutment (Figure 4). The joints were recaulked and otherwise repaired as rapidly as possible with lead and oakum caulking flown from Manila. The repair process was still under way on August 26, by which date much of the city was again receiving water.

An auxiliary water supply source, approximately 2 km south of the city, had already been constructed, consisting of eight wells ranging from 19 to 39 m deep, cased with CCI pipe and widened at the producing zones to make an underground collection area at each well. (Simplified logs appear in Table 3.) Six of the eight wells collapsed in the earthquake at the widened segments, leaving two still operating. The collapsed six suffered sandfilling of the widened segments and plugged perforations, and were scheduled for repair.

Additional small water supplies came from roof runoff catchment and tank truck delivery.

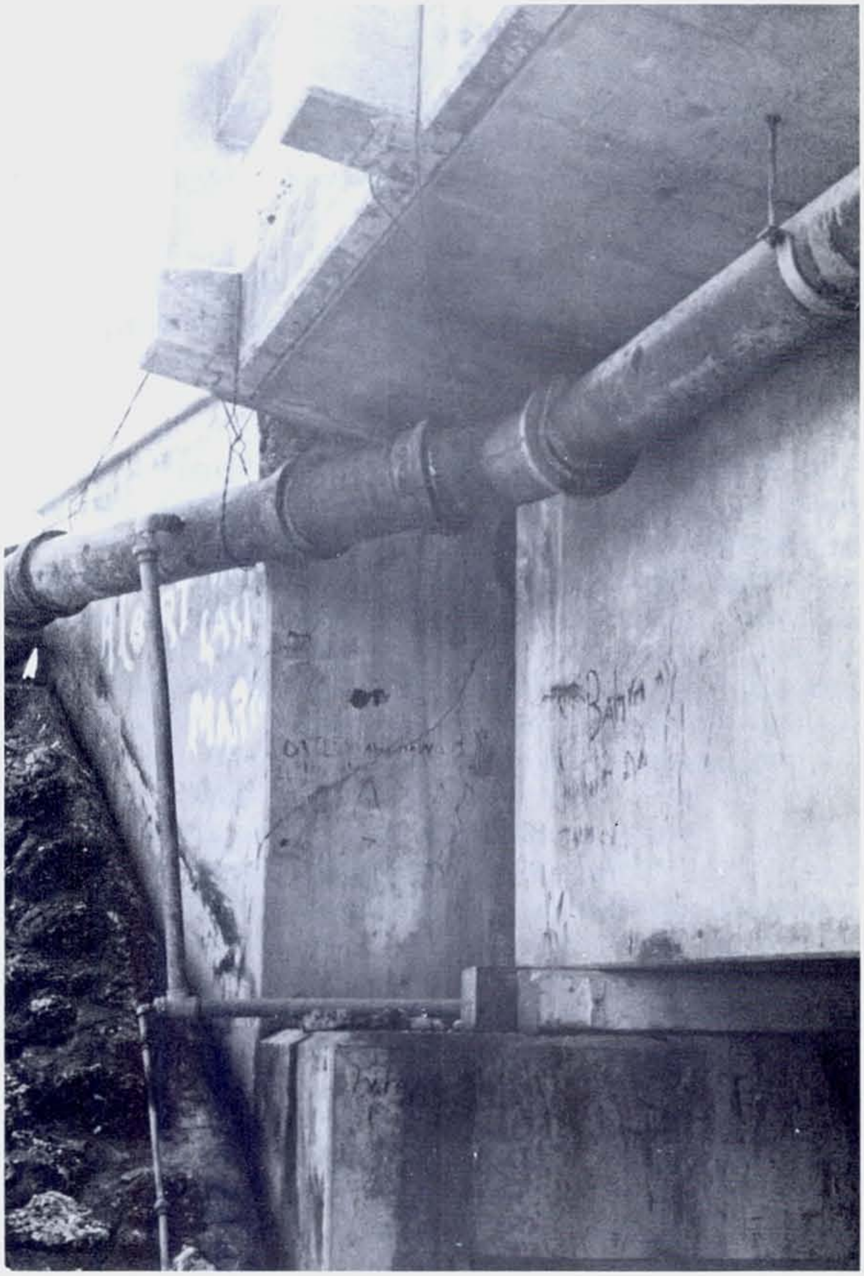

Figure 4. Shearing of Pipe at Tamontaka River Bridge

Figure 5. Balabagan Wharf

Figure 6. Tsunami Damage at Balabagan Wharf

Figure 7. Seashore Damage South of Cotabato City

Bongo Island is located in Illana Bay 25 km northwest of Cotabato City. This island, approximately 10 km long, running parallel to the Mindanao Coast, reportedly took the brunt of the tsunami, reducing the damage to the adjacent Mindanao coastline along Illana Bay. A fishing village on the northern seaward side of the island was heavily damaged (Figure 8).

The northwest limit of the team's helicopter tour was the municipality of Malabang, at the mouth of the Mataling River. The wave backwashed the river, destroying many of the residences and buildings along its shores (Figure 9).

Tsunami damage was also observed at villages on the Moro Gulf coast approximately 30 km north of Zamboanga City. The northernmost village visited was Bolong. This village was sparsely populated, and minor damage was visible. Huts were battered, boats displaced, and debris generally scattered. Overgrowth, some 75 m from the shore, was heavily pounded by the waves (Figure 10). The other village, San Golli, was more densely populated, with huts closely grouped. The outer huts offered some protection to the ones more inland (Figure 11). Some indication of the apparent wave height may be obtained from the figure.

Subsequent to the Mindanao trip, the team briefly reviewed its findings with representatives of the Joint Tsunami Research Effort, who concurred that the wave heights reported above seem to be in agreement with the documentation available.

Figure 8. Tsunami Damage on Bongo Island

Figure 9. Residential Damage at Malabang Due to Surges in Mataling River

Figure 10. Tsunami Damage North of Zamboanga

Figure 11. Protected Huts, Zamboanga

5. DAMAGE TO BUILDINGS IN COTABATO CITY

The heaviest concentration of seismic damage due to the Mindanao earthquake occurred in Cotabato City, as indicated in Figure 3. Names of the buildings indicated by number in Figure 3 are given in Table 4. These buildings were investigated by the EERI team.

Approximately 30% of the commercial buildings in Cotabato City were reported by Philippine engineers to be damaged. The undamaged facilities were used to shelter victims whose buildings suffered from the earthquake. Figure 12 is an overview of the city after the earthquake; the extent of damage is not clearly evident except for the tilted New Society Hotel (Bldg 11).

The principal materials of construction in Cotabato City are Philippine mahogany wood, concrete block masonry, and reinforced concrete. A number of the buildings have combinations of these materials. Wood floors are frequently used in reinforced concrete frame buildings. Damage to buildings occurred most often where reinforced concrete was used as a major component.

According to the Cotabato City Engineer's Office, most of the reinforced concrete buildings were constructed during the 1960's. The Philippine civil and structural engineers in Manila reported that, except for the Tison Building (15), buildings were not designed for seismic lateral load. They appeared to have lateral resistance only as a result of the gravity load design requirements.

According to architect Robert Atienza of Compact Construction, Cotabato City, concrete cylinder strength tests were not required for buildings constructed during the 1960's. Concrete used in recently constructed buildings has been tested according to engineer Augusto Chio, Cotabato City. Inadequate concrete strength seems to have been a contributing factor to the failure of some of the buildings.

There is no doubt that ground shaking was more severe in certain regions of the city than in others. Significant building damage occurred exclusively on the deltaic plain to the north and east of Colina Hill. This area has approximately 1 m of recent fill and is swampy as a result of its deltaic location, heavy rains, and runoff.

Wood friction piles 4.6 to 7.6 m long were used on most buildings. An exception is the Tison Building which had 12.2 m reinforced concrete piles.

Foundation settlement due to ground shaking was not detectable except at the Immaculate Conception Church (Bldg 20) and the Fire Station (Bldg 28). In buildings where column failures occurred, the undeflected column stubs were observable at grade level. Although building settlement was not an important factor in the failure at Harvardian College (Bldg 5), adjacent walkways showed signs of settlement and mud boils appeared at the site.

Figure 12. Panoramic View of Cotabato City

Building Damage Observed

Discussion of damage to individual buildings identified in Figure 3 and Table 6 follows.

Notre Dame University (Bldgs 1 through 4, Figure 3) is located on Notre Dame Avenue approximately 1.5 km southeast of the downtown area. The site has wet and soft marshy ground. Ground water appeared to be very near the surface, as ponds were evident throughout the site. Four buildings on this site suffered some degree of damage from the earthquake.

Fronting on Notre Dame Avenue are the Auditorium/Science Building which collapsed and the Administration (Burke) Building which suffered only light damage. At the southwest portion of the site, a complex of buildings is located which include the Technical School which suffered moderate damage. Toward the northwest end of the site a new residence hall nearing completion suffered only light damage.

The New Residence Hall (Bldg 1) is a rectangular, three-story structure (Figure 13). Its construction consists of concrete exterior columns and thin concrete exterior walls. Midheight windows run the full width of each bay throughout most of the building. There are some solid panels, especially at the south end. Interior columns and floor systems are wood, and the roof employs galvanized iron sheeting. For the most part, the interior partitions are constructed of plywood. Architectural vertical fins are located opposite all exterior columns, with a thin exterior floorline slab (15 x 61 cm wide) accenting horizontal lines. The team noted that the building had little, if any, built-in seismic resistance. Construction of the building was nearing completion, and the building was unoccupied at the time of the earthquake.

Damage to the building was light. The architectural fins were cracked at the floor line, and some columns were damaged at the sill line, showing column damage (Figure 14). Interior partitions were torn apart, and some of the ceiling panels (nailed to a suspended grid) fell (Figure 15). There was considerable cracking of the ground floor slab. At one location where two slabs were constructed with a vertical offset (46 cm), the slabs pulled apart more than 1.3 cm (Figure 16).

The Technical School (Bldg 2) (Figure 17) is a two-story building approximately 10 x 30 m (Figure 17). Built in 1965, it has a concrete frame consisting of column line girders and columns, with a concrete two-way slab floor. The columns are approximately 36 cm square reinforced with nine bars with plain ties at 23 cm spacing (No. 7 and No. 3, respectively). The exterior had windows running from column to column, with a 1.07 m sill height constructed of hollow block infill panels. Architectural concrete fins were poured adjacent to each column along one longitudinal side. This building is linked to an adjacent building by a common wood canopy.

Figure 13. Notre Dame Residence Hall

Figure 14. Residence Hall Exterior

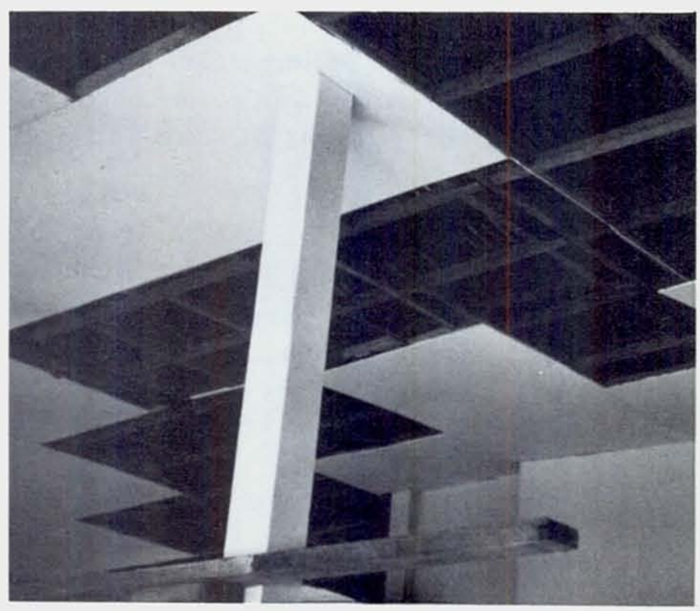

Figure 15. Interior Damage, Notre Dame Residence Hall

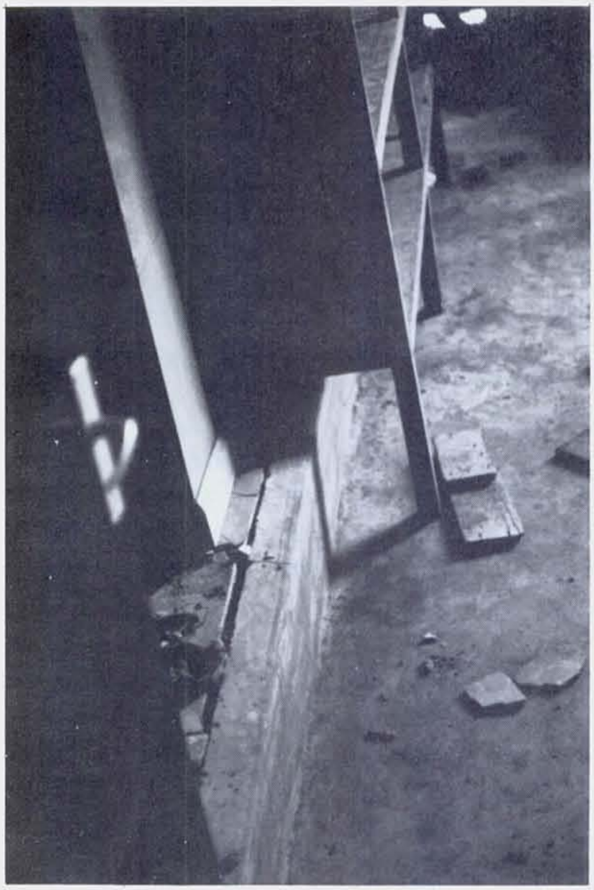

Figure 16. Slab Damage,
Notre Dame Residence Hall

Figure 18. Column Damage,
Technical Building

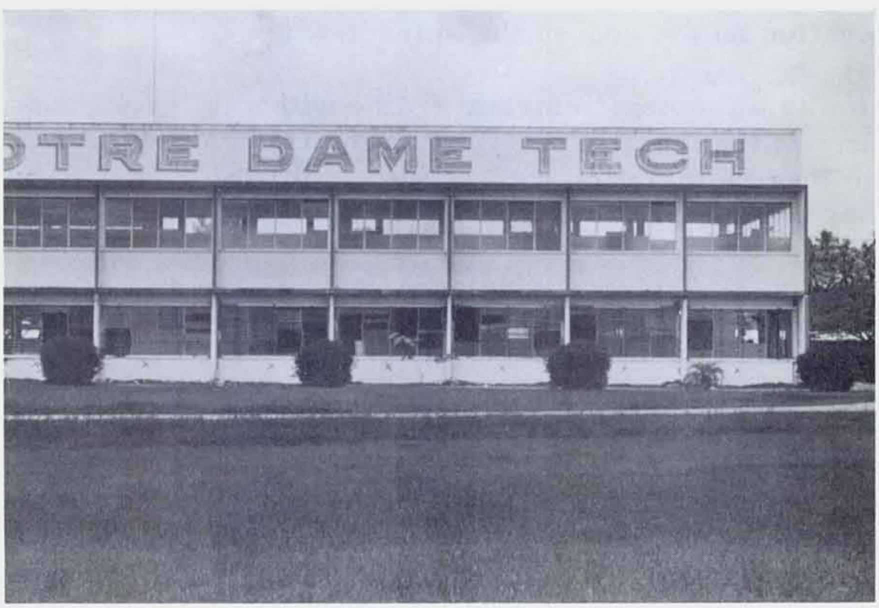

Figure 17. Notre Dame Technical Building

Damage to the structure was moderate. The first story columns were damaged at the head and sill levels, failing in shear (Figure 18). The fins were also damaged at similar locations. This canopy, supported on round steel columns, collapsed at its end bay.

The Administration Building (Bldg 3) is a rectangular three-story structure constructed in the early 1960's (Figure 19). It has an aspect ratio of 8:1. The building has a reinforced concrete frame of columns and girders with concrete floors. One longitudinal side has midheight windows the full width of each bay with sills about 76 cm high, made up of hollow block panels. There is a 3 m concrete panel at the entrance, which was severely cracked (Figure 20). The other longitudinal wall is set in from the edge, allowing for an exterior corridor. This wall has a 38 cm and a 76 cm high louver running continuously between columns at the top and bottom, respectively. The balance of the wall is hollow block. This side has a one-bay projection at midlength equal to approximately one-third the building's length. There are two longitudinal interior walls along a corridor constructed similarly to the louvered rear wall. The end walls are solid.

Damage to the building was light. The hollow block walls were damaged along with the louver mullions (Figure 21). As stated above, the front concrete panel was also damaged. Damage to the concrete frame was minor.

Notre Dame University Auditorium and Science Building (Bldg 4) (Figures 22 and 23) is a 48 x 30 m auditorium crossed at its entrance by a three-story 51 x 12 m science wing (Figures 22 and 23). The longitudinal axis of the wing lies N60W. For the present discussion it is assumed that the axis runs east and west. Constructed in 1969, masonry was used as the infill for the reinforced concrete frames. Smooth bars were used throughout the building. The first, second, and third story heights in the science wing were 3.5, 3.2, and 3.0 m, respectively. The auditorium roof had the same elevation as the roof of the science wing.

The science wing was a moment resistant frame with reinforced concrete floors and roof. Typical bays in the frame were 12 m in the transverse direction of the wing and 4.25 m in the longitudinal direction. The auditorium roof was corrugated sheet metal supported by purlins on steel trusses spanning the width.

Before the earthquake, the science wing appeared as shown in Figure 24. Lateral resistance in the longitudinal and lateral direction was provided by the moment frame, end walls, and a pair of stair towers at each end of the wing (Figure 24). The infilled walls at the ends of the wing and outside ends of the tower resisted transverse north-south motion (Figures 25 and 26). Note the diagonal cracking of slip around infills and stairway joint damage due to transverse north-south motion shown in Figure 26. Solid reinforced wall configurations resisted longitudinal east-west motion (Figure 27), with slippage and bending at the second floor construction joint.

