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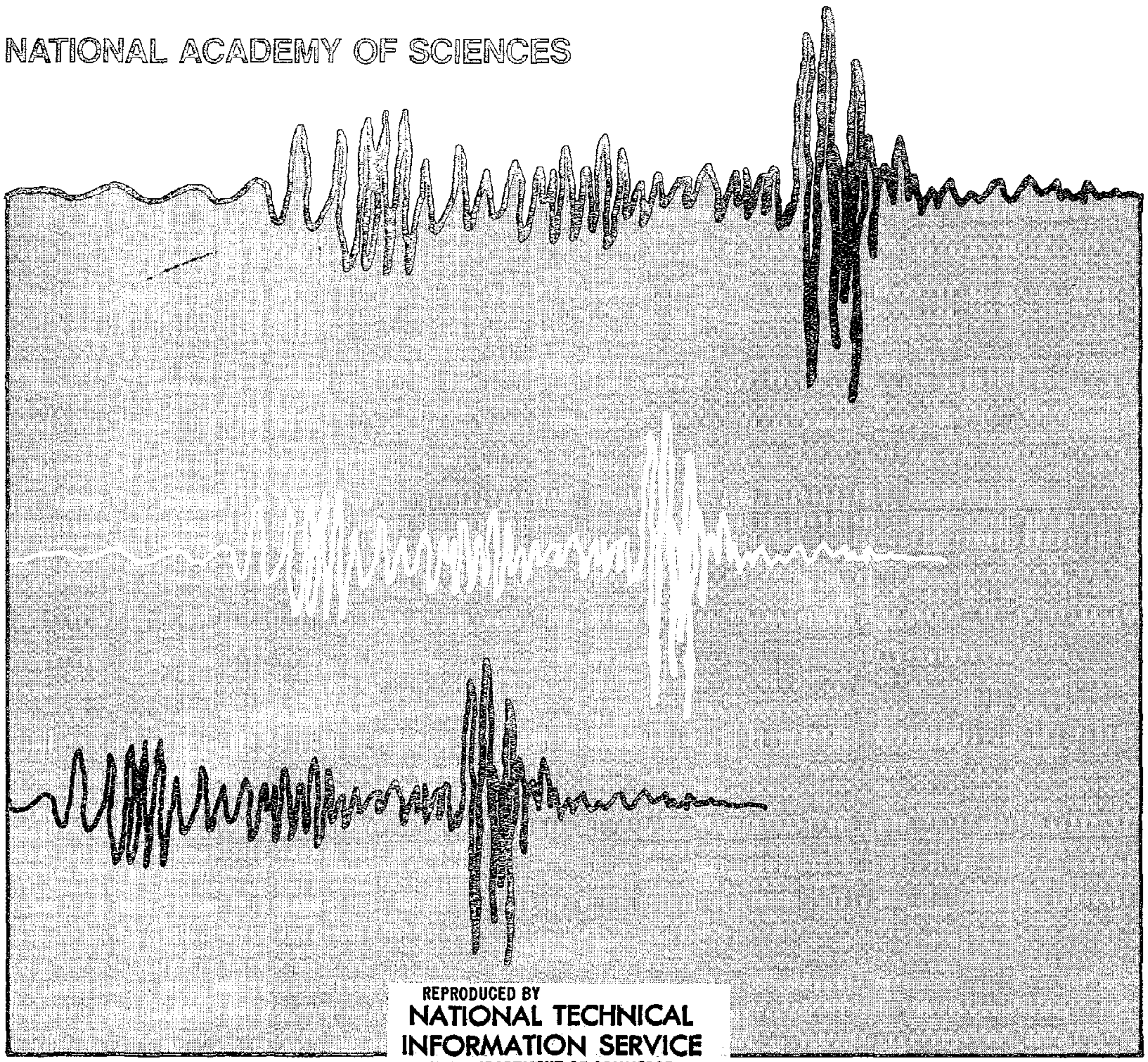
# ENGINEERING REPORT ON THE MANAGUA EARTHQUAKE of 23 December 1972

NATIONAL ACADEMY OF SCIENCES



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This report summarizes the results of an inspection of the earthquake disaster at Managua, Nicaragua on December 23, 1972 by the Committee on Natural Disasters of the Commission on Sociotechnical Systems of the National Research Council. As an introduction and as background information, an abstract of a presentation on the seismicity of Nicaragua is included. Strong-motion measurements of the earthquake and a general description of structural damage constitute the major portion of this report. The latter is subdivided into a summary, an introduction which includes a description of geology and soils, seismic history, the actual event, immediate social effects, structural history, and structural damage distribution. Another sub-section on impressions of structural damage discusses design vs. non-design, shear walls vs. frames, vital services, interaction of structural and non-structural elements, and emergency exits. Approximately one-half of the report consists of full-page photographs showing scenes of Nicaragua, before and after the earthquake, and maps depicting seismicity, accelerograms, and response spectra comparisons.

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# ENGINEERING REPORT
# on the
# MANAGUA EARTHQUAKE
# of
# 23 DECEMBER 1972

a report
by

Mete A. Sozen
University of Illinois
and
R. B. Matthiesen
U.S. Geological Survey

submitted to the

Committee on Natural Disasters
Commission on Sociotechnical Systems
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D.C.
1975

This report was prepared for the Committee on Natural Disasters of the Commission on Sociotechnical Systems of the National Research Council. The information contained herein is a part of the working papers of the Committee, but does not constitute a report of that Committee. All references and attributions should be solely to the authors.

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# FOREWORD

The Committee on Natural Disasters of the Commission on Sociotechnical Systems of the National Research Council arranges for inspection of damage from natural disasters such as earthquakes, windstorms, floods and conflagrations with the objective of determining how to apply engineering to improve public safety in the event of natural disasters, and to encourage the engineering research needed to cope more effectively with natural disasters.

As a part of this effort, the newly formed Panel on Earthquakes of the Committee sponsored the inspection of the Managua, Nicaragua earthquake of December 23, 1972 by Professor Mete A. Sozen of the University of Illinois and Dr. R. B. Matthiesen of the Seismological Field Survey, U.S. Geological Survey. This report summarizes the results of their inspection of the earthquake disaster at Managua.

The Panel on Earthquakes would like to acknowledge the cooperation and assistance of many Nicaraguan engineers during the time the team spent in Nicaragua, and in the preparation of this report. In particular, the efforts of Francisco Hansen are gratefully appreciated.

As an introduction to this report and as background information the authors have included an abstract of a presentation on the seismicity of Nicaragua given by Professor Hansen in 1972 at the Universidad Nacional de Nicaragua, prior to the earthquake.

Paul C. Jennings
California Institute of Technology
Chairman, Panel on Earthquakes
Committee on Natural Disasters

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# INTRODUCTION AND BACKGROUND:
## Seismicity of Nicaragua

by

Francisco Hansen A.*
Universidad Nacional de Nicaragua

Abstracted from a presentation given at the Universidad Nacional de Nicaragua, 1972 prior to the earthquake. Presented here with the kind permission of the author.

*Presently located at the Commission on National Territorial Studies, Mexico City, Mexico.

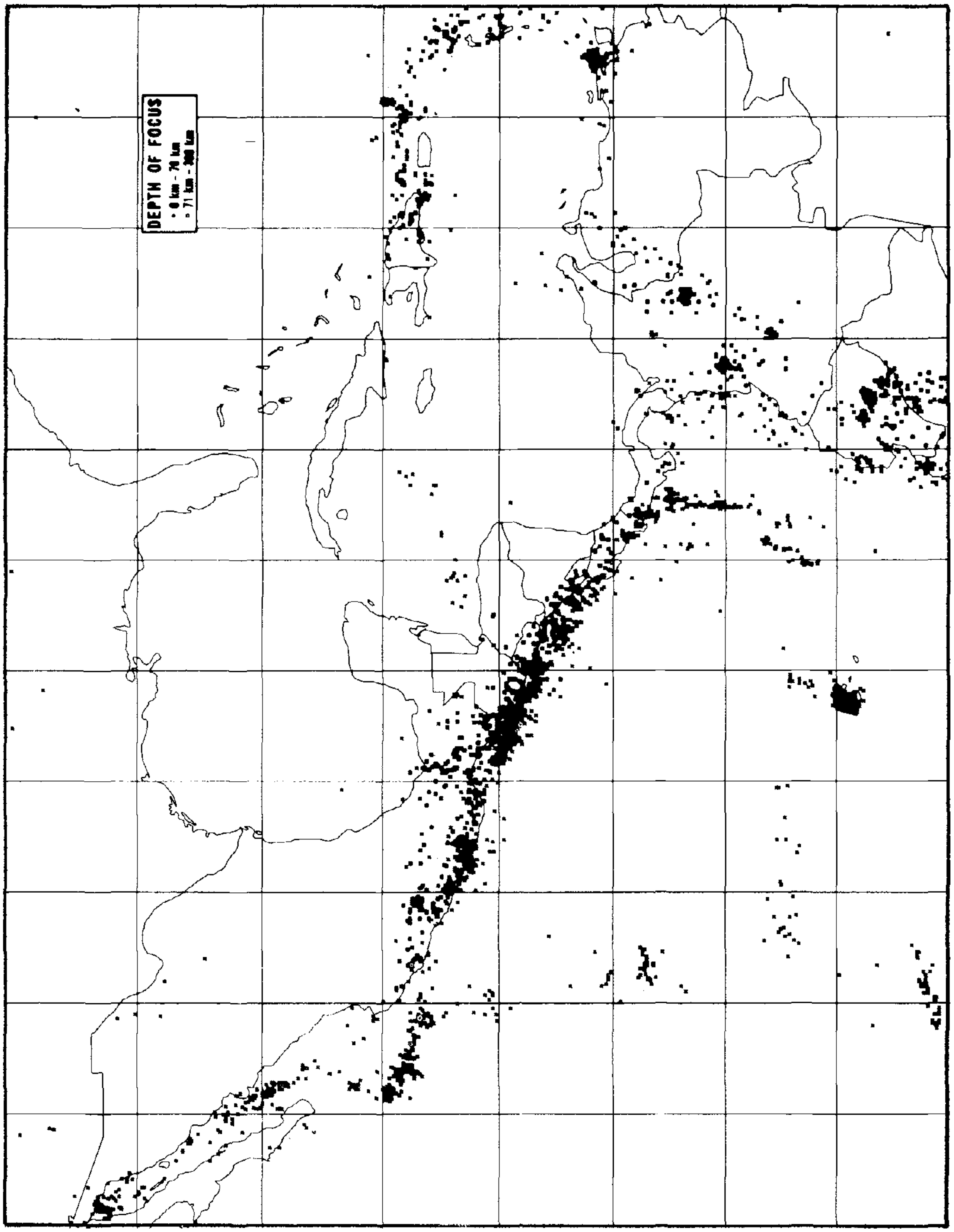


FIGURE 1   Seismicity of Mexico and Central America 1962 - 1969.

## INTRODUCTION AND BACKGROUND

### Seismicity of Nicaragua

Nicaragua is a part of the "Circle of Fire" of the Pacific in which the majority of earthquakes of the world have occurred. Figure 1 shows the epicenters of earthquakes occurring from 1962 to 1969 in Central America. This indicates the high concentration of earthquakes along the Middle American Trench off the Pacific coast of Nicaragua as well as outlining the edges of the Caribbean and Cocos plates. Figure 2 indicates the epicenters of earthquakes in Nicaragua for the period from 1964 to 1970. These maps are based on maps and reports received from the National Oceanic and Atmospheric Administration, Department of Commerce, United States.

It is important to observe the relative distribution of the epicenters and their concentration along the west coast of Nicaragua. The Pacific coast is seismically active, whereas to the north and on the Atlantic coast, the activity is significantly less. In the mountainous masses of the Segovias, for example, earthquakes very rarely originate or are felt. On the Atlantic coast, the occurrence is low and generally below human perception. In general, the northern and eastern regions of the country are relatively stable, and the probability of earthquakes is minimal although they do occur occasionally. For example, on August 14, 1961 an earthquake occurred in the vicinity of the mines. This was perceived in various populated areas in a region of some 60 km square with a maximum intensity of IV on the Mercalli scale. Although it caused alarm, it did not cause significant damage. The epicenter could have been in the vicinity of the Saslaya Mountains where landslides were observed.

The general tectonic structure of Nicaragua correlates reasonably well with that of a typical subduction trench profile. The Middle American Trench is at an average distance of 80 km from the West coast of Nicaragua. The depth of the trench ranges up to 6,200 meters in contrast to the maximum elevation of 2,100 meters in Nicaragua. The existence of gravity anomalies in Nicaragua has been observed. Although these observations only cover the continental region, they agree, in general, with the typical trench profile. However, there is a notable absence of islands or

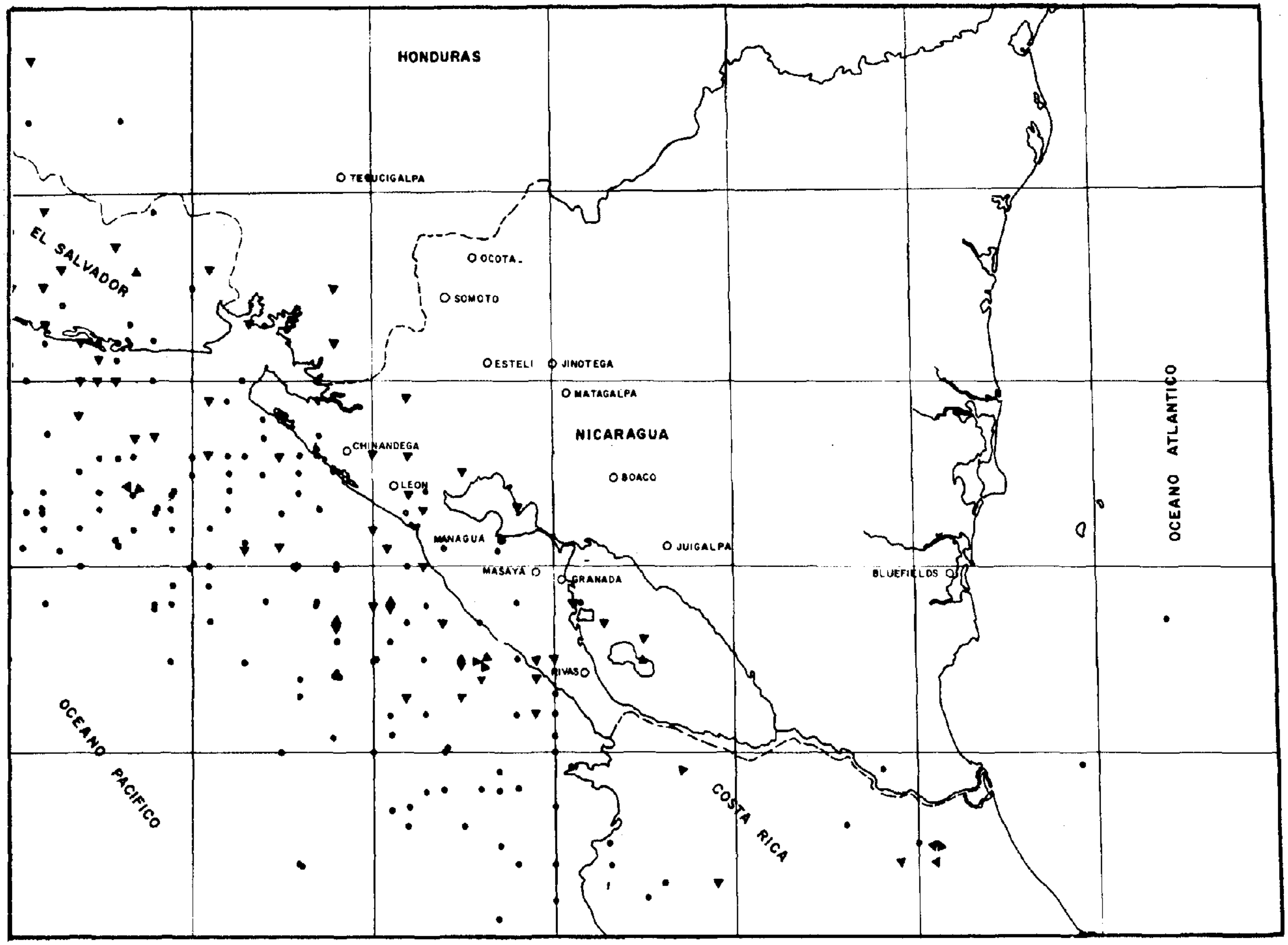


FIGURE 2 Seismicity of Nicaragua 1964 - 1970.

submarine mountain ranges, but this does not modify the general situation. On the other hand, active vulcanism is well defined with the general direction of the volcanic axis parallel to the Pacific coast and to other geological structures, all in accordance with the typical trench profile. Also, there is the existence of a previous volcanic belt, the eastern border of the Nicaraguan depression defining this characteristic. To complete the general picture, a plot was made of the focal depths of Nicaraguan earthquakes versus their positions along a section normal to the tectonic axis. The plot indicates a typical submerging surface, dipping downward to the east. In summary, Nicaragua has a typical tectonic trench profile and corresponding seismicity.

The seismic activity of the western region of Nicaragua is distributed such that the greater portion of the earthquakes occur under the continental platform, with an apparent concentration in the northwestern part of the country. Earthquakes are felt with the greatest frequency in the Department of Chinandega. These earthquakes are associated with a center of seismic activity in the Fonseca Gulf, as confirmed by instrumental records of the Seismological Service of El Salvador. These instrumental recordings also confirm the existence of another area of seismic activity southwest of the Gran Lago, which is responsible for the series of alarming earthquakes that occurred in 1954 and that affected a large part of the country.

The greatest number of Nicaraguan earthquakes occur at sea, off the west coast. On the continent, earthquakes occur less frequently and the larger earthquakes are at greater depth. Due to absorption, the waves have attenuated on their arrival at the surface. Hence, even though the area affected may be relatively large, the general effect may be minor, except for the major earthquakes. As an example of this situation, one could mention that about three weeks prior to the Managua earthquake of 1931, another earthquake of greater magnitude occurred with about the same epicenter but with a depth of 80 km. This earthquake was not felt according to reports of the time. The shallower the depth of the earthquake, the more the effects are localized, and the greater the damage for a given magnitude of earthquake. The general situation in Nicaragua is characterized by large earthquakes with focal depths up to 300 km, and shallow earthquakes which, with a very low magnitude, can be very destructive since the energy has not had an opportunity to dissipate in the lower layers. The great majority of Nicaraguan earthquakes are of relatively low Richter magnitude. These are small earthquakes and have a low destructive capacity unless they are shallow or special circumstances exist such as poor soil conditions, local resonance effects, or deficiencies in the strength of the structure.

There does not exist much scientific documentation on the Managua earthquake of March 31, 1931. An outstanding characteristic of this earthquake was that it was localized and it only affected the city of Managua. In nearby Granada, for example, it was not felt. This speaks in favor of a very surficial focus in contraposition to the teleseismic data that place it at a depth of 170 km.

Between the occurrence of the earthquakes of Managua of 1931 and 1954, the data is not readily available to define those earthquakes which would have been of interest, although it is known that there were some earthquakes that caused general alarm. In February of 1954 there occurred a series of earthquakes that affected the Republic and that caused great alarm but without appreciable damage. The epicenters of these earthquakes were placed to the southwest of the Gran Lago with intermediate and shallow depths for the different events.

After this date, there were some minor earthquakes and between April 21, 1956, and October 24, 1956, there was a noticeable absence of earthquakes. On October 24, 1956, an earthquake of magnitude 7.3 occurred with its epicenter on the continental shelf near Puerto Samoza. Even though it was felt in El Salvador and Costa Rica, and caused damage in the coastal region, this earthquake did not have major consequences besides causing general alarm to the population. One can assume that during the period of quiet, forces had a chance to build up without being alleviated in the form of smaller earthquakes. On December 7, 1957, an earthquake occurred that was located in the Atlantic coast of Nicaragua. This earthquake was of great depth and was not perceived in the country, the evidence of its occurrence being instrumental.

On June 27, 1958, a moderate earthquake occurred that was perceived quite well in the area of Chinandega with an intensity of VI on the Mercalli scale, or at the level of initiation of damage. This earthquake was felt in the area southwest of El Salvador where light damage occurred.

On November 2nd of the same year, another earthquake occurred that alarmed the population of Chinandega and Corindo, but no damage was caused. These last two earthquakes had their epicenters in the center of seismic activity in the Fonseca Gulf.

On November 14, 1958, a strong earthquake occurred whose epicenter was placed in the vicinity of San Francisco del Carnicero and that caused great alarm in the population, again without causing damage. It was felt with varying degrees of intensity in the entire country, even as far as Waspan. Unfortunately, even though this earthquake was perceived at the El Salvador seismological station, it was not possible to determine its epicenter or its depth. It must have been of great depth and large magnitude to have been felt throughout the entire country. The maximum intensity was V on the Mercalli scale. On December 4th of the same year, a small earthquake occurred with a maximum intensity of IV. It was felt with considerable alarm in a large portion of the west coast of Nicaragua, and corresponds to an earthquake of intermediate depth whose focus was placed to the southwest of the Masaya Volcano on the edge of the Nicaraguan depression.

On April 22, 1959, an earthquake was felt with an epicenter in the Marine Trench. There was no damage although there was general alarm. The remainder of 1959 and 1960 were characterized by a normal level of minor earthquakes.

On March 20, 1961, an earthquake occurred near the west coast with a depth of 25 km that was felt in Managua and in some other towns but without causing much alarm. On May 19, 1961, a barely perceptible earthquake occurred. On May 23, 1961, a great earthquake occurred that caused great alarm to the population. In Managua, plaster fell from some houses and in Leon and Masaya, some of the old houses suffered damage. The populated area most affected was Chinandega where a Mercalli scale intensity of VI was recorded; the earthquake was felt with greater violence in Morazan Port where it was reported that the intensity was between VI and VII on the Mercalli scale. The epicenter was in the southeast border of the Fonseca Gulf. On August 14, 1961, an earthquake occurred on the Atlantic coast, as already mentioned. On September 3, 1961, another earthquake occurred which was located on the submarine shelf and widely felt in the west coast region where light damage was reported.

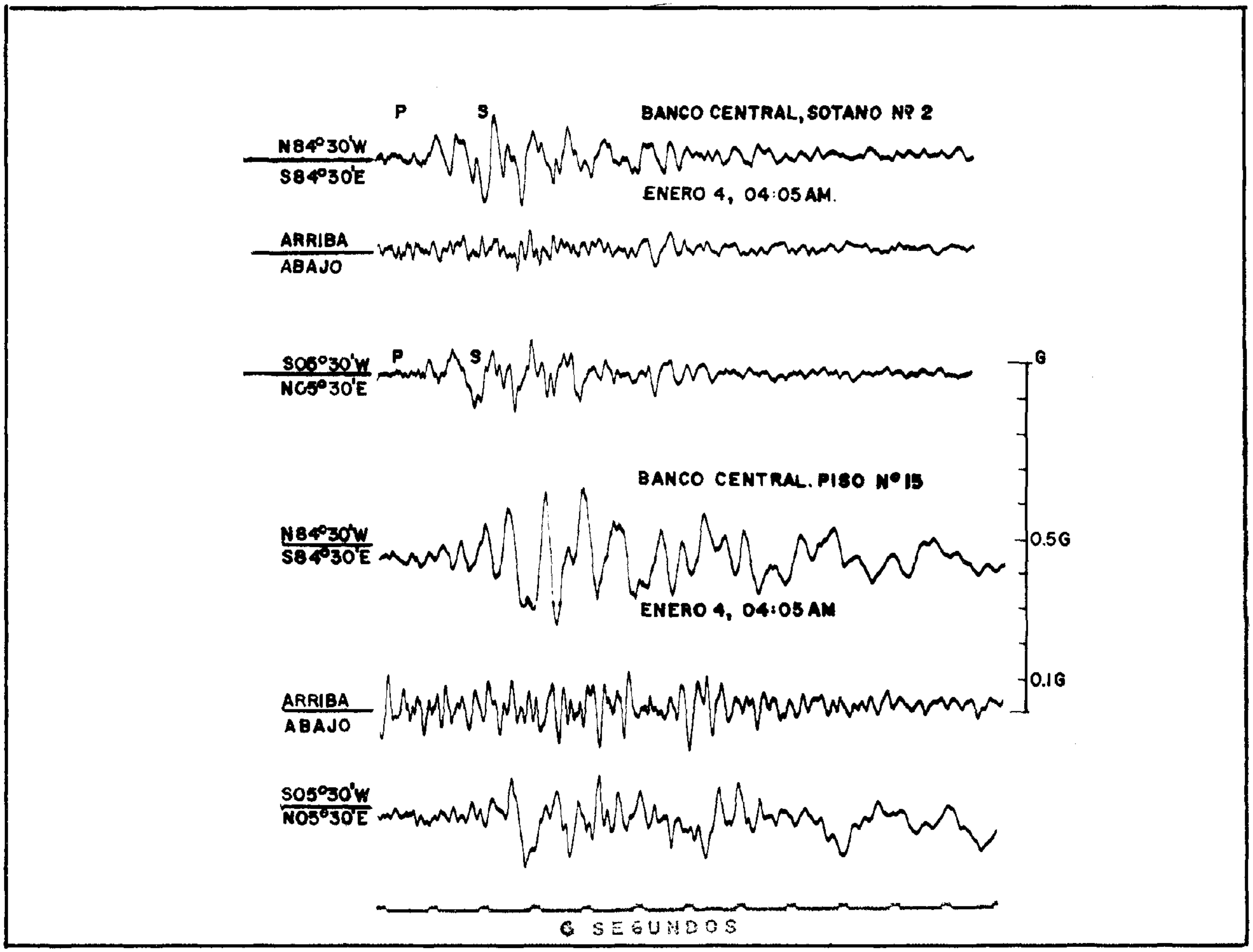


FIGURE 3   Accelerograms from the Earthquake of January 4, 1968.

At this point, one can observe that the general trend of seismic activity in the country is characterized by a relatively constant occurrence of earthquakes with magnitude about 4.5 and a frequency of 2 or 3 occurring annually. These may cause alarm without causing significant damage. This pattern was maintained until January 4, 1968, when an earthquake occurred that caused serious damage in the southeast portion of Managua.

The earthquake of January 4, 1968, appears to be a very localized phenomenon since it was not felt in other populated areas (2,3). On this occasion, the area affected was to the southeast of the city with a shallow depth, Richter magnitude of 4.5, a maximum Mercalli intensity of VII, and an instrumentally recorded ground acceleration of 15 percent of gravity. About the middle of 1966, two accelerographs were installed in the Banco Central de Nicaragua, one in the basement and one on the 15th floor. Both instruments recorded the earthquake, as shown in Figure 3. In general, the damage which resulted must be attributed to the deficiencies in the structures and possibly to the amplifying effects of the soil which is composed of loose unconsolidated material (3). The characteristics of soil caused a general subsidence throughout the epicentral area. Precision leveling indicated that this amounted to almost 4 cm at the Central American Colony. This earthquake was of small size but locally destructive because of its shallow depth.

During the series of earthquakes of January, 1972, records were obtained from three accelerographs installed in the Central Bank, Universidad Nacional, and ESSO Refinery. In addition, useful records were obtained, from 9 of 14 seismoscopes which are installed in various places in the city. In addition, the seismograph of Coyotepe recorded about 100 events between the 2nd and 6th of January. Approximately 25 events were perceptible to the population. These earthquakes were shallow and the effects were localized. The seismoscope plates clearly indicated that the ground motion was of greater amplitude in the west, with the maximum at the ESSO Refinery, almost nothing in the Escuela de Agricultura y Granaderia and very little in the Fabrica Procon in los Brasiles. In view of this and taking into account that the movements were felt with greater alarm in the western part of the city, it was thought that its focus was very superficial and very close, possibly located in or near the Mateare fault.

The earthquake of January 2nd caused maximum ground accelerations of 5.9 percent of gravity at the Banco Central and 14.3 percent of gravity at the ESSO Refinery. For the earthquake of January 5th, the accelerograph of the UNAN installed in the Recinto Universitario recorded 15.3 percent gravity against 20.1 percent gravity at the refinery. These earthquakes caused incipient damages in the city of Managua, and were assigned a maximum intensity of VI on the Mercalli scale with Richter magnitude of 4.3. In some of the earthquakes, especially the one that occurred at midnight of January 2, very strong vertical components were noticed of high frequency with a level of acceleration of approximately 10% of g. These earthquakes were extremely alarming, due to the memory of what had occurred exactly four years previously in the Centro American Colony and to the continuity of the events for several days.

Managua finds itself in a situation that requires care not so much in what pertains to the general seismicity of the country, but what could be the particular seismicity of the city with the production of earthquakes of shallow focal depth, that can be as destructive as the one in 1931 and December 1972, fairly destructive as the one in 1968, or incipiently destructive as the one in January 1972.

All of this seems to indicate that the seismic risk in Nicaragua depends a great deal on the pattern of occurrence of the earthquakes. One could almost say that the earthquakes of the Middle American Trench as well as those of the continental shelf constitute a minor hazard, although they represent the major source of seismic activity. In fact, the earthquakes which represent deviations with respect to the general pattern of trench tectonics are the ones which cause the most damage. This is the case with the earthquakes of shallow depth that occur on the continent itself.

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# STRONG-MOTION MEASUREMENTS OF MANAGUA EARTHQUAKE

by

R. B. Matthiesen

Director, Seismological Field Survey

U.S. Geological Survey

## ACKNOWLEDGMENT

The author acknowledges the cooperation of Ing. Francisco Hansen, Professor at the Universidad Nacional Autonoma de Nicaragua; Ing. Humberto Porta, Director of the Instituto Geografico Nacional; and Mr. Leroy Anstead, IAGS Representative, Nicaragua, during the time he was in Nicaragua. C. F. Knudson, Seismological Field Survey, accompanied the author while in Nicaragua and both he and V. Perez, Seismological Field Survey, have contributed to the analysis of the records.

