THE ROMANIA EARTHQUAKE SURVEY GROUP OF EXPERTS AND SPECIALISTS DISPATCHED BY THE GOVERNMENT OF JAPAN

SURVEY REPORT

June 1977

Japan International Cooperation Agency

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INTRODUCTION

We first set foot on Romanian soil at Otopeni International Airport in Bucharest, the capital city of the Socialist Republic, on the afternoon of April 9, 1977.

Just before landing, we viewed from our jet the vast farmlands of the nation extending to the distant horizon with clusters of houses dotting the vast area. Seeing no trace of the scars of the devestating earthquake, everybody wondered if an earthquake had really struck here.

However, upon entering the city center from the airport, we noticed many buildings reinforced with temporary supports and a number of structures flattened to the ground.

Reports estimate that the earthquake caused 1,570 fatalities, injured 11,300 persons and destroyed more than 32,900 dwellings, causing damage worth over ¥250,000 million.

In compliance with a request of the Romanian Government, the Japanese Government dispatched a team of seismologists and civil engineering experts from the Japan International Cooperation Agency from April 8 to April 28, 1977 to conduct technical inspections and offer advice and technical guidance.

As a result, the specially organized 'Romania Earthquake Survey Group' conducted the survey in Romania for 18 straight days working late into the night without a break after arriving at Bucharest on April 9th until leaving the city on the 26th.

Despite our short sojourn in that country, we were able to accomplish significant results thanks to the active cooperation and support of the Chairman of the National Council of Science and Technology of Romania, Mr. Ioan Ursu, the other Ministries and Institutes concerned, and also to the cheerful assistance rendered by the Japanese Ambassador to Romania, Mr. Yoshitaka Ishikawa and the able staff members of the Japanese Embassy in Bucharest.

We present here the full text of our survey report compiled by the members of 'Romania Earthquake Survey Group of Specialists'.

More than three months have passed since the Romania Earthquake. Both the government and people of Romania are firmly united in their effort to reconstruct their motherland. In submitting this report, all members of our group earnestly pray for the quickest possible recovery of the nation.

June 3, 1977

Kiyoshi Nakano
Leader of Romania Earthquake Survey Group
Specialist Japanese Government

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CHAPTER 1 OUTLINE

1.1 Purpose of Dispatching a Group of Seismology Specialists

March 4, 1977, 21:22 hours Local Standard Time. The Socialist Republic of Romania (hereafter referred to as Romania) was stricken by an earthquake with a magnitude of 7.2.

The epicenter was estimated about 110 km underground from Vidra (45.8° North and 26.8° East) which is about 160 km northnortheast of Bucharest, the capital.

The earthquake caused damage to a wide area of Romania and also afflicted some regions in Yugoslavia and Bulgaria. The southern regions of Romania were hit particularly severely. Large cities, including Bucharest, Craiova, Ploiesti, Pitesti, Alexandria and Turnu-Magurele and the town of Zimnicea, all far from the epicenter, also suffered losses of houses and damage to public facilities including educational, cultural and industrial facilities and public utilities. The quake also dealt a heavy blow to the economy and daily life of the citizens of Romania.

This earthquake has been a matter of grave importance to the government of Romania as shown by the following:

1. Damage was fairly widespread in proportion to the magnitude of the earthquake; severe damage occurred in areas up to 400 km from the epicenter.

2. Earthquake damage extended at southwest and south-southwest from the epicenter.

3. A large number of buildings were toppled.

To explain this phenomenon, the Romanian government requested Japan, an earthquake prone country, for assistance in a seismological survey and seismic engineering and aseismatic architecture studies.

The contents of the request from the "National Council of Science and Technology" of the Romanian Government to the Japanese Government for technical aid are as follows:

(1) To survey the epicenter of the earthquake and offer technical advice, guidance and cooperation regarding methods of seismological studies and earthquake prediction.

(2) To inspect damaged buildings and structures and offer technical advice, guidance and cooperation regarding aseismatic building construction.

(3) To survey aseismatic civil engineering facilities (including dams) and offer technical advice, guidance and cooperation regarding aseismatic structure design.