Figure 19. Notre Dame Administration Building

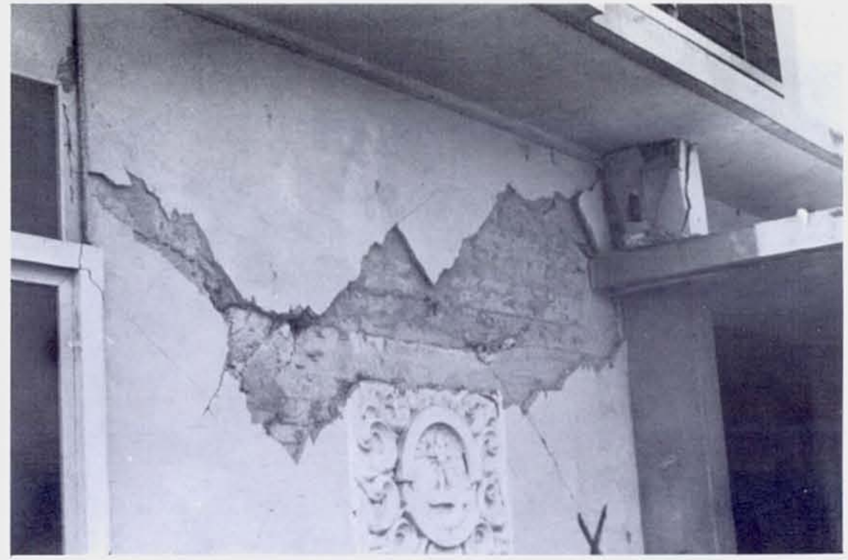

Figure 20. Diagonal Cracking, Exterior Panels

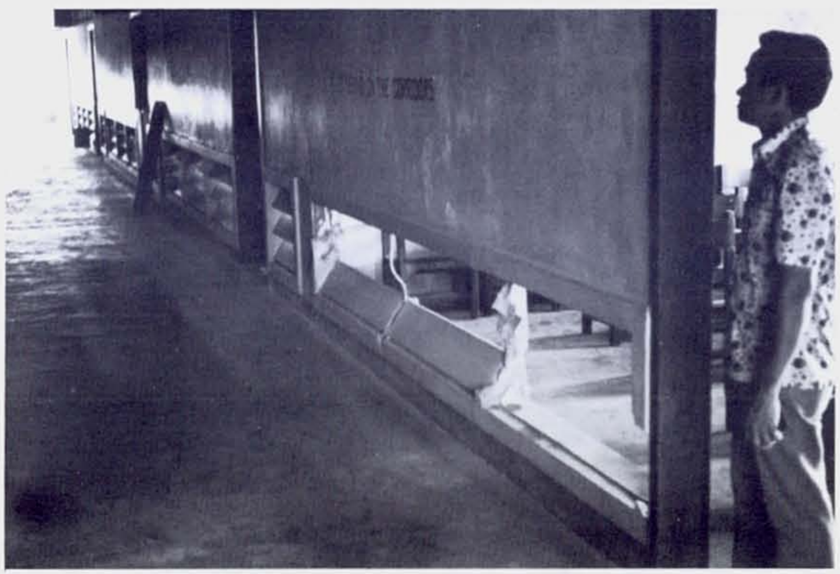

Figure 21. Louver Mullion Damage

Figure 22. Science Wing and Auditorium

Figure 23. Notre Dame Auditorium

Figure 24. Notre Dame Science Wing Before Earthquake

Figure 25. Science Wing After Collapse

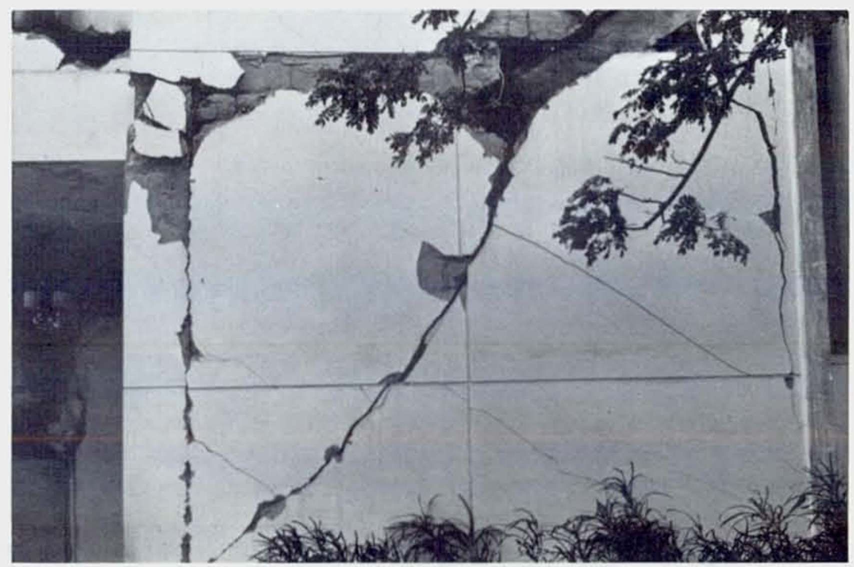

Figure 26. East Tower Damage

The tied column cross sections were of two principal types: a truncated wedgelike shape (Figure 24) or a rectangular shape. Haunched rectangular beams were used in the 12 m span transverse direction, while prismatic rectangular beams were used longitudinally. In general, the beams were larger than the columns, indicating a "strong beam/weak column" type of construction. Masonry infills were used below windows (Figure 24).

Figure 28 shows the science wing after the earthquake but before collapse. The conflagration was probably due to a spillage of chemicals, but an electrical short has also been suggested as the cause. The first and second story columns show heavy damage at the top of window infills and the soffit of beams due to longitudinal east-west motion. The columns supporting the entrance canopy show especially heavy damage. The transverse long span beams also had heavy shear cracks due to north-south motion.

The science wing collapsed after the fire had burned for several hours (Figure 25). The moment frame dropped three stories starting from the stair tower at the west end to a point just beyond the entrance canopy. At the east stair tower the frame did not collapse. There is a transition of floor elevations going from the entrance canopy to a location next to the east stair tower.

The west stair tower dropped three stories, but the east stair tower (Figure 25) remained standing. The uncollapsed stair tower is badly out of plumb in the second and third stories. Heavy slippage and bending at a second floor construction joint is indicated (Figure 27) due to collapse and longitudinal east-west motion. Motion in the north-south direction caused diagonal cracking and slippage at the joints between the frame and masonry infills in the first story of the east tower (Figures 25 and 26) and wing end wall (Figure 25).

The auditorium suffered heavy fire damage (Figures 23 and 29). The large sagging of the auditorium roof trusses in the stage area was due to the intense heat. The longer span trusses over the audience area dropped during the conflagration. Large areas of the trusses dropped simultaneously. The sheet metal was observed to be molded over the trusses as a result of the intense heat (Figure 29). The infilled frame walls of the auditorium did not suffer structural damage, but the entrance of the auditorium was destroyed when the science wing collapsed.

Reinforcement detailing on the auditorium-science wing building caused some local distress but did not have a major effect on the failure. A joint failure due to poor detailing occurred at the intersection of a stairway beam and second floor girder (Figure 25). Hooks from the intersecting beams could be seen in the joint, but no concrete remained.

Based on casual observation, the strength of concrete used in the building was not deficient. However, building plans made available to the EERI team did not include a specification of concrete design strength.

Figure 27. East Tower Damage

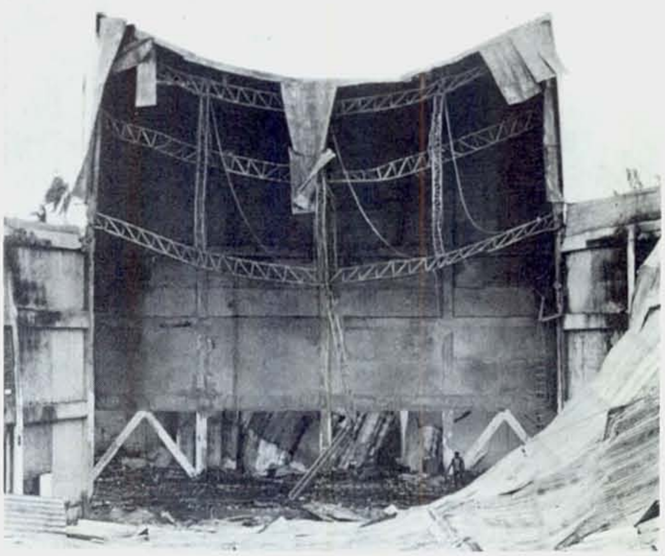

Figure 29. Auditorium Fire Damage

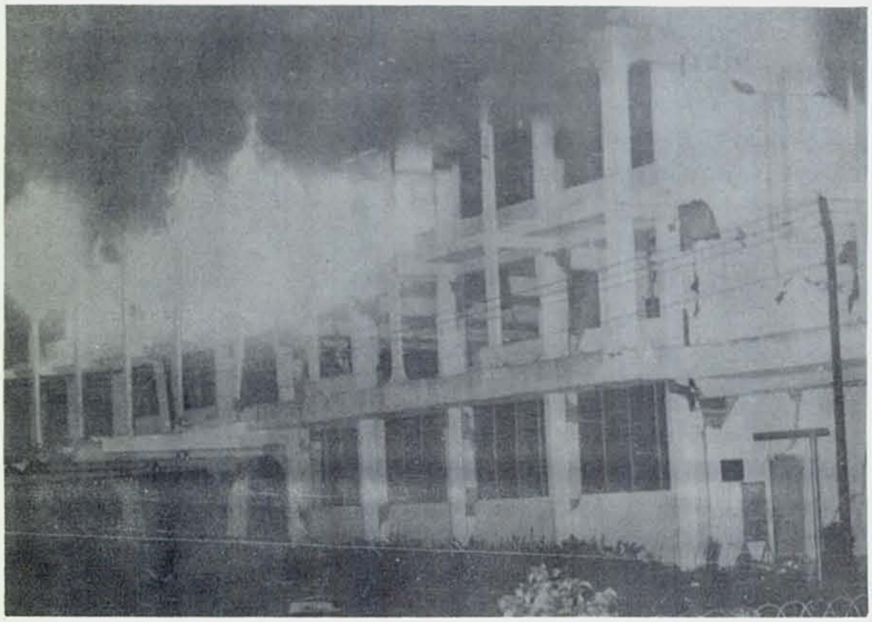

Figure 28. Science Wing During Fire

Harvardian College Campus includes several buildings. The EERI team only investigated a partially collapsed five-story structure (Bldg 5) at the southeast corner of the site (Figure 30).

The soil at the site is soft alluvium. The water table is very near the surface, and there are numerous shallow ponds in the area, including a swamp-like pond extending the full length of the building to the south. According to Dr. Wallace, mud boils occurred in a zone running parallel to and north of the building. In this zone, a walkway and overhead pergola settled approximately 20 cm (Figure 31). No building foundation settlement or footing rotation was detected. It appeared that the major effect of the wet ground was to increase the amplitude of the ground shaking. Heavy cracking of walkway slabs on grade (Figure 32) confirms the greater ground shaking at this site since this type of damage was not typical of Cotabato City.

The building had a plan dimension of 11 x 90 m. It was divided longitudinally into 19 equally spaced bays, and transversely into 2 bays of 3 and 8 m. The short bay was for an exterior walkway. Constructed in 1962, it had a reinforced concrete frame and reinforced concrete slabs at the second level and at the exterior walkways at the third, fourth, and fifth levels. The balance of the floors were wood joist with square laid planking. The top story was constructed completely of wood, and the roof had galvanized iron sheeting. Reportedly, the structure was originally designed for three stories, with the fourth and wood framed fifth story being added later with no strengthening of the lower stories.

The north side columns were 36 cm square, with the interior and southside columns being 43 x 46 cm. The short span (3 m) girder was approximately 30 x 38 cm, and the longer girder 38 x 69 cm, indicating a "strong beam/weak column" configuration. The larger columns were reinforced with nine 2.5 cm ϕ bars with 0.95 cm ϕ smooth ties at 41 cm on center. As is common practice in Cotabato City, the column bars were spliced below the slab soffit, and 10 cm (ID) cast iron downspouts were cast inside some of the south (rear) columns.

The longitudinal girders were 36 x 38 cm at the front and approximately 46 x 38 cm at the interior and rear bents.

The transverse end frames were infilled with hollow block, as was the rear bent. The rear bent wall had wood louvered openings throughout, running between columns at the top half of the story height. There was a stair tower at midlength of the structure, that was bounded by masonry infilled walls. The stair walls were the only interior transverse walls in the structure.

Mario V. Atillo, Executive Vice President, Philippine Harvardian College, observed the collapse of the building during the earthquake. Mr. Atillo, who was educated as a mechanical engineer, was standing 30 m to the north of the damaged building. The earthquake occurred 17 minutes after midnight, but he assured the

Figure 30. Harvardian College

Figure 31. Harvardian Walkway Settlement

Figure 32. Cracking of Slabs on Grade at Harvardian College

EERI team that the building could be clearly seen. According to his account, the building collapse occurred in the following sequence:

1) The building experienced heavy sway, predominantly in the north-south direction, i.e., in the building's transverse direction.
2) The fifth story, which was constructed of wood, collapsed but remained flat on top of the fifth floor.
3) A rapid sequence of popping sounds occurred, followed by a large tilting of the complete building toward the south (Figure 33).
4) The collapsed wood structure slid off the sloping fifth floor and fell into the pond on the south side of the building.

Steps 1 through 3 consumed 30 seconds according to Atillo, indicating a long duration of ground shaking. It is surmised that the popping sounds were associated with shear and splitting failures of the first story columns along the south side of the structure.

The first story columns collapsed totally at the south side. This was the extent of the collapse at the west end, but at the east end the south second story columns also collapsed. Starting from the east, there was a five to six bay transition zone to where there was no complete failure of the second-story columns. The structure also came to rest with a tilt to the east. Except for the fifth story, which slid off the structure, the rest of the structure was relatively damage-free, including the reinforced concrete girders. Figures 33 through 35 are views of the building after the quake.

Three principal types of failure were viewed in the first story: 1) shear failure at the top of the interior columns (Figure 36), 2) near vertical splitting of the columns with the encased downspouts (Figure 37), and 3) hinging at the top and bottom of the 36 cm square front columns (Figure 38).

Diaphram distortion occurred at the east end on the third through fifth floors (Figure 39). It was obvious that the wood joist with square laid planking and the moment resistant frames were unable to resist the in-plane loadings that occurred as the building tilted.

The structural failure and collapse were closely related to detailing of the columns. The south side first story columns failed because of: 1) column bar splices below the girder soffits; 2) wide spacing of column ties, especially at the splice zone; 3) masonry walls causing high column shears; and 4) cast iron downspouts encased in the column. Splicing column bars in a region of maximum moment is detrimental because bar bond stresses are at the largest value, allowing shear failures to be initiated more easily. Further, the wide tie spacing would not confine the concrete, thus increasing the chances of failure.