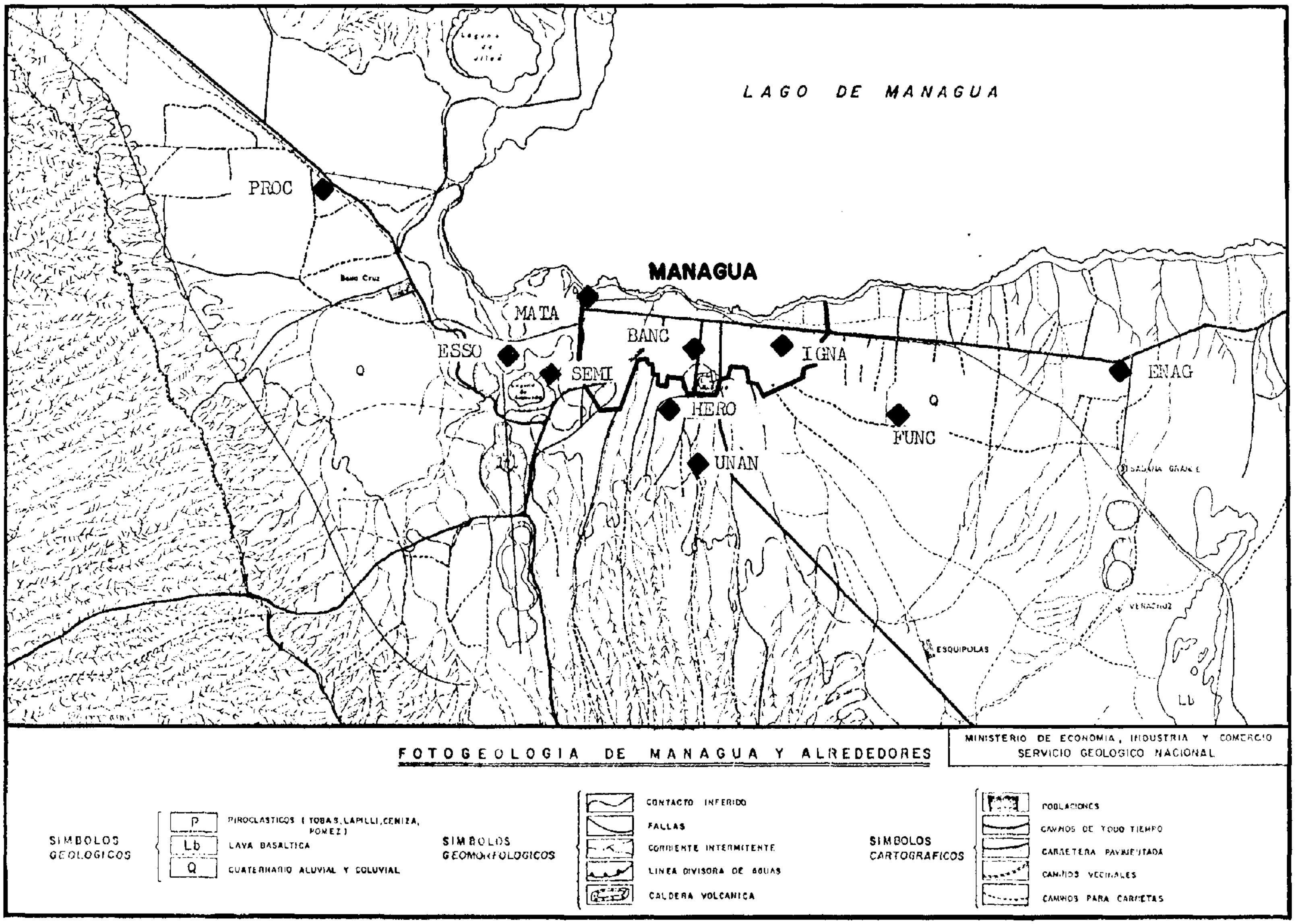


FIGURE I-1 Location of Strong-Motion Instruments in Managua.

## STRONG-MOTION MEASUREMENTS OF MANAGUA EARTHQUAKE

Sixteen strong-motion instruments were in the vicinity of Managua at the time of the earthquake of December 23, 1972. The instruments are owned by several different Nicaraguan organizations. Of these instruments, three were AR-240 accelerographs and thirteen were Wilmot seismoscopes. The locations of these instruments are shown in Figure 1. The three accelerographs were located at the Refineria Esso (ESSO), at the Banco Central (BANC), and at the Recinto Universario Ruben Darion (UNAN). One 0.75 sec seismoscope was located at each of the sites. In addition, a 0.5 sec seismoscope was located at ESSO, and two 0.75 sec seismoscopes were located on upper floors of the Banco Central. Figure 1 also indicates the general geological and soil conditions of the area. More detailed geological and soils information is being compiled by the USGS and as a part of investigations being conducted by the Earthquake Engineering Research Institute (EERI).

Only one accelerograph record was obtained from the three accelerographs in place at the time of the earthquake. The accelerograph at UNAN was on battery operation without trickle charger and the battery voltage was too low for operation. The accelerograph in the basement of the Banco Central (BANC) appeared to have had a dry (and therefore dead) battery. The one accelerograph record was obtained at ESSO, where the instrument has a nominal range of 0.5 g. A reproduction of the initial portion of this record is shown in Figure 2. There were no records from foreshocks preceding the main portion of the record which corresponds to the magnitude 6.25 event at 0630 GCT. The peak acceleration on this record was in the east-west direction and has a value of 0.39 g. The peak north-south acceleration has a value of 0.34 g whereas that in the vertical direction has a value of 0.33 g. The high amplitude portion of the record starts one second after the triggering of the instrument and lasts for five seconds with a nominal acceleration of 0.2 g. There is some longer period motion in the subsequent portion of the record which could be more important for longer period buildings than the high accelerations. This lasts approximately an additional five seconds. In the total

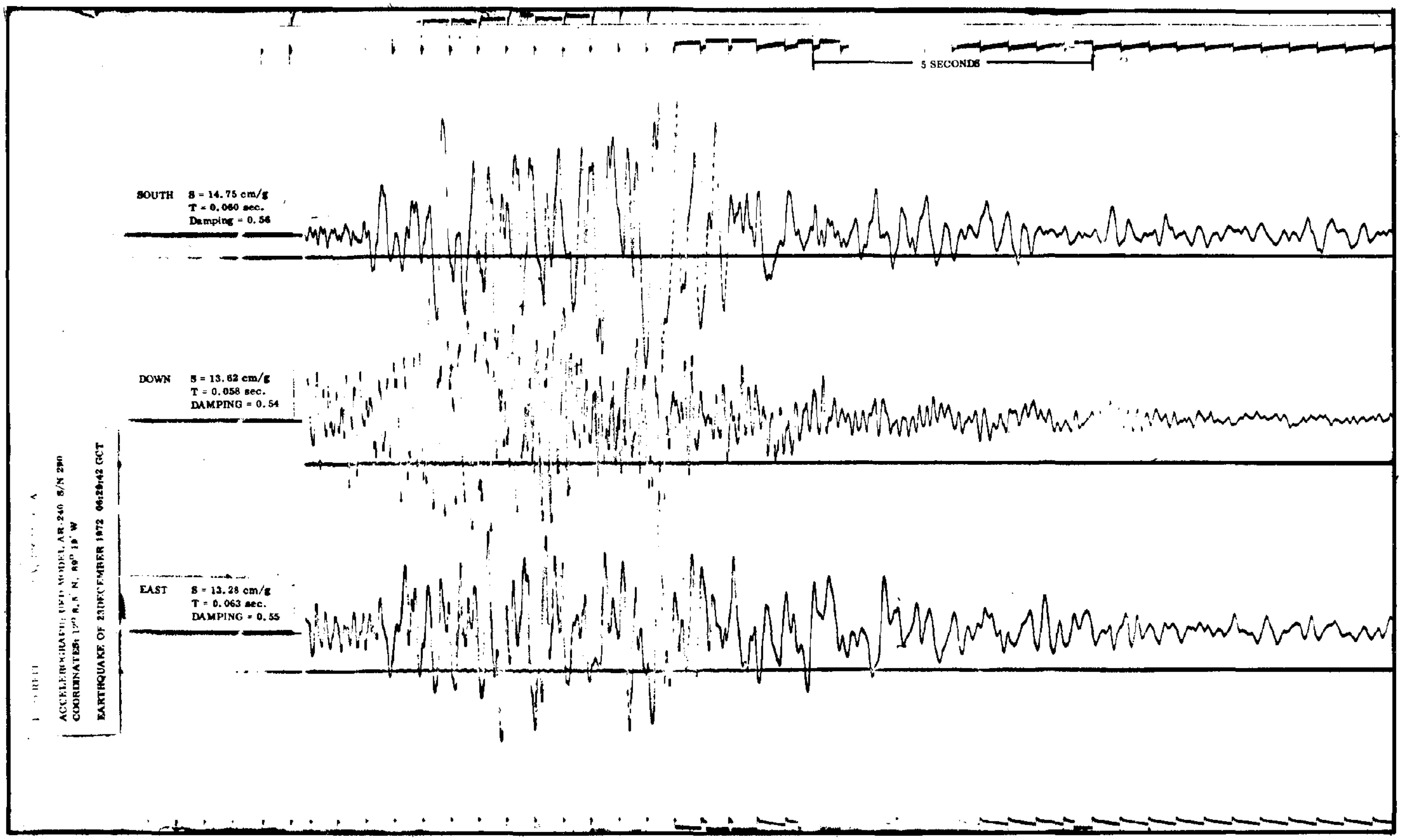


FIGURE I-2 Accelerograph Record from Refineria ESSO, December 23, 1972.

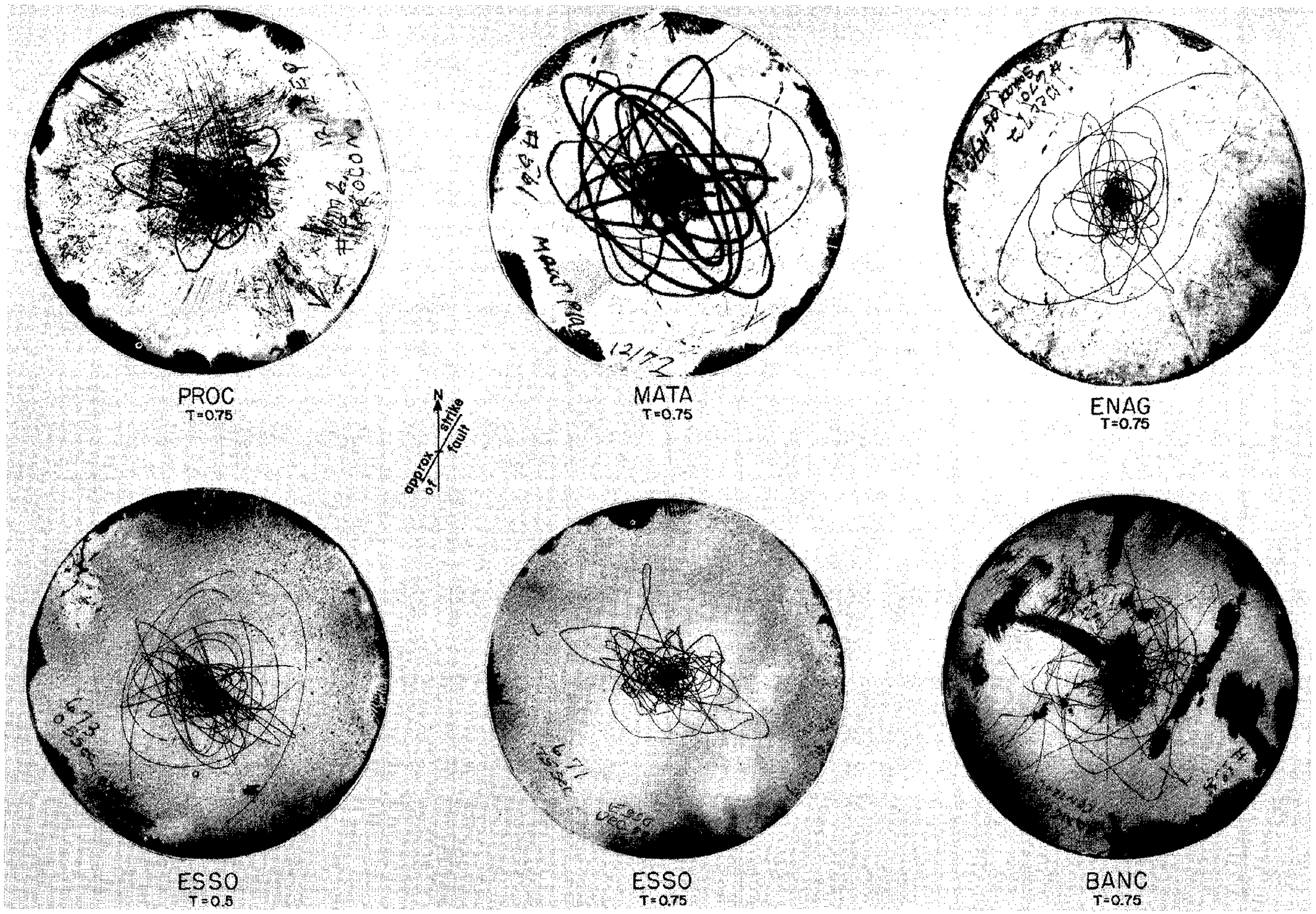


FIGURE I-3 Seismograph Records, Managua Earthquake of December 23, 1972.

record obtained from the ESSO accelerograph there are 20 aftershocks including two corresponding to the magnitude 5 and 5.25 aftershocks which occurred at 0718 and 0719 GCT. Spectra from the three components of the accelerograph record are shown in Figure 5 of Part II of this volume.

Of the eleven seismoscope records of ground motion, four provide complete records of the motion (two of the four are at ESSO); two exceeded the maximum range of the seismoscope (one of these was smudged while removing it from the instrument); one had a poor record due to light stylus pressure; and the remaining four were dislodged from the seismoscopes during the earthquake. Preliminary results obtained from these seismoscopes are summarized in Table I, and reproductions of the records at PROC, ESSO, MATA and ENAG are shown in Figure 3. The values of maximum excursion on the seismoscope plates have been converted to relative displacement response ordinates and these are summarized in Table I.

The plates from the seismoscopes on the upper floors of the Banco Central were dislodged from the seismoscopes and fell to the east. These records do not provide any indication of the nature of the motion prior to the dislodgement of the plates.

From these results and the map of instrument locations, it is apparent that the ground motion was generally high throughout all of Managua, with a greater motion at Escuela Nacional Agricultura y Granaderia (ENAG), near the east end of the international airport, than at the ESSO refinery west of the city. The maximum motions at BANC and MATA (Matadero Modelo) exceeded the range of the seismoscopes, but are interpreted as being just off scale. The seismoscope records suggest that the ground motion in the central part of the city was somewhat greater than that at ESSO.

TABLE 1

SEISMOSCOPE RESULTS, MANAGUA, NICARAGUA

DECEMBER 23, 1972

| Station | Instrument | Maximum Excursion | Relative Displacement Response Ordinate, $S^d$ |
|---|---|---|---|
| PROC | #672 | 0.69 in. | 1.7 in. |
| ESSO | #671 | 0.83 in. | 2.0 in. |
| | #673 | 1.1 in. | 1.5 in. |
| SEMI | #574 | a | -- |
| MATA | #561 | 1.25 in.[b] | >3.0 in. |
| BANC | #558 | 1.25 in.[b] | >3.0 in. |
| HERO | #576 | c | -- |
| UNAN | #555 | c | -- |
| IGNA | #669 | c | -- |
| FUNC | #579 | c | -- |
| ENAG | #670 | 1.17 in.[d] | 2.8 in. |

Notes:
a) Low stylus pressure caused excessive skipping.
b) Record exceeded maximum radius of the plate.
c) Smoked plate dislodged from seismoscope by the earthquake.
d) Stylus appears to have snagged on a plate retaining spring during the maximum excursion which approached full scale.

# A GENERAL DESCRIPTION OF STRUCTURAL DAMAGE

by

Mete A. Sozen

Professor, Department of Civil Engineering

University of Illinois

## ACKNOWLEDGMENT

The following report is based primarily on my observations during a ten-day stay in Managua starting on December 24, 1972, as an observer for the U.S. National Academy of Engineering Committee on Natural Disasters. It is also influenced by my visits to Managua before and after that occasion, the Earthquake Engineering Research Institute Conference on the Managua Earthquake, and my conversations with various engineers and other professionals who have studied different aspects of the damage.

I owe particular acknowledgment to Mr. Filadelfo Chamorro, for his generosity in providing technical information and the photographs in Figures 22 and 23 as well as to Mr. Cristobal Rugama and Mr. E. Pereira for their help.

The photographs showing Managua before and after the earthquake were taken by Mr. Modesto Armijo of Mexico City.

In Managua, I benefited from the advice and company of Dr. Abdel Karim Conrado of Managua, and Dr. Richard N. Wright and Mr. Samuel Kramer of the U.S. National Bureau of Standards.

The corrected accelerogram records and response spectra were provided by Dr. A. G. Brady of California Institute of Technology.

# SUMMARY


On December 23, 1972, a moderate-magnitude earthquake shook Managua, a city of approximately 400,000 in Central America (Figures 1 and 2). The epicenter of the earthquake, which had a very shallow focus, was within city limits (Figure 40) leading to catastrophic structural damage. Casualties exceeded 2,000. Over 250,000 people were left without shelter. The total financial loss was comparable to the gross annual domestic product of the entire republic of Nicaragua. Detailed views of Managua before and after the earthquake are shown in Figures 24-39.

Construction in the city was predominantly low rise with two moderate-rise buildings and several others in the six- to eight-story range (Figures 22 and 23). Because earthquake design regulations were not enforced in the city (which had been devastated by an earthquake in 1931), the designed lateral strength of the buildings in the city ranged from accidental to adequate in relation to the Zone-3 requirements of the U.S. Uniform Building Code.

Other earthquake disasters in various parts of the world have time and again emphasized the need for special design provisions for buildings housing essential services. The strongest warning that emanates from the tragic experience of Managua is in relation to this point. The main shock destroyed the central fire station and put out of action the hospitals, power station, and administrative centers of the city, as well as severing the water supply lines. The tragedy would have been magnified had the earthquake been followed by a general conflagration, a flood, or another contingency which would have required centralized reaction.

With respect to structural design, the Managua experience does hold a special place because:

(1) The ground motion was very strong, well in the upper range of design strong motions currently anticipated (Figures 4-8).

(2) Many of the major buildings in the city were designed in accordance with the current methods of earthquake resistant design.

(3) Major structural damage observed was caused exclusively by ground shaking.

Combination of these three factors make the Managua 1972 earthquake a meaningful test of the current state of the art leading to the following observations.

Behavior, inferred from observed damage, of the buildings which had been designed to resist lateral loads was on the whole consistent with the intent of the design philosophy selected by the engineer. There were no surprises even if the events were anticipated strictly through the logic of current codified practice, except of course with respect to the magnitudes of forces actually developed in buildings.

Comparisons of the behavior of buildings which relied primarily on shear walls with the behavior of those which relied primarily or exclusively on frames would indicate that the current tendency of building codes to encourage the designer toward the ductile frame should be reconsidered.

The presence of buildings without any intentional lateral strength in a city with a severe earthquake history re-emphasized the need to pass and enforce laws to prevent the construction of such buildings in seismic regions.

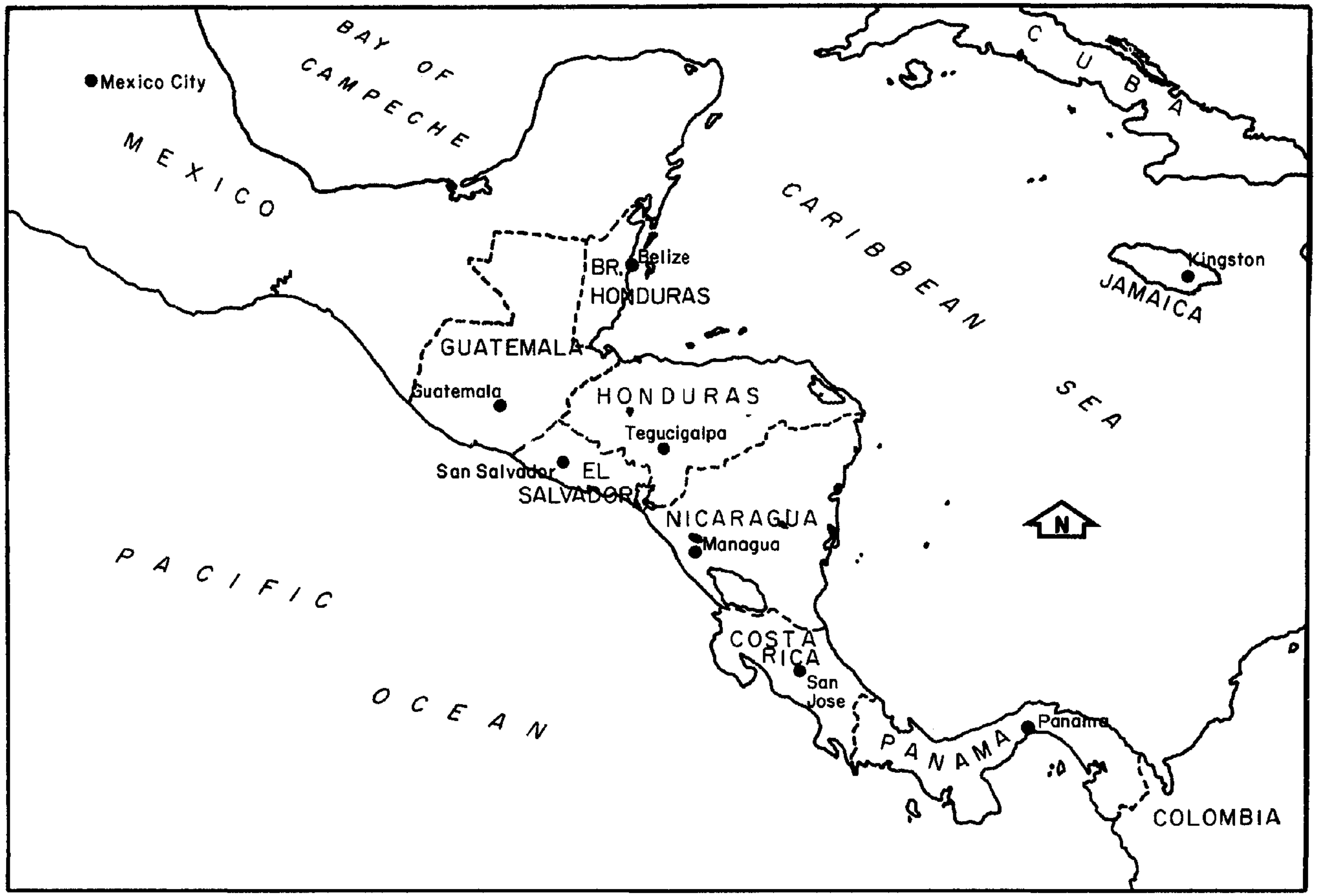


FIGURE II-1 Nicaragua and Neighboring States.

# INTRODUCTION

Managua, capital of the Nicaraguan republic (Figure 1), is a relatively young Central American city on the south shore of Lake Managua. Its latitude and longitude are approximately 12°N and 86°W. It is almost as far west of Greenwich as Chicago. Its position with respect to the equator compares to that of Saigon. The lake is at an elevation of approximately 130 ft above sea level. Downtown Managua (Figure 2) close to the lake, is at approximately 200 ft. The city lies on a gentle slope, interrupted by hills, rising toward the south.

A national census in 1967 indicated a total population of 1,800,000 for the entire nation, with 381,000 living in Managua and environs. It was then estimated that the population of the city would exceed 400,000 by 1972 (1).

Compared with other Central American cities, Managua has a short history. The village of Santiago de Managua was elevated to city rank by Jose Leon Sandoval in 1846. As a compromise in the political rivalry between the cities of Leon (relocated because of volcanic damage problems in 1610) and Granada (founded in 1524), Jose Guerrero moved the seat of government to Managua, equidistant to the rival cities, in 1847 (2).

## Geology and Soils

McBirney and Williams (3), in their study of the volcanism of the region, divide Nicaragua into four geologic and geographic provinces as shown in Figure 3. Managua falls within the Nicaraguan Depression which is characterized by a quaternary accumulation of alluvium, lake sediments and deeply weathered volcanic ash exceeding a thickness of 1,000 m in the center and along the southwest side. The origin of the Nicaraguan Depression is found to date from the Mio-Pliocene period with subsidence along the southwest side continuing to the present. Volcanic activity in Nicaragua has been concentrated, since Pliocene time, near the fault systems bounding the Nicaraguan Depression (3).

Available information on soil conditions has been summarized by J. E. Valera (4). The main portion of the city is built on alluvium. In downtown Managua (around the two bank buildings, Figure 2), rocklike

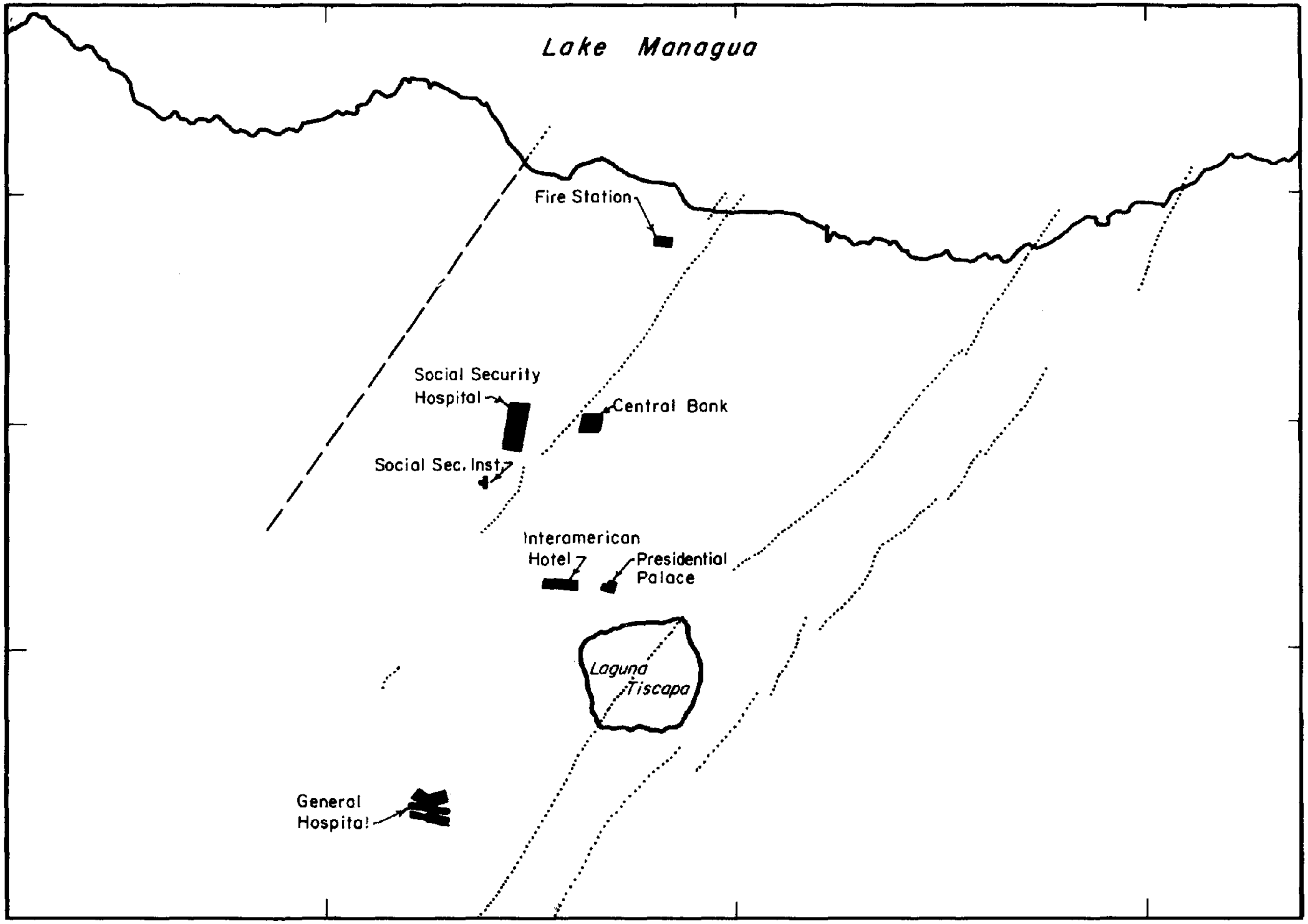


FIGURE II-2   Managua (1931 and 1972 Faults).

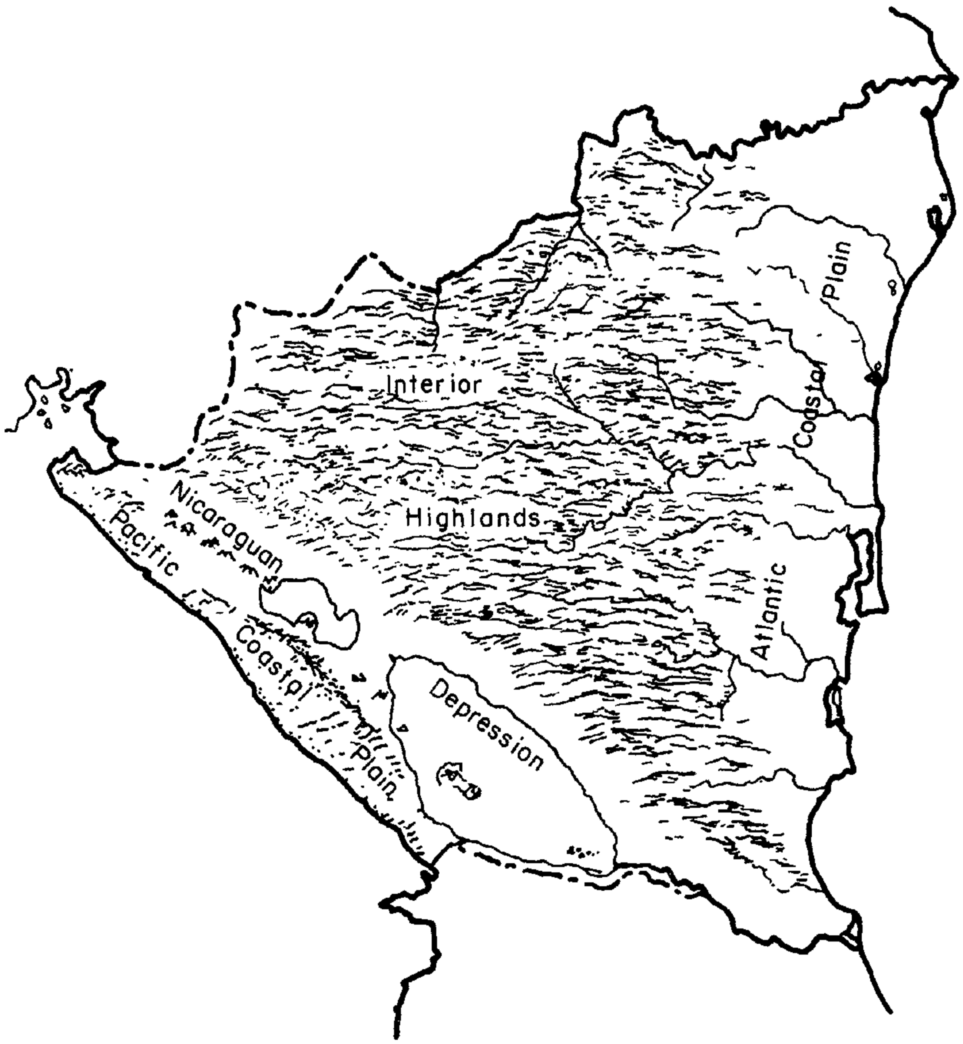


FIGURE II-3 Physiographic Provinces in Nicaragua.

material (volcanic tuff) is encountered very close to the surface, within 12 ft. In outlying areas this depth increases. At the ESSO refinery (approximately two miles east of downtown Managua) rocklike material was not encountered by a boring to 75 ft. Foundation material above the tuff provided by top soil and dense silt or sand and sand and gravel is good as indicated by the permissible soil pressure values ranging from 6,000 to 8,000 psf.