(4) To offer technical advice, guidance and cooperation regarding the establishment of a 'Seismic Engineering Center.

To comply with the request of the Romanian Government, the Japanese Government held a meeting of heads of sections in the ministries and agencies concerned with natural disasters, centered on the Ministry of Foreign Affairs and National the Land Agency, on March 22 and 23. After a series of discussions, the meeting decided to fully comply with the request of the Romanian Government by dispatching a group of experts to that country for 21 days, from April 8 to April 28.

1.2 Members of the Group of Seismology Specialists

The special group dispatched to the Socialist Republic of Romania was composed of the following nine members:

Instead of organizing a survey team of government officials, it was decided to dispatch a group of seismology experts. The team was headed by researcher Kiyoshi Nakano of the Building Research Institute of the Ministry of Construction.

Member	Specialty	Affiliation and Position
Kiyoshi Nakano (Group Leader)	Aseismic Building Structure	Deputy Director-General, Building Research Institute, Ministry of Construction
Toshi Asada	Earthquake Prediction	Professor, Department of Physics, Tokyo University
Keisaburo Kubo	Aseismic Structural Engineering	Professor, Productivity Technology Center, Tokyo University
Akio Takagi	Earthquake Prediction Experimental Seismology	Professor, Department of Physics, Tohoku University Vice Director, Earthquake Prediction Observation Center
Masaya Hirosawa	Aseismic Building Structure	Chief, Soil Mechanic Section, Building Research Institute, Ministry of Construction
Eiichi Kuribayashi	Aseismic Structural Engineering	Chief, Aseismic Research Section, Public Works Research Institute, Ministry of Construction
Kazuhiro Matsuno	City Administration	Specialist, Street Section, City Bureau, Ministry of Construction
Masaharu Sakata	Earthquake Prediction Geology	Earthquake Prediction, Promotion & Planning Section, Research Coordination Bureau, Science and Technology Agency
Koji Kaneko	Disaster Prevention	Disaster Relief Measures Section, Secretariat, Director of the National Land Agency

1.3 Itinerary

The itineary of the seismology specialists group was as follows:

Date	Time	Contents of Survey
April 8 (Fri)	11:00	Left Tokyo International Airport (Haneda) JAL Flight 447
April 9 (Sat)	15:35	Arrived at Bucharest (Otopeni Airport)
	16:00 ~ 17:40	Received explanation of earthquake damage, reconstruction progress, and basic plan of the Romanian Government's National Council of Science and Technology from Chairman, Mr. Ioan Ursu. Self introduction
	18:00 ~ 23:15	Held first group meeting to decide survey methods at the quarters in the National Physics Center
April 10 (Sun)	08:20 ~ 09:30	Met with Romanian government officials to discuss the itinerary and survey methods. (The Romanian government was represented by Dr. Ionescu, Dr. Radu, Dr. Iosif and Dr. Serbanescu)
	09:30 ~ 18:35	Inspected afflicted areas in Bucharest and received explanations
	19:00 ~ 21:20	Conducted group meeting to discuss the itinerary and survey methods suggested by the Romanian government. Based on the Romanian government's proposals, the group decided to conduct the survey in four teams: Seismology, Architecture, Civil Engineering Facilities and Disaster Prevention
April 11 (Mon)	08:00 ~ 11:40	Consulted with officials of the Romanian Government on itinerary and survey methods. The Romanian government was represented by Dr. Ionescu, Dr. Radu, Dr. Iosif, Dr. Serbanescu, Dr. Broea, Dr. Stetan, Mrs. Apopel and Dr. Firipas
	11:40 ~ 18:00	The survey group, dividing into Seismology, Architecture & Civil Engineering and Disaster Prevention teams, began survey work together with Romanian specialists