Figure 33. Harvardian College at West End Tilted Toward South

Figure 34. South Side of Harvardian College

Figure 35. Two-Story Collapse at Harvardian East End

Figure 36. Shear Failure at Top of First Story Interior Columns

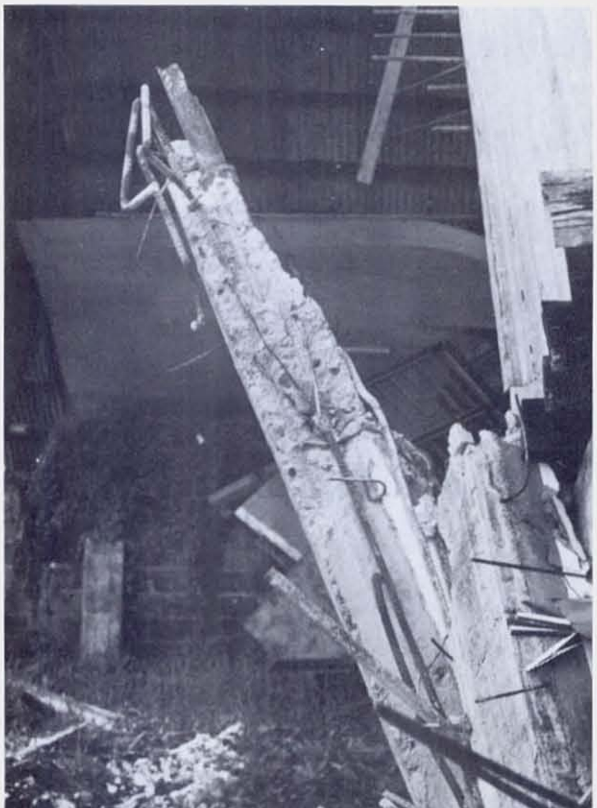

Figure 37. Vertical Fracture of First Story Column at Southeast Corner

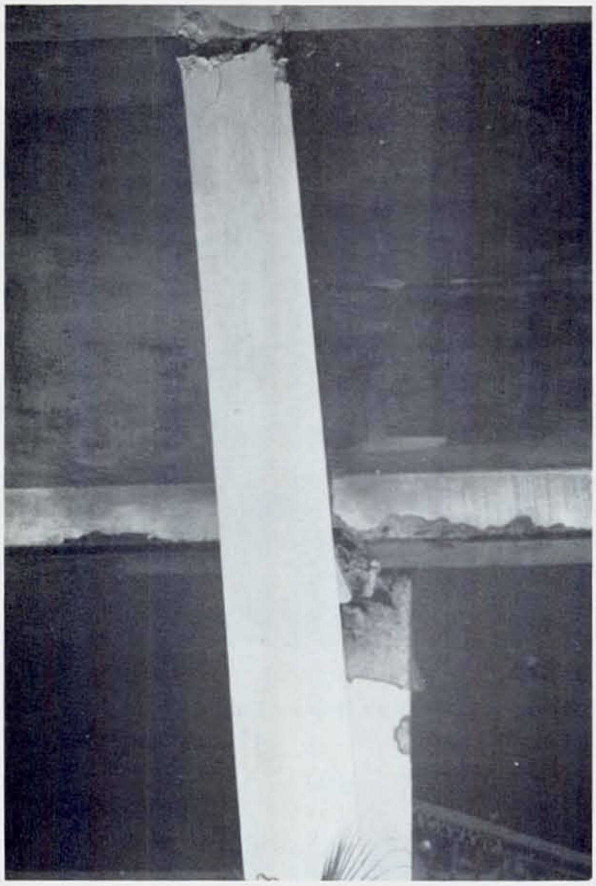

Figure 38. Moment Hinging of Northside Columns

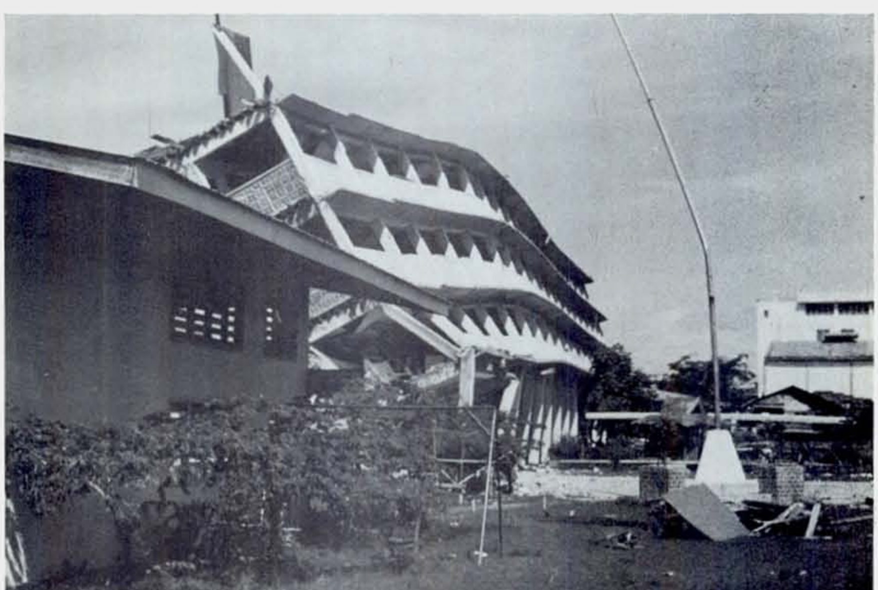

Figure 39. Diaphram Distortion

The Amicus Building (Bldg 6), Sagittarius Hotel (Bldg 7), and D'Max Restaurant (Bldg 8) form a complex of three adjacent buildings that collapsed. The remains of these buildings, shown in Figure 40, lie to the left and below the tractor shown in the picture. All of these buildings "pancaked".

The Amicus Building, a four-story reinforced concrete frame commercial building constructed in 1969, was approximately 12 x 15 m in plan. Remains of this building are located directly adjacent to the tractor shown in Figure 40. The "pancaked" floor can be observed in the background of Figure 41.

The Sagittarius Hotel was a four-story reinforced concrete frame building constructed in 1965. It was approximately 12 x 15 m in plan. Remains of the building are shown in the lower left corner (through the reinforced concrete grillwork) of Figure 40.

The D'Max Restaurant was a two-story reinforced concrete plus wood building constructed in 1968. It was approximately 10 x 15 m in plan. Remains of the building are located in the upper left portion of the damaged area shown in Figure 40. A view is shown in Figure 41. Note the damaged wood roof truss lying in the foreground of Figure 41.

First Gift and Book Store (Bldg 9) (also known as the Yap Building, named after the building owner) was a four-story building which had collapsed (Figure 42). Built in 1968/69, the building was 15 x 20 m, had a reinforced concrete frame, and was on a timber pile foundation. Demolition of this building was well under way when the team arrived in the area; therefore, first-hand information is minimal.

Reportedly, the first floor collapsed during the initial earthquake tremor and fire broke out within the structure. It was not until 5 to 6 hours later that complete collapse of the structure took place.

It was observed that this building leaned north into the adjacent three-story structure, knocking it into a third building, the City Evangelical Church. Damage to the church was light (Figure 43).

Sultan Hotel (Bldg 10). Figures 44 and 45 show the Sultan Hotel before and after the earthquake. The collapse of the structure with the second floor resting on the ground must have been rather slow since the portion above the second floor remained relatively intact. The portion above the second floor cantilevered out about 2.4 m past the front first story columns. Except for the front wall which had windows, the other three exterior walls were solid. The front wall above the second floor was relatively stiff due to short columns (in comparison to the other interior concrete frames designed for vertical loads only) and probably carried about half of the lateral load in the east-west direction. However, the wall in the first story was made up of tall columns only and high torsional forces were imposed on the first floor structural elements. This type of failure, with sudden change in rigidities compounding the torsional problem, has been noted in other earthquakes. Therefore, the structural engineer should carefully consider the

Figure 40. Collapsed Amicus Building, Sagittarius Hotel, and D'Max Restaurant

Figure 41. View of D'Max Restaurant and Amicus Building Looking East

Figure 42. First Gift and Book Store

Figure 43. City Evangelical Church

Figure 44. Sultan Hotel

Figure 45. Sultan Hotel After Earthquake

sudden changes in rigidities, the method of transfer of the forces created by this condition, and the shear and flexural distortions of the horizontal diaphrams trying to redistribute these forces.

New Society Hotel (Bldg 11) was a four-story reinforced concrete frame and shear wall building constructed in 1968. The 4 x 4 bay building is a square in plan; dimensions are 21 x 21 m. The first story height is 6 m, while the upper story heights are 3.5 m. A mezzanine story 3 m high extends three bays in each direction from the south and east sides of the building. The south side of the building is covered by a wall with pilasters aligned with the frame. The east side of the building is covered by a wall with window openings and pilasters spaced to match with the frame. The remainder of the building is constructed with an approximately square grid of moment resistant frames. The side dimension of a typical bay in the grid is 4.5 m. Floors and roof are reinforced concrete slabs.

A view of the north side of the building during construction (Figure 46) shows the 6 m first story and 3.5 m upper stories. The shade beam at the two-thirds point on the first story column is typical of Philippine construction practice.

The dimensions of beams and columns are comparable; but when the effect of slab action, both in bending and twisting, is considered, the beams appear to be considerably stronger than the columns. This is borne out by the damage that occurred in the building.

Reinforcement detailing and the presence of cast iron downspouts in the columns (see Figure 118 in Section 9) significantly reduced the strength and toughness of the structure. It is conventional practice in Cotabato City to splice column reinforcement below the soffit of the beam. Figure 47 shows the upper region of a first story column and the second floor beam joint for a north or west side column.

The "as-built" column dimensions measured 80% of those specified on the plans. The 36 cm diameter column had twelve No. 7 bars with circular hoops spaced at 10 cm. In some of these columns No. 3 hoops were used, while in others the hoops alternated between 0.6 and 0.95 cm diameter.

Detailing of beam reinforcement is given in the structure design plans, but the splicing of column reinforcement and placement of rain downspouts are not spelled out.

The New Society Hotel is within 30 m of the Rio Grande, whose elevation is 2 m below street level. The columns are founded on wood piles with reinforced concrete pile caps; 20 cm diameter wood piles 7.6 m long were used. The pile cap and water elevation are nearly coincidental.

Proximity of the river and the high water table would suggest the possibility of specially strong ground shaking. The failure features of the New Society Hotel (Figure 48) also suggest possible ground settlement. However, other factors rule out these possibilities. These factors are: 1) the lack of cracking in adjacent

Figure 46. North Side of New Society Hotel During Construction

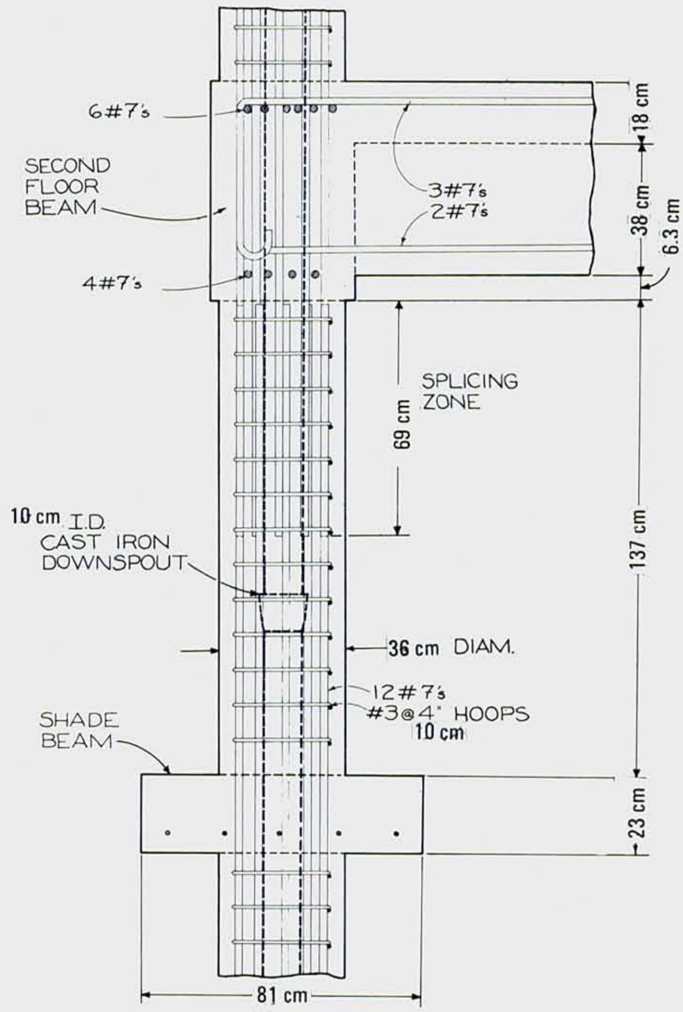

Figure 47. Column Splice and Joint Details

Figure 48. New Society Hotel After Earthquake

concrete sidewalks and in streets that overlay wet ground, plus the lack of other reinforced concrete building failures in the immediate area, indicates that ground shaking was not unusually intense; and 2) the presence of plumb column stubs and dowels at grade that have not settled shows that settlement was not important.

Instead, flaws in the structure were the principal causes of failure. The circular first story columns on the north and west sides of the building hinged at the top and bottom as the building experienced a heavy twisting motion. Collapse ensued (Figure 49) as follows: 1) the building twisted in a counterclockwise direction; 2) the northwest corner second floor level dropped, on a heliocoidal path 6.7 m long, to the street; and 3) the opposite southeast corner, where walls intersect, suffered a torsional failure in the corner pilaster (Figure 50) and out-of-plane shearing of adjacent walls. The frame and walls above the first story were practically undamaged. A view of the second story is shown in Figure 51. The floors did not suffer from diaphram response, but during the collapse the second floor "mounded up" in a few locations over rubble from the first story.

A closeup showing the heavy hinging, deterioration of the core, cast iron downspout, and slipping of dowels at the top of the first story column is presented as Figure 52. Damage to second floor beam is light (Figure 53), and in most cases the columns became disconnected from the second floor beam as the building collapsed. This occurred because the splice pulled apart. The walls suffered out-of-plane shearing damage as the building rotated.

Concrete used in the building appeared to have a sandy texture. In some of the columns the EERI team found that fragments of the concrete could be pulled apart with the fingers. The concrete tended to split through the cement paste.

Apart from the structure not being designed to resist lateral forces, the major causes of failure in this building were: 1) reinforcement detailing, 2) large structural eccentricity, and 3) poor quality concrete.

LCT Hardware and Auto Supply (Bldg 12) is a two-story reinforced concrete structure with wood trusses and galvanized sheet iron roof (Figure 54). During the earthquake, the first story collapsed toward the west.

Cotabato Auto Supply (Bldg 13) was on a main street running east-west. As shown in Figure 55, it had a three-story reinforced concrete frame, concrete floor, and hollow block infill exterior walls. Interior partitions were timber and plywood. The 15 x 60 m building was built in 1968. The first and second stories were used for auto parts sales and storage, the third floor for the proprietor's living quarters.

The first story of this building collapsed, with the upper stories coming to rest approximately 3 m west of its original location. The front and rear faces of the building were open with doors and windows, but the extent of the openings is not known. In any event, the openings left the structure with a softer first story. It should also be noted that the structure was not designed for seismic forces and,

Figure 49. Collapsed North and West Sides

Figure 50. Failure of Southeast Corner Pilaster and Wall

Figure 51. Inside Second Story of New Society Hotel

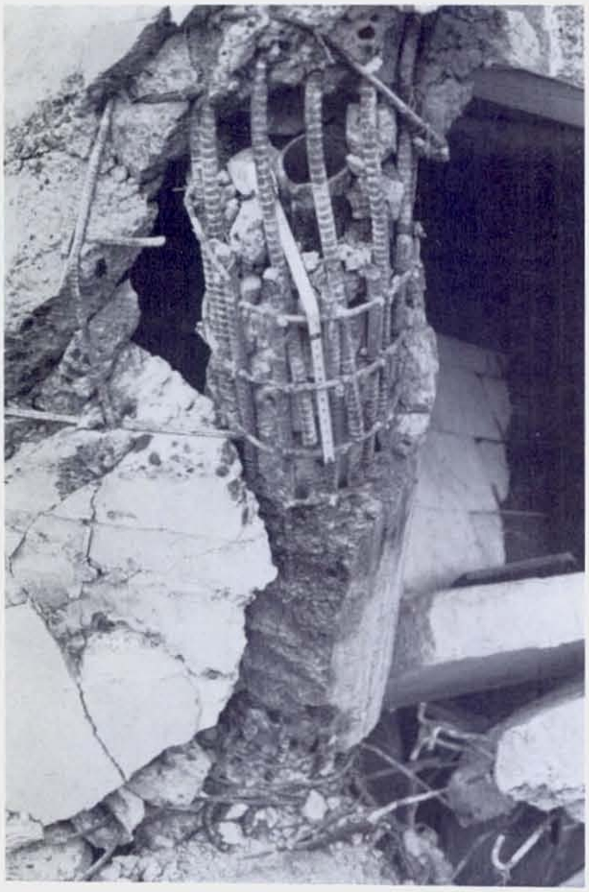

Figure 52. Top of First Story Columns

Figure 53. Collapsed Columns

Figure 54. LCT Hardware and Auto Supply

Figure 55. Cotabato Auto Supply

Figure 56. Lean-to at Cotabato Auto Supply

therefore, the first story experienced lateral stresses beyond normal overstress levels.

The balance of the building was free of damage, except for minor cracking. The collapse was gradual. The proprietor claimed that he was upstairs during the earthquake and was let down in a gentle motion. Storage shelves in the second floor were still standing after the quake.

A one-story lean-to concrete structure behind this building also collapsed, falling transversely to the west (Figure 56). Note block at the left.

South Seas Trading (Bldg 14) was a three-story structure which pancaked (Figure 57). Built in 1967, it was 20 x 30 m and had a concrete frame and concrete floor slab. It is important to note that the columns of this structure also contained downspouts. This architectural detail was found in many of the collapsed structures in the area. Although the engineers reportedly say that this condition is considered in the design, it was the finding of the team while viewing new construction that beam-to-column connections are severely weakened by reinforcing details applied to this joint (see Figure 117 in Section 9).

Tison Building (Bldg 15) was the only building in Cotabato City reputed to have been designed with seismic considerations (Figure 58). It was designed by Manila engineers using the "California Code" (exact year not known). It survived the quake with no structural damage and only a slight crack in a concrete block partition.

Some water tanks on the roof in concrete saddles moved to the west about 0.6 cm (Figure 59). Some flower pots on the roof moved about 8 cm to the west (Figure 60).

The Tison Building was placed on 20 cm precast concrete piles about 12 m long. It was located close to Colina Hill (good soil), but the piles were still friction piles (no piles reached firm ground).

This structure serves as an excellent example to show that properly engineered structures can be made to behave satisfactorily during seismic vibrations.

Melbourne Hotel (Bldg 16) is a three-story reinforced concrete frame with masonry infills, constructed in 1970, and has a plan dimension of 20 x 30 m (Figure 61). The four by four bay frame has a first story height of 6 m, while upper story heights are 3.5 m. A mezzanine story 3 m tall covers the full width in the north-south direction and three bays going from east to west. The front of the building is open, the back has masonry infills with openings, and the north and south exterior walls are completely infilled.