The water table depth ranged from 60 ft near the center of town to 10 ft near the lake virtually eliminating the likelihood of liquefaction. In general, the foundation conditions in Managua did not lead to any particular problems related to serious slides or local amplification of ground motion.

## Seismic History

A detailed list of the destructive earthquakes of Nicaragua has been compiled by D. J. Leeds (5). It is of interest to note that there have been 99 Nicaraguan earthquakes with estimated magnitudes exceeding 6.0 since the year 1520, or approximately one earthquake with serious damage potential every five years. Two relatively recent shocks, prior to 1972, caused serious structural damage in Managua. One, on November 5, 1926, caused partial destruction of the cathedral in Managua and extensive damage to residences. Another one, on March 31, 1931, caused general heavy damage and may have been comparable in intensity to the event of December 23, 1972. Loss of life was estimated at 1,100 (out of a population of 60,000) with the financial loss valued at $15,000,000 (1931 dollars).

## The Event of December 23, 1972

From seismological data and the local strong-motion records, it appears that the catastrophe of December 23, 1972, was caused by a main shock at 12:30 a.m. local time followed by two aftershocks at 1:18 a.m. and 1:20 a.m. The body-wave magnitude assigned to the main shock is 5.6 (surface-wave magnitude of 6.2). The aftershocks were rated at 5.0 and 5.2 (body wave).

The hypocenter of the main shock was located by Dewey *et al.* (6) in an area approximately coinciding with downtown Managua at a depth of two to eight km.

The corrected strong-motion records measured at the ESSO refinery (location shown in Figure 1, Part I and Figure 40) are given in Figure 4. The surface faults identified after the December 23rd earthquake, as well as the 1931 fault, are shown in Figures 2 and 40.

Spectral response curves for horizontal components of the ESSO 1972 record are compared with those for the north component of El Centro 1940 in Figure 6 at two extreme values of damping. The responses are of comparable magnitude over a range of frequencies from 0.5 to 10 Hz. Figure 6 compares the spectrum intensities (7) for El Centro 1940 and ESSO 1972. The spectrum intensity is approximately the same for the two strong-motion records.

A special study was carried out to evaluate the damage potential on reinforced concrete structures of the strong-motion at the site of the ESSO refinery (8). The response histories of a series of single-degree-of-freedom systems at different initial stiffness and yield capacities were calculated for ESSO 1972 (E) and El Centro 1940 (N). The SDF systems had hysteretic response characteristics simulating the response of reinforced concrete elements (9) with the tensile strength of the concrete assumed to be zero and the slope of the shear-displacement relationship after yielding set at five percent of the slope before yielding. Calculated representative displacement and acceleration histories are shown in Figure 7a through 7f having initial natural periods of 0.5, 1.0, and 2.0 sec. and yield base shear strengths equal to 16 percent (for T=0.5 and 1.0 sec.) or 12 percent (for T=2.0 sec.) of the weight of the system.

Comparison of the response histories of El Centro 1940 and ESSO 1972 in Figure 8 indicates that the damage potential of the two ground motions was approximately the same in terms of maximum as well as repeated effects. With respect to El Centro 1940 the duration of ESSO 1972 is relatively short. This is not seen as a critical factor in downgrading the indication from maximum acceleration, spectral response, and spectrum intensity measurements, that the ESSO 1972 record represents a ground motion with a structural damage potential comparable to that of El Centro 1940.

From the estimated location of the hypocenter somewhere underneath downtown Managua, it follows that the ground motion in central Managua was more intense than that recorded at the ESSO refinery site. Johnson *et al.* (10) have made a preliminary estimate of 0.6g for the maximum acceleration

(Text continues on page 46)

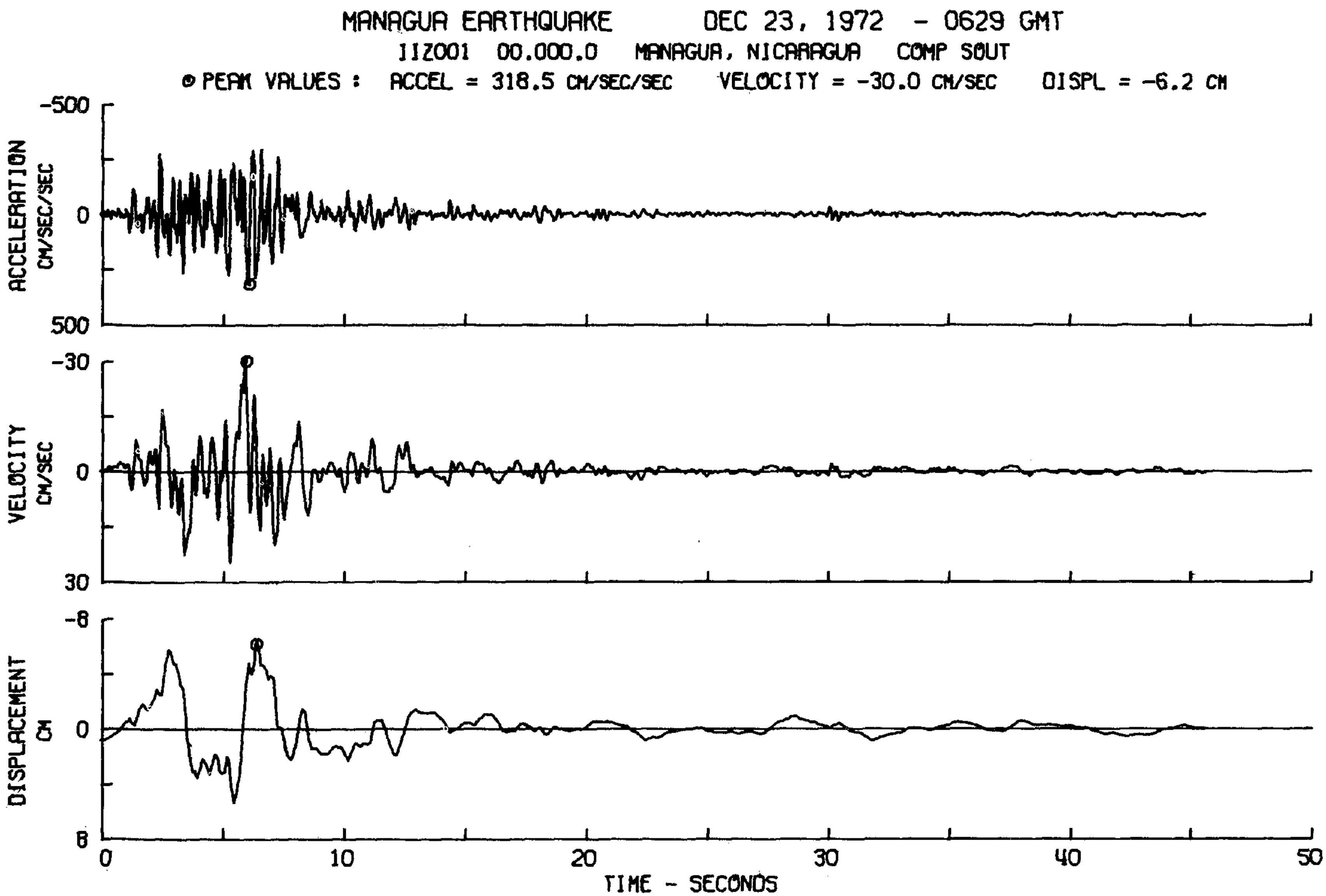


FIGURE II-4a South Horizontal Component of Corrected Ground Motion Record ESSO Location.

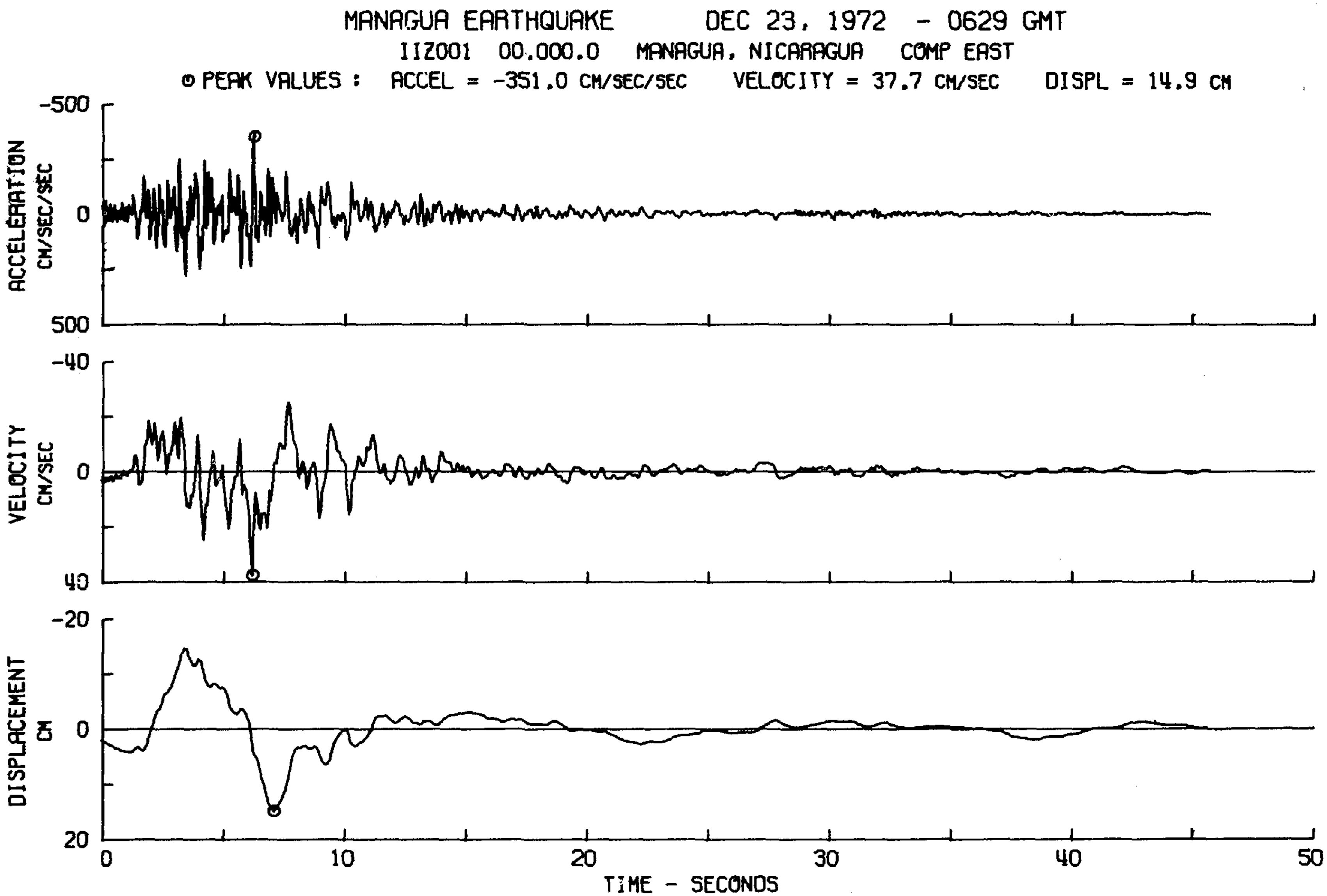


FIGURE II-4b East Horizontal Component of Corrected Ground Motion Record ESSO Location.

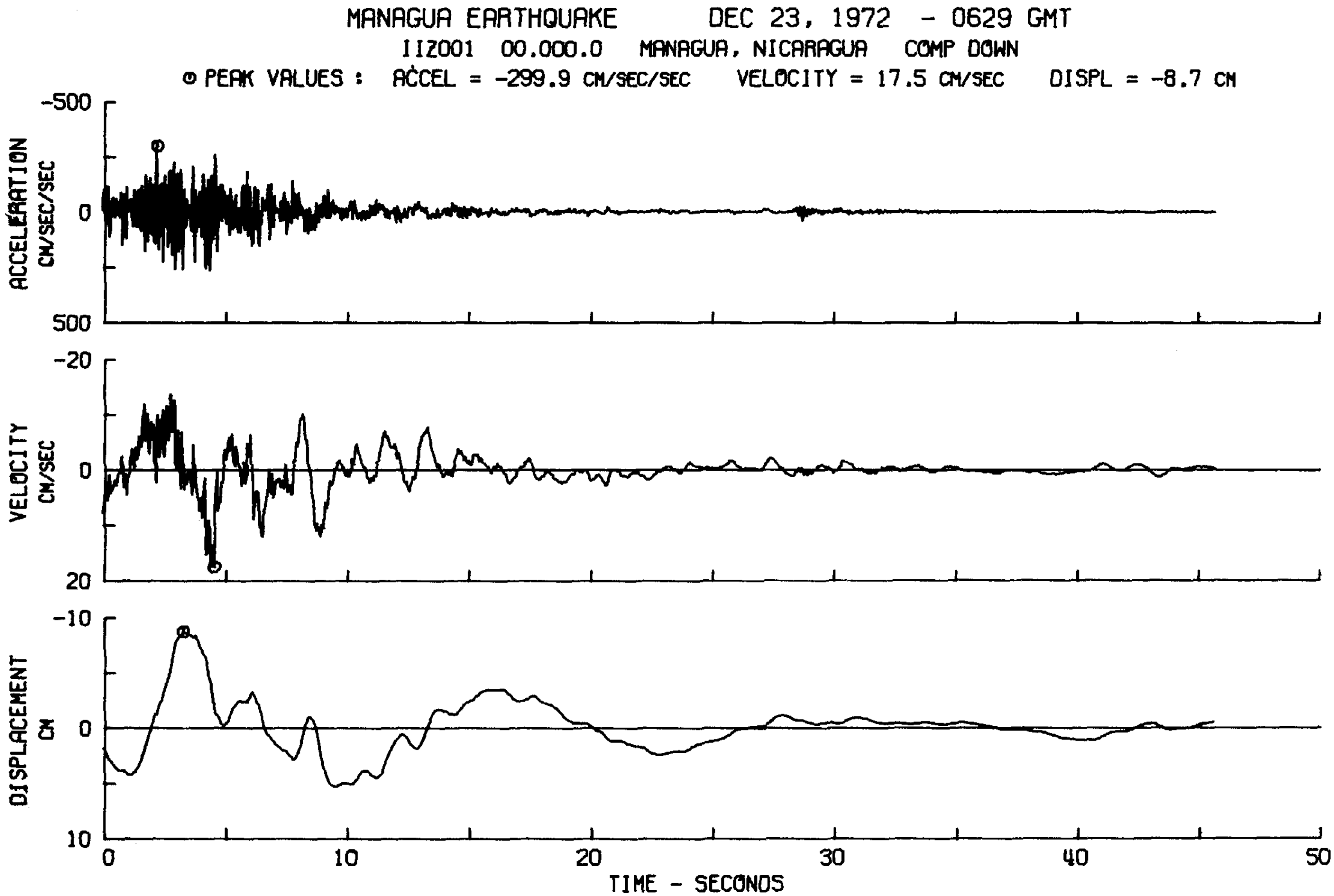


FIGURE II-4c Vertical Component of Corrected Ground Motion Record ESSO Location.

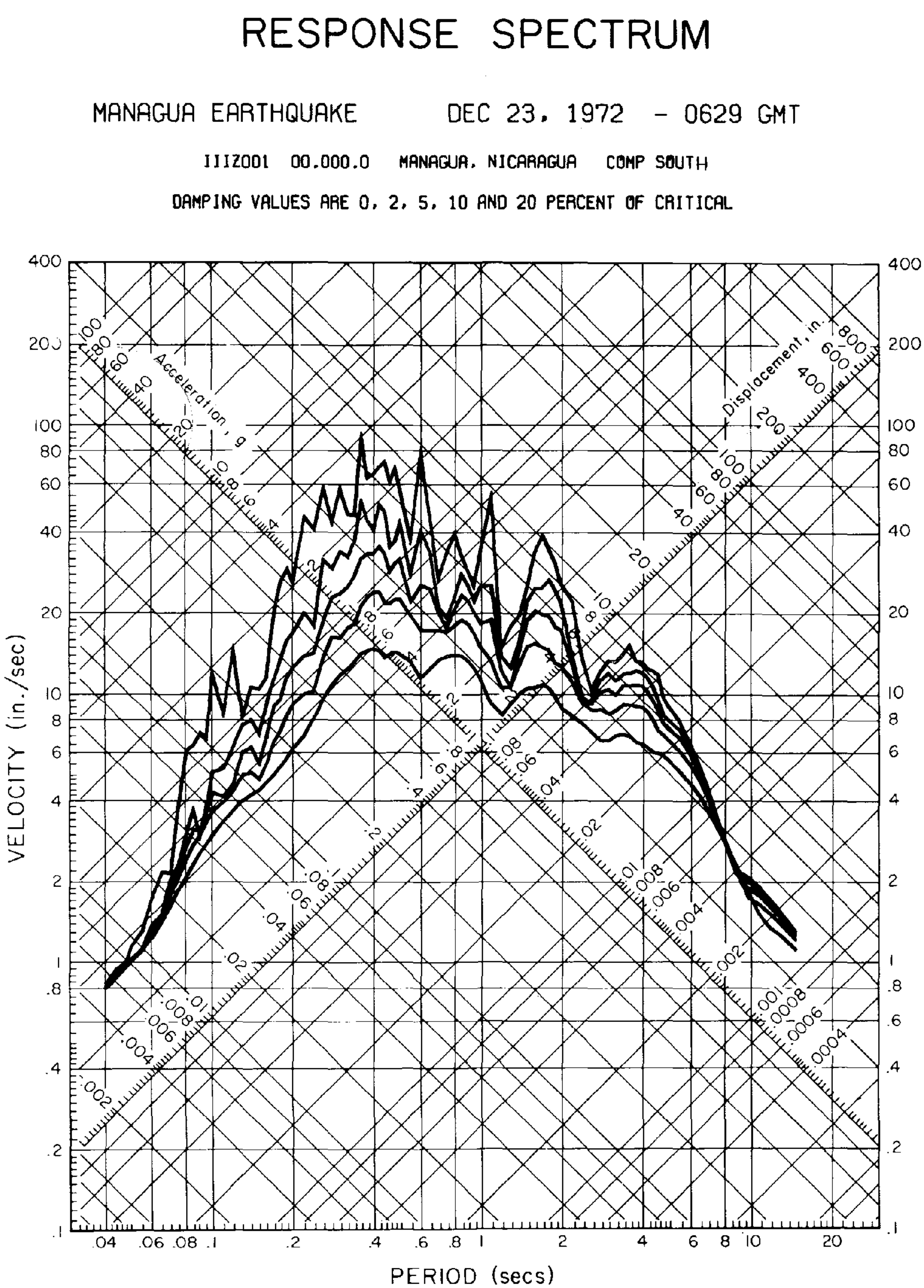


FIGURE II-5a Response Spectra -- North.

# RESPONSE SPECTRUM

MANAGUA EARTHQUAKE DEC 23, 1972 - 0629 GMT

IIIZ001 00.000.0 MANAGUA, NICARAGUA COMP EAST

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

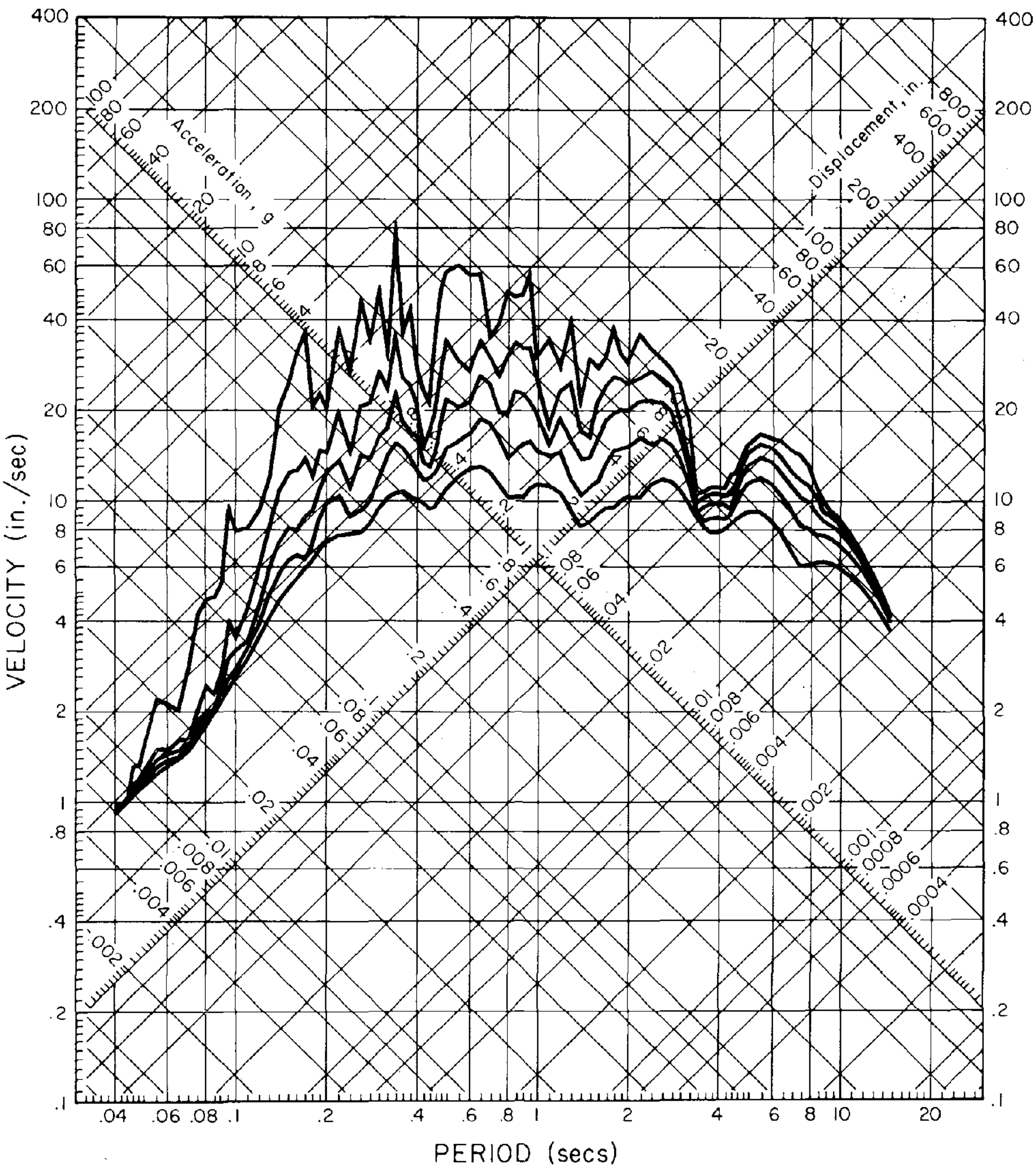


FIGURE II-5b Response Spectra -- East.

# RESPONSE SPECTRUM

MANAGUA EARTHQUAKE DEC 23, 1972 - 0629 GMT

IIIZ001 00.000.0 MANAGUA, NICARAGUA COMP DOWN

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

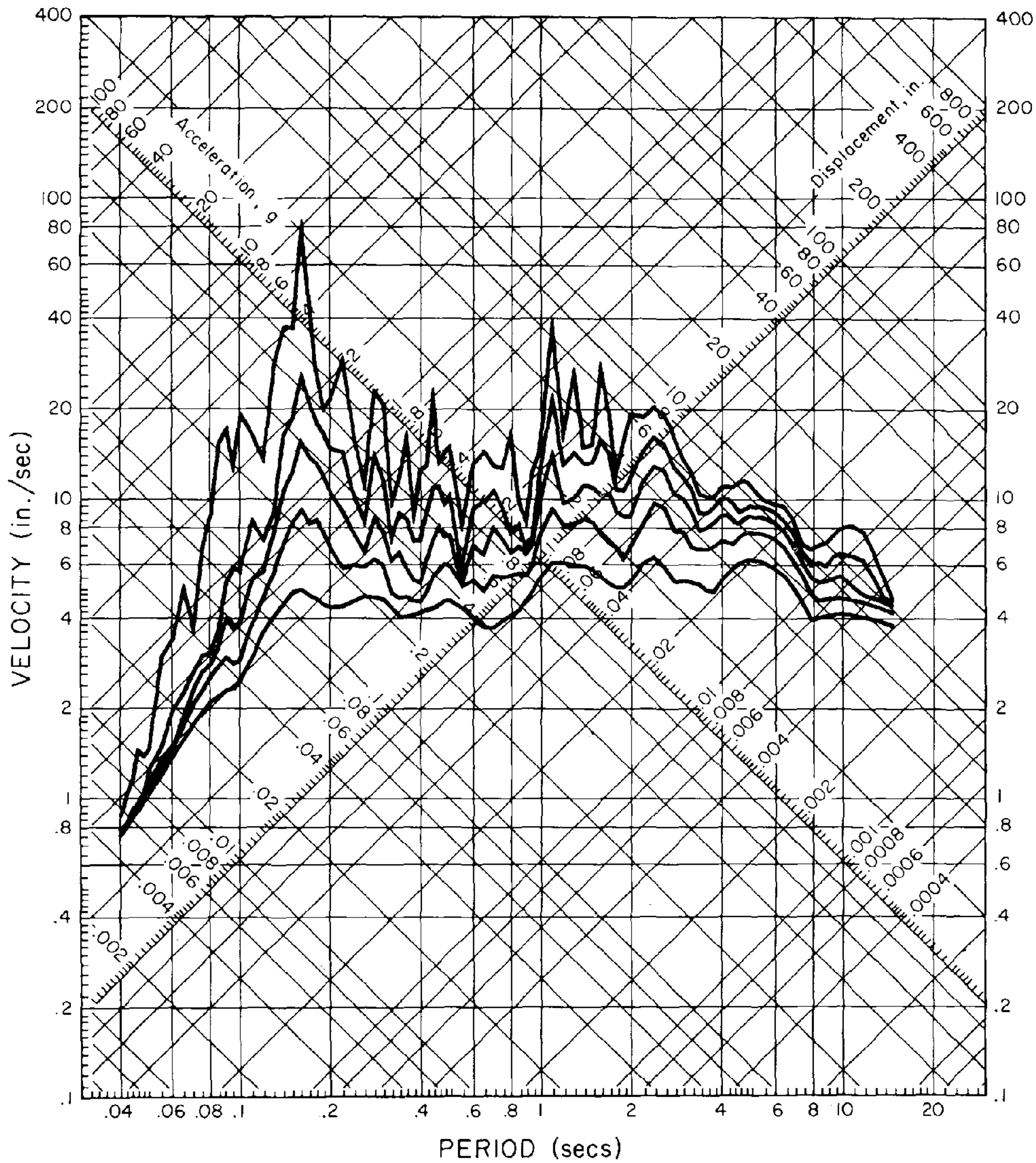


FIGURE II-5c Response Spectra -- Vertical.

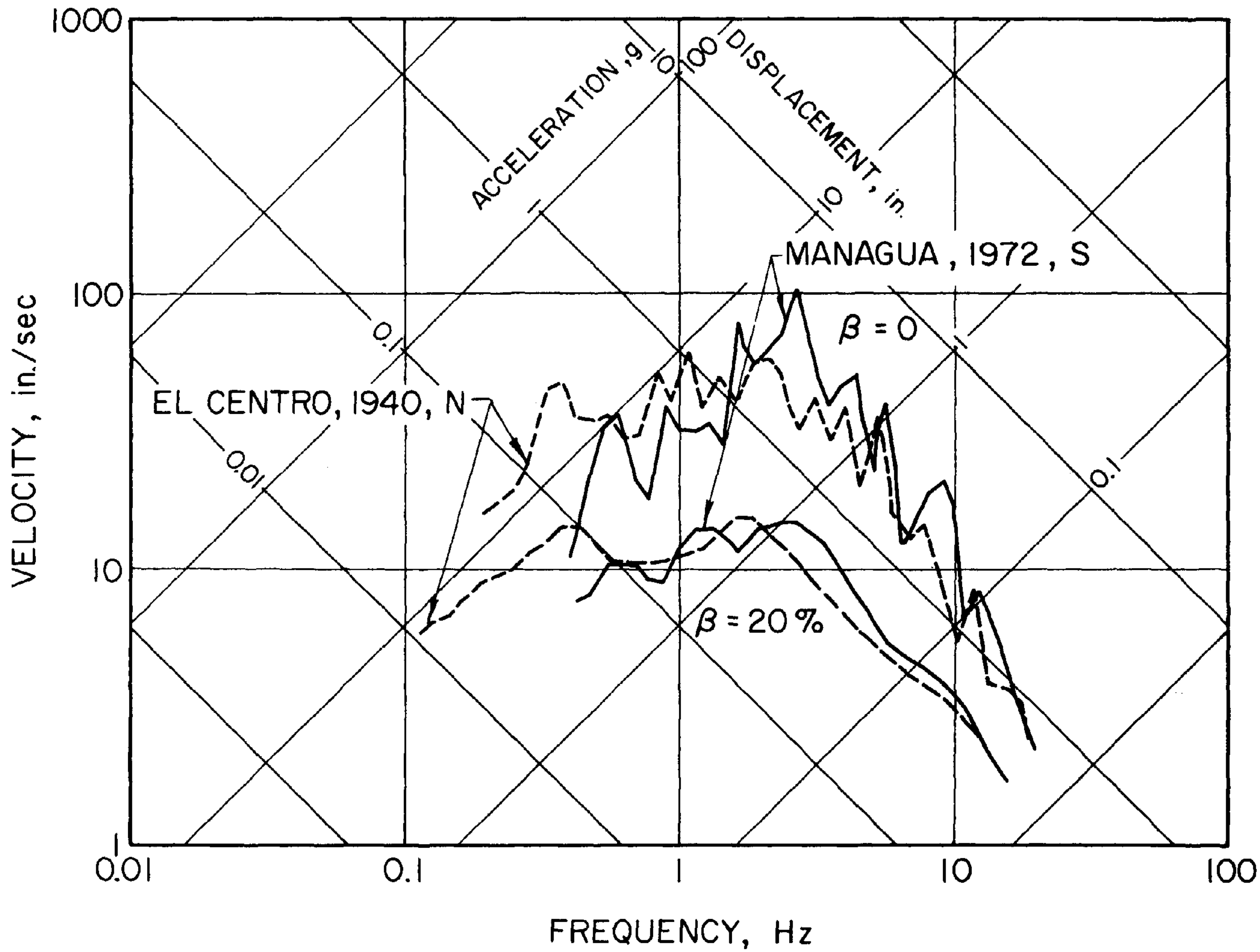


FIGURE II-6a   Comparison of Response Spectra -- El Centro 1940N vs ESSO 1972S.