Date	Time	Contents of Survey
April 11 (Mon) 〜 April 23 (Sat)	08:00 〜 18:00	Survey by each team. (Details of the survey are explained later.)
April 24 (Sun)	08:00 〜 18:00	The group reported survey results to the Romanian Government and the Japanese Embassy in that country. The group also prepared to answer questions regarding architecture and civil engineering matters forwarded by the Romanian government.
	20:00 〜 02:30	Held group meeting to study survey results.
April 25 (Mon)	07:30 〜 09:00	Inspected implements and tools and packed up.
	09:00 〜 13:30	Conducted final group meeting on the mtthods of compiling survey report to be submitted to the Romanian government and to the Ministries concerned upon returning to Japan.
	14:00 〜 16:30	Conducted final session with the officials of the Romanian Government and exchanged views and submitted the survey report.
April 26 (Tue)	09:35	Left Bucharest airport (Otopeni)
April 28 (Thu)	11:20	Arrived at Tokyo airport (Haneda)

1.4 Survey Activities by Each Team

To facilitate survey work of the group of seismologists and to perform the survey and technical cooperation requested by the Romanian Government, the group conducted survey activities in four separate teams:

1. Seismology Team

   Toshi Asada, Akio Takagi and Masaharu Sakata.

2. Building Team

   Kiyoshi Nakano, Masaya Hirosawa and Koji Kaneko.
   (Koji Kaneko was also a member of Disaster Prevention Team).

3. Civil Engineering Team

Keisaburo Kubo, Eiichi Kuribayashi and Kazuhiro Matsuno.
(Kazuhiro Matsuno was also a member of Disaster Prevention Team.)

4. Disaster Prevention Team

Kazuhiro Matsuno and Koji Kaneko.

An outline of the survey and technical cooperation activities performed by the four teams of the group of seismologists from April 11 to April 23 is given below.

(1) Team One: Seismology (Asada, Takagi, Sakata)

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 11 (Mon)	08:00 ~ 18:00	°Greeting by Dr. C. Mihulece °Mrs. Apopei explained about the earthquake and other historical earthquakes. °Mr. Marza explained post-earthquake minor tremors activity. °Dr. Iosif and °Dr. Radu supplied necessary data and information, and guided the team through the earthquake observatory.	Dr. Iosif, Mrs. Apopei and Dr. Aorza of the institute of earth physics Seismology	
Apr. 12 (Tue)	08:00 ~ 18:00	°Mr.V.Marza and Dr.T.Iosif lectured on seismological research organizations in Romania °Dr. Radu then showed us collection of relevant documents.	"	

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 13 (Wed)	07:30 ~ 19:00	Unpacked luggage, Inspected observation seismometers. Checked crystal chronograph at astronomical observatory for exact standard time.	Dr. Iosif, Mrs. Apopei and Dr. Aorza of the institute of earth physics Seismology	
Apr. 14 (Thu)	08:00 ~ 18:00	°Set up seismometers. °Departed to set seismometers at four separate observation points. °Made a courtesy call at Vice-governor of Proiesti (to set a seismometer). °Positioned a seismometer at the first point near Groapa Chetatuje (CHEIA). Obtained cooperation of residents. (Stayed overnight in Brasov city).	"	
Apr. 15 (Fri)	08:00 ~ 18:00	°Set up seismometers. The second point was next to that of the Balvanyos West German Seismic Observation Team. The third point was dug totally underground at Casin. Received cooperation from Forest Police. (Stayed overnight in Facusani).	"	
Apr. 16 (Sat)	08:00 ~ 22:10	°Set up seismometer. Fourth point was at Carcaliu (East bank of the Danube).	"	
Apr. 17 (Sun)	07:30 ~ 18:00	The whole team conducted inspection tour of Predeal and Codlea.	"	

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 18 (Mon)	09:00 ? 17:00	Visited Institute of Geology and Geophysics in Bucharest. Received full explanation of geophysic activities in Romania and exchanged views. As a result, an exchange of opinions was obtained with Romanian seismologists.	Dr. Iosif, Mrs. Apopei and Dr. Aorza of the institute of earth physics Seismology	
Apr.20 (Wed)	08:00 ? 18:10	°Documents pertaining to the features of Romanian earthquake and seismic characteristics of Romania were arranged for the Japanese seismologists. °Team meeting in the evening	"	
Apr. 21 (Thu)	08:00 ? 18:00	°Arranged data. Began preparation of report. °Visited to the Japanese Embassy to prepare materials.	"	
Apr. 22 (Fri)	08:00 ? 18:00	°Asada left for IPCT for explanation. °Explained method of determining seismic center by P wave °Toured city where fissures and sand blows appeared.	"	