The first story columns suffered heavy damage as a result of north-south motion. A first story permanent offset of 15 cm to the south remained after the quake. At the west side of the building, the tall first story columns hinged at the base and

Figure 57. South Seas Trading Building

Figure 58. Tison Building

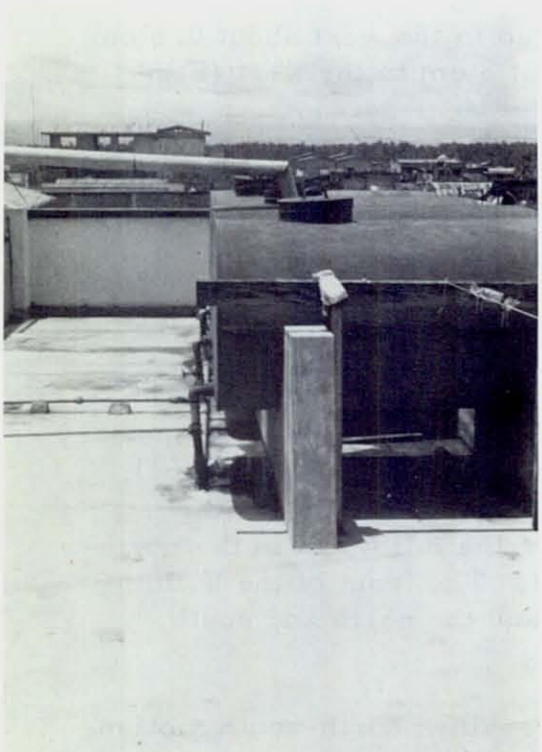

Figure 59. Water Tanks on Tison Building Roof

Figure 60. Flower Pots on Tison Building Roof

Figure 61. Melbourne Hotel

Figure 62. Hinging of First Story Columns Due to North-South Motion

directly below the shade beam (Figure 62). Going one bay to the east where the mezzanine begins, there were heavy shear failures in the columns (Figure 63). The shear failures occurred in the mezzanine columns and not in the taller west side columns for the following reasons: 1) the shorter story height caused higher column shears; 2) the failure over short distance of decorative masonry piers which surrounded the columns caused high shears; and 3) the window infills in the mezzenine story caused high column shears. On the east side of the building, masonry panels were pushed out, and window infills in the mezzanine story buckled outward (Figure 64) because of heavy frame action. North and south walls were undamaged (Figure 65).

Imperial Hotel #2 (Bldg 17), Rita Theater (Bldg 18), and Imperial Hotel #1 (Bldg 19) are situated together and face toward the south (Figure 66). The fronts of these buildings interacted strongly during the earthquake. Imperial #1 and Rita drifted to the west and pushed against Imperial #2 (Figure 67).

Imperial #1 is a four-story reinforced concrete frame with masonry infills constructed in 1963. The approximate plan dimensions are 20 x 30 m. The building has a 6 m first story and 3.5 m upper stories. There is a mezzanine in the first story. The building experienced a 38 cm permanent offset in the first story (Figure 68). The rear portion of the building collapsed (Figure 69).

Rita Theater (Figure 70) is a two-story, 12 m tall reinforced concrete frame in front, with a reinforced concrete plus masonry plus wood auditorium section in the rear. The auditorium roof has two elevations. Plan dimensions are 20 x 35 m. The frame section in front drifted 38 cm west, along with Imperial #1. The auditorium frame, plus infilled wall on the east side (Figure 71), was knocked over by Imperial #1. The "rod and block" truss roof in this part of the roof collapsed. Further to the rear of the theater, collapse did not occur because the roof elevation was lower and Imperial #1 did not hammer the wall.

Imperial #2 is a six-story reinforced concrete frame structure (Figure 66) constructed in 1967. Approximate plan dimensions are 35 x 30 m. The building suffered minor damage consisting of the following: 1) a column in the architectural frame in front was damaged when the Rita Theater impacted against the hotel (Figure 67), 2) infill panels suffered diagonal cracking in the first story adjacent to the Rita Theater, and 3) the slab on grade in the northwest corner of the building showed heavy cracking. Imperial #2 came through the earthquake with superficial damage. Its front was capable of carrying its own lateral forces plus the impact forces from the front of the Rita Theater and Imperial #1. A portion of this impact force caused a shear failure of the second story column in the architectural frame (Figure 67).

The EERI team found (Figure 72) typical Cotabato City reinforcement details on the roof of Imperial #2: 1) large downspouts in the columns with tees in beam column joints and 2) splicing of column reinforcement below the beam soffit. The building performed well, but these reinforcement details waste precious lateral building resistance.

Figure 63. Shear Failures in Mezzanine Columns

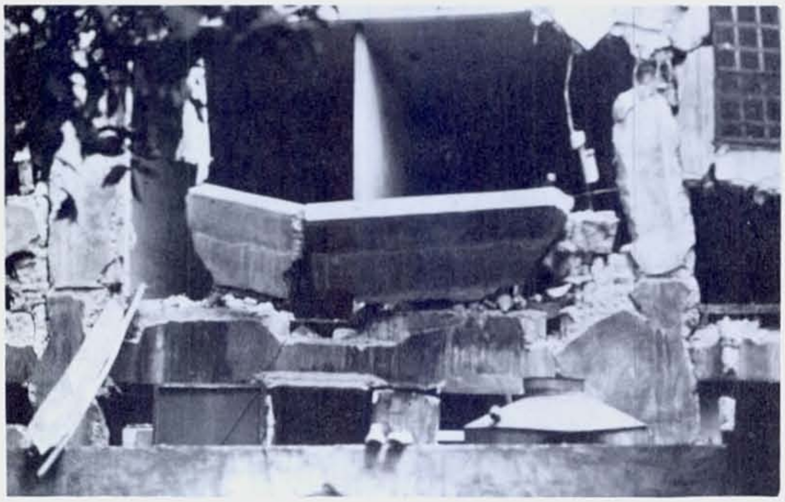

Figure 64. Mezzanine Story Damage on East Side of Melbourne Hotel

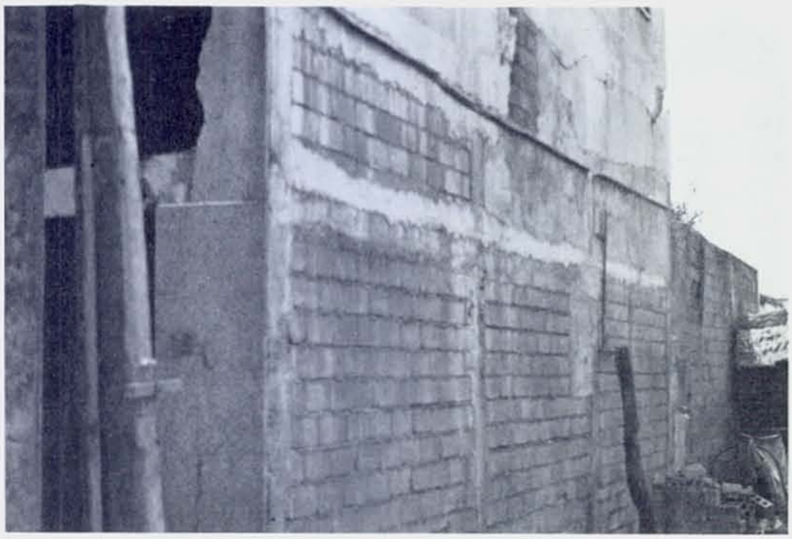

Figure 65. South Exterior Wall of Melbourne Hotel

Figure 66. Imperial Hotel 2, Rita Theater, and Imperial Hotel 1

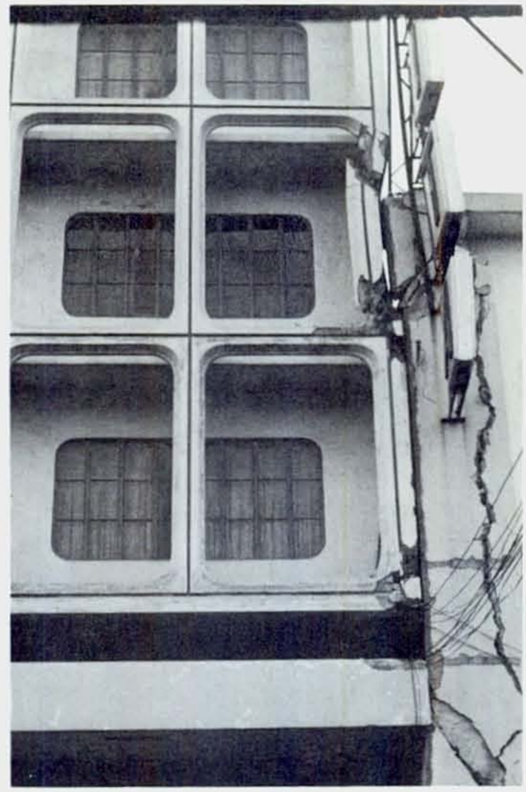

Figure 67. Rita Theater Hammers Against Imperial Hotel 2

Figure 68. First Story Drift of Imperial Hotel 1

Figure 69. Rear Collapse at Imperial Hotel 1

Figure 70. Roof Collapse at Rita Theater

Figure 71. East Wall and Roof Collapse

Figure 72. Reinforcement Details, Imperial Hotel 2

Immaculate Conception Church (Bldg 20): The only noticeable damage to this church across the street from the Tison Building was a settlement of about 15 cm of its tower (Figure 73). A loose ornament on the tower was thrown to the west a distance of about 3 m from the top (Figure 74). The church grounds were very soft, and the tower was apparently not on piles.

Melineen Building (Bldg 21) was a two-story reinforced concrete structure that pancaked. Very little is known about this structure since demolition was well under way when reviewed by the team. The concrete was being knocked off the reinforcing steel by hand, thus leaving the reinforcing steel intact. The slabs had one layer of reinforcing consisting of light bars at 15 cm on center each way. It is suspected that continuity over the supporting girders was minimal. Columns were light (26 cm square). Figure 75 is a view of the structure from across the street.

Tamontaka Catholic Church (Bldg 22) was reputed to have been built by the Spaniards 104 years ago. It was the only structure noted to be constructed of unreinforced brick walls with interior timber columns and wood roof. Figure 76 is a "before" picture which shows some structural cracking due either to previous earthquakes or differential settlement. Figure 77 shows the destruction caused by the earthquake. The severely damaged church was located near the Tamontaka River and Bridge and founded on soft marshy soil.

Waterfront Warehouses (Bldg 23) in large numbers were located at the edge of the Rio Grande west of the Manday River. This area is called Lugay Lugay and is in a Moslem zone. Practically all of the warehouses collapsed (Figures 78 and 79). They appeared to be constructed of masonry walls, timber trusses, and corrugated metal roof (no diaphrams). They were poorly built, apparently non-engineered structures, except perhaps for wood trusses, and most certainly had no seismic resistance.

Cotabato Chinese School Gymnasium (Bldg 24) is a reinforced concrete plus wood structure constructed in 1962. The four outer walls have reinforced concrete columns, reinforced concrete beams, and wood beams. Masonry infills were used in the outside walls. The roof is "rod and block" wood truss with galvanized sheet iron covering. The stands inside are wood. During the earthquake, the walls fell outward and the roof fell in (Figure 80).

Cotabato Chinese School Administration Building (Bldg 25) is a two-story reinforced concrete frame (Figures 81 and 82). The building suffered minor damage on some of the masonry frame infills. It was reported that the building was designed for three stories. A pile foundation had been used. The building was less than 3 years old. The EERI team concluded that the structure performed well during the earthquake.

Figure 73. Immaculate Conception Church

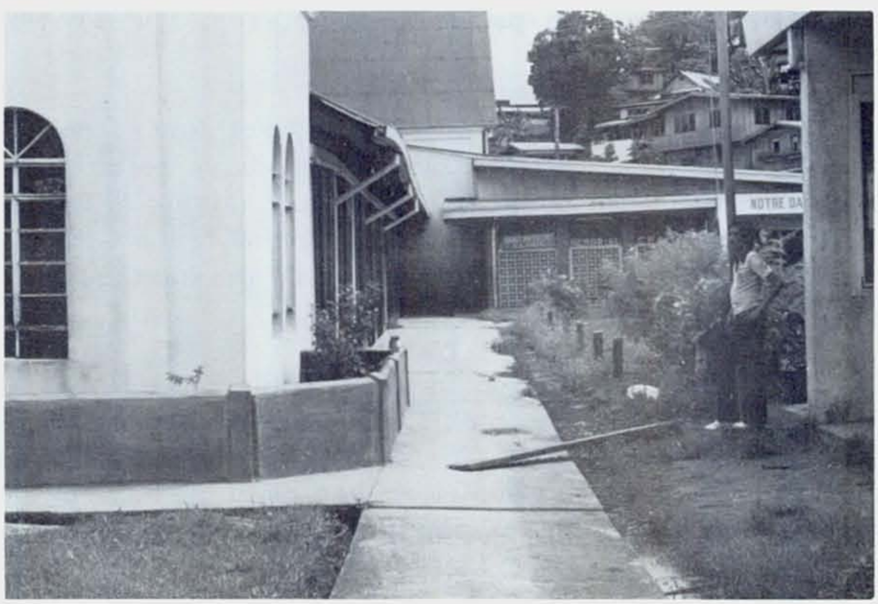

Figure 74. Loose Ornament Thrown Toward West

Figure 75. Melineen Building

Figure 76. Tamontaka Church
Before Earthquake

Figure 77. Tamontaka Church
After Earthquake

Figure 78. Waterfront Warehouses

Figure 79. Waterfront Warehouses

Figure 80. Cotabato Chinese School Gymnasium

Figure 81. Cotabato Chinese School Administration Building

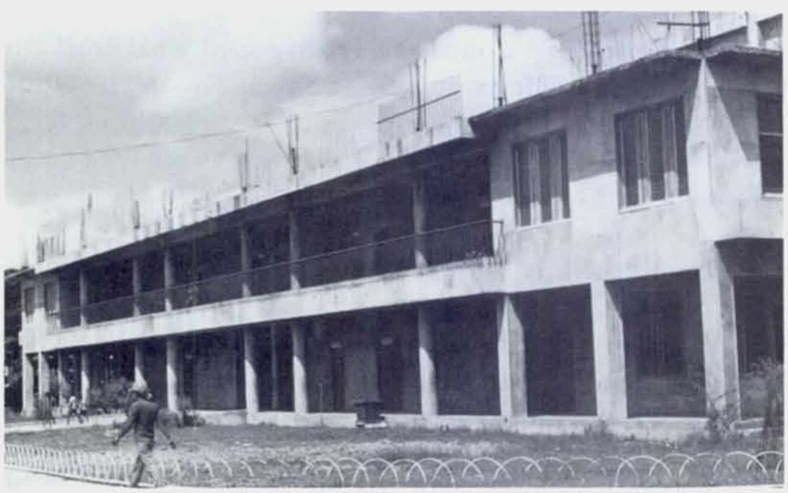

Figure 82. Cotabato Chinese School Administration Building

Cotabato Movie Theater (Bldg 26) is a large structure to the rear of the Sultan Hotel. The hotel and the theater were somehow connected; however, due to lack of drawings it was not possible to determine exact configurations. Figure 83 does show that when the hotel portion collapsed it caused severe structural damage to the theater complex. It could not be determined whether collapse of the hotel caused failure of the theater or merely contributed to an already damaged structure. Figure 84 shows the theater from the rear, and the hotel can be seen leaning at the front of the theater. Note that the side walls of the theater are leaning dangerously. The theater complex suffered severe structural damage.

Boston Bakery (Bldg 27) is a two-story reinforced concrete building constructed in 1965. The plan dimensions are 15 x 20 m. The building experienced 60 cm drift to the west in the first story (Figure 85).

Cotabato Fire Station (Bldg 28) (combined with the police station) settled toward the river during the earthquake (Figure 86). Figure 87 shows a plumb bob suspended from near the roof. Since the height and depth of the structure are the same, the settlement would be about equal to the out-of-plumb dimension. This settlement caused the fire chief to park all of his equipment outside the fire station to avoid damage should an aftershock cause the station to collapse. The firemen did, however, sleep within the confines of the building. Although the station settled slightly toward the river, no structural failures were noted in the structure itself.

Francel Theater (Bldg 29) was a reinforced concrete plus wood building constructed in 1966 (Figure 88). The reinforced concrete frame portion of the building collapsed, causing a failure of the "rod and block" wood truss roof.

Tan Bo Building (Bldg 30) is a four-story building constructed in 1971-72. It was designed and built using a local engineer and contractor. The structure is a reinforced concrete frame with hollow block infilled walls and was built on timber piles 7.6 to 9.1 m long. Although the team had limited access to the building, it was able to climb the stair tower and found little or no damage. The only damage noted was the cracked infilled panels at the stair core (Figure 89).

Dawns Hotel (Bldg 31) is a six-story reinforced concrete frame and wall building. The only damage of note was a working of the floor joints of the wall on the south side of the building (Figure 90).