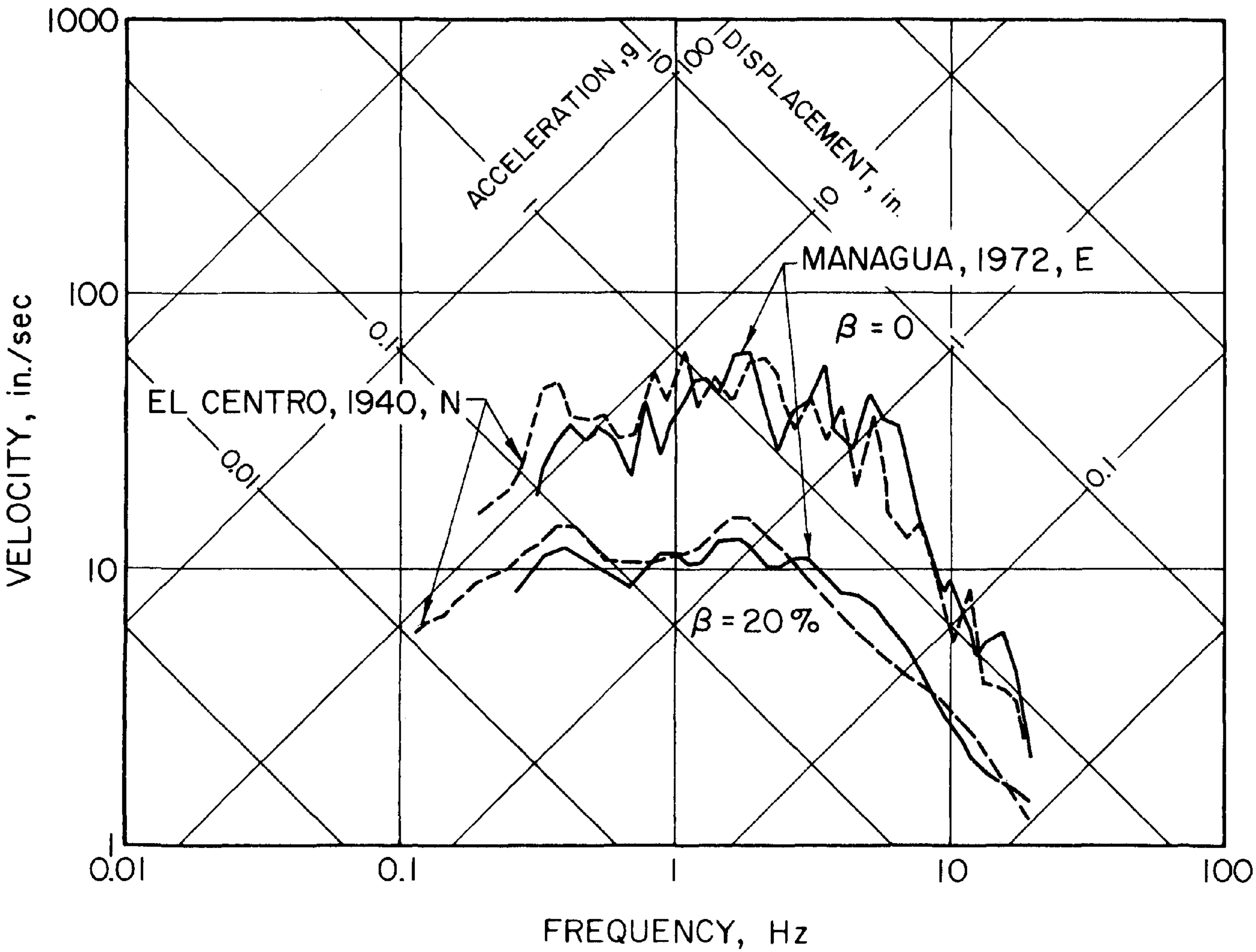


FIGURE II-6b   Comparison of Response Spectra -- El Centro 1940N vs ESSO 1972E.

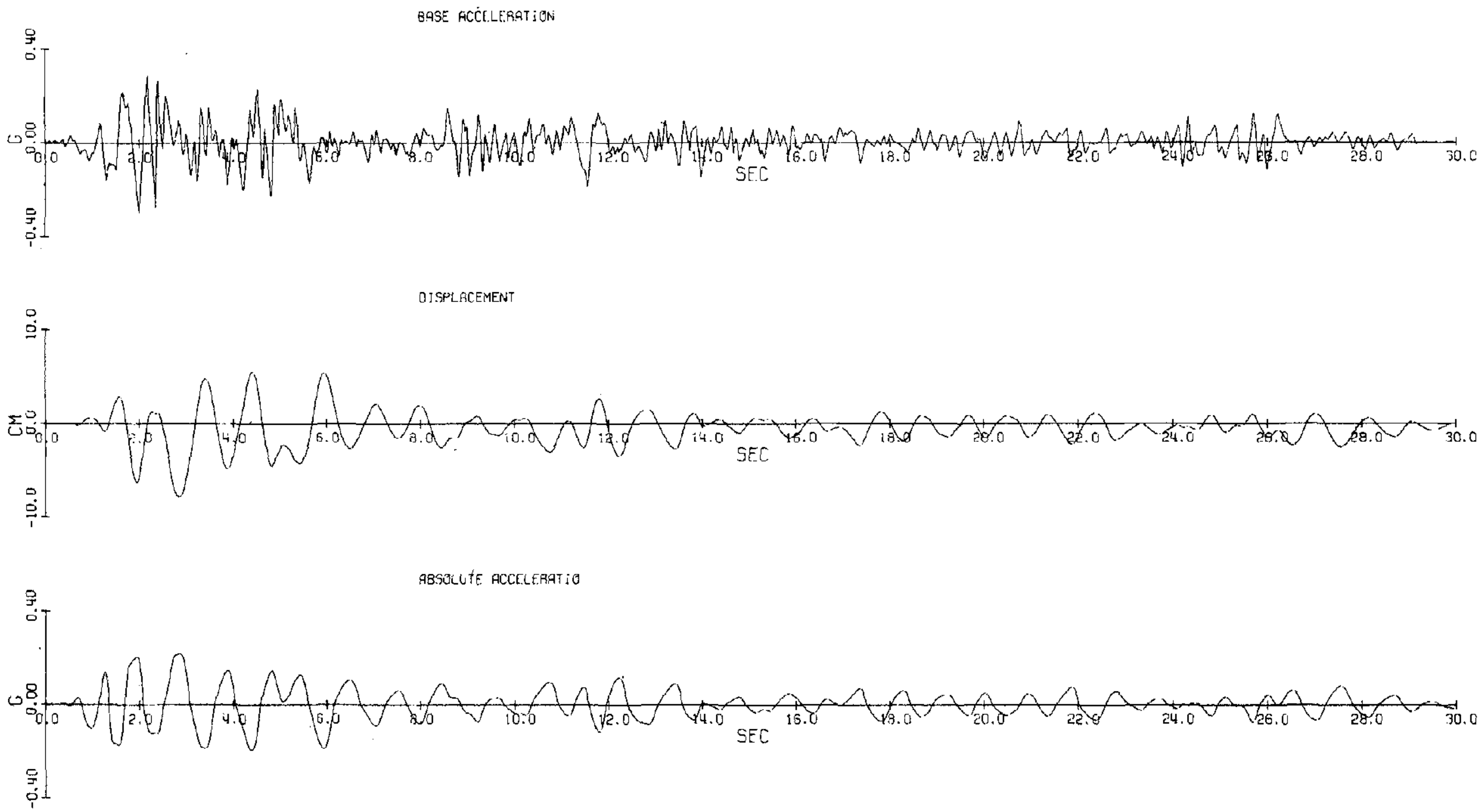


FIGURE II-7a Response History of "Reinforced Concrete" SDF Structure -- Initial period = 0.5 sec., Yield base shear coefficient = 0.16, Ground motion: El Centro 1940N.

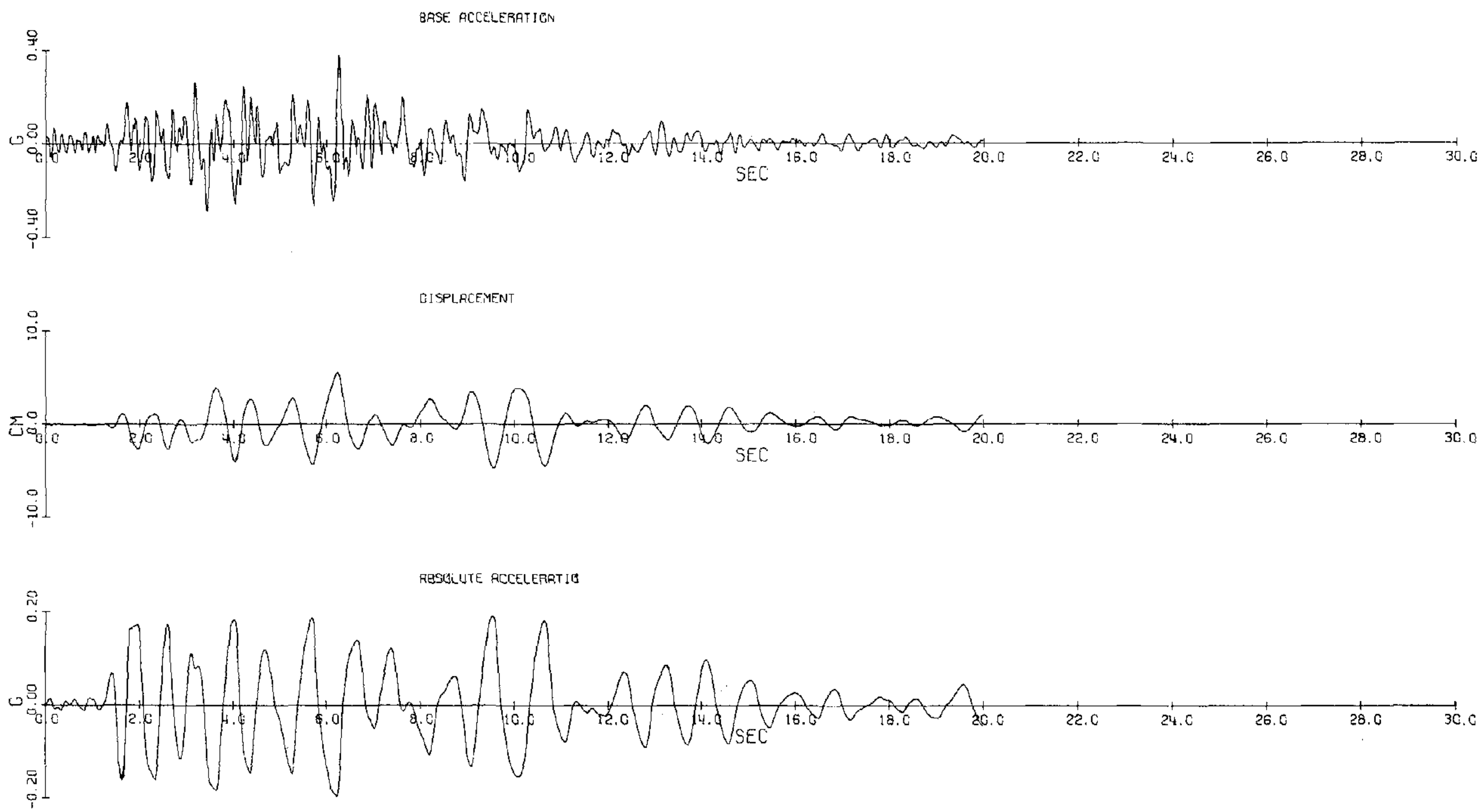


FIGURE II-7b Response History of "Reinforced Concrete" SDF Structure -- Initial period = 0.5 sec., Yield base shear coefficient = 0.16, Ground motion: ESSO 1972E.

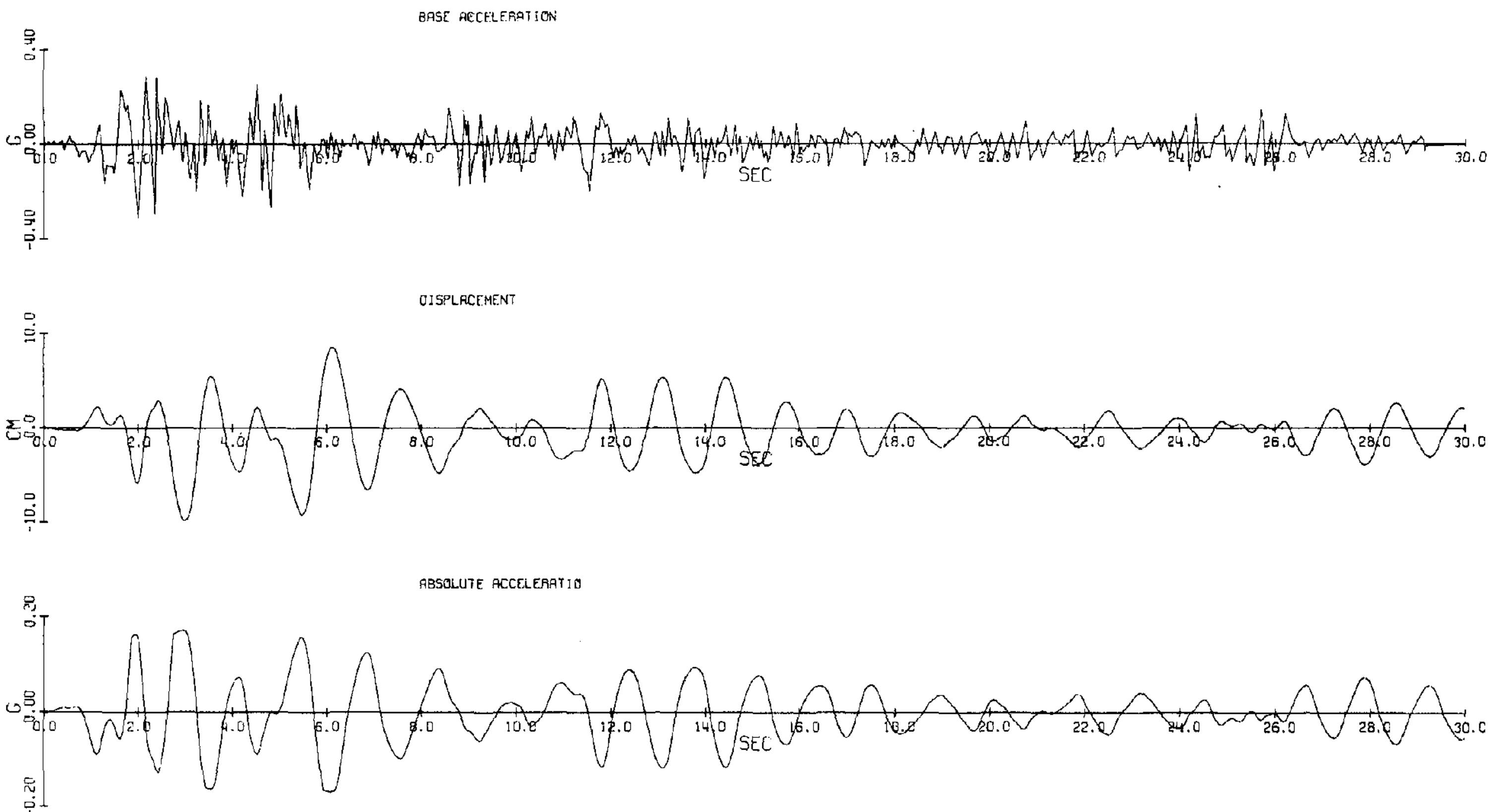


FIGURE II-7c Response History of "Reinforced Concrete" SDF Structure -- Initial period = 1.0 sec., Yield base shear coefficient = 0.16, Ground motion: El Centro 1940N.

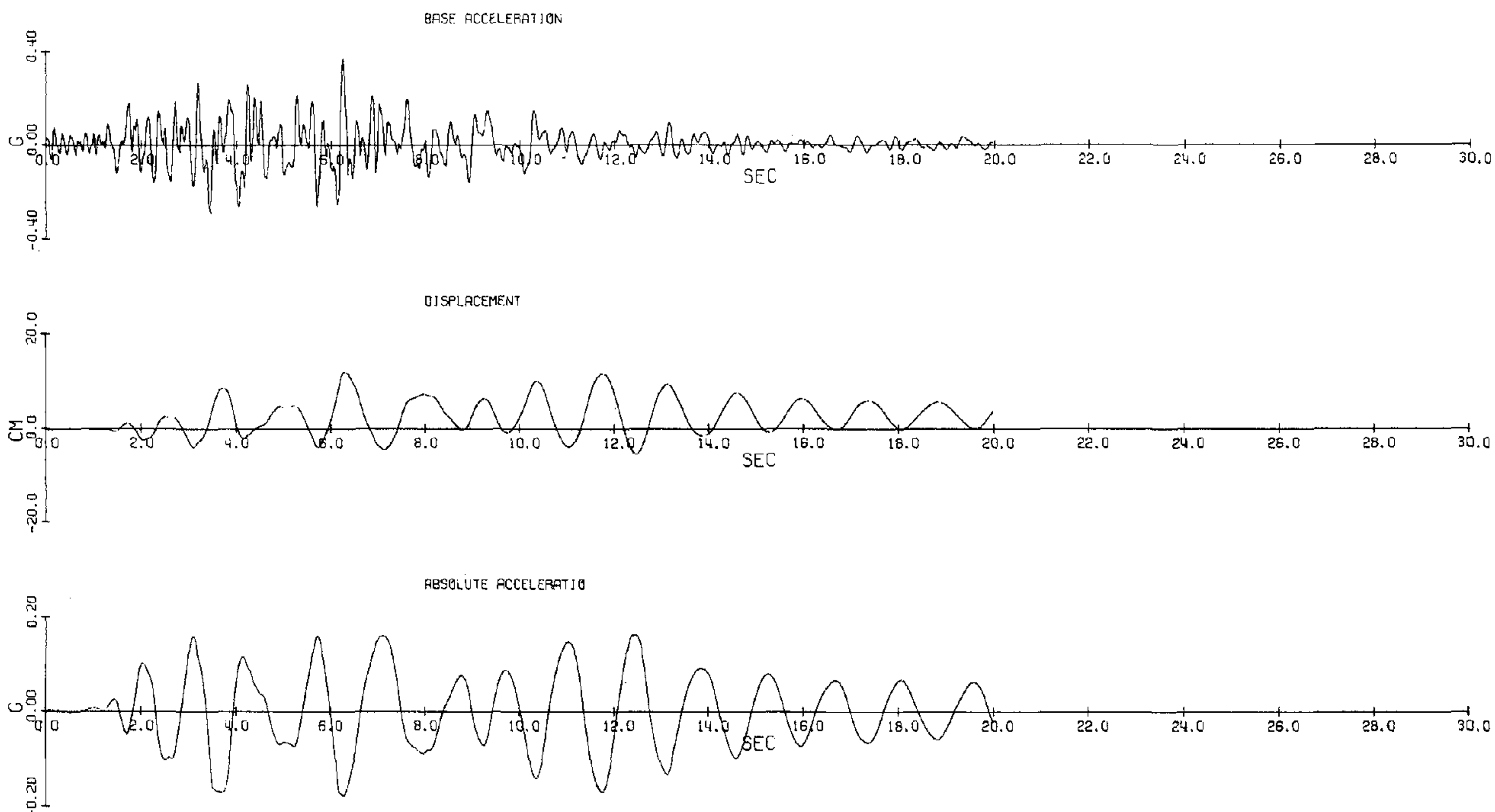


FIGURE II-7d Response History of "Reinforced Concrete" SDF Structure -- Initial period = 1.0 sec., Yield base shear coefficient = 0.16, Ground motion: ESSO 1972E.

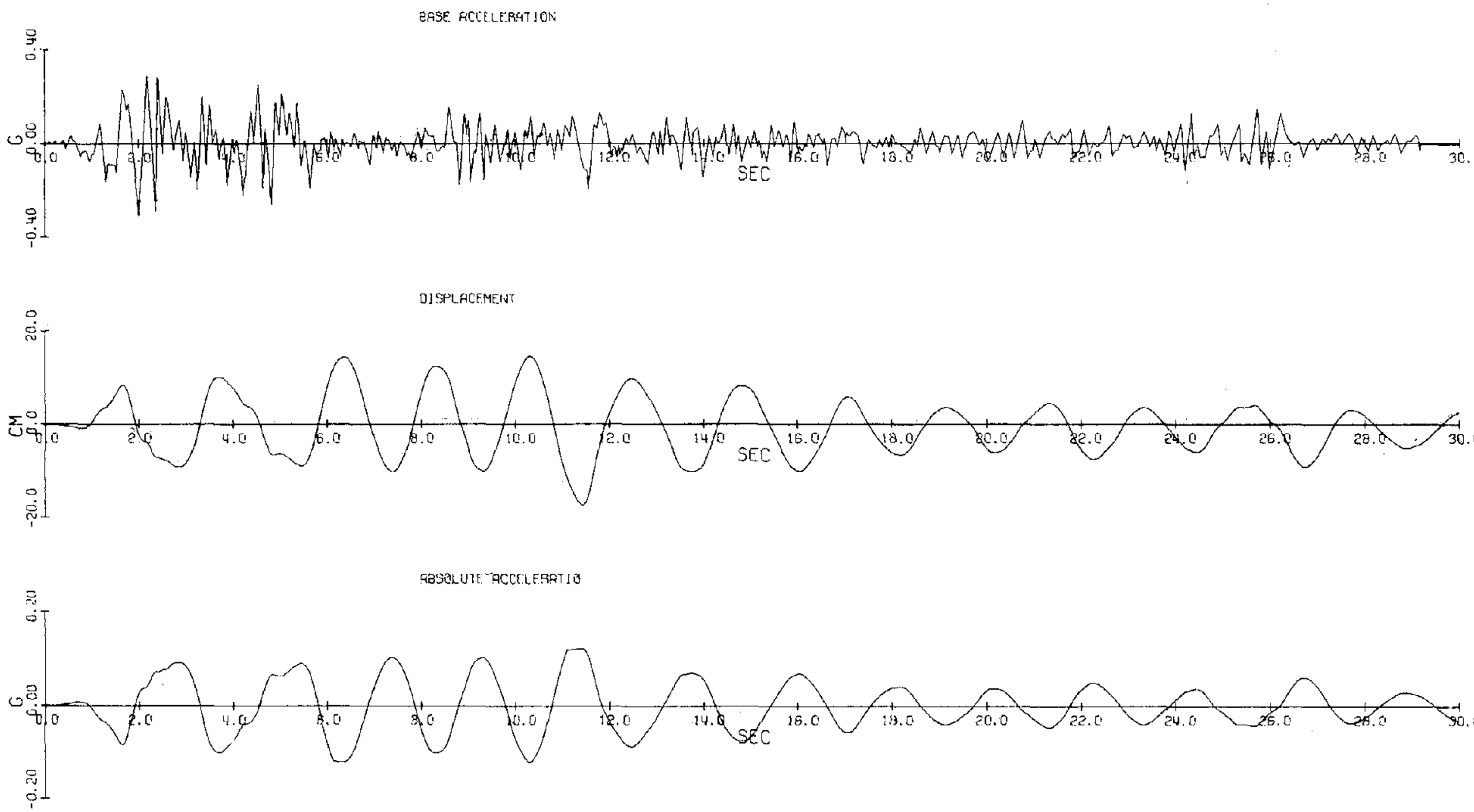


FIGURE II-7e Response History of "Reinforced Concrete" SDF Structure -- Initial period = 2.0 sec., Yield base shear coefficient = 0.12, Ground motion: El Centro 1940N.

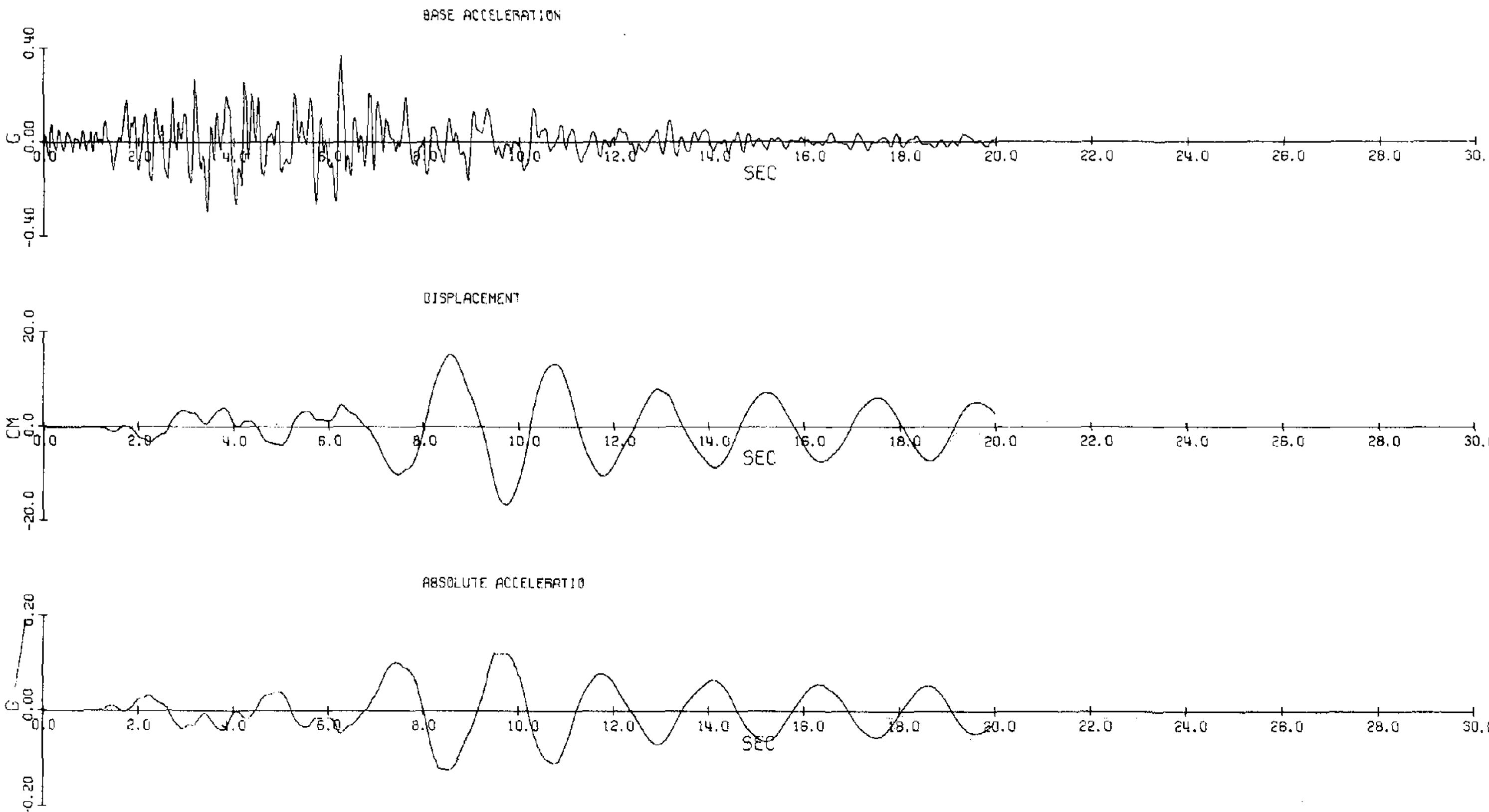


FIGURE II-7f Response History of "Reinforced Concrete" SDF Structure -- Initial period = 2.0 sec., Yield base shear coefficient = 0.12, Ground motion: ESSO 1972E.

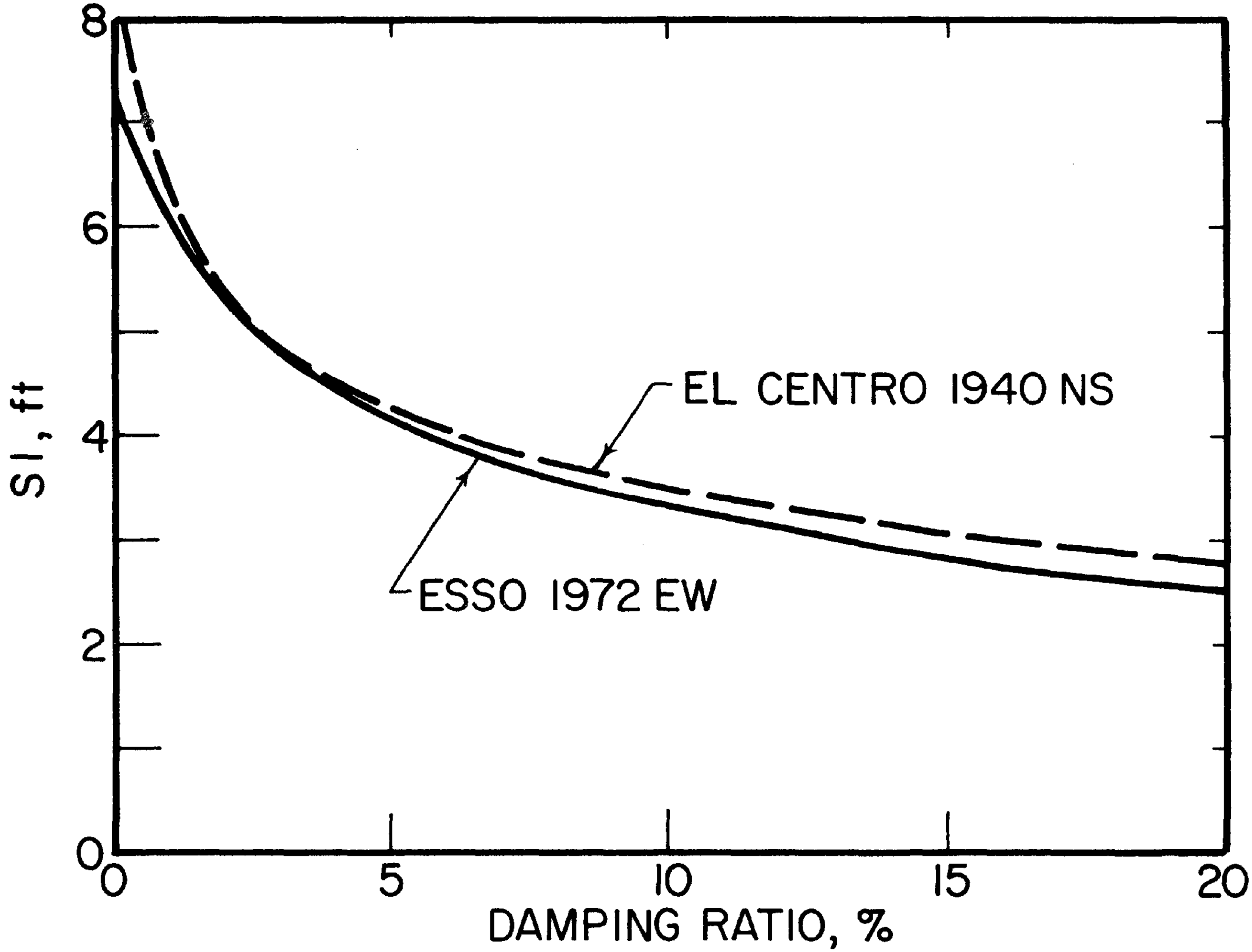


FIGURE II-8a   Comparison of Spectra Intensity for El Centro 1940N vs ESSO 1972E.