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 23 (Sat)	08:00 ≀ 22:30	°Asada attended IPCT meeting in the morning. °Left for Carcaliu to gather equipment in the afternoon. (stayed overnight in Constanta) °Takagi and Sakata left to equipment at three other points. (Stayed overnight in Gheorge-Gheorghiu Dej)	Dr. Iosif, Mrs. Apopei and Dr. Aorza of the institute of earth physics Seismology	
Apr. 24 (Sun)	08:30 ≀ 23:50	°Asada returned in the evening. °Takegi and Sakata returned at 8pm. °Immediately corrected time with crystal timepiece. °Began packing.	〃	
Apr. 25 (Mon)	07:30 ≀ 21:00	°Completed packing. Team meeting. °Exchanged opinions with Romanian experts.	〃	

(2) Team Two: Building (Nakano, Hirosawa, Kaneko)

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 11 (Mon)	08:00 ? 18:00	°Adjustment of survey schedule. °Inspected damaged buildings in Bucharest.	°Design Construction Headquarters (IPCT) Dr. Serbanescu Dr. Broen Dr. Apopei Dr. Stetan	
Apr. 12 (Tur)	08:00 ? 18:00	°Inspected damaged buildings in Bucharest. °Held meeting to discuss reinforcement.	"	
Apr. 13 (Wed)	08:00 ? 18:00	"	"	
Apr. 14 (Thurs)	08:00 ? 18:00	°Inspected the extent of damage in Craiova, and held a study meeting.	"	
Apr. 15 (Fri)	08:00 ? 18:00	°Inspected the extent of damage in Ploiesti, and held a study meeting.	"	
Apr. 16 (Sat)	08:00 ? 18:00	°Inspected the extent of damage in Bucharest, and held a study meeting.	"	
Apr. 17 (Sun)	07:30 ? 18:00	°All members visited Predeal and Codlea to conduct on the spot inspection	"	
Apr. 18 (Mon)	08:30 ? 18:20	°Inspected damaged buildings in Bucharest. °Inspected continuous tromometer measurement of box-frame construction houses.	IPCT Dr. Serbanescu	

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 19 (Tue)	07:30 ≀ 17:20	°Inspected damaged buildings in Bucharest. °Inspected continuous tromometer measurement of box-frame construction houses.	IPCT Dr. Serbanescu	
Apr. 20 (Wed)	09:30 ≀ 18:20	°Inspected plant structures and held study meeting.	IPCT Dr. Vernescu Eng. Dabija	
Apr. 21 (Thurs)	08:00 ≀ 19:00	°Study meeting concerning design of future plant structures	"	
Apr. 22 (Fri)	08:00 ≀ 18:00	°Study meeting concerning design of future plant structures. °Study meeting concerning forcing RC °Study meeting concerning general design methods.	"	
Apr. 23 (Sat)	08:00 ≀ 18:00	°Study meeting concerning general design methods. °Study meeting of the plan to construct a Seismic Engineering Research Institute.	"	
Apr. 24 (Sun)	08:30 ≀ 18:00	°A review session of overall observations.	Building Research Institute (INCERC) Dr. Serbanescu Dr. Sandi	

(3) Team Three: Civil Engineering Facilities
(Kubo, Kuribayashi, Matsuno)