Orientation of Earthquake Effects

The preponderance of failures appeared to be in an east-west direction. While no failure occurred in the Tison Building, the sliding of flower pots to the west is clearly visible in Figure 60. Movement of the front portions of Imperial Hotel #1 and the Rita Theater to the west and pushing against the front of Imperial Hotel #2 are evident. The picture showing the fire in the Notre Dame University Auditorium and Science Building reveals earthquake damage at the top and bottom of window openings, indicating east-west motion; damage to end walls from north-south

Figure 83. Cotabato Movie Theater

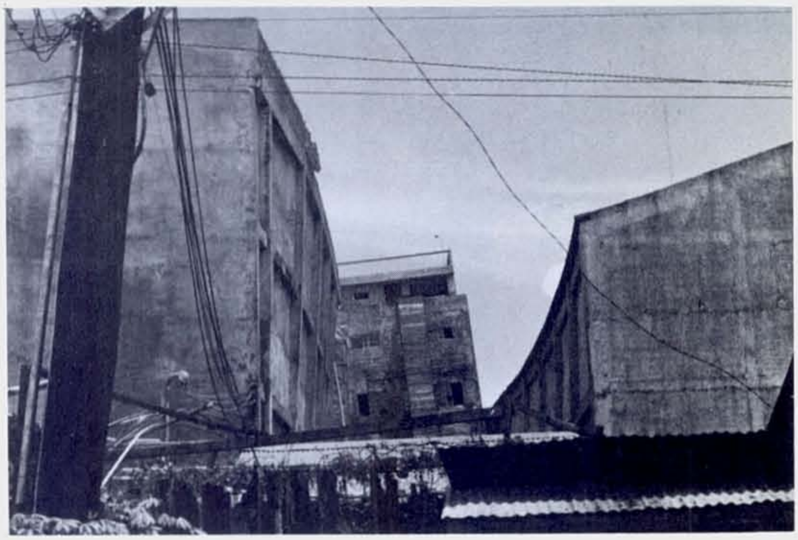

Figure 84. Cotabato Movie Theater From Rear

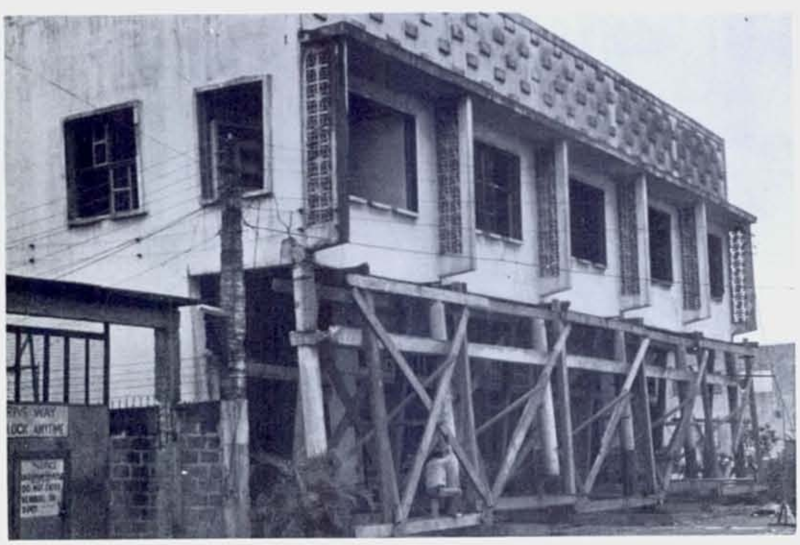

Figure 85. Boston Bakery

Figure 86. Cotabato City Fire Station

Figure 87. Plumb Bob Shows Tilt of Structure

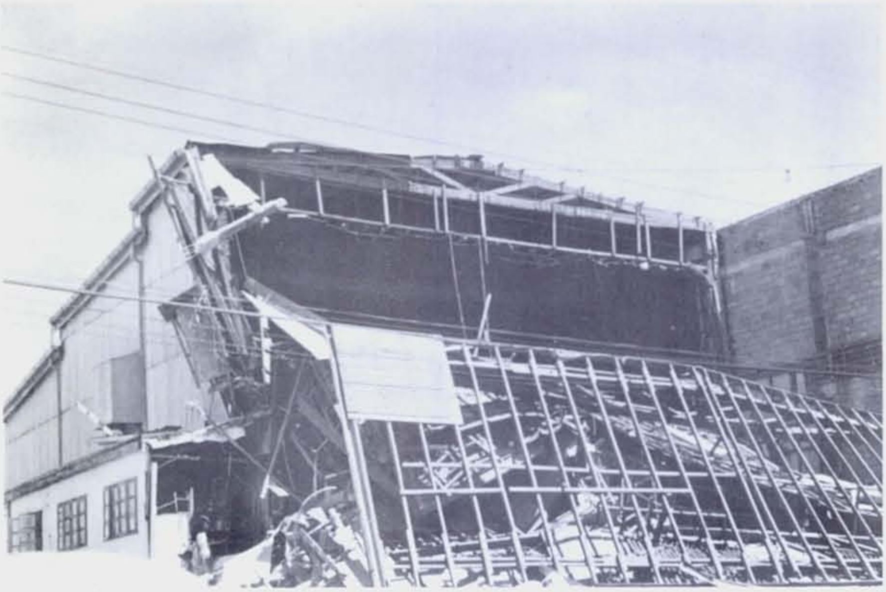

Figure 88. Francel Theater

Figure 89. Tan Bo Building

Figure 90. Dawns Hotel

motion is also evident. An ornament displaced from the tower of the Immaculate Conception Church was thrown directly to the west. The Tamontaka Bridge slid to the west, while the Quirino Bridge slid to the east. Although it can be argued that neither bridge was allowed north-south motion because of end abutments, their failures occurred in the east-west direction.

In addition, the LCT Hardware and Auto Supply Building fell directly to the west into the street. Similarly, the Cotabato Auto Supply structure fell toward the west. The Boston Bakery was seen to be leaning dangerously toward the west. A residence across from Harvardian College was also leaning dangerously to the west. Moreover, the South Seas Trading Building pancaked by moving toward the west.

It should be noted that the major streets run east to west and most of the structures noted above were located on these streets. Since buildings have large openings on the streets they face, their weaker direction will be parallel to the front of the building. This configuration undoubtedly contributed to some of the problems encountered.

6. DAMAGE IN ZAMBOANGA CITY

On August 27, 1976, two members of the EERI team traveled to Zamboanga City to investigate damage to that area. To expedite the investigation, the team relied on City Engineer Benjamin V. Limbaga for an assessment of the damage along with guidance as to which structures were most worth a cursory review.

Generally, damage was minor to moderate. According to the best information available, there were no total collapses and no buildings had to be condemned as a result of earthquake damage. The team assessed the area as an intensity of VI on the Modified Mercalli Scale.

Zamboanga City has a population over 90,000. Its downtown area is fairly dense with three to five-story structures. Although new and old structures are intermixed, the majority were built in the late 1950's to late 1960's. Materials of construction vary, with reinforced concrete being most common.

Tourist trade plays a large part in the economy of this city. Therefore, most of the newer structures are hotels along the coastline. Even though these structures appeared to be founded on the softer beach sands, there was no evidence of damage.

The team visited six structures, selected because of relatively new construction and amenability to analysis.

Zamboanga City A. E. College is a four-story structure of reinforced concrete construction located downtown. The parapets were damaged, with some beam-to-column connections being distressed in the upper floors.

Diamond Bazaar is of three-story concrete frame with masonry infill panels. Damage was to the second story exterior columns and to the adjoining architectural block screen (Figure 91). The sand aggregate mix used in the structure was very poor. The same may be said for that used in the repair work (Figure 92).

Chien Tian Un Building is a three-story plus mezzanine structure, with plan dimensions of 15 x 20 m, constructed in 1962. The framework is reinforced concrete with infill masonry panels. The first story plaster cover spalled, and the infill panels and adjoining columns had shear cracks (Figures 93 and 94). It was reported that the mezzanine was very heavily loaded, which contributed to the damage in the first story.

Mendoza Building (Shopping Center) was constructed in 1970. It has three stories with a reinforced concrete frame and slabs. It houses retail shops at the street level with office space above. Damage occurred at the wall panels, especially adjacent to the open stair, and at the windowed interior panels (materials unknown) (Figures 95 and 96).

Figure 91. Diamond Bazaar Damage, Zamboanga

Figure 92. Diamond Bazaar Repair Materials

Figure 93. Chien Tian Un Building Damage

Figure 94. Chien Tian Un Building Damage

Figure 95. Mendoza Building

Figure 96. Mendoza Building

Asiatic Commercial Building is a two-story structure erected in 1950. The structural system is unknown except that the exterior had solid panels. Damage consisted of shear cracking of the piers in the windowed exterior walls (Figure 97).

Figure 97. Asiatic Building

To Tek So Building is a four-story reinforced concrete structure (Figure 98), located on a corner site. The first story corner piers and columns experienced shear cracking (Figures 99 and 100).

The tour through these buildings was very rapid as time was limited. Therefore, detailed descriptions of the buildings' structural systems and of the damage itself are brief. The damage shown does, however, exemplify the earthquake damage which occurred in Zamboanga City.

It was interesting to see that a majority of the damaged structures had been "repaired" by the time the EERI team arrived in Zamboanga City, 10 days after the earthquake. Repair work consisted primarily of plastering over the cracks. It was not apparent that there were design schemes conceived in order to maintain structural integrity prior to doing the work; hence, the structures remained in a weakened state, subject to cumulative damages in future earthquakes.

Other buildings reported partially damaged include: Southern City College (one unit building), Kang Ha Wee Family Building, V. Fargas Residential Building, Zen Hong Trading Building, Zamboanga General Hospital School of Nursing, Ever Building, Carlos Wee Building, Espranza Seng Building, and Pilar College Building and Chapel.

Figure 98. To Tek So Building

Figure 99. First Story Column Shear Damage

Figure 100. First Story Column Shear Damage

7. RESIDENTIAL DAMAGE

Statistics on this earthquake show that less than 60,000 persons were left homeless in the entire Mindanao area.* By itself, this number may seem staggering, but when compared to deaths of nearly this amount caused by other large earthquakes it is necessary to investigate the reasons of why losses in the Philippines were minimized. This earthquake occurred at 12:11 a.m. (local time), when most residents were at home. Therefore, one may conclude that the residences in the Mindanao area were able to withstand seismic forces.

In South America, Central America, Europe, and the Middle East, deaths have occurred in residences constructed of masonry, adobe, or similar non-ductile materials. The residential areas of Mindinao had houses constructed primarily of timber.

The typical residence seen in the Cotabato City area was built above the ground on polelike foundations (Figure 101). The superstructure was framed from native timber poles approximately 10 cm round and covered with palm leaves or similar thatching, or with sawn lumber covered with Philippine mahogany. At construction projects where the workers lived at the site, homes were built of scrap form-wood. To add to their stability, the pole structures were braced. It was noted that the bracing's primary purpose was not structural in nature but to keep livestock from beneath the home.

Figure 101. Typical Wood Residence

*Of this total, approximately 30% were made homeless because of vibration damage, with the balance attributable to tsunami effects and other causes.

Although the authenticity of the livestock theory may be questioned, it is a fact that for whatever reason - climate, economics, etc. - the residences were built of a light, flexible material, they were tied together, and the weakened portions were braced. These practices saved thousands of lives since actual deaths due to vibration damage in Cotabato City were only 153.

Only minimal damage was observed by the team. Total collapse caused by the earthquake alone was to old or very weak structures. The most spectacular residential damage noted in Cotabato City occurred at the local lumber yard, where the residence of the proprietor collapsed. The house (Figure 102) was built in 1971-72. It was a luxurious structure built of sawn timber framing and Philippine mahogany paneling. To facilitate lumber storage below, the home was built on unbraced stilts.

One residence constructed of concrete suffered dramatic failure (Figure 103). This residence was located across the street from the Harvardian College. Strong ground motion added to the problem at this location.

Figure 102. Damage to Quality Residence

Figure 103. Damage to Concrete Residence

Quirino Bridge

The Quirino Bridge is a four-span structural steel bridge. Each span of this bridge over the Rio Grande de Mindanao River is 40 m long. The second span from the south end collapsed into the river during the earthquake, as shown in Figure 104.

Each span was supported on rollers at one end and pinned at the other. The collapse was caused by the second span sliding off its bearing plates in the easterly direction (Figure 105). Lack of consideration of seismic forces was obviously the reason for this failure.

As noted in other portions of this report, the predominant motion seemed to be in the east-west direction. However, the effect of motion in the north-south direction is also noticeable, as shown by the positioning of the rockers at the north abutment (Figure 106). It could not be determined whether this motion was caused by the earthquake or was a result of the collapsed span. It appeared that the northerly pier could be leaning slightly toward the north.

The failure occurred by the span sliding to the east off the dumbbell-shaped supports. The supports as constructed would not allow for much east-west movement before the spans would collapse. Figure 107 shows the pier, and it appears that a motion on the order of 60 cm would be sufficient to cause this collapse. Other notable damage is the near collapse of the third span from the south. Figure 108 shows new piling plus the tieing together of spans two and three to prevent further damage. Figure 109 shows damage to the piles at the base of the south abutment. Shear cracks appear several centimeters below the base.

Figure 104. Quirino Bridge Collapse

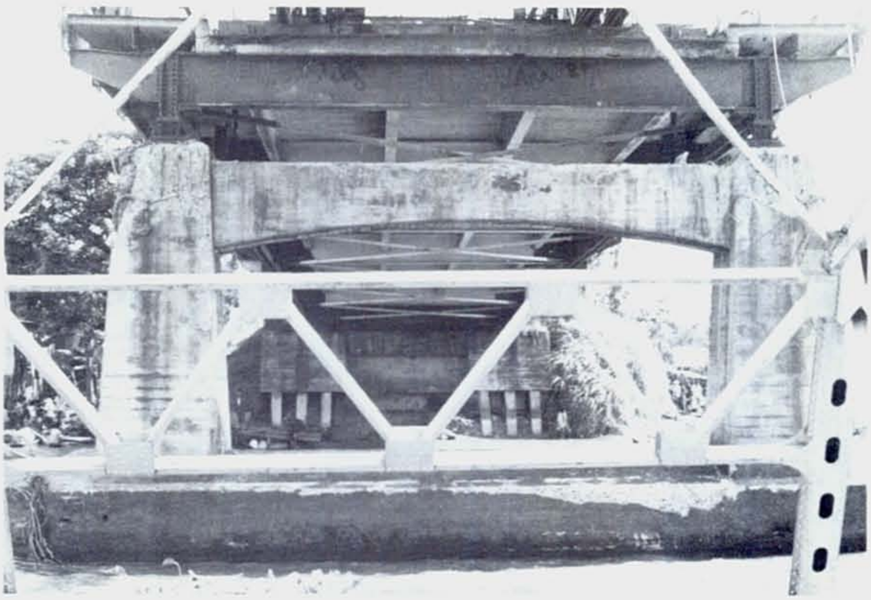

Figure 105. Quirino Bridge Collapsed Span

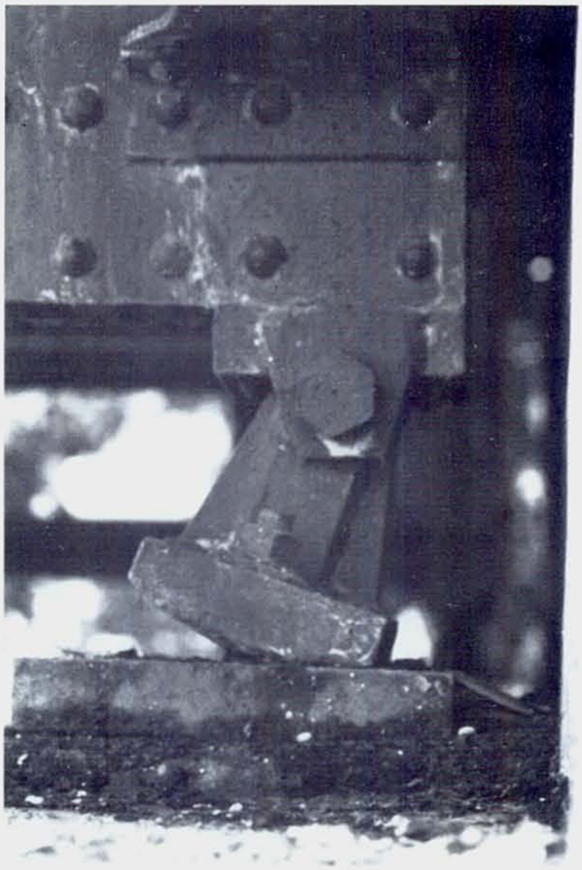

Figure 106. Rocker at North Abutment of Quirino Bridge

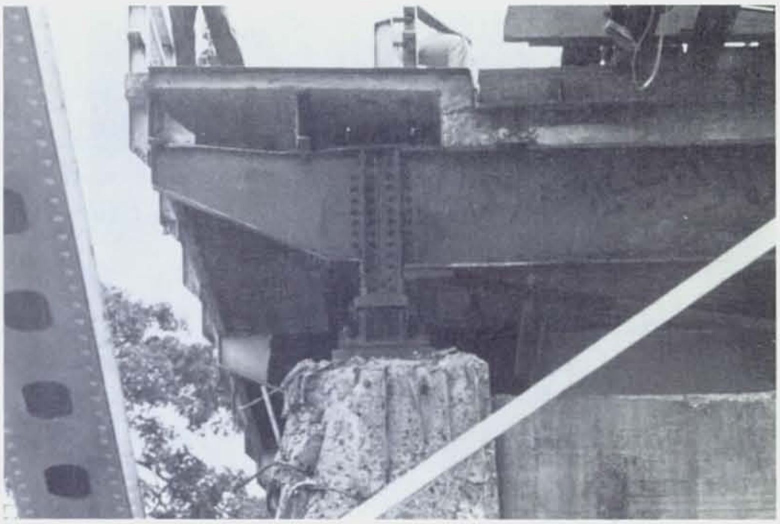

Figure 107. Quirino Bridge Pier

Figure 108. Quirino Bridge Repair

Figure 109. Abutment Pile Damage at Quirino Bridge

A Bailey bridge was being installed over the fallen span while the EERI team was in Cotabato City. The completion date for this bridge was to be August 29, 1976. It is intended that a temporary bridge will be constructed at some point to the east of the Quirino Bridge. After completion of the new temporary bridge, the Quirino Bridge is to be reconstructed.

Approximately two blocks west of the Quirino Bridge, ground motion was very evident on both sides of the river. It appeared as though the ground were sloughing in on both sides toward the center of the river. Figure 110 shows a ground crack on the south bank about 20 cm wide and 1.5 to 1.8 m deep, with the river side some 20 to 26 cm lower. Similar ground motion was evident on the north side.

Figure 110. Ground Cracking Near Quirino Bridge

Tamontaka Bridge

The Tamontaka Bridge (Figure 111) is located approximately 6 km south-southwest of central Cotabato City. Spanning some 230 m across the Tamontaka River, the bridge is made up of six spans resting on pile-supported piers. The 180 cm deep box girder sections, as well as the piers and piles are of reinforced concrete.