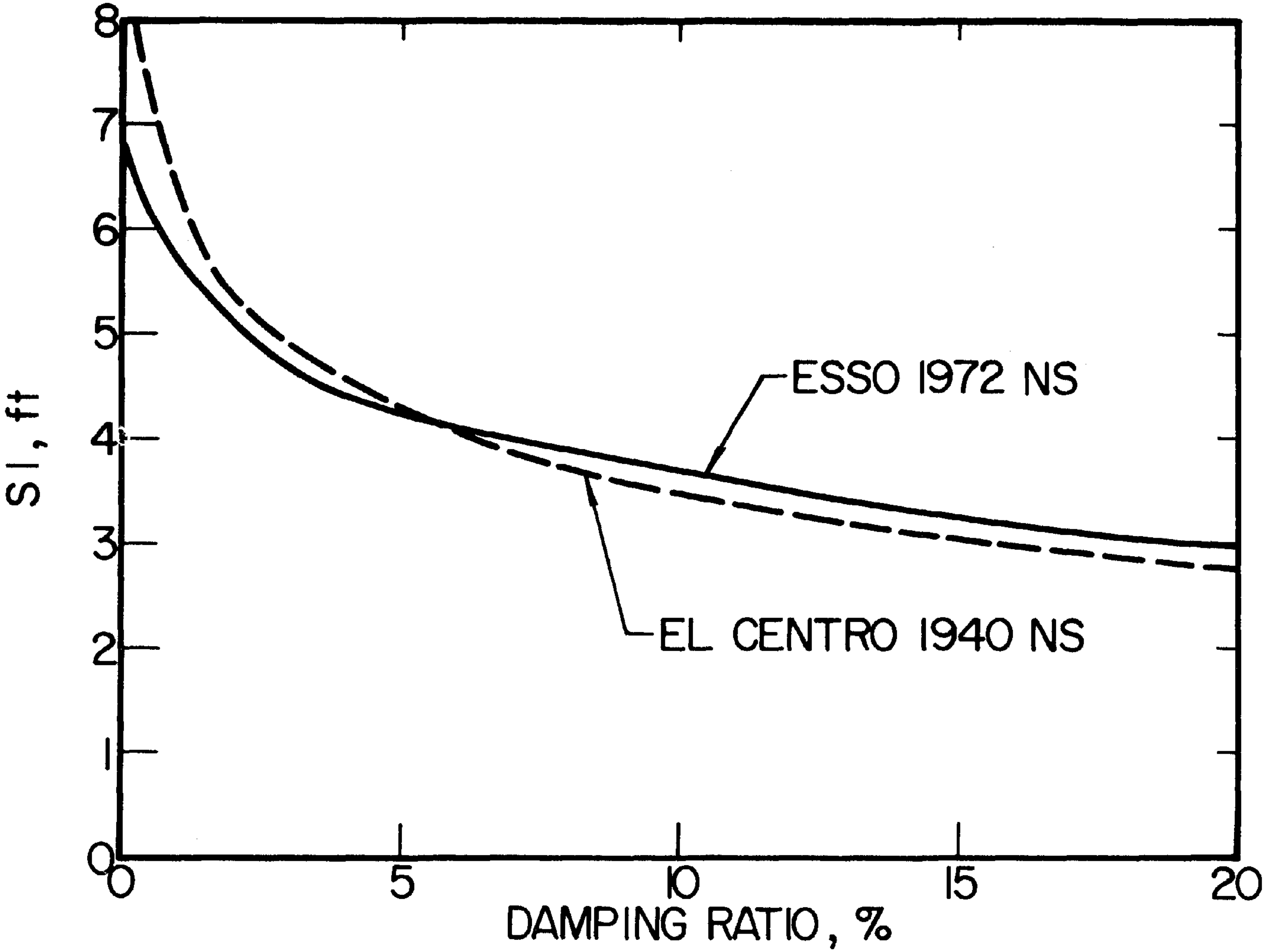


FIGURE II-8b Comparison of Spectra Intensity for El Centro 1940N vs ESSO 1972N.

in downtown Managua. Because this estimate involves knowledge of the "source" location of the main shock, a quantity which can be off by a kilometer or two, and assumes linearly elastic soil properties, it may not be a thoroughly reliable quantity. However, it is not incredible and an index value of 0.5g for the intensity of motion in downtown Managua is acceptable. This would suggest that the motion in Managua, though short lived, would have a structural damage potential larger than that for El Centro 1940.

## Immediate Social Effects of the Earthquake

Soil and economic effects of the earthquake have been discussed in detail by Pereira and Creegan (11). Although the scope of this report is limited to structural damage, it is worthwhile to summarize some of the information they quote in order to provide an overall view of the entire catastrophe.

There has been no reliable information on loss of life, estimated from two to thirty thousand. Credible estimates range around four thousand.

Property damage was estimated to be $700,000,000. To put this figure in perspective, it may be compared with the value of the gross domestic product of the country which was approximately $600,000,000 in 1967 (1).

The severity of the economic impact of the earthquake is reflected in the following data prepared by the Nicaraguan Ministry of Economy.

Estimated 1973 Economic Values vs Averages For Period 1971 - 1972

| | |
|---|---|
| Per Capita Income | 40% |
| Industrial Production | 15% |
| Commerce | 35% |
| Services | 40% |
| Exports | 10% |
| Imports | 20% |

## Structural History

The structural terrain on which a particular earthquake etches its signature depends on the history of the city, the frequency of past earthquakes as well as the economy of the region and the culture of the people. Old cities with continuous histories in seismic regions become palimpsests, the works of man erased by earthquakes and rebuilt, construction changing with repeated destruction, not always improving because of the feebleness of old wisdom confronted with new pressures.

Despite the existence of very old (in New-World terms) cities in Nicaragua and despite the active seismological history of the country, there were overriding factors at work in Managua which eroded popular wisdom and led to the mixed bag of successes and failures.

Managua is even younger than its founding date (middle of the nineteenth century) would imply. Its population expanded rapidly during the last three decades, from approximately 50,000 in the early forties to over 400,000 in the seventies, creating a strong pressure to build rapidly in an environment with little regulation. The catastrophe of 1931, somewhat vague in the memory of the builders of the sixties, had not hurt the local adobe-plus-timber construction which thus had implicit approval. That the impact of the 1931 earthquake was vividly in the professional consciousness was manifest in the design of many of the major buildings. But the triumph of convenience over experience was evident in too large a proportion of construction which had been built with minimum concern for lateral forces.

The ambience in which Managua's builders built is best described by Filadelfo Chamorro (12):

> "Designs were based solely on strength requirements, using ACI or other foreign codes as a reference. Since stiffness was not a design criterion, the general trend was towards slender structures. For earthquake loads, they depended on proven structures, building shapes, or types of construction; on high safety factors; on good workmanship, and perhaps an indiscriminating reliance on their newly learned concrete technology. Seismic forces were used, probably for certain buildings, but not very frequently. Furthermore, since most buildings were low, strong tremors infrequent, and wind loading not a serious problem, lateral loading was not given its due importance. In April 1972, a lateral force code, which was a modified version of the SEOAC code, was enacted into law in Nicaragua but its regulation was never realized."

It appears from the above that the types of construction in the city would defy any effort at a well delineated classification. However, the bulk of Managua's construction can be described in three broad categories according to building height rather than according to function or material.

One- to Two-Story Construction: The dominant medium of construction in this category was taquezal, adobe bricks filling a light timber grillage or framework (Figures 9, 10). With a light roof, this system does present certain advantages in relation to earthquake resistance. Presumably its success during the 1931 earthquake was due to its capability to resist distortion with the help of tensile strength provided by the timber. The general failure of this type of construction in the 1972 event has been attributed to relatively heavy roofs and rotten timber.

Suburban housing typically comprised reinforced masonry or concrete walls with heavy reinforced concrete roof slabs. The weight of the slab was in most cases resisted by the wall area provided, resulting only in cracked walls and displaced slabs. In the case illustrated in Figure 11, lack of adequate bearing surface made the displacement of precast concrete roof slabs a major problem.

This category also included steel industrial shed-type buildings, and one-story factories and warehouses with heavy concrete shell roofs. The latter type sustained severe damage in almost every instance.

Two- to Five-Story Construction: Nonenforcement of building regulations showed itself most emphatically in this category for which the dominant construction medium was reinforced concrete. The range of actual base shear strength coefficient (shear strength/weight of building) was wide. On one end of the scale were institutional buildings (Figures 12 and 13), heavy but with considerable wall area. On the other end of the scale were relatively light but vulnerable modern buildings (Figure 14).

Medium-Rise Construction: Managua has several reinforced concrete buildings in the six- to nine-story range and two major bank buildings. These were uniformly well designed and built. Examples are shown in Figures 15 through 21.

An idea of the distribution of the categories listed above can be obtained from Figures 22 and 23 which show the central part of the city.

## Structural Damage Distribution

A series of photographs taken before and after the earthquake provide a visual record of the intensity of the damage (Figures 24-39).

Assessment of the intensity level distributions by two groups (6, 13) are summarized in Figure 40. Considering the subjectivity of the evaluation, the agreement between the two is very good and in conformity with the location of the hypocenter based on instrumental data.

# IMPRESSIONS OF STRUCTURAL DAMAGE

There have been various detailed structural analyses of some of the notable structures in Managua (15-19). To avoid reprise as much as possible, this report will confine itself to overall impressions and implications of the structural damage. What Managua emphasized in relation to structural design may be discussed in the following topical categories:

## Design vs Nondesign

There was a small but notable group of low- to moderate-rise structures in Managua. These were designed and constructed more or less in accordance with the modern principles of design also used on the West Coast of the United States. Examples are the Intercontinental Hotel (Figure 15), the Enaluf Building (Figure 16), LaProtectora Building (Figure 17), the INSS Building (Figure 18), the two bank buildings (Figure 20), and several others. Most of these were reasonably light structures with much of the lateral structural resistance derived from structural elements.

Glossing over specific details of failures and accepting that the ground motion experienced in town was that corresponding to a great earthquake, the overall performance of these buildings demonstrated first that the current design procedures did produce the intended performance (whether the intended performance was always desirable is another question) and second that the current design procedures are likely to minimize casualties. The generally positive performance of these buildings is further underlined by the catastrophic events which occurred in buildings which had not been designed to resist earthquakes.

In a city with a severe earthquake history, the very existence of buildings not designed to resist earthquakes leads to the conclusion that society must enforce minimum lateral strength requirements in seismic regions. No matter how enlightened the professional community, economic pressures force some builders to take unnecessary and intolerable risks. The existence of buildings not designed to resist earthquakes in such a highly active seismic region cannot be assumed to be a local problem.

The recommendation by Freeman reproduced in Figure 41 (14) apparently went unheeded. The post-1931 U.S. Embassy building is the two-story (before the earthquake) structure with a heavy list, in the left middle portion of Figure 17a.

## Shear Walls vs Frames

There were several generally comparable buildings in Managua in some of which the structural resistance was provided substantially by shear walls and in some substantially by frames. Furthermore, in contrast to what usually happens in buildings, the frame was not stiffened by nonstructural elements.

The major example derives from the relative performance of the buildings for the Banco Central and the Banco de America (Figures 20, 21 and Figures 42-49). As shown in the figures, the lateral resistance for Banco de America was provided primarily by four shear cores whereas the lateral resistance for Banco Central was provided primarily by frame action. Both buildings survived the earthquake with some damage (8, 15, and 16). However, the interior of Banco Central was in shambles while the interior of Banco de America was virtually intact.

Another comparison is provided by the Enaluf Building in contrast to two others, the LaProtectora Building (Figure 17) and the INSS Building (Figures 18 and 19).

As indicated by the column and shear wall layout in Figure 16b, the Enaluf Building utilized a frame in addition to a shear core. The other two buildings relied on the frame. The same phenomenon was repeated. Despite some local failures around openings in the shear core of the Enaluf Building, the contents of the building were in good shape after the earthquake. The other two buildings had severe damage to nonstructural components and contents as well as some structural damage.

The examples which occurred in Managua are not by themselves the final answer to the decision that the structural designer must make about the relative desirability of frames and shear walls. One may not conclude categorically from the evidence observed on behalf of the shear wall and against the frame. But there is no question about the fact that the observations cast serious doubt on the current fixation with the ductile frame.

## Vital Services

The main shock of December 23, 1972, crippled Managua's fire fighting force (Figure 49), its hospitals (Figures 50-53) and most of its communication and power systems. These critical events emphasize the obvious. Vital services must be designed to survive the credible earthquake.

## Interaction of Structural and Nonstructural Elements

As in the aftermath of other earthquakes, Managua provided many examples of the antipathetic symbiosis of structural and nonstructural elements (Figures 54-57). The construction in Figure 57 is an interesting example in that the nonstructural wall "saved" the frame to the third level. Above the third level, the frame was severely damaged because the joints had to work, a requirement eliminated by the wall below that level. Figures 54 through 56 show various examples of captive columns.

## Emergency Exits

One of the subtle phenomena observed in the Banco Central Building was the jamming of emergency exits. A building with a flexible structural system is not likely to return to its original geometry after a damaging earthquake and it takes little distortion to jam a stiff door. Had the earthquake been followed by a fire, the jamming of these exits during working hours, with the elevator system inoperative, would have been catastrophic.

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FIGURE II-9a Taquezal Construction.


FIGURE II-9b   Taquezal Construction.

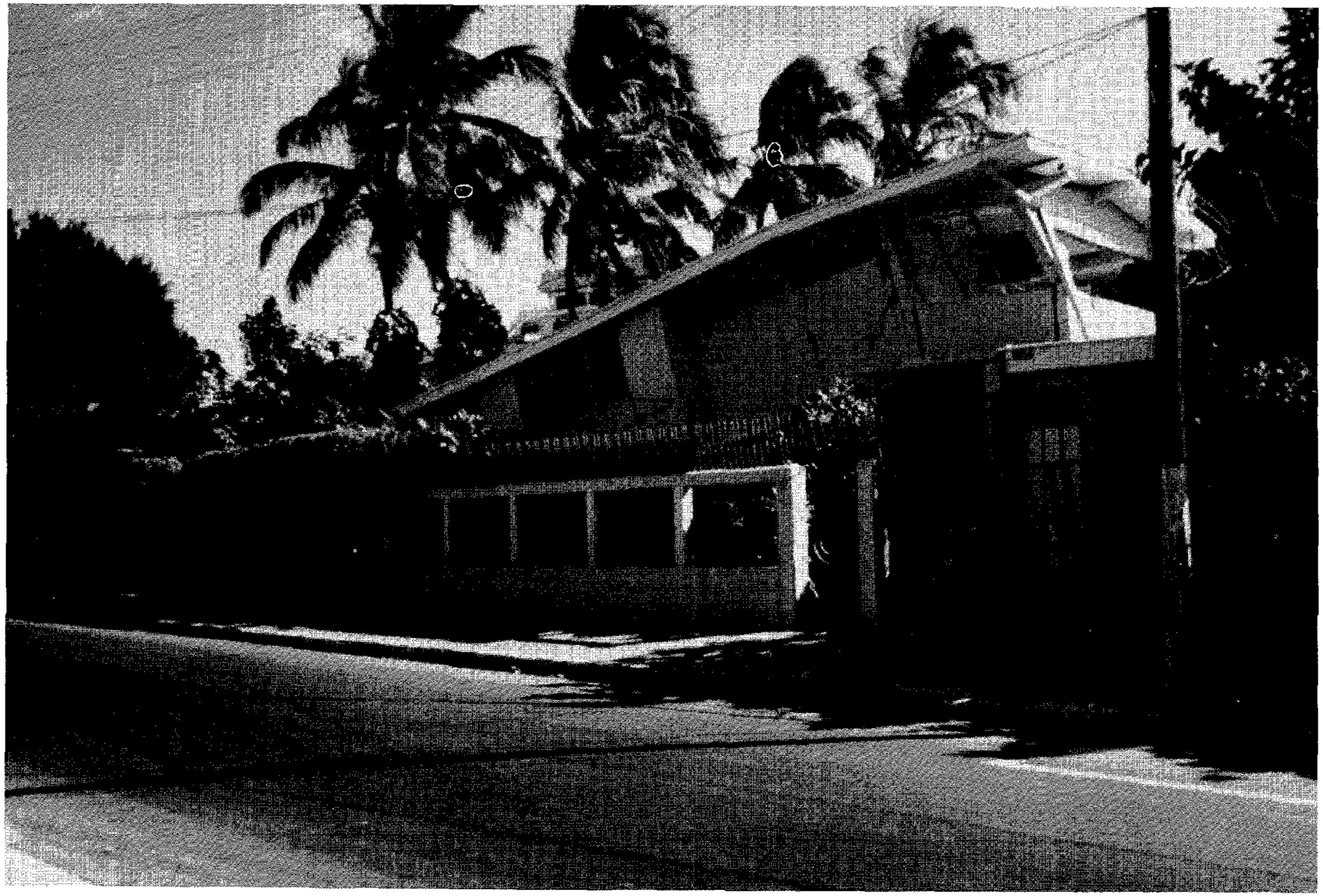


FIGURE II-10 Modern Taquezal.

FIGURE II-11 Precast Concrete Roof.


FIGURE II-12 National Palace.

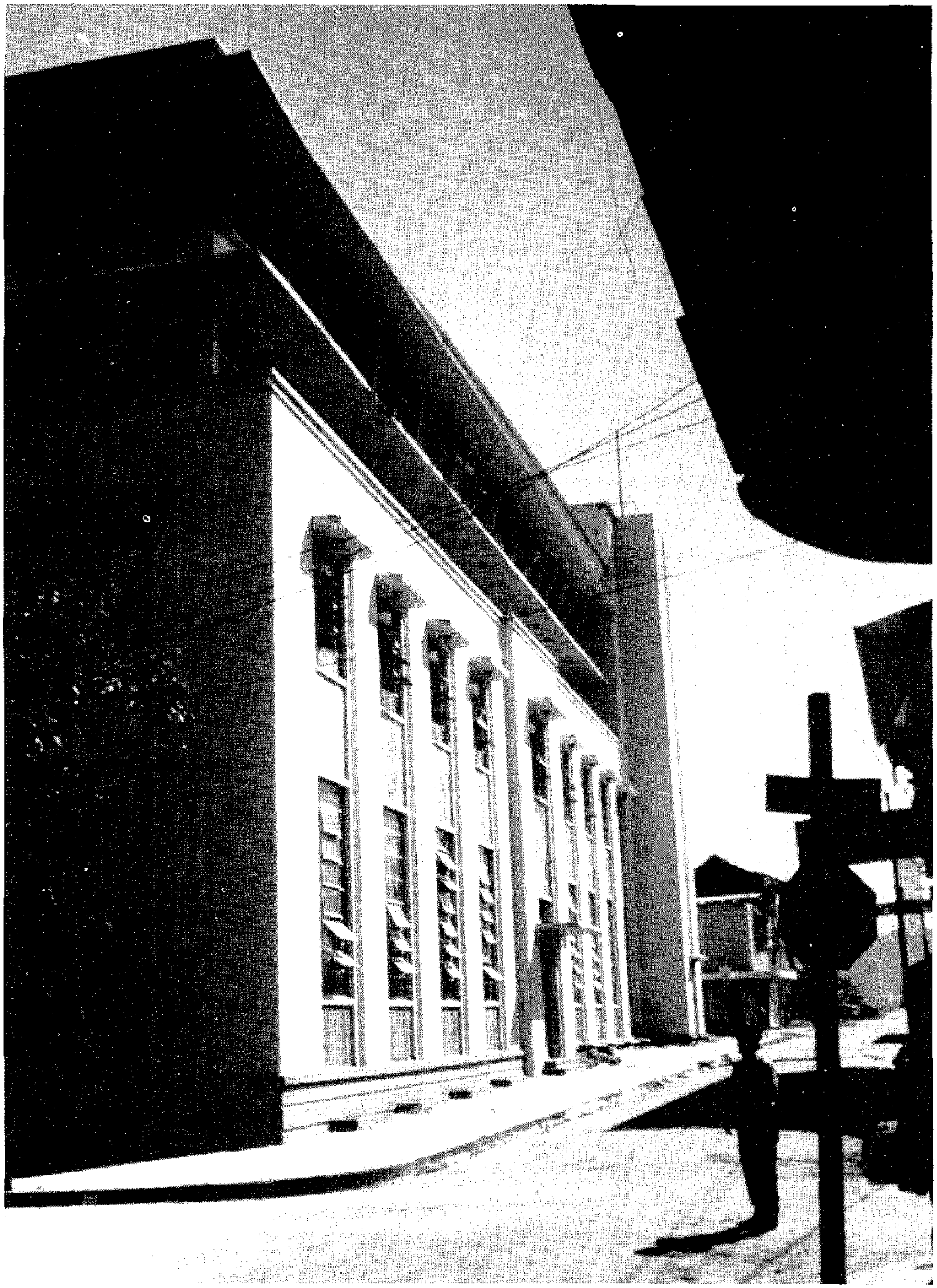


FIGURE II-13 Communications Building.

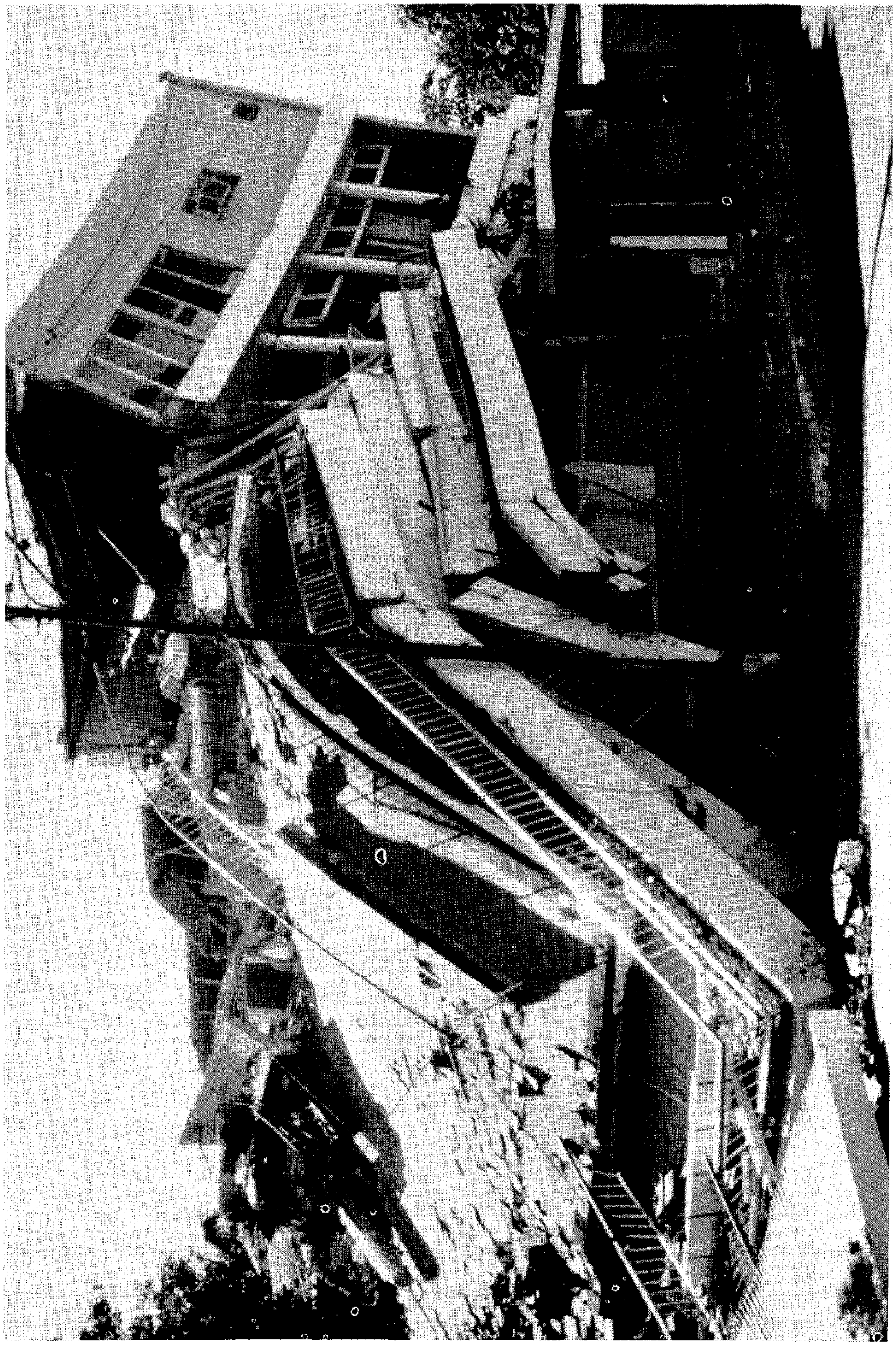


FIGURE II-14a  Guerrero Pineda Building.

FIGURE II-14b   Guerrero Pineda Building.

FIGURE II-15 Intercontinental Hotel.

FIGURE II-16a ENALUF (Light and Power) Building.

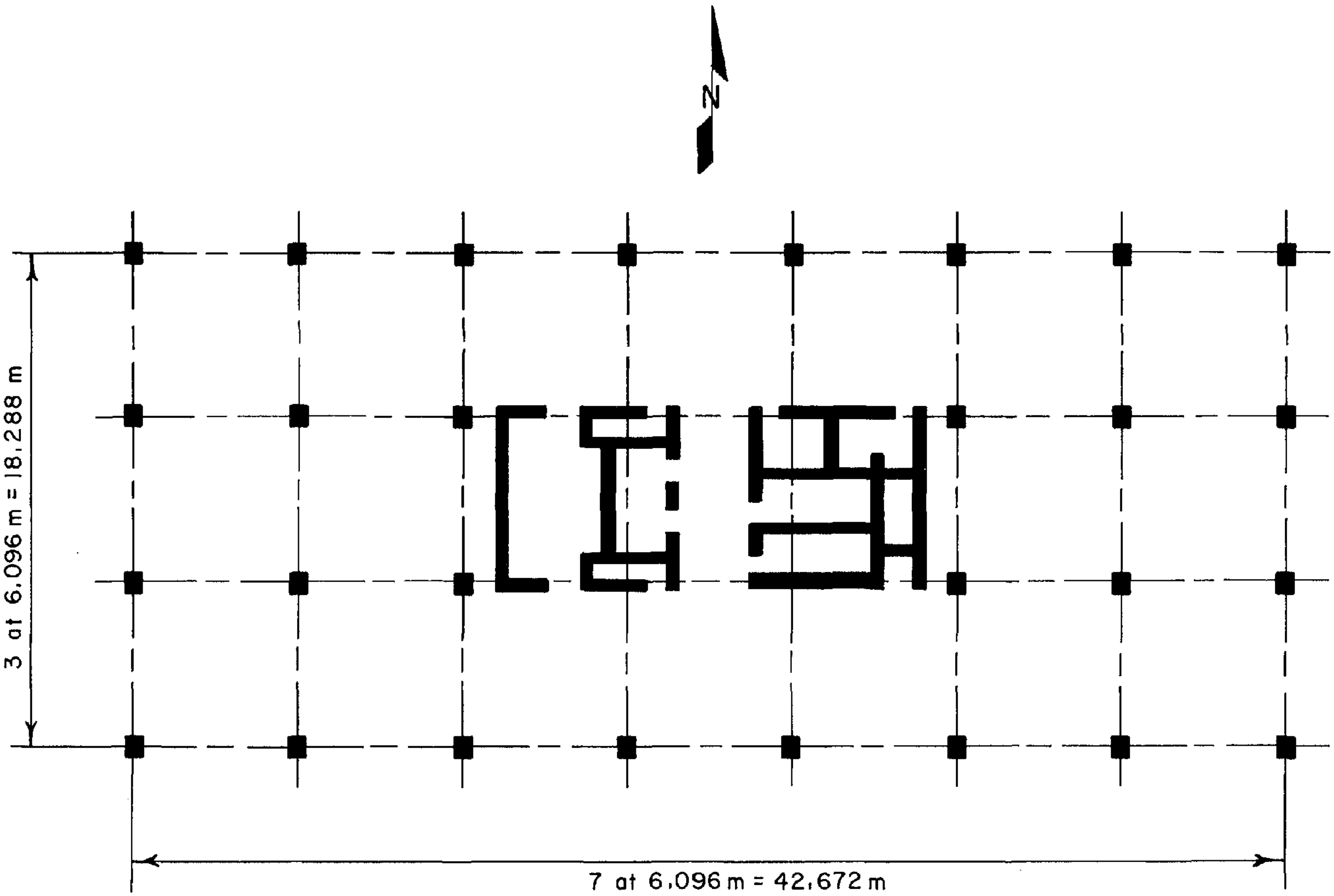



FIGURE II-16b ENALUF (Light and Power) Building -- Column and Shear Wall Layout.