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 11 (Mon)	09:00 ~ 10:00 10:30 ~ 12:45 13:00 ~ 15:00	°Courtesy Call at Central Institute of Physics. °Received explanation of outline of damage and outline of itinerary. °Surveyed the extent of damage in Bucharest.	°Mrs. Apopei, Chief of Nuclear Energy Research Institute °Design Architecture Headquarters (IPCT) Mr. Negru Building Research Institute Mr. Serbanescu	
Apr. 12 (Tue)	09:00 ~ 10:50 ~ 11:00 ~ 18:00	°Compiled schedule. °Studied record and schedule of tremors.	°IPCT Mr. Radu, Mr. Negru °INCERC Mr. Serbanescu	
Apr. 13 (Wed)	09:00 ~ 18:00	Discussed dam-related facilities	°Waterways Structures Research Institute (ICH) Mr. Hancu	
Apr. 14 (Thurs)	08:00 ~ 18:00	Surveyed devastated areas in Craiova, and held study meeting.	°Deputy Mayor of Craiova	
Apr. 15 (Fri)	08:00 ~ 11:00 12:00 ~ 18:00	°Surveyed extent of damage in Ploiesti °Surveyed extent of damage to Brazi thermoelectric power plant and held study meeting	°Power Development Agency (ISPE) Mr. Chitu °Chief of Brazi Power Plant	

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 16 (Sat)	08:00 ~ 15:00	°Surveyed extent of damage to Vidraru Dam and hydro-electric power plant and held study meeting	°Mr. Pop, Head of Water Resources Corporation (ISPH) Vidraru	Mr. Cacilescu
Apr. 17 (Sun)	07:30 ~ 18:00	°All members inspected Predeal and Codlea.		
Apr. 18 (Mon)	08:00 ~ 15:00	°Surveyed roads and bridges along the Danube. °Review meeting.	°Mr. Buzuroi of Transportation and Communication Ministry (IPTANA)	
Apr. 19 (Tue)	08:00 ~ 18:00	°Inspected roads and bridges along the Danube and held study meeting.	°Mr. Tomi of Railroad Construction Corporation (IPCF)	
Apr. 20 (Wed)	09:30 ~ 18:00	°Held a meeting on aseismicity of bridges	°Mr. Marinescu of IPTANA Mr. Tomi of IPCF	
Apr. 21 (Thur)	09:00 ~ 18:00	°Elastic wave inspection regarding aseismicity of dams and held a study meeting.	°ICH Mr. Flegont Civil Eng. Inst Mr. Stemativ	
Apr. 22 (Fri)	09:30 ~ 18:30	"	"	
Apr. 23 (Sat)	08:30 ~ 18:00	°Held a study meeting concerning general general design methods and the plan to establish a Seismic Engineering Research Institute.	°IPCT Mr. Negru	
Apr. 24 (Sun)	09:00 ~ 18:00	°Reviewed overall observations	°INCERC Mr. Serbanescu ICH Mr. Morianu	

(4) Team Four: Disaster Prevention (Matsuno, Kaneko)

Date	Time	Outline of Survey	Officials of Romanian Government	Remarks
Apr. 19 (Tue)	10:30 ~ 12:00	Surveyed disaster relief measures taken after the earthquake and exchanged opinions	°Ministry of Health (MINISTERUL-SANATATII) Mr. Mihail Mr. Mihailscu	
	12:00 ~ 14:10	Surveyed the extent of damage and disaster prevention measures at gas facilities and exchanged opinions.	°Gas Corporation (ENTREPRISE OF GAZ) Mr. Stefan Mr. Radulescu	
Apr. 20 (Wed)	09:30 ~ 11:00	Surveyed the extent of damage and disaster prevention measures at waterworks facilities and sewage facilities. Later held a meeting exchanging views.	°Waterworks Corpora- (ICAB) Mr. Enescu Mr. Radulescu	
	11:20 ~ 13:30	Surveyed the extent of damage and disaster prevention measures at electric facilities and exchanged views.	°Electric Power Ministry Mr. Ion Mr. Bordea	
Apr. 21 (Thu)	11:00 ~ 13:30	Surveyed disaster relief measures in Bucharest, and exchanged views on city disaster prevention measures.	°Bucharest City Office (IPB) Mr. Traian Mr. Miron Mr. Stanescu	

CHAPTER 2 SEISMICITY OF ROMANIA

2.1 Seismicity of Balkan Region and Tetonic of Romania

The seismicity of the Balkan Region including Rumania was investigated in detail. The Survey of the Seismicity of the Balkan Region was compiled by UNESCO in 1976 and many drawings and figures related to seismicity for the purpose of evaluating earthquake risk were published.