Figure 111. Tamontaka Bridge

For this discussion, a longitudinal direction of north-south will be assumed although the actual axis is rotated some 30 degrees clockwise.

The bridge was constructed in three sections. Two expansion joints are located approximately 56 and 30 m from the north and south ends, respectively.

Sighting along the railing, it could be seen that each section acted with the deck as a rigid diaphram. After the earthquake, the bridge's longitudinal axis had a permanent displacement, with the ends closing to the west.

The bridge experienced a great deal of movement predominantly in the east-west direction. The center section moved east and west in excess of 38 cm each way, as evidenced by the broken concrete keepers (Figure 112) on each end of the supporting piers. It came to rest approximately 30 cm east of its original position. The northern section moved even greater distances. The north end of this portion again moved both east and west, coming to rest 46 cm west of its original location on the abutment (Figure 113). The south portion moved but with less amplitude. At the south, only the keepers on the east side of the piers were damaged.

Damage to the abutments as a result of longitudinal movement was not evident below the bridge surface although the bearing plates at the north abutment did reveal a 8 cm permanent offset to the north. There was damage to the railings at both abutments and at the expansion joints. This damage was most extensive at the north end (Figure 113). It appeared that the damage to the railings at the expansion joints was due more to the opening and closing of the joints from the heavy east-west movement (bowing of the bridge) than to longitudinal movements.

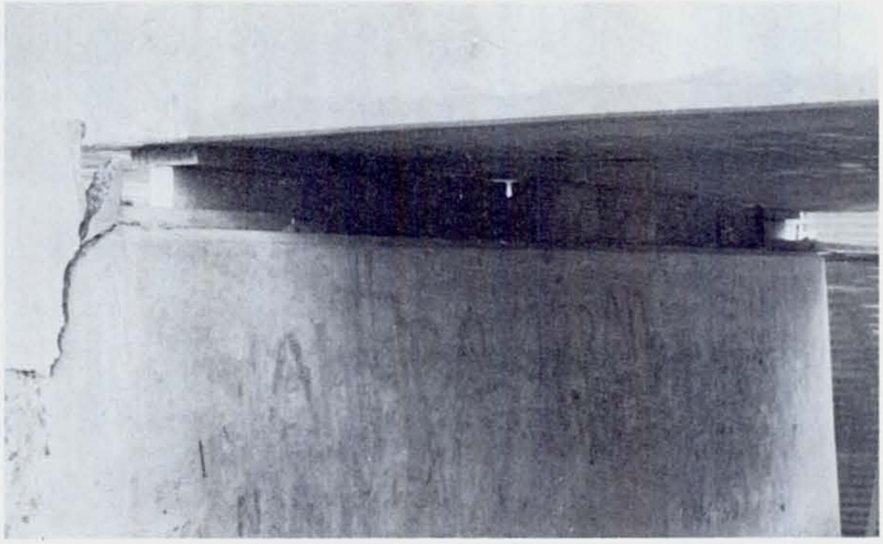

Figure 112. Keeper Damage at Tamontaka Bridge

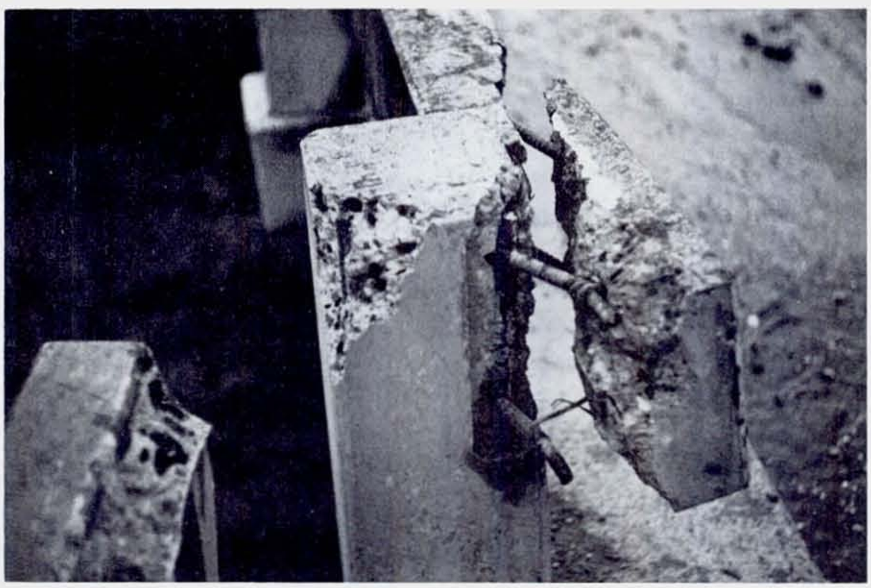

Figure 113. Railing Damage at North Abutment of Tamontaka Bridge

The box girder sections rested on the piers supported by bearing plates. There were two rockers per pier. Rockers were achieved by rounding the edges of the bearing surfaces. There were no keepers except for the concrete pieces cast with the piers. At the north abutment, where the greatest movement was seen, the bearing plates were very wet and badly corroded. At the east side, the rocker slid along the bearing plate (Figure 114). In fact, another few cm movement to the west would have caused the rocker to move off the bearing plate. At the west side, the rocker fell out. The sliding may also be seen on dryer plates in Figure 115, taken at the first pier from the north end.

Figure 114. Rocker Movement, East Side, North Abutment of Tamontaka Bridge

Figure 115. Sliding of Bearing Plates at Tamontaka Bridge

Soft, swampy land surrounds the bridge. The abutments also experienced some movement relative to the land, as can be seen in Figure 116. Some displacement was visible between the roadway and its apron, north of the bridge. Although these movements did not interrupt traffic on the bridge, they did interrupt the city water supply. As noted elsewhere in this report, the bridge carried a 26 cm cast iron pipe which supplied water to the city from the diversion dam south of this location. The 46 cm displacement of the north end of the abutment sheared the pipe (Figure 4).

Figure 116. Abutment Movement
at Tamontaka Bridge

Comments

A coefficient of friction would help in determining the forces that acted on the bridge. However, development of the coefficient of friction of roller bearing on a bearing plate is difficult. The following variables preclude good determination:

1) Type of alloy

2) Were bearings case hardened?

3) Amount of work hardening due to motion of bridge for many years

4) Was there a rocking action in conjunction with the transverse sliding action?

5) Had the working of the rollers tended to free carbon on the bearing plates?

6) How much water was on the bearing plates?

7) The carbon and water could actually produce a lubricant on the plate.

Bridge designs must encompass the following considerations:

1) Keepers must be located to prevent transverse motion at end supports which are placed on rockers.

2) Where the span is anchored at one end, that anchorage must be designed to resist all of the seismic load in the longitudinal direction, and presumably one-half of the seismic load in the transverse direction.

3) Considerations of seismic coefficients should include the following thoughts:

   a) Soft, marshy areas where bridges may be required may tend to amplify earthquake characteristics.

   b) Use of piles for foundations may tend to reduce damage.

   c) The response of one large structural mass (i.e., the mass of the span) on a support will differ from the response of building structures; therefore, studies should be made to determine proper coefficients to be used.

4) Piers must be designed to take lateral loads that are transferred to the pier by the type of anchorage of the span.

5) It would appear that in a multispan bridge the end abutments should receive the fixed supports, while the rollers would be placed at the first pier. This would simplify the resistance of lateral forces in the longitudinal direction. (It is simpler to resist lateral forces at end abutments rather than interior piers.) At the Quirino Bridge, rockers were used at end abutments (Figure 106).

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9. SUMMARY AND OBSERVATIONS

This EERI report focuses on the damage in Cotabato City. The following remarks pertain to the ground response and damage which occurred there.

The ground motion characteristics at Cotabato City were controlled by the conditions: 1) a Magnitude 8 earthquake; 2) an epicentral distance of 100 km, and 3) a distinct variation in local site conditions. These conditions were dominant factors influencing the following points concerning the damage:

1) All damage was concentrated on the soft marshy soils.

2) The magnitude of an earthquake cannot by itself be an indication of the extent or severity of damage that may be expected.

3) All collapses of concrete buildings, although on small wood piles, were strongly affected by increased ground shaking due to soft foundation materials.

The practice in building and bridge design and construction had a strong influence on the structural performance during the earthquake. The points concerning practice which the EERI team found to be important are:

1) Reinforced concrete buildings can be designed to behave satisfactorily during an earthquake. An example of satisfactory design and performance is the Tison Building.

2) The response and damage to similar reinforced concrete buildings within a small uniform region of marshy deltaic ground varied significantly; some collapsed and others were undamaged.

3) Buildings impacted against each other since apparently no design consideration was given to seismic lateral response.

4) Buildings were weaker in directions parallel to the streets because of open fronts.

5) Large torsional eccentricities caused some buildings to fail. They were not designed to resist seismic torsional forces.

6) Reinforcement detailing was done without apparent consideration of load paths in the structure and elements. Among the serious problems noted were a) splicing of column reinforcement below the soffit of the beam, b) cast iron downspouts in the columns and joints (Figure 117 and Figure 118), c) excessive column tie spacings not based on seismic shear and confinement requirements, and d) beam reinforcement not anchored for seismic building response.

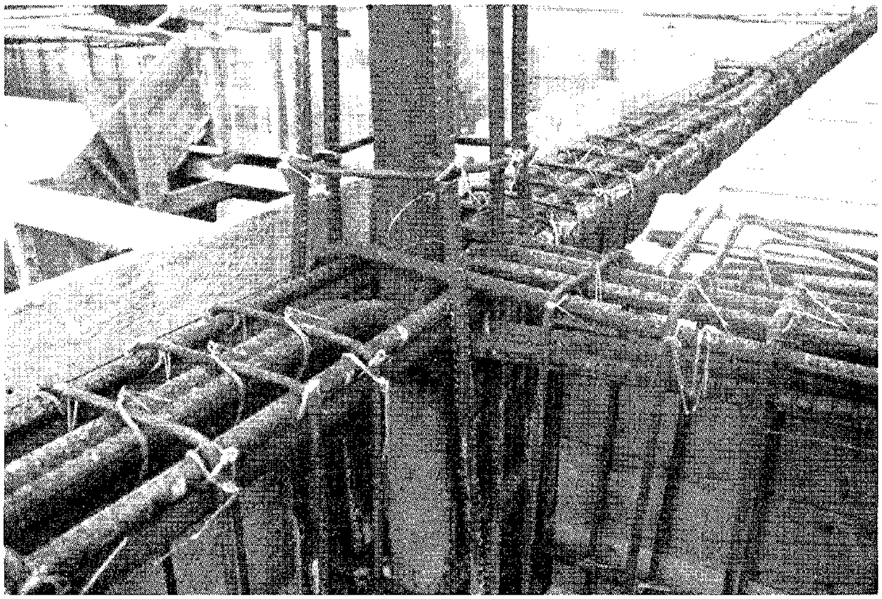

Figure 117. Downspout in Concrete Column

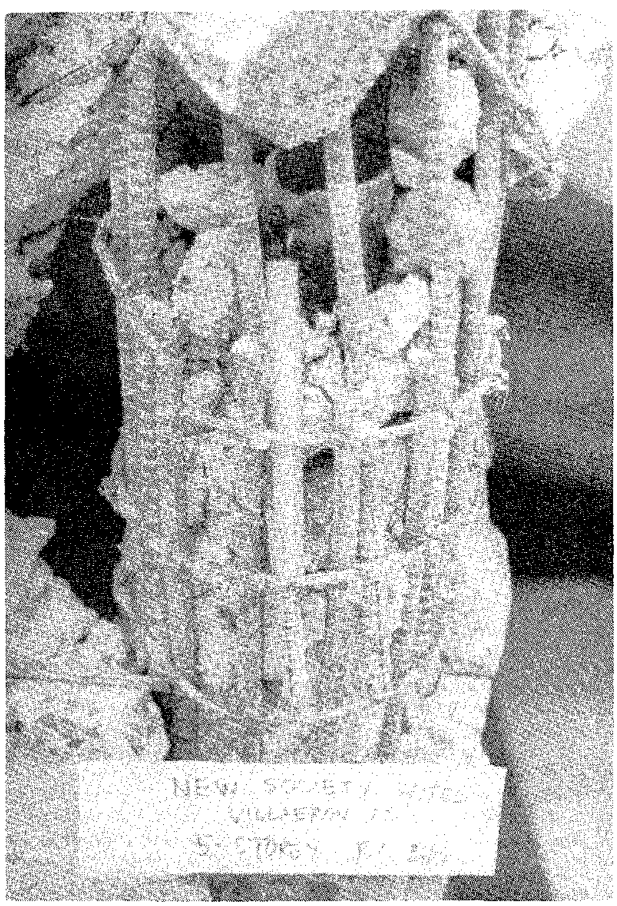

Figure 118. Downspout in Reinforcing Splice

7) The structural plans used in Cotabato City were very brief. Predominant practice is for the contractor to play a major role in establishing the structural details of the building.

8) Concrete strength tests were not required for all buildings.

9) Inspection of buildings by the EERI team uncovered discrepancies between as-built and plan dimensions.

10) Bridge supports apparently were not designed with consideration for seismic forces. It should be noted that the coefficient of friction between rollers and bearing plate can be very low under certain conditions. Design considerations for lateral forces on pins, rollers, keepers, piers, and piles are essential. Existing bridges can be strengthened against lateral forces if keepers or snubbers are added.

11) Besides ground motion and design practice influencing the earthquake damage in a building, it was shown that contents may have a strong influence on the resulting damage. Using the chemical fire hypothesis at Notre Dame Science Building, it can be argued that if the bottles had been contained the building might have remained in repairable condition.

12) Crippling damage to water, electricity, transportation, fire fighting, and other lifeline systems was evident. Large numbers of deaths did not occur because of failures in these systems, but the susceptibility of lifeline systems to seismic damage was clearly demonstrated.

13) It is a common practice in Cotabato City, as it is throughout the Philippines, to construct exterior walls, as well as interior partitions, out of masonry. Infilled within a frame, these walls tend to stiffen the frame line and therefore attract seismic loads. Since the walls contain little, if any, reinforcing steel, the walls explode. The loads immediately overstress the frame, causing it also to fail.

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10. SOCIAL SCIENCE OBSERVATIONS ON THE RESPONSE OF COTABATO CITY

Patterns of Authority

Established patterns of authority coincided with functional requirements during the emergency. The Philippines have been under "martial law" since 1972 although currently civilians rather than military personnel carry out the normal functions of civil government. But President Ferdinand Marcos, supported by the military, sets policy on almost all matters of importance. Further, top administrators, including mayors, are personally appointed by the president rather than being elected.

Since this authority relationship had been in effect for several years, there was little doubt following the earthquake about who would enumerate policy and make important decisions nor who would see to it that those decisions were carried out.

When a sudden impact, no-warning disaster strikes, several immediate requirements stand out: 1) a quick assessment of the extent of casualties; 2) an estimate of the extent of damage and disruption to structures, lifelines, and other physical systems; and 3) rapid action to ensure that additional casualties and losses do not occur. The authority relationship between the military and local government officials, as well as the resources of the military, made it possible to fulfill these functional requirements with dispatch.

In Cotabato City, a military contingent was headquartered on a hill above the city. Its primary mission was to direct the military effort against the rebels who, in 1975, were on the edge of the city firing mortar shells into the military base. A midnight to 6:00 a.m. curfew was still in effect the night of the earthquake.

The earthquake occurred shortly after midnight. Soon thereafter, a senior military officer contacted top city officials and "urged" them to establish promptly a disaster coordinating committee at City Hall. Although it took a few hours before the committee's activities were fully operational, the response was remarkably prompt when compared to what usually develops under similar conditions.

In addition, the military soon threw a cordon around the city and posted guards in areas of damage to prevent looting and bodily injury in the event of aftershocks causing further damage to buildings.

A related strategy by the military with the cooperation of civil authorities seemed especially effective. The earthquake produced an electric power failure in the damaged areas of the city. All local radio stations were knocked out. It would be difficult to communicate with the public under such conditions. Immediately after the earthquake, guns were fired into the air repeatedly. Apparently there were several reasons for doing so. One was to scare off any rebels who might try to take advantage of the possible confusion produced by the earthquake. A second reason was to awaken people to warn them of the danger of aftershocks. Shortly after the firing of guns, vehicles with loud speakers were sent throughout the city to inform the populace of the danger of aftershocks, to tell them that they should get outside, away from buildings (normally the curfew would prohibit such action), and to announce that an official "state of calamity" had been declared. (Apparently in the Philippines, it is understood that in a "state of calamity" the military is in complete control of all matters of public interest.)

The military did what most military units are trained to do. There was a rapid assessment of the extent of damage and injury combined with a quick mobilization and allocation of resources (equipment and personnel) as need dictated. The civil authorities were accustomed to the military presence in Cotabato City and understood the basic nature of the power relationship between the military and local officials. The military command acted promptly and decisively in most instances, especially during the first several days. The military was visibly in charge of the larger search and rescue operations in Cotabato City and in securing the area generally.

Units of civil government also responded promptly and worked in close cooperation with the local military unit. From an observer's perspective, most of the effort after the first few days was being carried out by civil units of government, aided by volunteers. Behind the scenes, however, most of the policy decisions were being made or strongly influenced by the military.

Early Communication. Within Cotabato City, early rapid communication provided the basis for responsible action. Efforts to provide information for the local population via sound trucks were especially helpful since all public radio stations were knocked out by the earthquake. However, information being broadcast from radio stations from distant cities added to the confusion by disaster reports which in the early hours were often ambiguous or incorrect. The valid information available to local officials or volunteers was difficult to disseminate except by word of mouth, but the less valid and often contradictory information about the dimensions of the disaster was easily received from these stations outside the area.