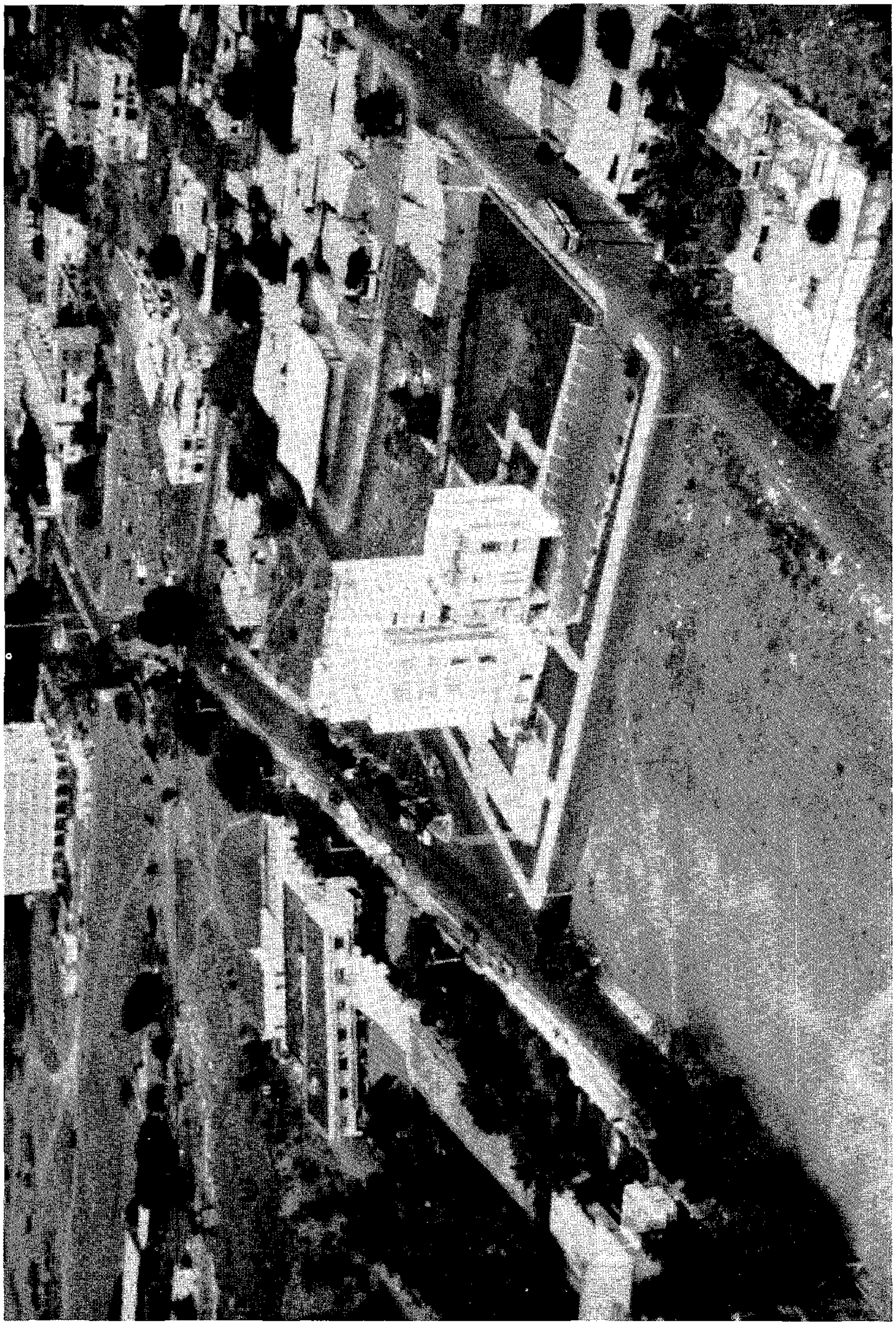


FIGURE II-17a La Protectora Building.

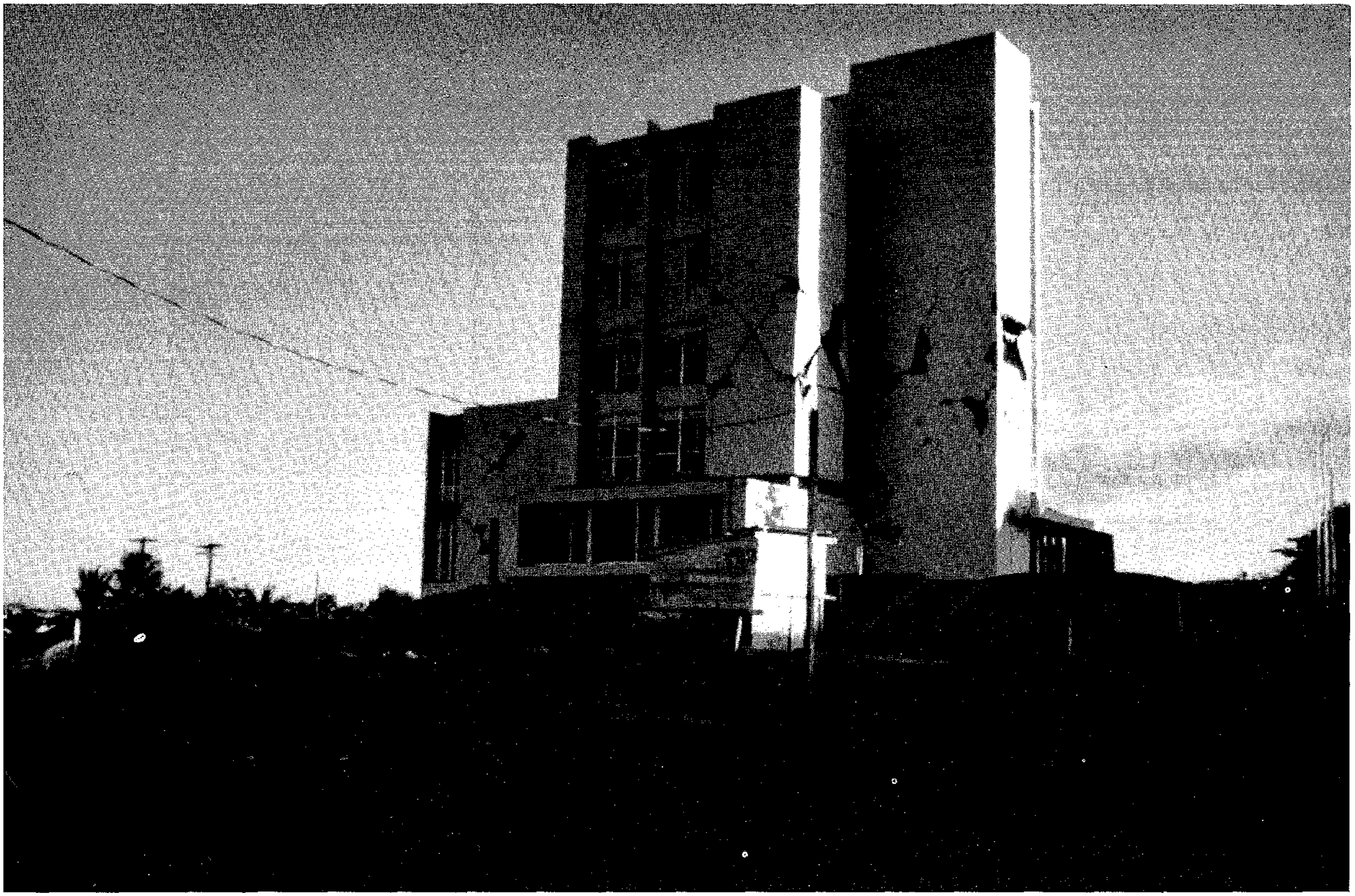


FIGURE II-17b La Protectora Building.

FIGURE II-18 Social Security Institute Building After Earthquake.

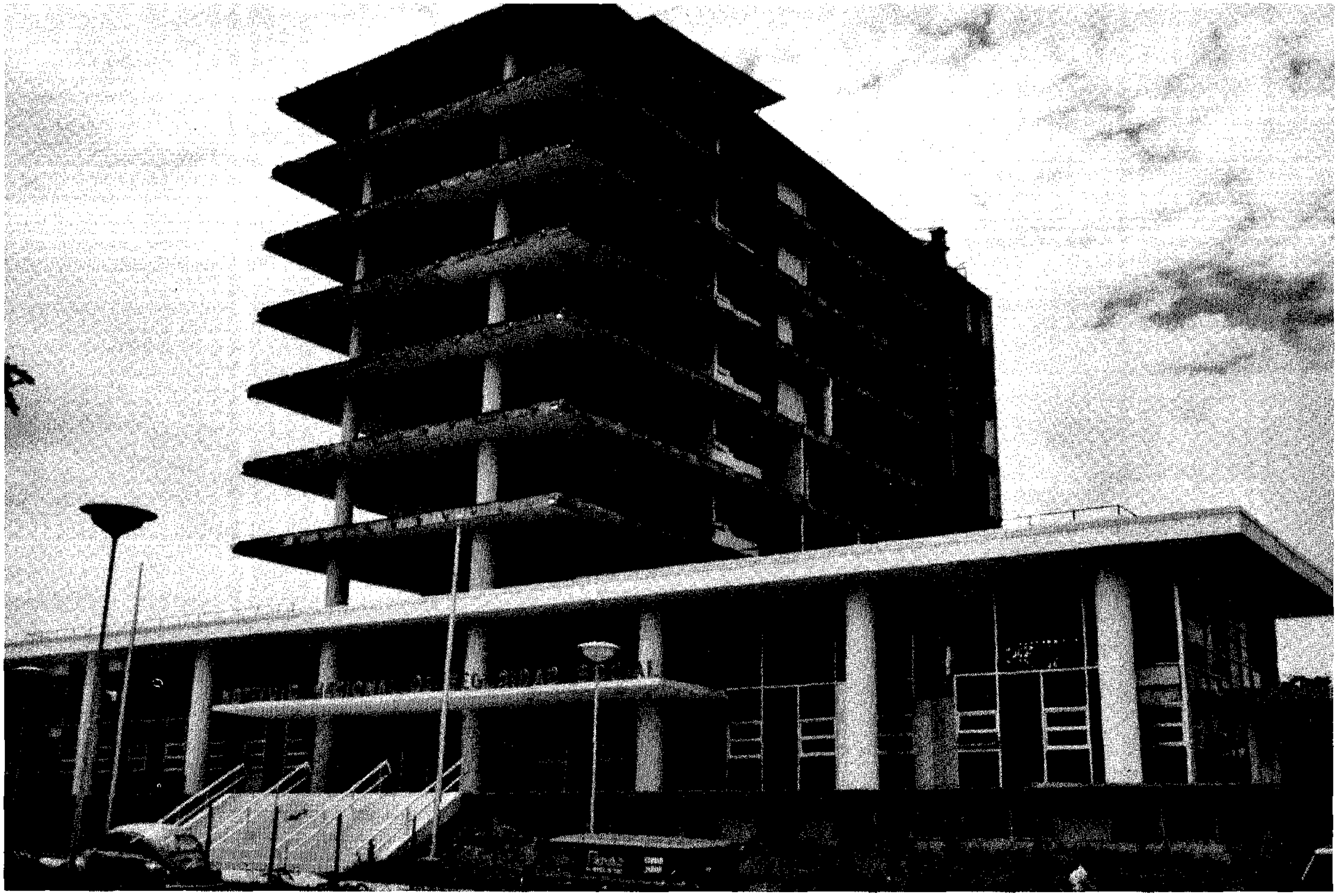


FIGURE II-19 . Social Security Institute Building After Removal of Non-structural Elements.

FIGURE II-20 Banco Central and Banco de America Buildings, Looking North.

FIGURE II-21 Banco Central and Banco de America Buildings, Looking East.

FIGURE II-22 Downtown Managua, Looking North.

FIGURE II-23 Managua, Looking South.

FIGURE II-24   View Before Earthquake, Looking North from Banco de America Building.

FIGURE II-25 View After Earthquake, Looking North from Banco de America Building.

FIGURE II-26 View Before Earthquake, Looking N-N-E from Banco de America Building.

FIGURE II-27 View After Earthquake, Looking N-N-E from Banco de America Building.

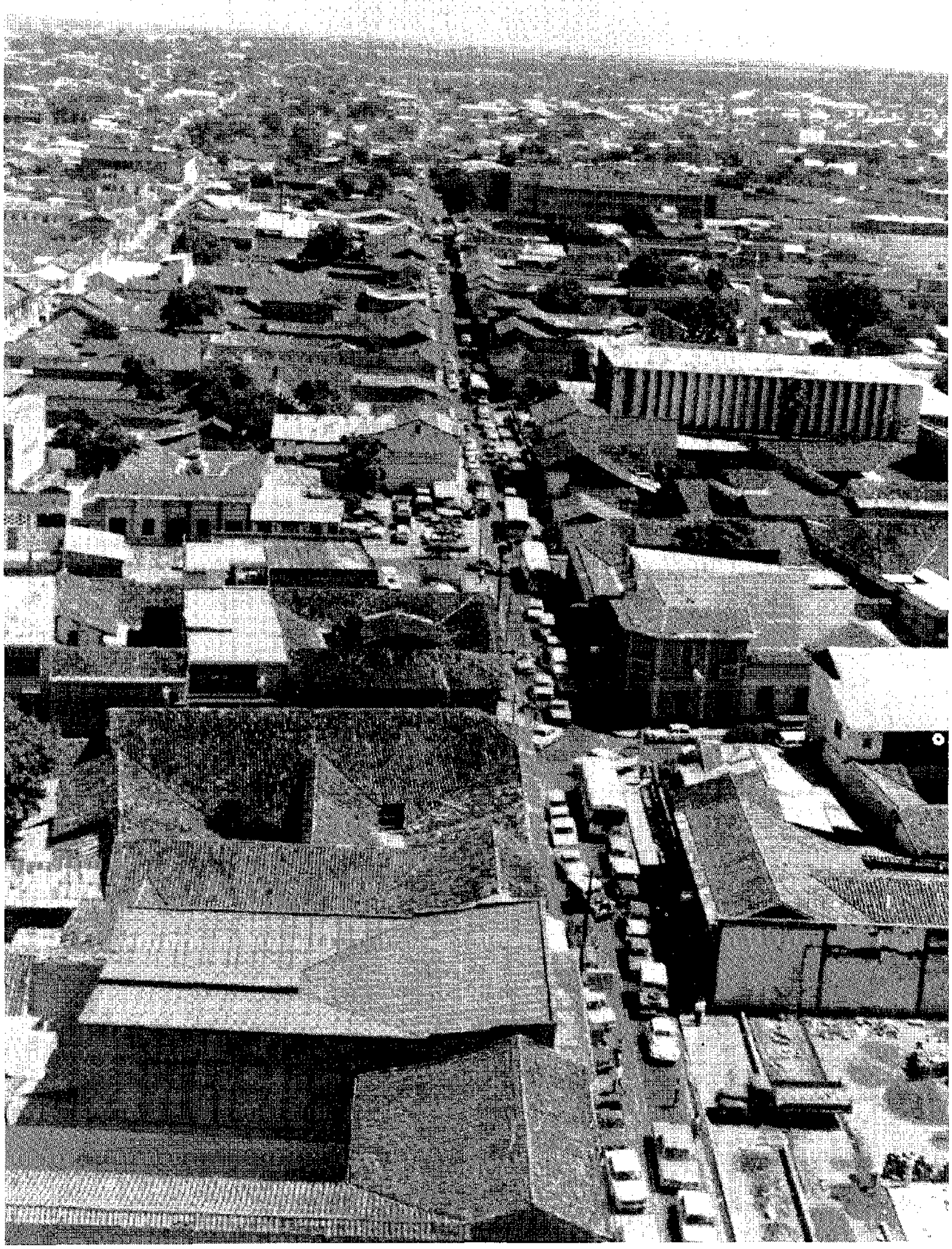


FIGURE II-28 View Before Earthquake, Looking East from Banco de America Building.

FIGURE II-29 View After Earthquake, Looking East from Banco de America Building.

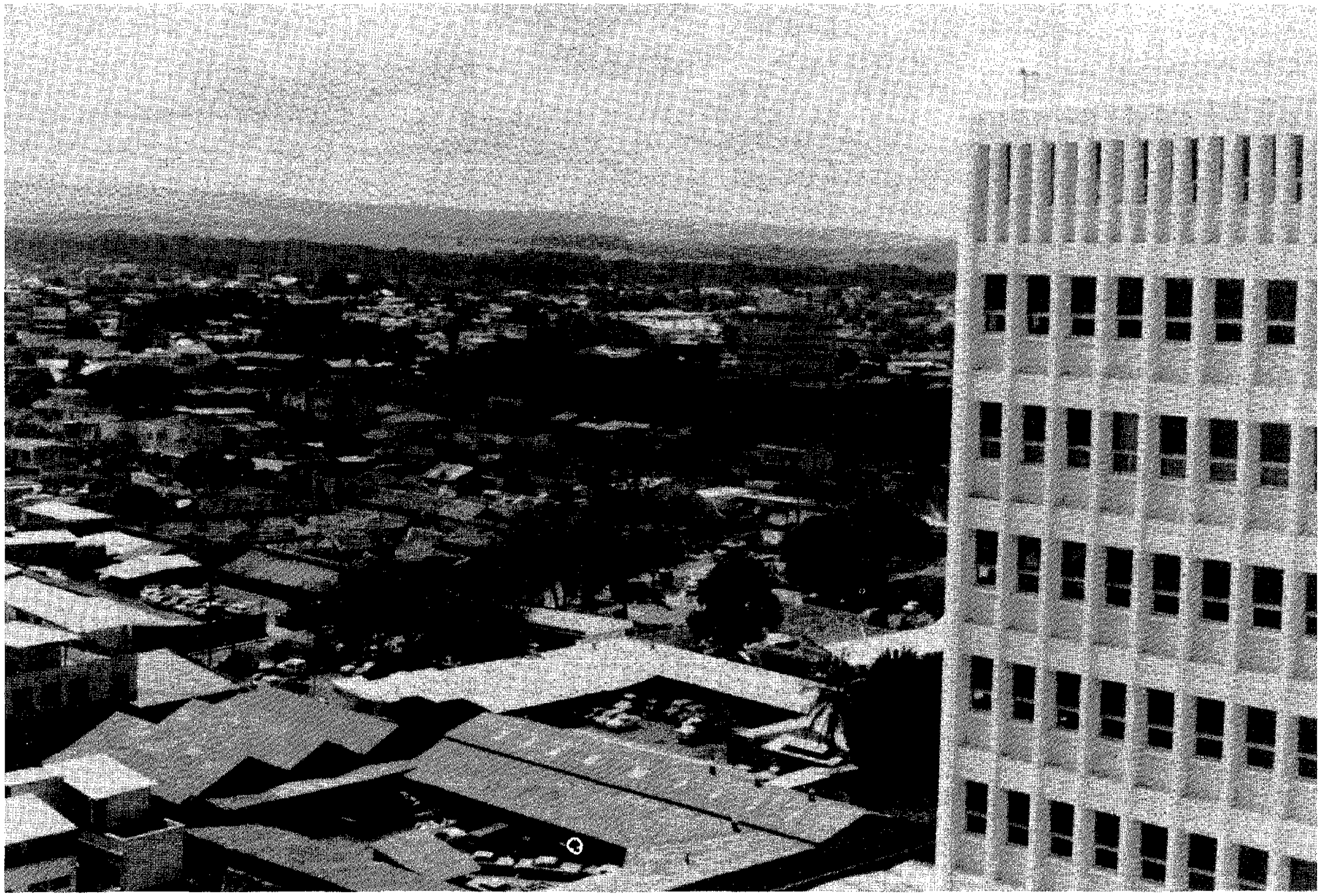


FIGURE II-30 View Before Earthquake, Looking Southwest from Banco de America Building.

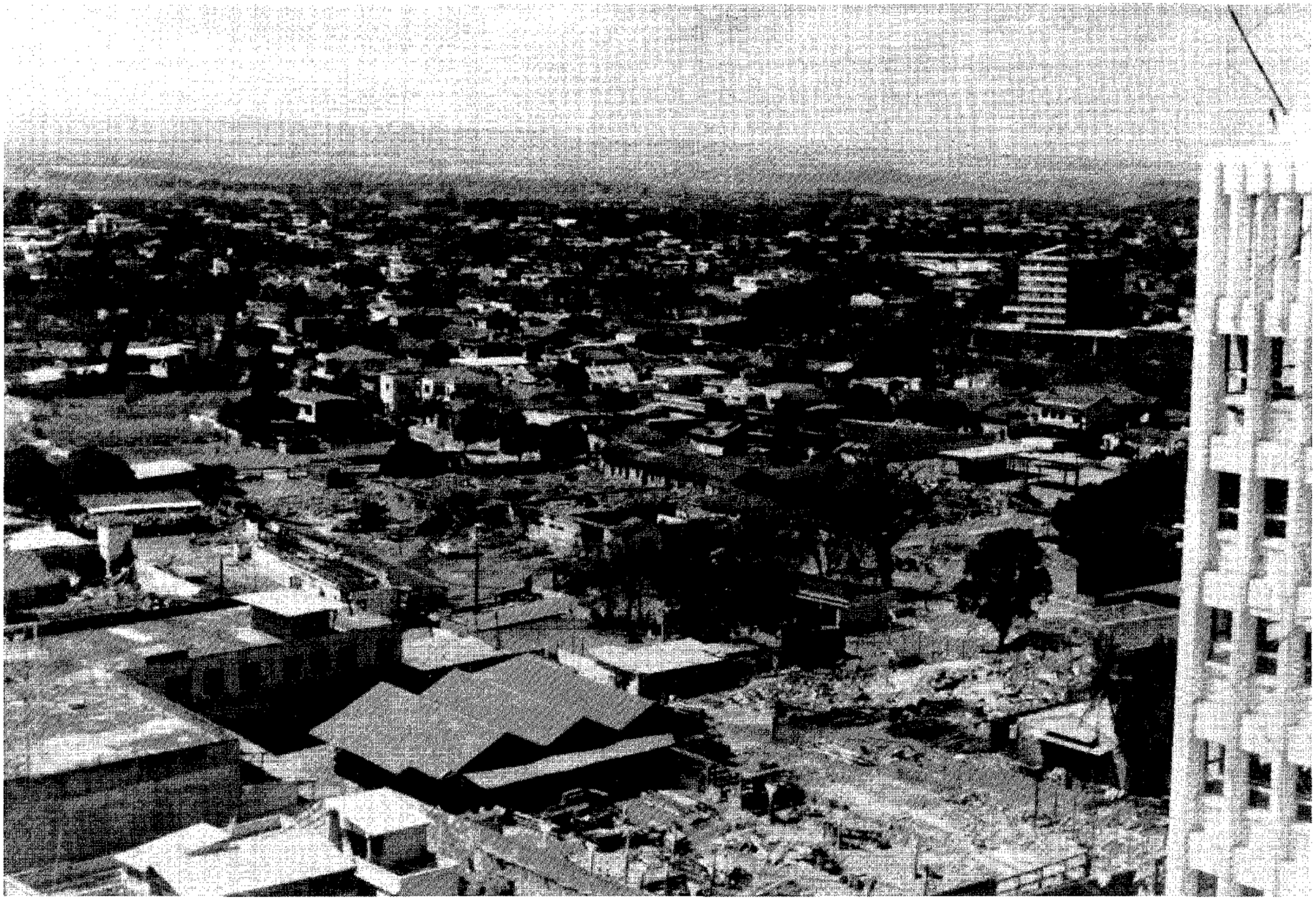


FIGURE II-31 View After Earthquake, Looking Southwest from Banco de America Building.


FIGURE II-32 View Before Earthquake, Looking West from Banco de America Building.

FIGURE II-33 View After Earthquake, Looking West from Banco de America Building.

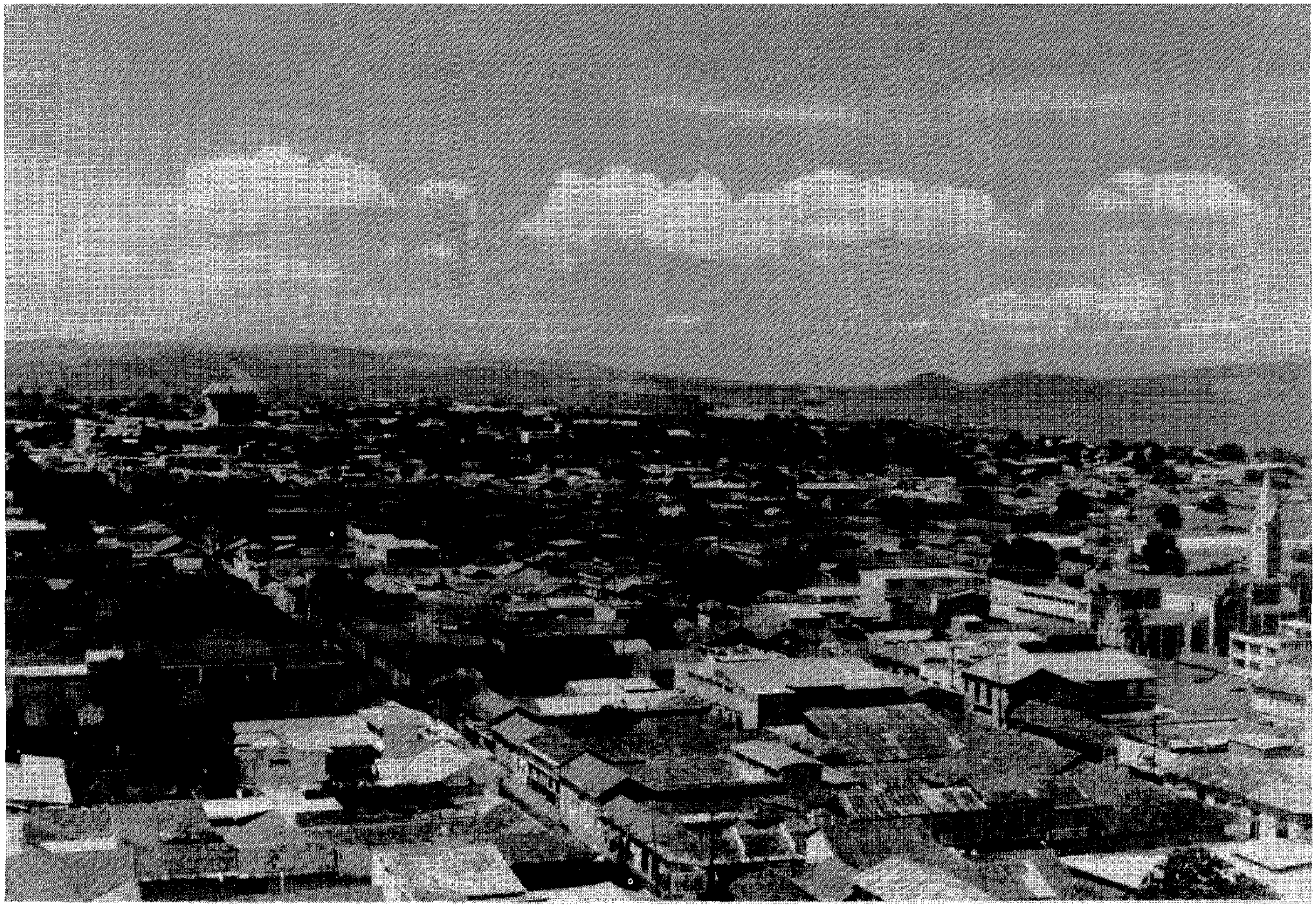


FIGURE II-34 View Before Earthquake, Looking W-N-W from Banco de America Building.

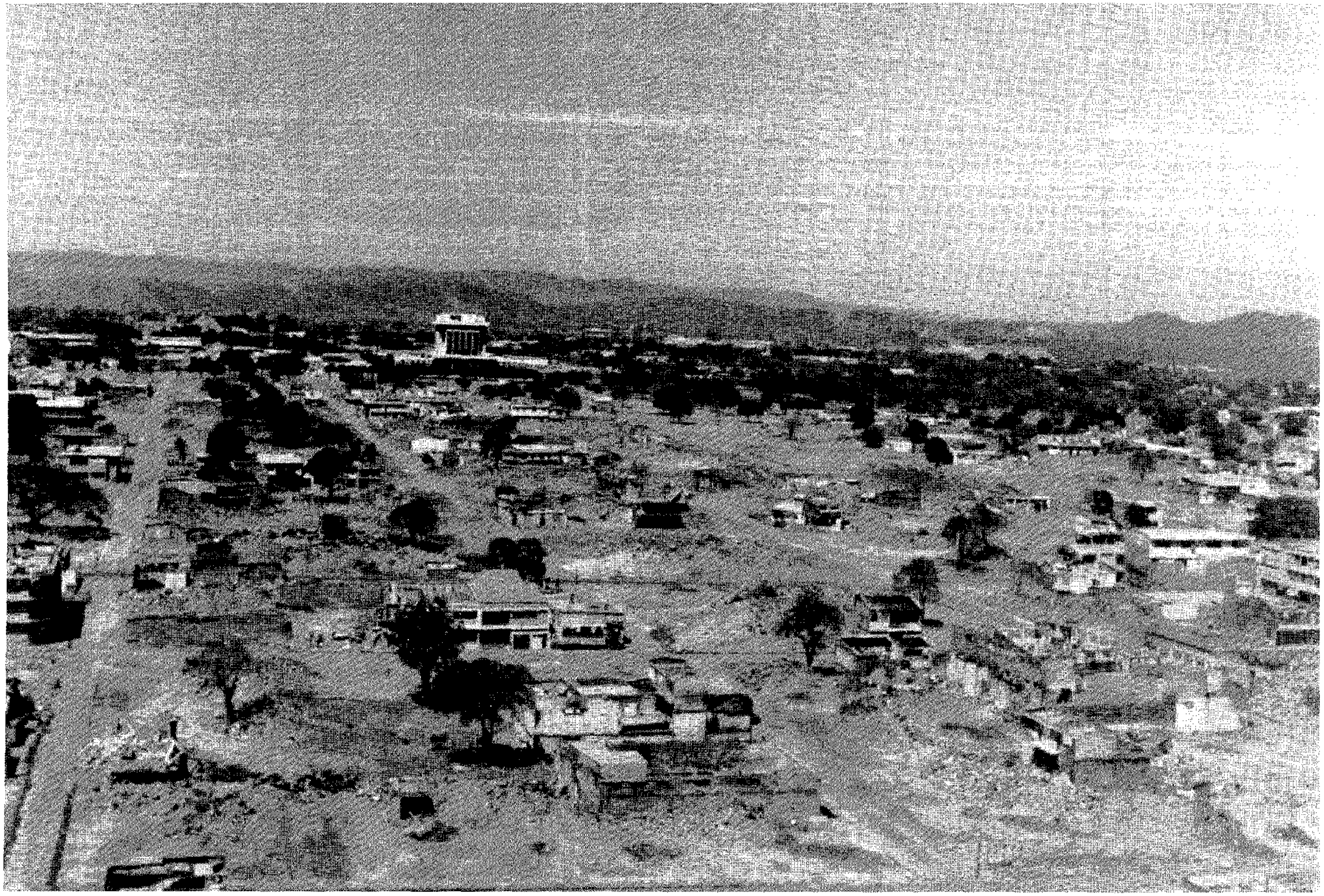


FIGURE II-35 View After Earthquake, Looking W-N-W from Banco de America Building.