Fig. 2.1 Distribution of Maximum Magnitude Recorded.

Figure 2.1 and Fig. 2.2 show the distribution of maximum seismic magnitude and meizoseismic areas in each region. Figure 2.1 shows that the areas of high seismic activities are distributed widely around the Aegean Sea, while the seismic activity distribution in Romania is extremely localized and limited to the Vrancea Region and adjoining areas.

When viewing the distribution of maximum seismic intensity, it is obvious from Fig. 2.2 that the distribution of maximum seismic intensity in excess of VIII covers a comparatively wider range of the area centering on the Vrancea Region in Romania than the other Balkan regions. It shows that the seismic activity in Romania is very special in nature. In other words, major seismic activity in Romania can be oreduced to moderately deep shocks originating deep underground in the Vrancea Region.

Figure 2.3, Fig. 2.4 and Fig. 2.5 shows the tectonics of Romania while Fig. 2.3 indicates the movements of the Quaternary Period and the distribution of recent thermal activity. Figure 2.4 illustrates the geological movements of the Quaternary and Pliocene Periods. Furthermore, Fig. 2.5 indicates the tectonic movements in light of the tectonic faults. Figure 2.11 shows the vertical movements obtained by recent levellings. From these figures, it is apparent that, from a comparatively new geological period to the present era, the tectonic movements follow a particular pattern along the Carpathian Arc, although there may be regional differences pertaining to the scale of movements.