So far as could be learned, communications within the military throughout the nation were never impaired. As is so often the case during the emergency period following a large-scale disaster, radio-equipped vehicles (both government and private) played a crucial role in reconnaissance for early damage assessment and in the coordination of emergency actions.

Relief

Limited Aid From Abroad. Soon after the earthquake, President Marcos decided not to seek or accept aid from foreign governments. Indeed, foreign aid from any source was quite limited. Unlike other widely reported earthquake disasters in 1976 (e.g., northern Italy, Turkey, and Guatemala), there was no massive influx of supplies and personnel from other countries although the League of Red Cross Societies did send some aid. There was some evidence of small amounts of aid from areas outside the Philippines.

This unusual "go-it-alone" policy had some interesting consequences. The usual indicators of convergence were absent. There were no problems with excess aircraft or their cargo at the Cotabato City airport. There was little evidence of large quantities of unprocessed supplies or materials awaiting appropriate storage or distribution. Unlike the case following most dramatic disasters, here there were no complaints from officials that they had to spend inordinate amounts of time escorting and meeting with dignitaries from other countries. There was none of the usual talk of quarreling among competing relief groups nor of time spent in coordinating outside relief efforts.

In small part, these atypical events are attributable to the fact that, while this was a greater disaster in lives lost, the amount of physical destruction was moderate. The problems after the dead were buried were not as large nor as complex as those in Managua (1972) and Guatemala (1976). Nevertheless, the disaster did receive a lot of attention internationally; and, had it not been for the Marcos go-it-alone policy, most of the usual problems of convergence, oversupply, and rumors of misuse of supplies would almost certainly have been present.

How were the needs met without significant outside assistance? While there was insufficient time to examine that question in detail, the available evidence indicates that the principal focus for the first 2 weeks was on food supplies; and these were either available locally or brought in from other parts of the nation. Water transportation was used more than air transportation. Given the standard of living to which most of the victims were accustomed, simple foods simply prepared were considered adequate. Rations were meager by United States standards, but apparently not by theirs.

There were a few occasions where there were temporary food shortages for the victims in evacuation centers, but they did not seem to be serious or persistent. There were some complaints about waiting for hours in food lines, but the long waits appeared to be more a matter of organization than of food shortage.

On the whole, the Marcos policy seems to have provided a more relevant and adequate relief effort than would have otherwise been the case.

Nature of Evacuation Center Aid. Most of the evacuation centers for the entire impacted area were in Cotabato City, and most of those centers were in schools. Schools are normally in session during August, but those filled with the victim families could not be used for their normal functions. Thus, for several weeks many children could not attend school.

At the evacuation centers, there was no mass feeding of food prepared in quantities. The schools were not equipped with cafeteria facilities. Rather, family members queued up to receive rice, beans, and such other foodstuffs as were being handed out on any given day. Having received the food, each family was on its own. Most families then proceeded to prepare their food as best they could. In most cases this meant trying to find scrap wood wherever possible to use as fuel to cook the food. A few large stones would be used to create a makeshift open hearth. A few simple cooking utensils were used for cooking.

This approach to the provision of food to shelter occupants had several consequences. First, it put wood of all kinds in very high demand. It was a common sight to see children of all ages going through damaged and collapsed buildings searching for scraps of wood. While it was a way to avoid the boredom which is often a problem of shelter victims, it was perhaps not the safest activity for children.

Second, it meant that there was food preparation activity (and fires) scattered all over the school grounds. While it is not highly unusual for the poorer segments of the population to prepare food outside, it is also true that this approach was a long way from the ideal of sanitary food preparation.

Third, this approach permitted an opportunity for family privacy, which is often lacking in mass feeding. Such an opportunity may have been especially important since sleeping quarters were anything but private - up to a dozen families used a single classroom without any dividers. Everyone slept on simple mats on the floor.

Fourth, since some families had almost no utensils with which to prepare food while others had been able to bring their cooking ware with them, there were obvious inequalities in coping with one of the most basic needs, food.

Most Profiteering Prevented. One of the first actions insisted upon by the military was an inventory of critical supplies throughout Cotabato City, with emphasis on food and gasoline. It was broadly hinted that any shopkeeper caught "underreporting" would be severely punished. While it appeared that the food supply would be adequate until new supplies could arrive, it was not clear that that would be the case for gasoline; so a rough form of rationing was put into effect. For several days service stations were permitted to pump only a limited number of gallons into each vehicle until it became clear that there would be adequate fuel for all needs. Armed military personnel made occasional spot checks, and in a few instances a guard was posted for several hours at a time at a service station to ensure compliance with the rationing directive.

There were price controls on food long before the earthquake occurred. Enforcement of price ceilings, especially on rice and gasoline, was stepped up sharply following the disaster. The military, and to a lesser extent civil government officials, were very blunt. The message was repeatedly broadcast that anyone caught selling above the price ceilings would be severely punished. The continued presence of armed military personnel in the vicinity of stores (and most everywhere else) likely deterred many of those who might have been inclined to take advantage of the situation to make extra profit.

Coordination Did Not Eliminate All Duplication. Most relief agencies want to make their own survey of need. Each government agency that needs to take special action wants to collect that information for itself following the disaster. It was not much different in Cotabato City despite serious efforts to coordinate activities and avoid duplication. The duplication that existed was primarily in information gathering and not in provision of services or planning.

Reconstruction

Activity Patterns Shaped by Characteristics of Unemployed. The living victims of the tsunami action were mostly fishermen, who had lost both their homes and means of livelihood. Until they could somehow get boats, nets, and other needed equipment, they would have no means of surviving without disaster aid. These families living in the Cotabato City refugee centers had never been urban dwellers and often spoke a different dialect than that most frequently used in Cotabato City by the non-English speaking part of the population. It was recognized that they were ill-equipped to compete for jobs even if some were available.

Within the first 10 days, President Marcos announced that to the fullest extent possible all reconstruction work would be planned and carried out in a manner to make it most labor-intensive. Wherever possible (e.g., road building) manual labor would be used in place of more efficient machines. This approach would provide rapid employment opportunities, especially for the coastal refugees located in evacuation centers and temporary housing in and around Cotabato City. Most of the jobs would not require much skill, and the labor pool was large.

This approach may not have been the most efficient by normal U.S. standards, but it made good sense in Cotabato City after the earthquake.

Disaster Stimulated Reform. This great disaster may well significantly reduce the vulnerability of the population to a similar event in the future. Two major decisions were made which, if carried out over the next 5 to 10 years, will lead to reduced vulnerability to both earthquakes and tsunamis.

The major loss of life in this disaster was along the coast of Moro Gulf, where families live in stilted dwellings on the water's edge. Such a location is part of the traditional life style in the region. It has many advantages, a principal one being that family members are able to keep watch on the fishing boat and equipment, the sole source of family survival. But the disadvantage was now clear. When a tsunami comes, many lives are lost and the homes destroyed.

Within 2 weeks after the disaster President Marcos acted with a speed and degree of wisdom that is seldom seen in such circumstances. He decreed that in rebuilding along the coast all dwellings must be at least 200 m inland from mean high tide. It is probably easier to make and enforce such a decision when a country is under martial law. But, as witness the case of Nicaragua after the 1972 earthquake, overwhelming presidential power does not at all ensure that swift decisions regarding the use of land will be made and enforced.

After a dramatic disaster, there is always talk about rebuilding a safer community. It seldom turns out that way to any appreciable degree; a decade from now the land use along the coast of Moro Gulf may not be any different than it was prior to the August 1976 disaster. But at least the first and probably most critical step has been taken - new homes must be built in safer locations. If that decision is followed in all of the rebuilding along the coast, tens of thousands of families will be largely immune to tsunami action in the future.

Other complications may develop from this sudden change in land use and some of them may not be trivial; but as long as life is highly valued, the disadvantages of such a move are not likely to outweigh the advantages.

A second significant change initiated by the disaster was an upgrading of the enforcement of the building code. The engineers who contributed to those revisions are able to judge best the likely payoff in terms of reduced vulnerability to future earthquakes. The available evidence suggested that the revision effort was a serious one and would indeed represent a significant improvement if enacted and enforced. Consistent enforcement is often the "Achilles heel" in the effort to reduce earthquake hazard. It remains to be seen if that will be the case in the rebuilding of Cotabato City and the other damaged areas in Mindanao.

In the Philippines there are what are commonly called "idle lands." They are huge tracts of land, a remnant of the Spanish conquest, which are not being used in any productive way. In sharp contrast are the thousands of landless peasants who want to farm the land. President Marcos decided that the early post-disaster period was the time to announce that these estates would be broken up and the land made available to victims of the disaster if they wished to be resettled. This land reform might have come anyway given enough time, but clearly the earthquake and tsunami victim families provided an extra reason and an appropriate time for this far-reaching land use decision.

Societal Values

Potential Role Conflict Generally Resolved in Keeping with Basic Societal Values.

When large-scale disaster strikes without warning, many employees of organizations face a dilemma. Family demands are at odds with employment obligations. Frequently, it is not possible to meet both sets of obligations equally well during the first few hours or days. Either the organization will suffer from absenteeism of distracted employees or families will be neglected. The dilemma may be short-lived if disaster impact subsides quickly, but it may continue for several days or even weeks under unusual circumstances.

In Cotabato City the most common resolution of the dilemma was to put the family first. This appears to be in keeping with the basic societal values. In practically all instances, families of military personnel were known to be located well outside the impacted area. Furthermore, military personnel found themselves in a situation of strict discipline which assured total commitment to their organization. Local civilian employees, however, did face the dilemma. They were with their families when the earthquake struck after midnight. In cases where a member of the family was injured or the dwelling damaged, the needs of the family were clear. Potential demands of the job did not compete seriously with obligations to the family. The response appeared to have been much the same also for employees where the impact was less serious. Fear of aftershocks and lack of electricity and water also contributed to the feeling that all family members ought to stay close by. While this "family first" approach was not universal, it was the most common way of resolving the dilemma. Many respondents indicated that they stayed with their families for the first day or two and then checked in with the employer. In many instances it was then agreed that the employee could spend most of his (her) time for an additional few days with the family. Evidence indicates that, in most cases, both employer and employee viewed the needs of the family as more important than those of the organization. Given this orientation of employers, it is not surprising that no complaints were heard about absenteeism or dereliction of duty.

The usual problem with convergence of excessive numbers of volunteers apparently did not develop in Cotabato City during the first 24 to 36 hours. While other factors, such as possible confusion about whether the curfew was still in effect the night of the earthquake, may have contributed to the nonconvergence of volunteers, it is likely that the general pattern of giving top priority to the family was the main determinant. It seems that the most important needs of the organizations were met adequately without great numbers of volunteers.

Land Use Decisions Key to Restoration Period. Most homeless families did not go to evacuation centers; the usual pattern of seeking refuge with kin seems to have operated also. But there were 20 official evacuation centers, 13 of which were in Cotabato City itself. Schools were the most common site for these refugee centers, and within 10 days pressure began to build to return the schools to their normal use. About 80% of the homeless in the Cotabato City evacuation centers were from outlying areas. This fact raised the question of temporary resettlement - the possibility of movement out of the evacuation centers into nearby temporary housing areas rather than having the families return to their previous home areas scattered over many miles along the coast.

Thus, an early land use decision had to be faced. Where should temporary housing be constructed? On whose land? How would the land be secured? How did alternative locations fare in regard to available utilities?

That basic land use decision had not yet been made by President Marcos 2 weeks after the disaster. Materials for the temporary housing were already arriving in Cotabato City, however, and the decision was expected shortly. Only after temporary housing units in adequate numbers were available for occupancy could it be said that the restoration period was under way and the emergency period ended.

Ethnic Differences and Illiteracy Impeded Relief and Restoration Efforts. The rural areas of the Philippines represent many dialects and cultural differences. Some 114 dialects are spoken throughout the nation. The island of Mindanao seems filled with one ethnic enclave after another. Hostility and mistrust are common. Cotabato City itself reveals such differences in muted form - the Christians and the Moslems generally get along, but the comments one hears are reminiscent of the white-black relations in the United States of a few decades ago.

Evidence suggests that there was a conscious effort on the part of relief workers not to allow ethnic considerations to come into play. Nevertheless, one heard complaints to the contrary from the victims in relief centers. Perhaps part of the irritation between workers and victims stemmed from differences in life styles. Observation suggested that many of the victims were rural and desperately poor, while many of the workers were urban and middle class.

In one evacuation center, at least one ethnic group appeared to be given preferential treatment. No satisfactory explanation was available.

Perhaps the major source of confusion, irritation,and potential discrimination was the language difficulty. There were a number of dialects represented in the relief centers. Often those giving instructions or information to victims did not speak in the dialect used by many victims. Such messages did not get through to the victims or did so in garbled or incomplete form. Often the victims could not communicate their needs and desires to those who might be able and willing to help.

Illiteracy also was a problem. Even where the worker and victim knew the same dialect, inability to read makes communication difficult and slow. There was concern that poor non-victims would join the food lines in the relief centers, so dated food authorization slips were provided to those families who were eligible. This was a procedure foreign to many of the victims, and not being able to read what was on the paper simply compounded matters.

Finally, plans for temporary housing for victim families were being developed. Now ethnic differences became critically important. Feelings of hostility were said to run deep. For some, living even temporarily in another locality represented a great threat. Certain areas traditionally belonged to certain ethnic groups, and for other ethnic groups these geographic localities per se were considered "unfriendly." Providing temporary housing on short notice for victim families is always difficult; here it was made more difficult by the cultural diversity of the people.

Conclusions

When a disaster occurs in a small city, those who are competent to carry out social research are likely to be involved in aiding victims and thus very little of the needed research gets done. Some social research ought to be done on such a rare large-scale set of events. Research carried out in a reasonable fashion will at least enrich the cultural heritage of the area. Further, other cities or nations can learn from such a disaster.

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11. MINDANAO SEISMICITY

The seismicity of the Mindanao area can best be understood by a review of the large earthquakes reported over the past 370 years. A list of almost 90 such earthquakes is presented here. The list includes only those seismic events with Rossi-Forel intensities of VII or larger since, at that level, traditional Philippine construction begins to suffer damage. Intensity VII on the Rossi-Forel scale corresponds with VII+ Modified Mercalli. In addition to the events listed, there have been approximately 100 other earthquakes with magnitudes of 6.0 or larger; these have not been listed here since there are no corresponding reports of damage for them. Of these omitted events, 45 were reported by Gutenberg and Richter (1900-1952) and 28 by Rothé (1953-1965). The balance (since 1965) are noted in other more recent publications.

If the list is assumed to be coherent for the data of the past century, that may be interpreted as 170 earthquakes per century for 40 square degrees (5° to 10°N, by 121° to 128°E longitude, or approximately 350 by 500 nautical miles). This reduces to more than four potentially destructive events with magnitudes greater than 6.0 for each square degree in the Mindanao-Moro Gulf area each century. This is indeed a high rate of activity, with several events having magnitudes exceeding 8.0.

Generalized tectonics show the Philippines roughly divided by the Taal Line into two areas: the Northern Luzon Island arc to the north and the Visaya-Mindanao Block to the south. Details of the tectonic structure are covered by a number of authors: Maso & Smith 1913, Smith 1925, Alcaraz 1947, Allen 1962, Gervasio 1966, Fitch 1970, and Rowlett & Kelleher 1976. The overall pattern (Eiby 1973) is that of an asymmetrical arc with the deep and narrow Mindanao Trench facing toward the east to the oceanic Philippine Basin, and with vigorously active volcanoes and a belt of deeper focus earthquakes to the west.

Improvement in instrumentation, with resulting better epicentral determinations and fault-plane solutions, is leading to a greater understanding of the mechanisms and tectonics of the area. A study of the more recent referenced papers will help in visualizing the tectonic framework.

The following summary simplifies (perhaps oversimplifies) by dividing Mindanao seismic activity into two zones, or regions. The Philippine Deep Region consists of the eastern portion of Mindanao, which is periodically shaken by earthquakes originating there and along the trench fronting the eastern (Pacific) margin of the southern Philippine Islands. This is the most active area, with events well into the Magnitude 8.0 range.

The second zone, the Sulu-Viscayan Region to the west, includes western Mindanao, the Sulu Archipelago, and portions of the Sulu and Celebes Seas.

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Focal depths extend to 60 km in the Philippine Deep Region and to 300 km in the Sulu-Viscayan Region. Structural indications of transcurrent (strike-slip) faulting are present, similar to those found in Chile, New Zealand, Alaska, and California (Allen 1962). Locally, other mechanisms are reported (Fitch 1970, Hamilton 1974) which show predominant thrust, or normal, fault mechanisms.