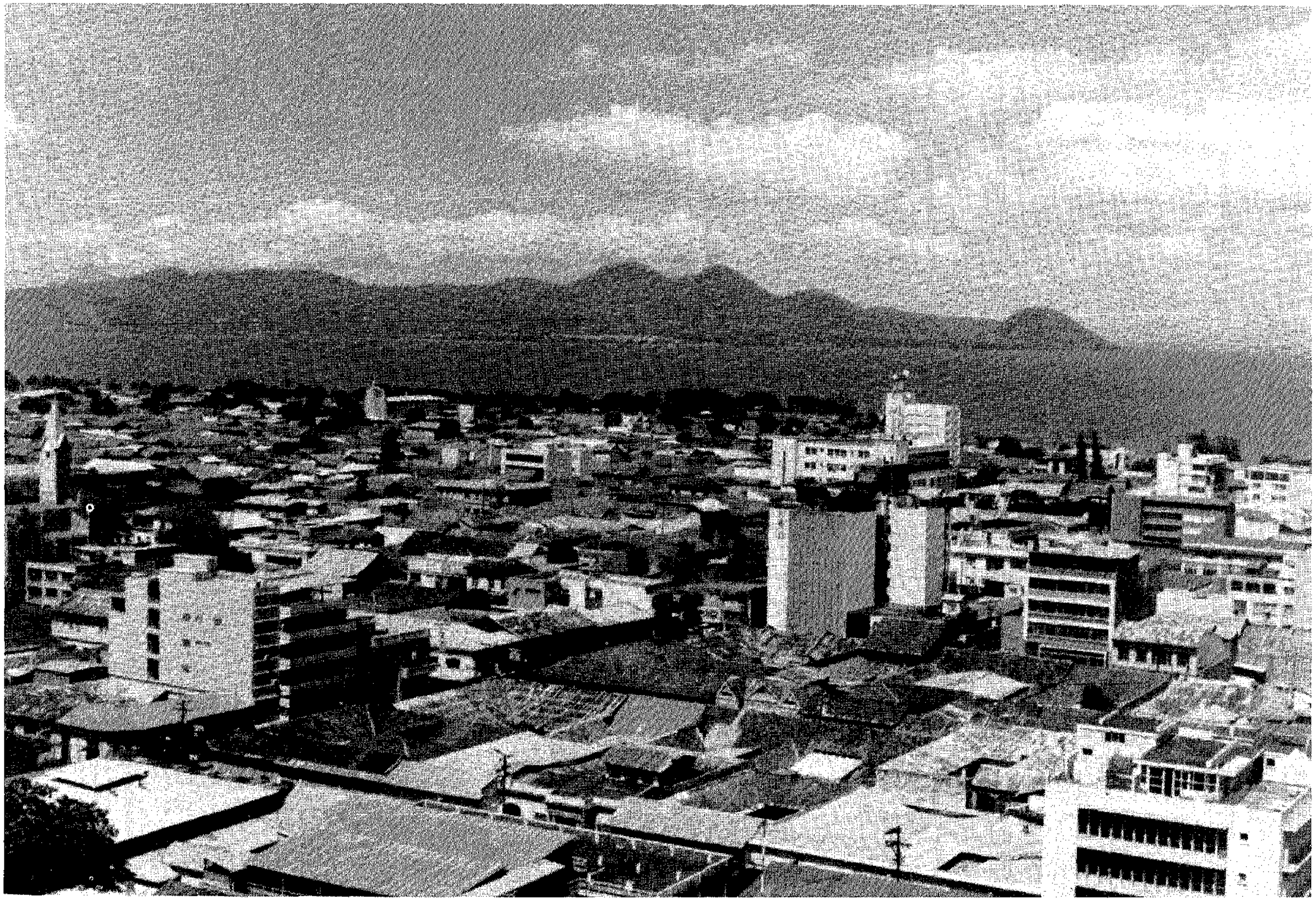


FIGURE II-36 View Before Earthquake, Looking Northwest from Banco de America Building.

FIGURE II-37 View After Earthquake, Looking Northwest from Banco de America Building.

FIGURE II-38 View Before Earthquake, Looking N-N-W from Banco de America Building.

FIGURE II-39 View After Earthquake, Looking N-N-W from Banco de America Building.

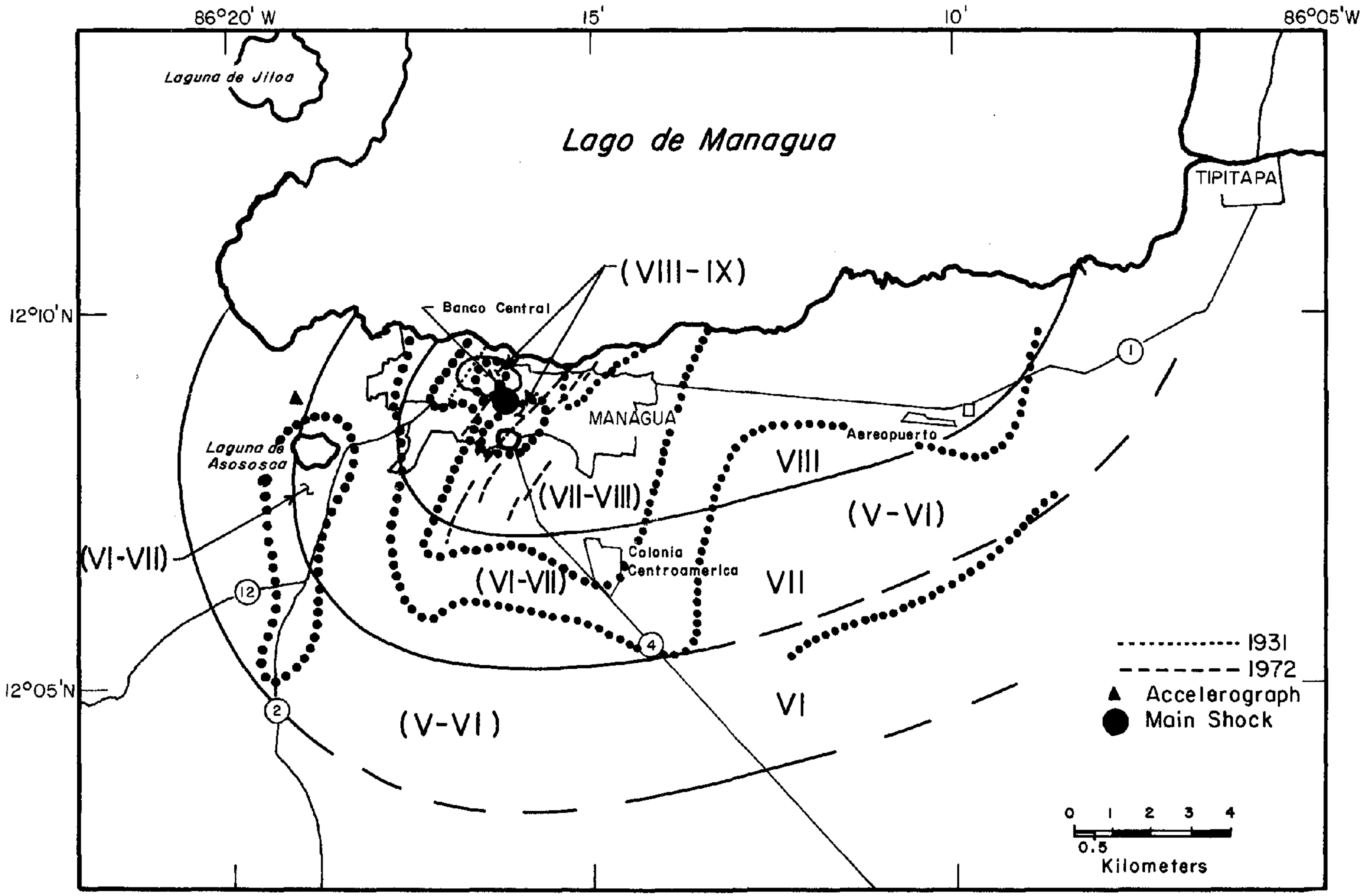



FIGURE II-40 Damage Intensity Distribution.

FIGURE II-41 United States Legation Building.

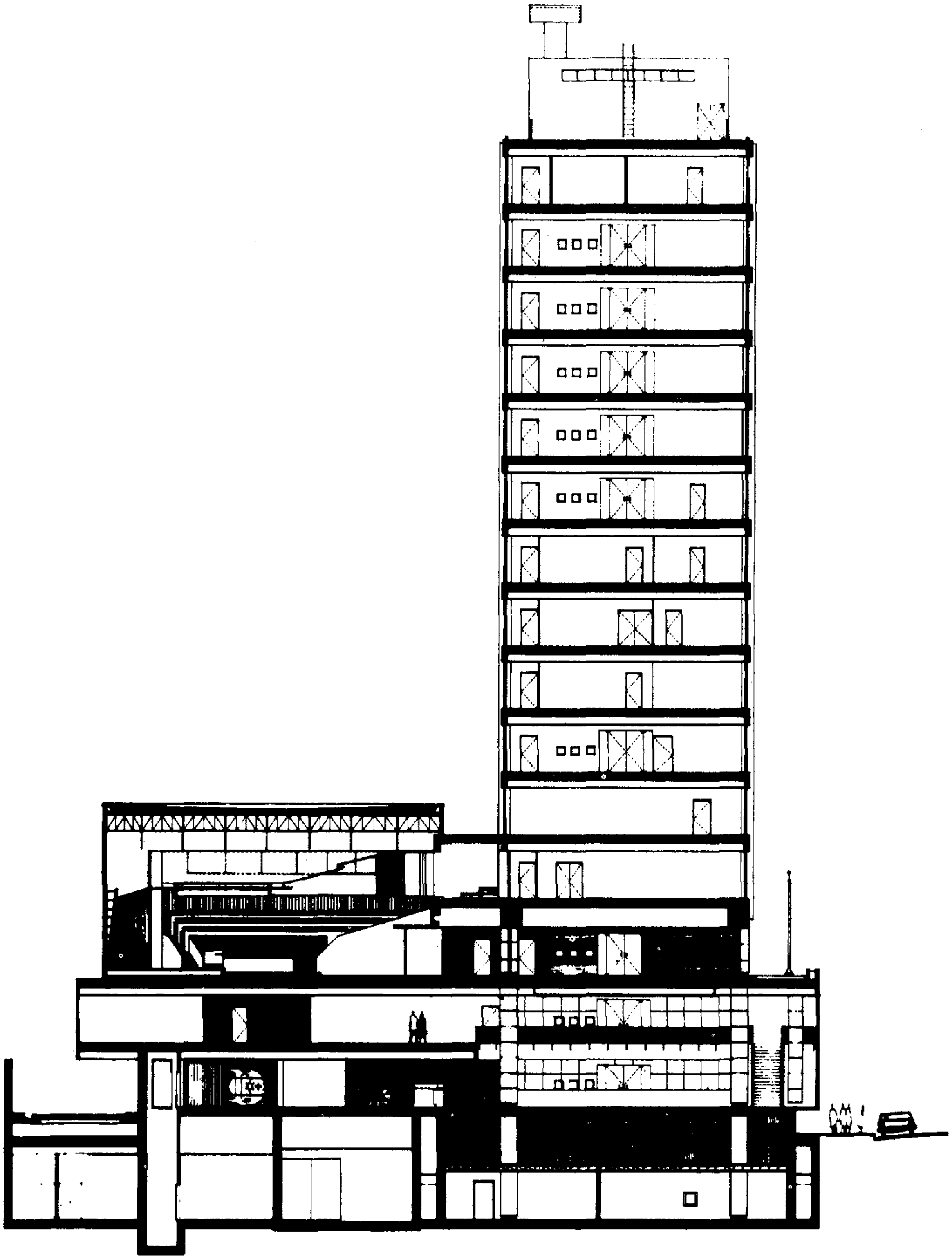


FIGURE II-42 Banco Central Building (Section).

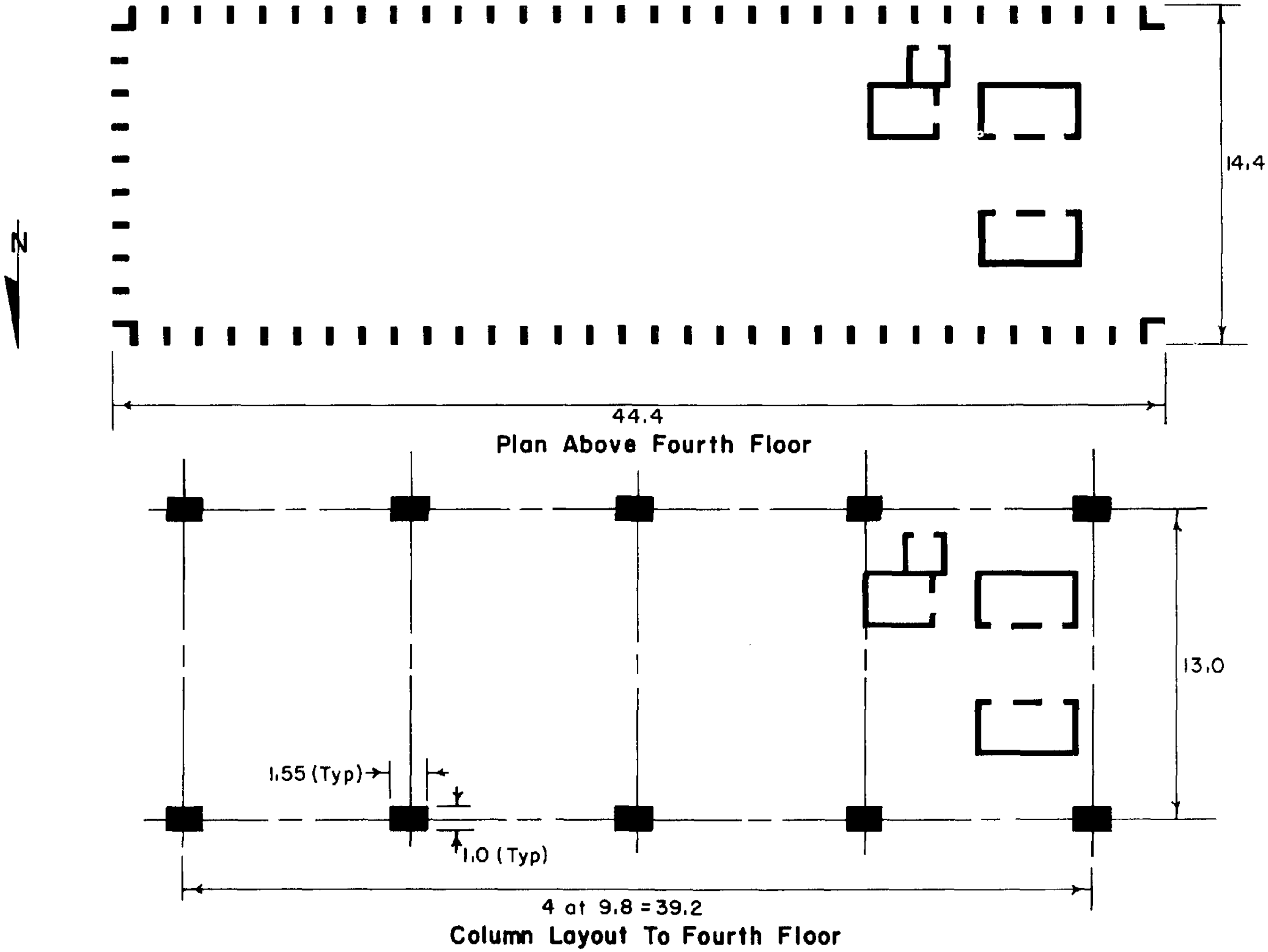
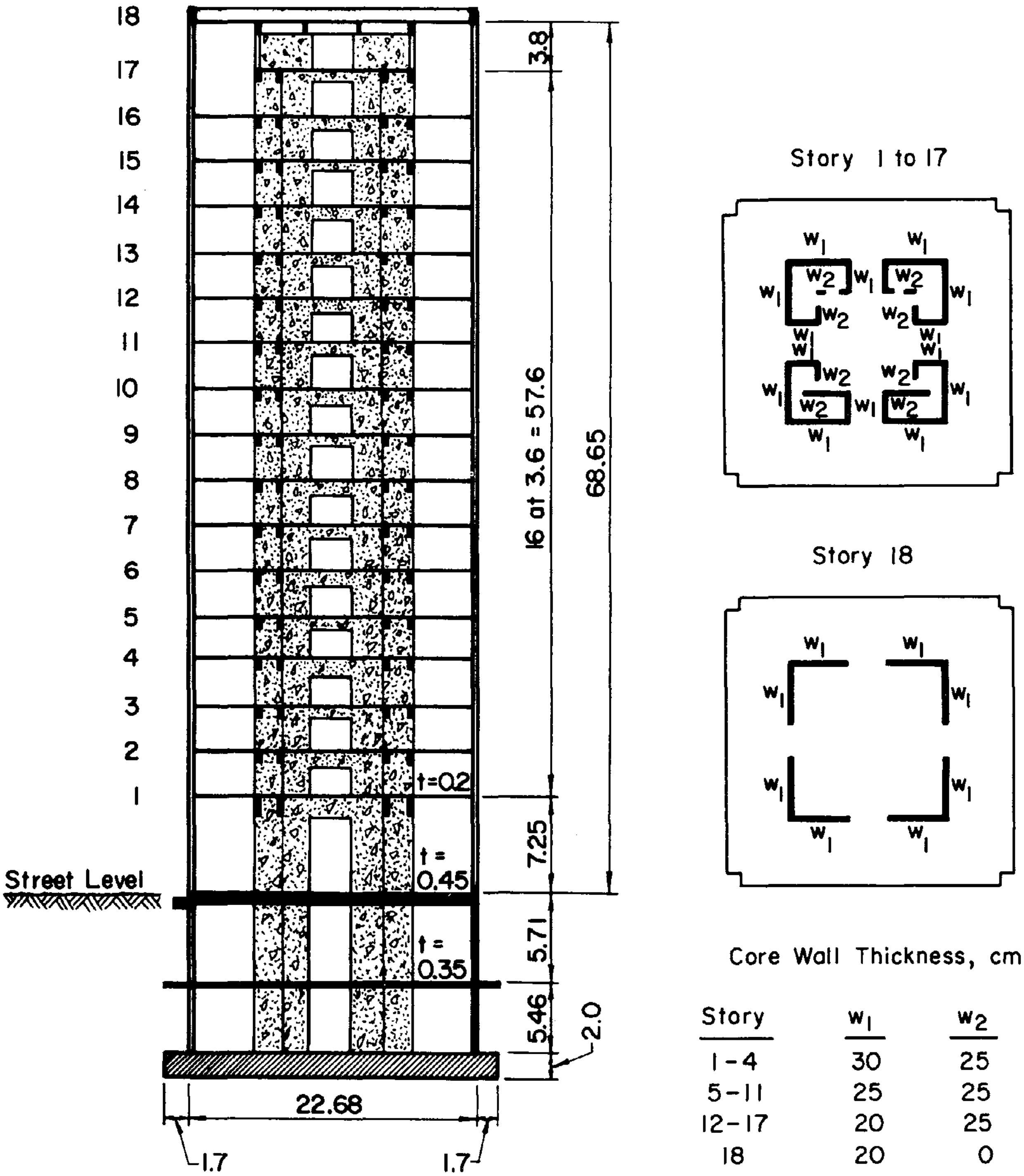



FIGURE II-43 Banco Central Building (Column Layout).




Core Wall Thickness, cm

| Story | $w_1$ | $w_2$ |
|---|---|---|
| 1-4 | 30 | 25 |
| 5-11 | 25 | 25 |
| 12-17 | 20 | 25 |
| 18 | 20 | 0 |

FIGURE II-44 Banco de America Building (Section).

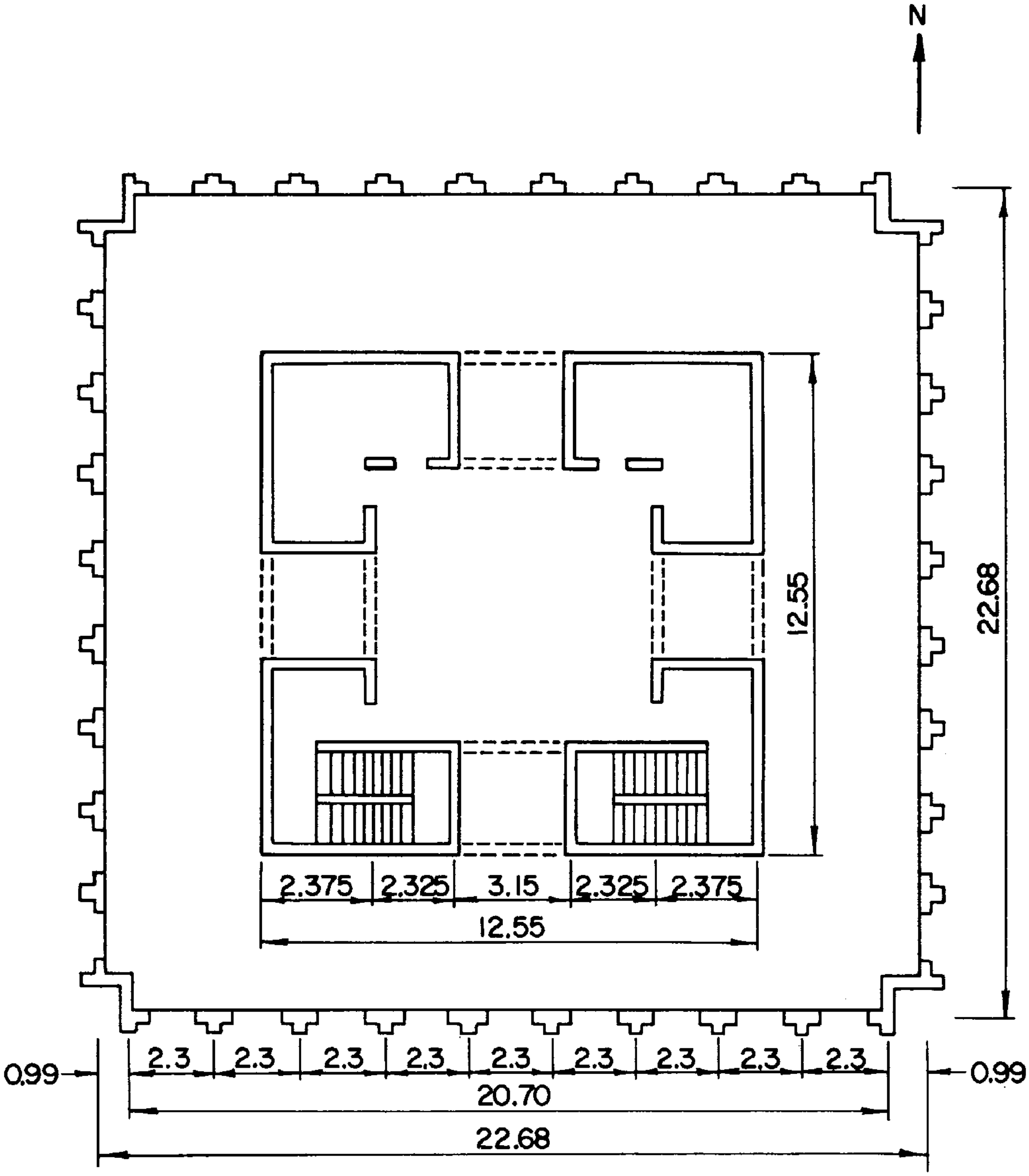



FIGURE II-45 Banco de America Building (Plan).

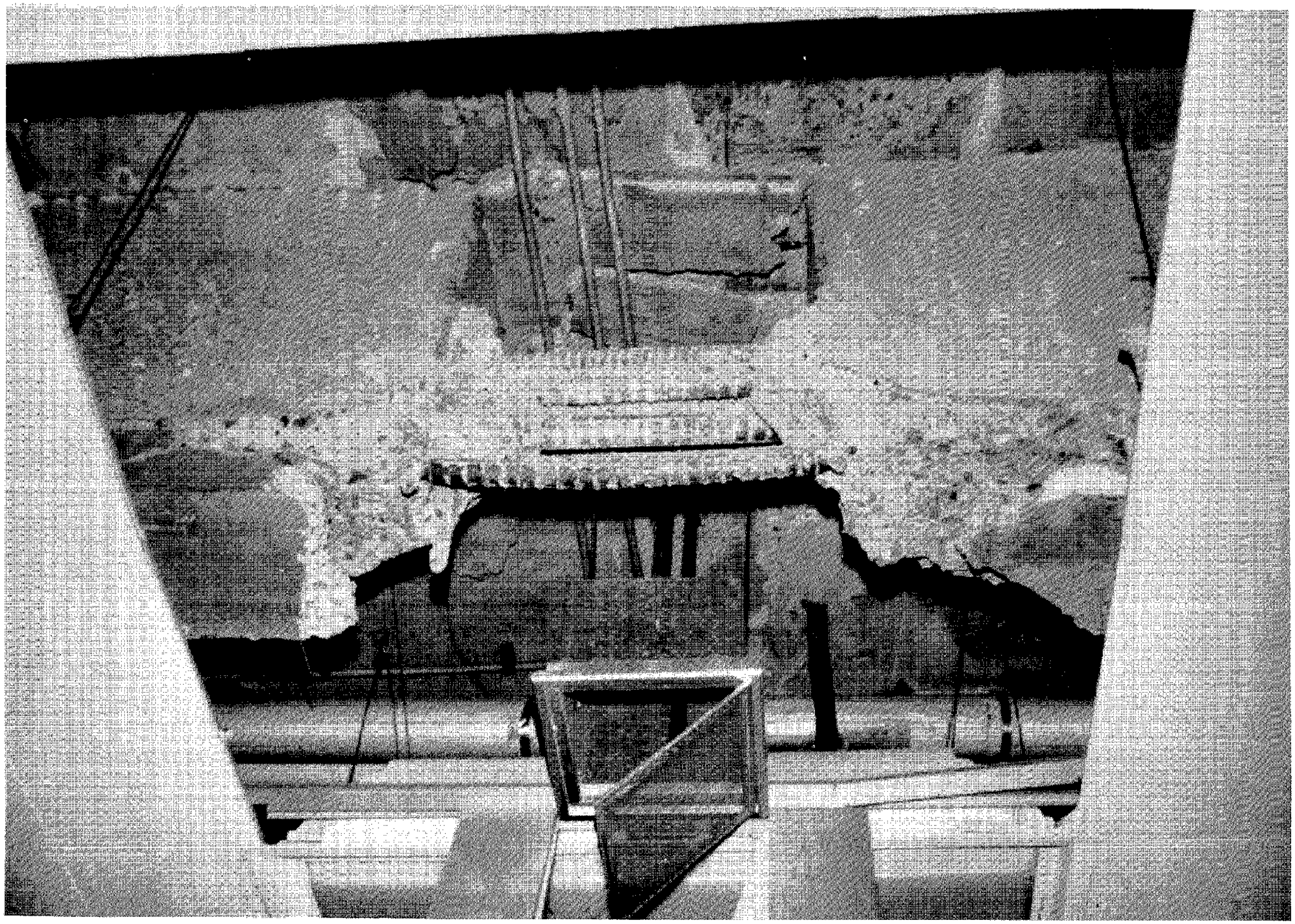


FIGURE II-46    Banco de America Building, Damaged Connecting Girder.

FIGURE II-47 Banco Central Lobby.

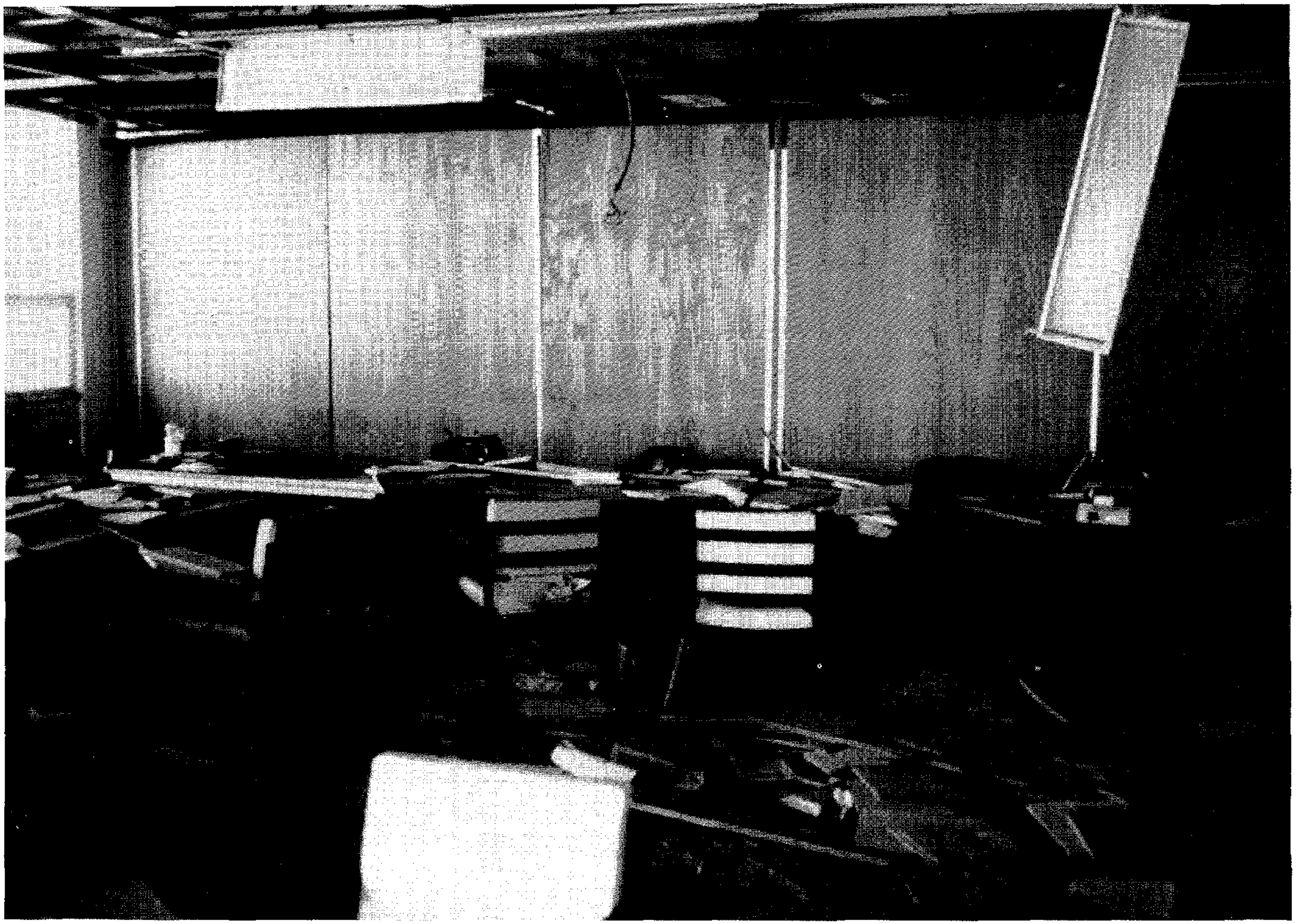


FIGURE II-48 Banco Central Office.

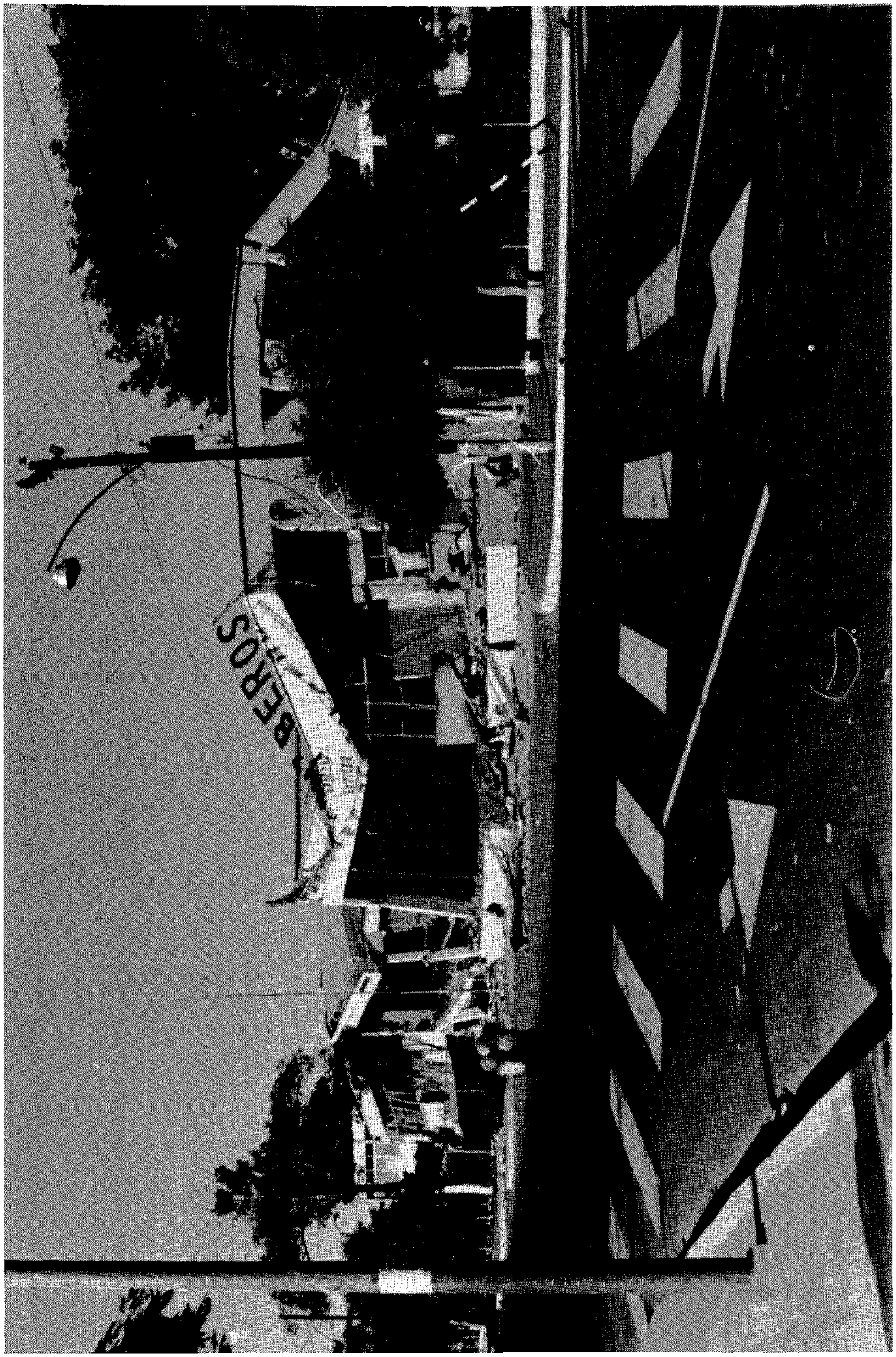



FIGURE II-49 Fire Station.

FIGURE II-50 General Hospital, Overall View.

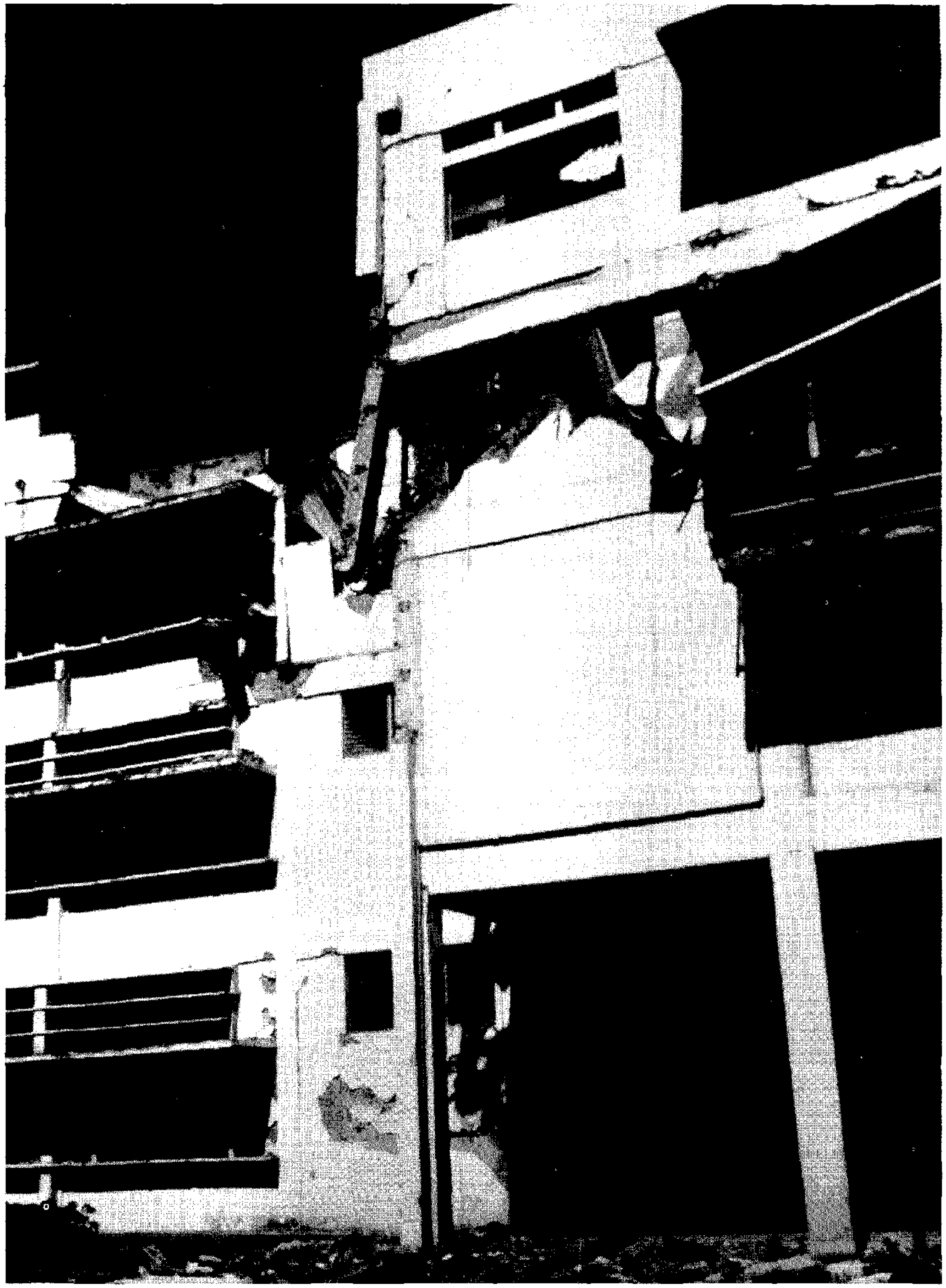


FIGURE II-51 General Hospital, Detail.

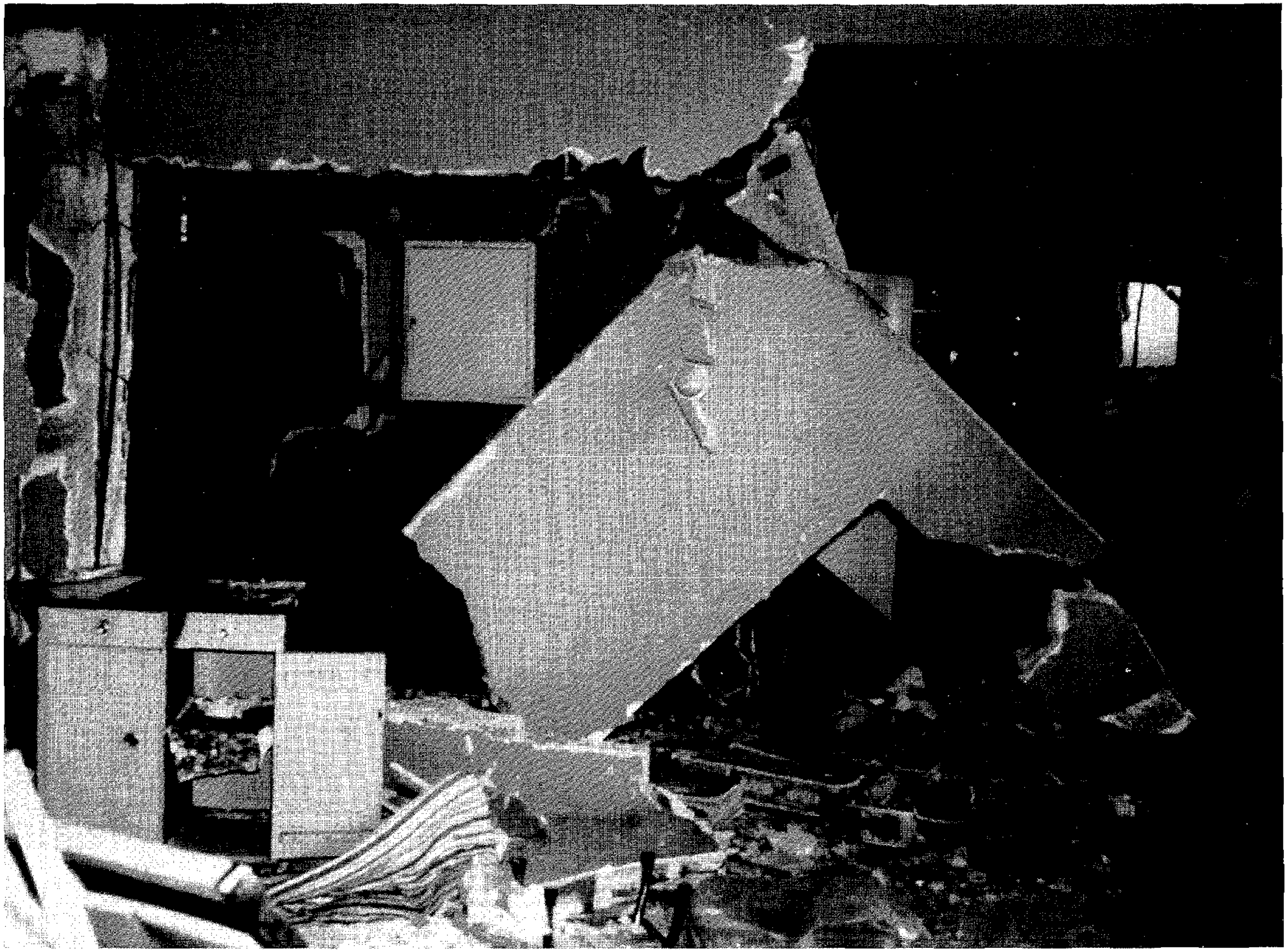


FIGURE II-52a   Social Security Institute Hospital.

FIGURE II-52b Social Security Institute Hospital.

FIGURE II-53 Social Security Institute Hospital, Corridor.

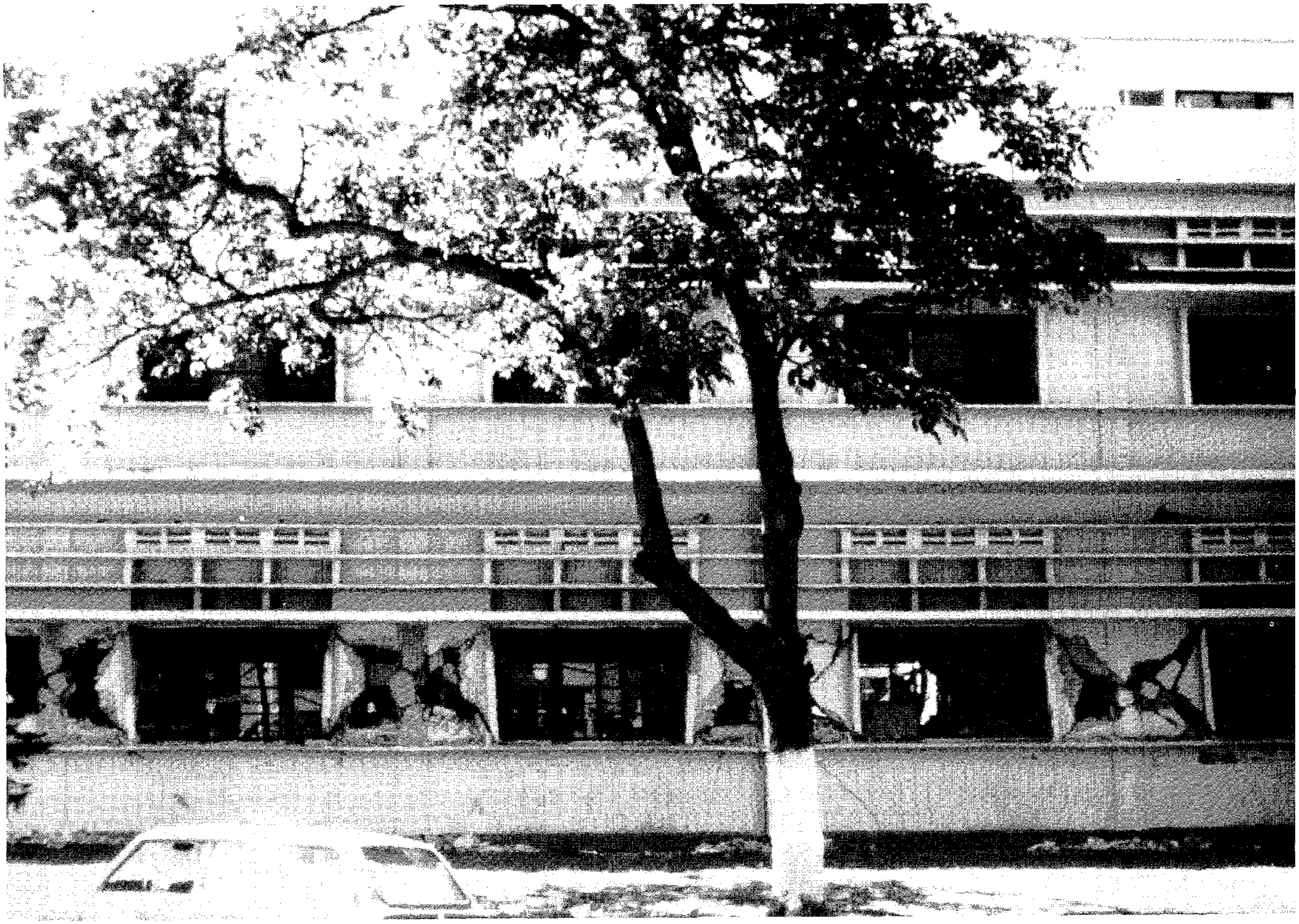


FIGURE II-54   General Hospital.

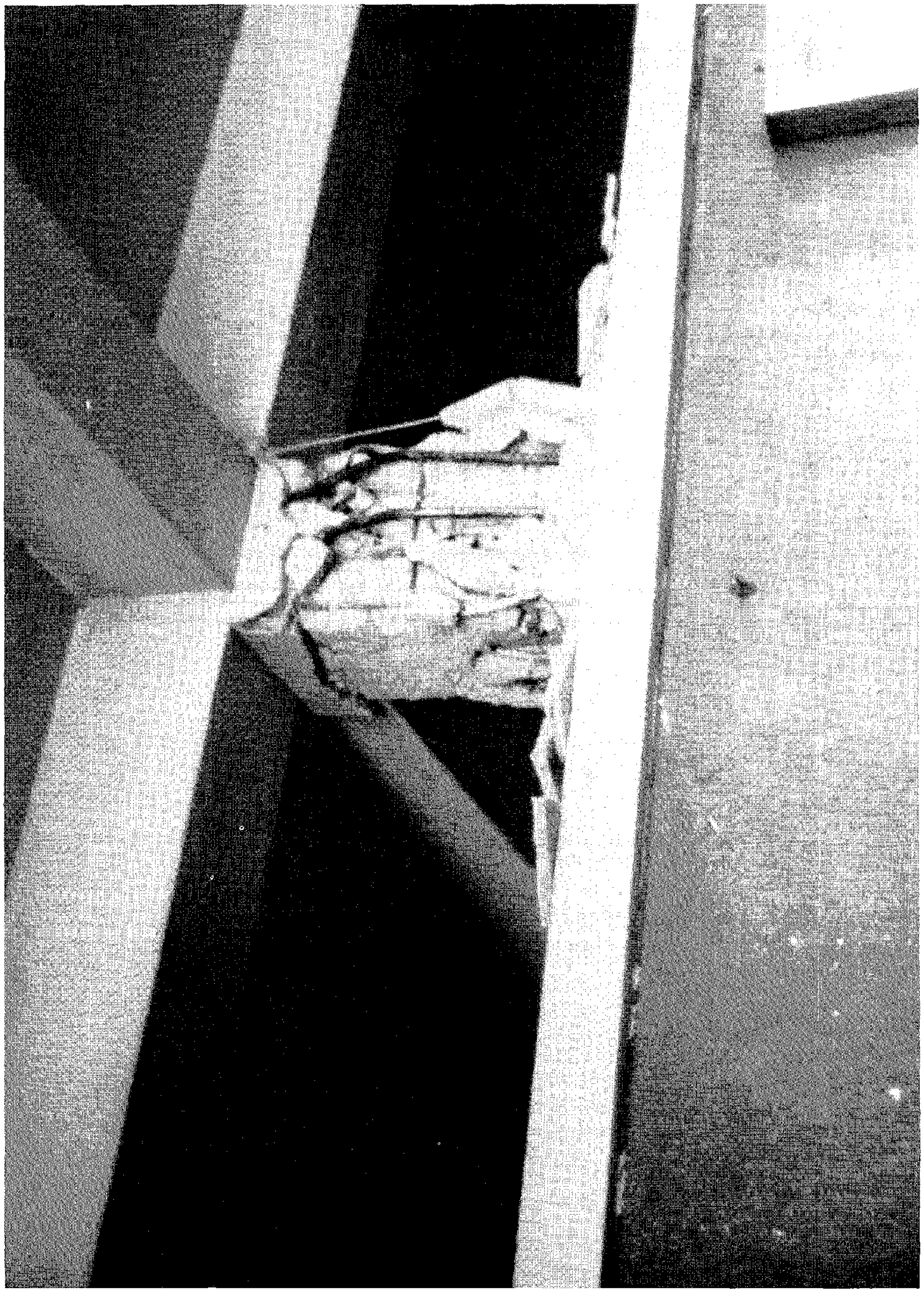


FIGURE II-55 "Short" Column.

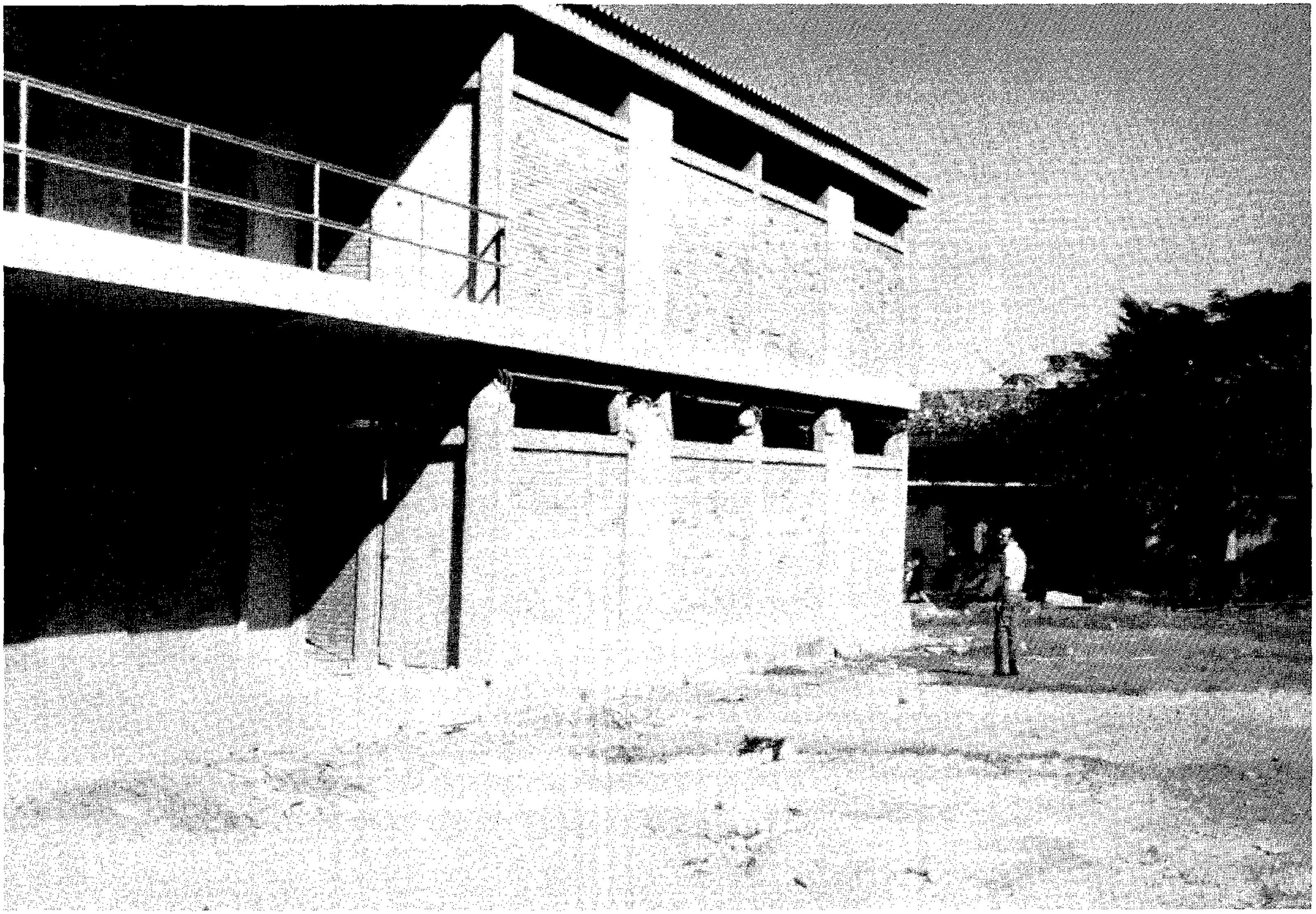


FIGURE II-56 "Short" Columns in School Building.

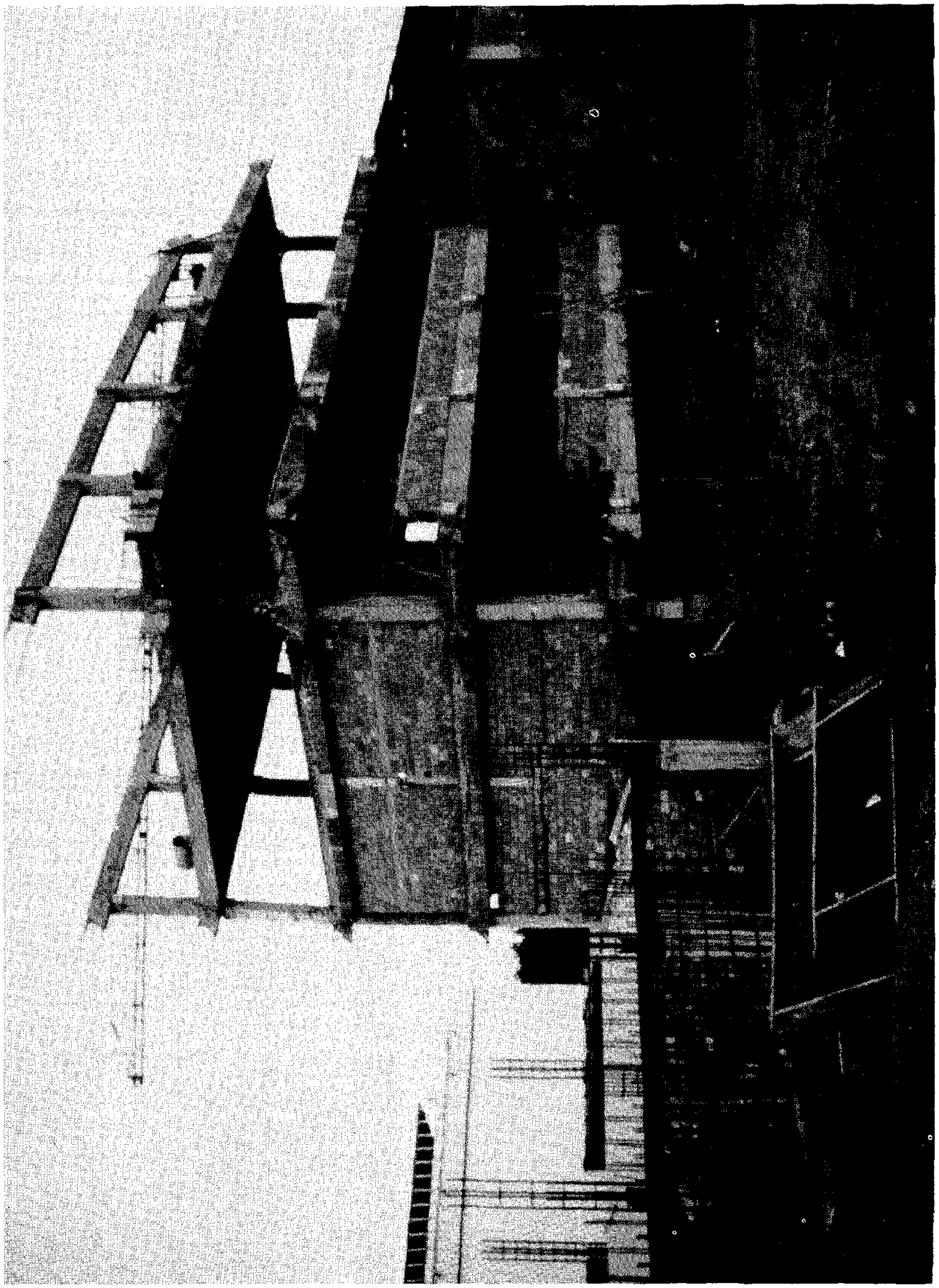


FIGURE II-57a Construction.

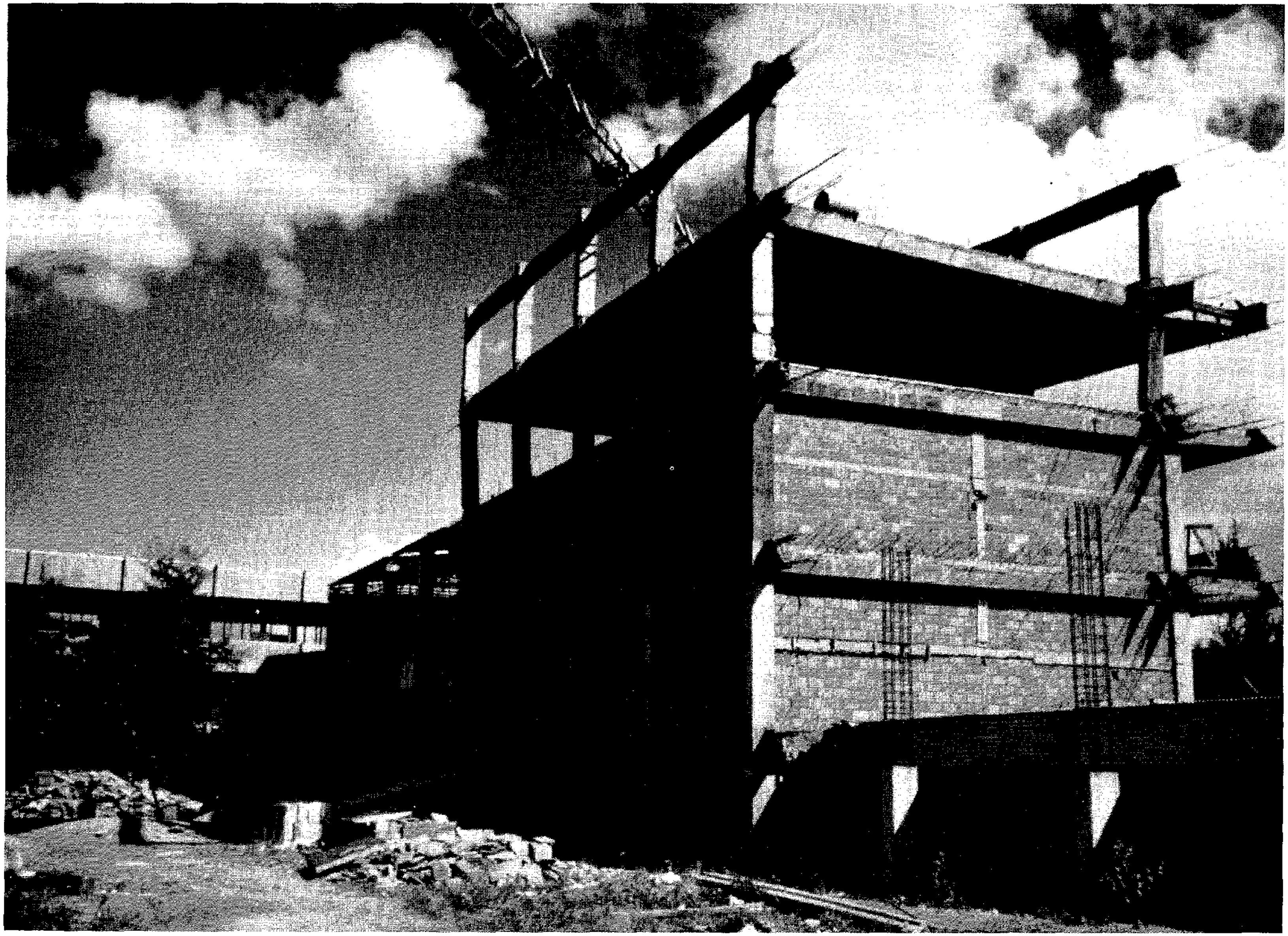


FIGURE II-57b   Construction.