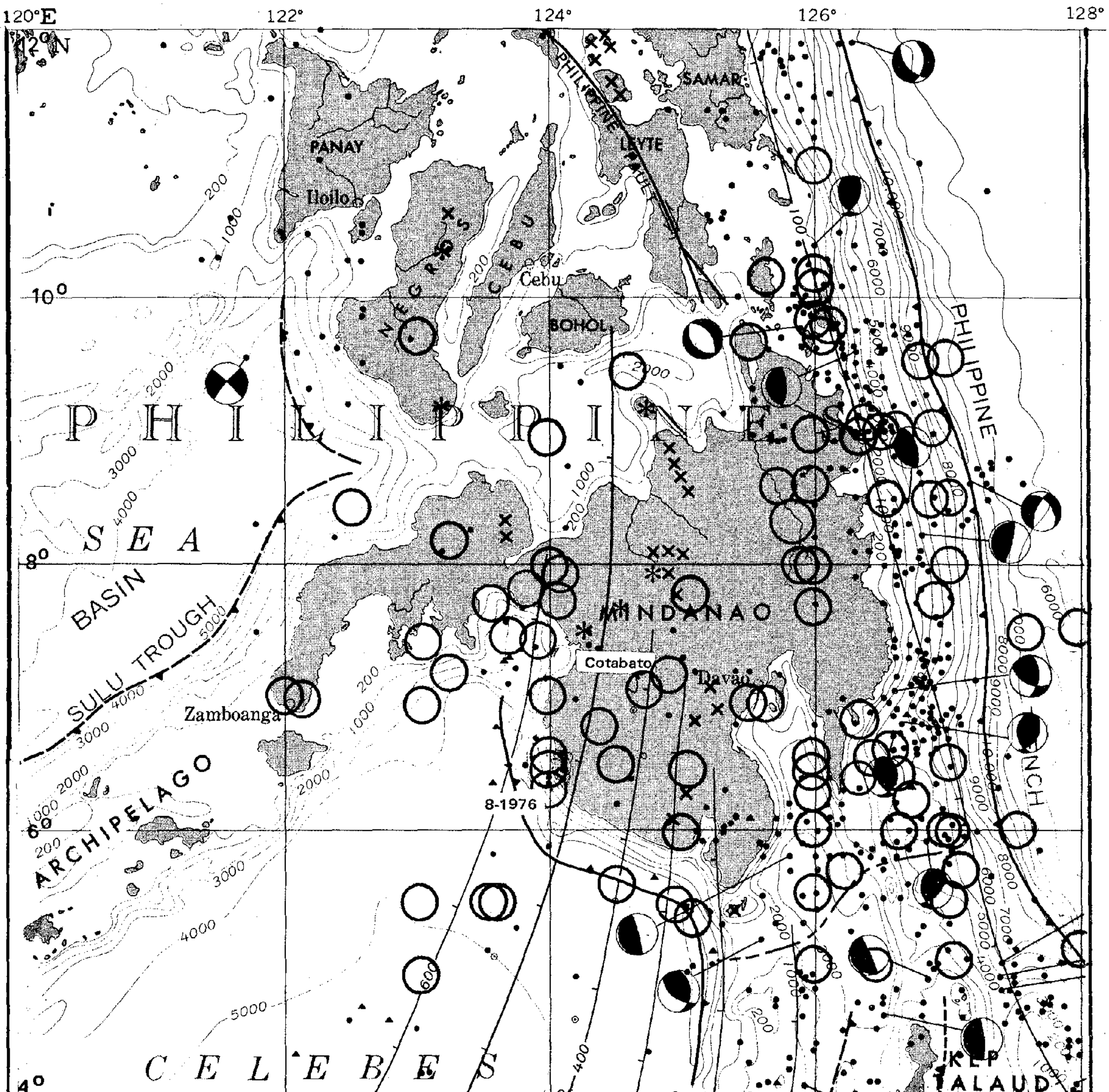
Submarine epicenters are frequently accompanied by tsunamis. Even the large inland Lake Lanao has experienced damaging seiche waves. Much of the tsunami-induced loss of life has been a consequence of the short travel times of the nearby events from the Pacific and the adjoining seas. Only infrequently are damaging tsunamis due to distant earthquakes.

Ground cracking and surface deformations have been frequently reported along with damage from the larger events. These have not been checked out as possible evidence of earthquake-related faulting. Detailed geologic maps, however, show some faults cutting Quaternary sedimentary and volcanic rocks. One of southern Mindanao's fault systems strikes northwest, with the northeast side down relative to the southwest. The zone strikes from northwest of Glan toward Cotabato. Epicentral determinations discussed here are not adequate for assignment of seismic events to specific faults.

The seismic history of the Philippines has been treated specifically by a number of authors (Perrey 1860; Maso 1895, 1902, 1910; Willis 1944; Repetti 1946; Kintanar et al. 1955; Sevilla et al. 1965) as well as having been included in more general listings (Sieberg 1932, Gutenberg and Richter 1954, Berninghausen 1969, Rothé 1969, Lomnitz 1974, and Tarr 1974). The present listing borrows freely from all of these sources, with emphasis on the listings where field data and source are presented, or where epicenters have been recomputed from additional data. The sheer bulk of the data is sufficient to demonstrate the high level of seismicity of the area, with its resultant history of damage.

Figure 119, "Mindanao Seismicity," uses Warren Hamilton's 1974 "Earthquake Map of the Indonesian Region" as a base map to show the location of significant Mindanao earthquakes. The base map, along with bathymetry and some suggestions of structure, shows fault-plane solutions as partially filled circles, for some well recorded recent earthquakes. The epicenters, shown as small dots, circles, or triangles, are for precisely located earthquakes for the period 1961-1971, with a lower magnitude limit of about 4.5. The larger, added open circles represent only the well located historical Mindanao earthquakes with a Rossi-Forel intensity of VIII or larger, or a magnitude of 6.5 or higher. The locations of seismic events before about 1961 are not considered particularly accurate.

NOTE: An annotated bibliography of selected Mindanao earthquake references, usually with the author's abstract and significant data, may be found in the Earthquake Engineering Research Institute NEWSLETTER for January 1977, pages 85-130.



M ≥ 4.5 1961-1971

EPICENTERS

Depth of focus in kilometers

• 0–99

• 100–199 ▲ 200–299

∘ 300–399 ⊙ 400–499

• 500–599 ▲ 600–699

Volcanoes

* Active

× Inactivated within Quaternary time

◯ M ≥ 6.5; RF ≥ VIII

BATHYMETRIC CONTOURS
CONTOUR INTERVAL 1000 METERS, WITH
200-METER CONTOUR ADDED

Base map after Hamilton 1974, USGS I-875-C

MERCATOR PROJECTION EQUATORIAL SCALE 1:5 000 000

100 0 100 200 KILOMETERS

100 0 100 STATUTE MILES

Figure 119

MINDANAO SEISMICITY

Selected Mindanao Earthquakes

1606 Mar 9	Cotabato Valley. "The earth shook several times." Earliest mention of Mindanao earthquake.(R. 1946)*
1636 Dec 21	Western Mindanao. RF IX. Illana Bay. Landslides. (M. 1910; S. 1932)
1637 Mar 7	Eastern Zamboanga and south Lanao. RF IX. (KQA. 1955)
1651 May 18	Eastern Mindanao. Linao, Agusan Valley. Strongest buildings wrecked. (R. 1946)
1808	Zamboanga, Mindanao. Violent earthquake damaged Fort Pilar. (R. 1946)
1818	Dapitan. Long series of earthquakes. RF VII. (M. 1910; R. 1946)
1836 Jan 3 or 5	Illana Bay. RF VII. Severe at Cotabato and Zamboanga. Very violent, many volcanoes active. (M. 1910; R. 1946)
1864 Jan 3 - Feb 26	Davao, southeast Mindanao. Swarm of shocks felt, some strong. (R. 1946)
1869 Apr 29	Mindanao. Wall of Fort Pollok fell; some military buildings cracked. Strong earthquake. (R. 1946)
1870 Nov 4	Central Mindanao. Three strong shocks of long duration. RF VII. Landslides buried four men. Many aftershocks. Intensity sufficient to damage store buildings. Light buildings undamaged. (M. 1910; R. 1946)
1871 Jun 28	Davao. Intense. RF VI with many aftershocks. (M. 1910; R. 1946)
1871 Oct 4	Davao. Strong, long earthquake. RF VII. (M. 1910; R. 1946)
1871 Nov 5	Surigao, northeast Mindanao. Very violent and prolonged. Felt throughout Mindanao and all Visayan Islands. (M. 1910;R. 1946)
1871 Nov 29	Zamboanga. RF VII. Some houses damaged. (M. 1910; R. 1946)
1871 Dec 8	Lanao, Cotabato, Davao. RF IX. Not a single building standing in Cotabato or Pollok. Two destructive shocks. (Classified as important event by Sieberg, 1932 and Lomnitz, 1974; M. 1910; R. 1946)
1871 Dec 9	Same region of Lanao and Cotabato. RF VIII. Subterranean noises louder. Felt 500 km. (M. 1910)
1871 Dec 19	Surigao to Davao. RF VII. (M. 1910; R. 1946)
1873 Jan 16	Eruption of Makaturing Volcano, Lanao. 100 victims; no earthquake reported. (KQA. 1955)
1874 Aug 25	Zamboanga. Damaged masonry buildings, overturned walls. Large fissures opened near beach. RF VIII. (M. 1910; S. 1932; R. 1946)

*Repetti, W.C., 1946 (see "References", page 106.

1875 Apr 6	Davao. Strongest ever experienced. RF VII. (R. 1946)
1875 Aug 12	Cotabato and Zamboanga. Damage to public and private buildings. RF VII. (R. 1946)
1876 Jul 25 or 26	Eastern Visayas and Mindanao. Wharf damaged. RF VII. (R. 1946)
1878 Sep 16	Gulf of Davao. Government House at Davao wrecked. RF VII. (M. 1910; R. 1946)
1879 Jul 1	Surigao Peninsula (northern Mindanao). Destructive, with topographic changes. RF X. Aftershocks continued to end of year. (M. 1910; S. 1932; R. 1946)
1882 Mar 18 - 30	Swarm at Cotabato. Some violent with rumblings. RF VI. (M. 1910; R. 1946)
1885 Feb 22	Dapa, Island of Siargao. RF VIII. Fissures, landslides. (M. 1910; S. 1924; R. 1946)
1885 Jul 23	Dapitan, northwest Mindanao. RF IX. Cracks emitted water, landslides. Visible waves in ground. (M. 1910; S. 1932; R. 1946)
1885 Sep 9	Malindang. Range of hills separated into two parts. (R. 1946)
1885 Sep 30	Northeast Mindanao. RF VI. (M. 1910; R. 1946)
1889 Jan 12	Surigao and Taganaan. RF VII. (R. 1946)
1889 Feb 5	Mindānao and Panay. RF VIII. In Cotabato an earthquake of terrifying character which lasted more than a minute. (M. 1910; R. 1946)
1889 Oct 6	Eastern Mindanao, Agusan River. RF VII. (M. 1910)
1891 Jun 25	Mindanao: Butuan, Davao, Hinatuan, Cotabato, Agusan Valley. RF VII. (M. 1910; R. 1946)
1893 Jun 3	Western Mindanao. RF VII. (M. 1910; R. 1946)
1893 Jun 21	Agusan River Valley. Bamboo and wooden houses destroyed in Davao. Cracks in ground. Subsidence. 30 minute duration. RF X. (M. 1910; S. 1932; R. 1946)
1893 Jul 1	Agusan River. RF VII. (M. 1910)
1894 Feb 10	Davao. RF VIII. (M. 1910; R. 1946)
1894 Jun 29	Veruela – church badly damaged. Talacogon – houses tilted. Similar to 1893 June 21. RF VIII. (M. 1910; R. 1946)
1894 Jun 30	Agusan River. Repeat of June 29. RF VII. (M. 1910; R. 1946)
1897 Feb 16	Cotabato, Tandag, Davao. RF VII. (M. 1910; R. 1946)
1897 Apr 8	Agusan River, Davao, Gigaquit, Veruela. RF VIII. (M. 1910; R. 1946)
1897 Sep 21	Mindanao, Sulu Archipelago, and Visayan Islands. Cracks in ground. 6 m tsunami. RF IX. Magnitude 8.7. Foreshock Mag. 8.6. "Greatest seawave ever recorded in Philippines," (B. 1939). (M. 1910; S. 1932; R. 1946; B. 1969; L. 1974)
1898 Jan 30	Zamboanga, Sulu Archipelago. RF VII. (M. 1910; R. 1946)

1902 Aug 21	Southwestern Mindanao, Lanao, Cotabato. Submarine telegraph cables broken and buried by debris. RF X. (M. 1910; S. 1932)
1903 Dec 28	East of Davao Gulf, Mati, Caraga, Sigaboy. Fissures and displacements in limestone near Caraga. Mag. 7.8. RF VIII. (M. 1910; S. 1932; L. 1974)
1904 Oct 1	Agusan River. RF VII. (M. 1910)
1905 Dec 11	Agusan River, Mindanao, and eastern Visayas. Topographic changes. RF VIII. (M. 1910; S. 1932)
1909 Mar 18	Agusan River mouth to Pacific coast. Damage at Bislig. RF VIII. (M. 1910)
1910 Dec 16	Cotabato, Davao. RF VIII. (SVB, 1965)
1910 Dec 30	Agusan. RF VIII. (SVB, 1965)
1911 Jul 12	Agusan Valley, Suriago, Davao. 9°N, 126°E. Mag. 7.7. Depth 50 km. RF VIII-IX. (M. WB July 1912; S. 1932; GR 1954)
1912 May 10	North Agusan, Butuan. RF VII. (SVB. 1965)
1913 Mar 14	Cotabato, Davao, south and southeast Mindanao. RF IX, Mag. 8.3. (SVB. 1965; T. 1974)
1913 Apr 17	Eastern Mindanao and northern Davao. RF VII. (SVB. 1965)
1913 Apr 18	Northeast Mindanao and south Surigao. RF VIII. (SVB. 1965)
1913 Apr 24	Northeast Mindanao and south Surigao. 9.5°N, 127°E. Mag. 7.2. RF VIII. (SVB. 1965; GR. 1954)
1915 Sep 5	Central Agusan. RF VII. (SVB. 1965)
1917 Jan 31	South Mindanao, Cotabato, Glan, Celebes Sea. Mud spouts several meters high. Landslides. 4' tsunami. RF VIII-IX. Seven killed. (M. 1917)
1918 Aug 15	Cotabato. RF X. Mag. 8.3. Celebes Sea. 5.5° N, 124.5°E. Tsunami, Lebak to Glan. Aftershock Mag. 7.0. (M. 1918; S. 1932; GR. 1954; T. 1974)
1919 Jan 1	Northeast Mindanao. 8°N, 126°E. Mag. 7.4. RF VII. (GR. 1954; SVB. 1965)
1920 Mar 19	Butuan Bay. RF VII. (SVB. 1965)
1920 Jul 23	Butuan Bay. RF VIII. (SVB. 1965)
1921 Nov 7	Davao. RF VIII. (SVB. 1965)
1921 Nov 11	Davao and east Mindanao. 7°35'N, 127°10'E. Waves at Manai; RF VIII. Mag. 7.5. (GR. 1954; SVB. 1965; B. 1969)
1922 Nov 11	Zamboanga. Chilean tsunami waves reported. (B. 1969)
1923 Feb 23	Rio Grande de Cagayan. 6°45'N, 123°35'E. Waves entered river at Cotabato. (B. 1969)

1923 Mar 2	Cotabato. 6.5°N, 124°E. Mag. 7.2. RF VII. Tsunami. (GR. 1954; SVB. 1965)
1924 Apr 14	Davao. 6.5°N, 126.5°E. Mag. 8.3. RF IX. (S. 1932; GR. 1954; SVB. 1965; B. 1969)
1924 Aug 30	Surigao and Agusan. 9°N, 126°40'E. Mag. 7.3. RF IX. Tsunami at Bislig. (GR. 1954; SVB. 1965; B. 1969)
1925 Dec 26	East Mindanao and Visayas. RF VII. (SVB. 1965)
1926 Jan 23	East Mindanao and Visayas. 11°N, 126°E. Mag. 5.6. RF VII. (GR. 1954; SVB. 1965)
1927 Nov 16	Davao, Cotabato, Lanao, Cagayan, Bukidnon, Agusan, and Surigao. Mag. 7.0. RF VII. (GR. 1954; SVB. 1965)
1928 Dec 19	Cotabato, Zamboanga. 7°N, 124°E. Mag. 7.3. RF VII. (GR. 1954; SVB. 1965; B. 1969)
1928 Dec 28	Cotabato, Zamboanga. 7.5°N, 123°E. Mag. 6.9. RF VII. Tsunami. (GR. 1954; SVB. 1965)
1929 Jun 13	Agusan. 8.5°N, 127°E. Mag. 7.2. RF IX. Small tsunami. (GR. 1954; SVB. 1965; B. 1969)
1929 Nov 17	Butuan, Agusan. RF VII. (SVB. 1965)
1931 Mar 23	Cotabato. RF VII. (SVB. 1965)
1931 Jul 14	Butuan. RF VII. (SVB. 1965)
1931 Aug 19	Lanao. RF VII. (SVB. 1965)
1931 Oct 30	Butuan. RF VII. (SVB. 1965)
1932 Jun 8	Misamis, Bukidnon, Agusan, Surigao. RF VII. (SVB. 1965)
1932 Sep 15	Sulu, Jolo. RF VII. (SVB. 1965)
1943 May 25	Off Mindanao. Mag. 8.1. (L. 1974)
1952 Mar 19	Off northern Mindanao. Mag. 7.9. (L. 1974)
1955 Apr 1	Lanao. 7°55'N, 124°05'E. Mag. 7.6. RF VIII. 0.5 g. Depth = 55 km. Four hundred dead. Landslides and seiche on Lake Lanao. Quays and bridges destroyed. Two Mag. 6.4 aftershocks. (KQA. 1955; Ro. 1969)
1972 Dec 2	Southeast coast of Mindanao. 6.5°N, 126.6°E. Mag. 7.8. Intensity MM-VI. Depth 60 km. Davao. Small tsunami. (UNESCO Annual Summary, 1972)
1976 Aug 17	Gulf of Moro, Celebes Sea. 6.3°N, 124.0°E. Mag. 8.0. Philippines' worst earthquake disaster. 4000 to 8000 dead. 5 m tsunami.

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