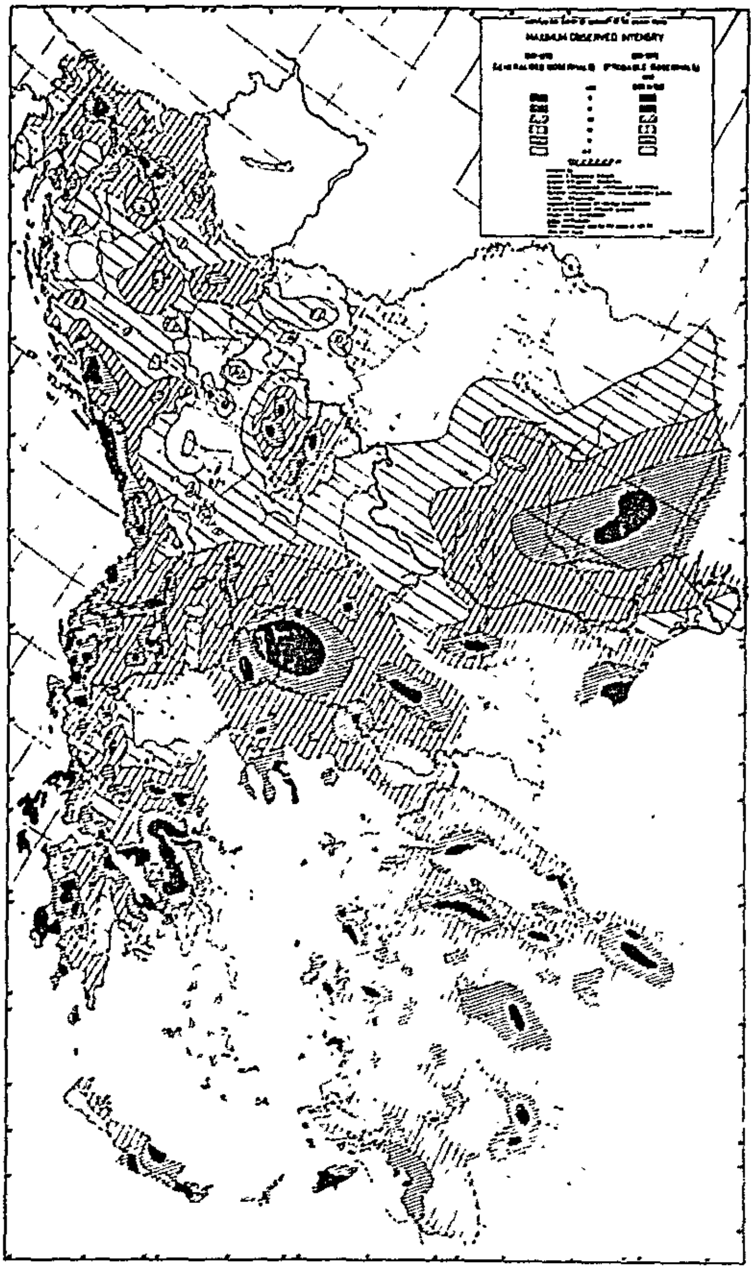


Fig. 2.2 Distribution of Meizoseismic Areas.

These tectonic movements are easily understood by the recent theary of plate tectonics. If we consider that there are three large plates interacting with each other under the Vrancea Region and adjoining areas, the phenomena of the depression and uplift in the Vrancea Region, the deep earthquakes originating directly underneath, the volcanoes inside the Carpathian Arc, the large attenuation of seismic waves and the large thermal flow, it is obvious that they all reflect the plate movements underneath the Vrancea Region.

And all these phenomena can be explained as the results of the plate movement depressing towards the northeast.

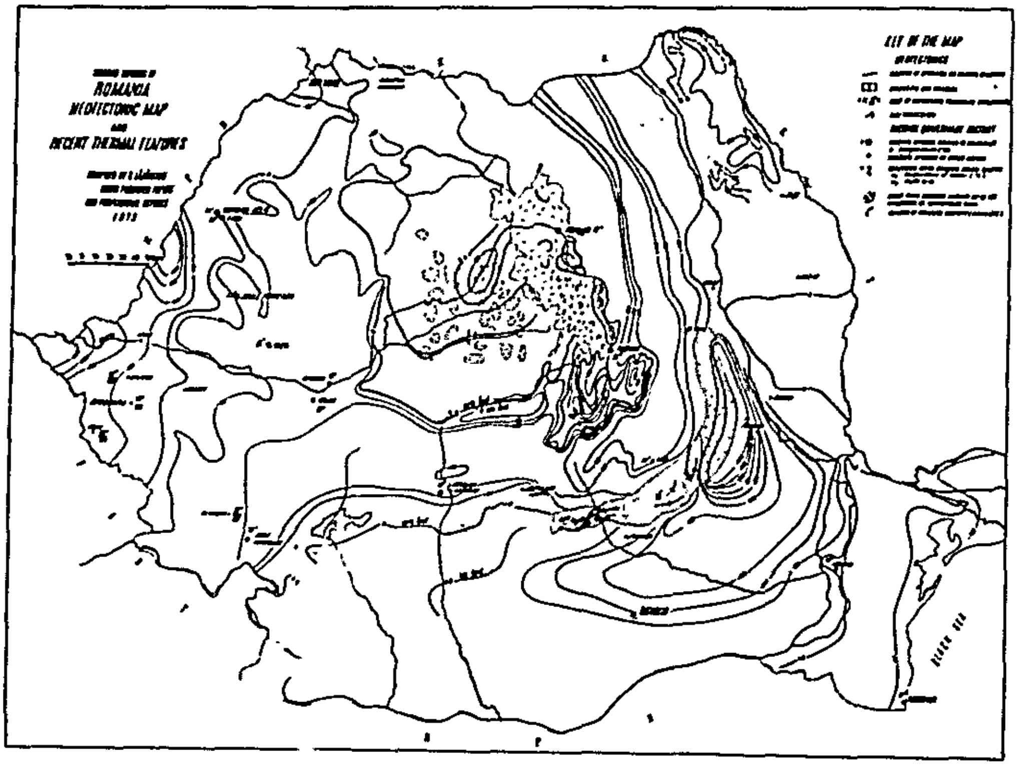


Fig. 2.3 Neotectonic Map and Thermal Distribution.

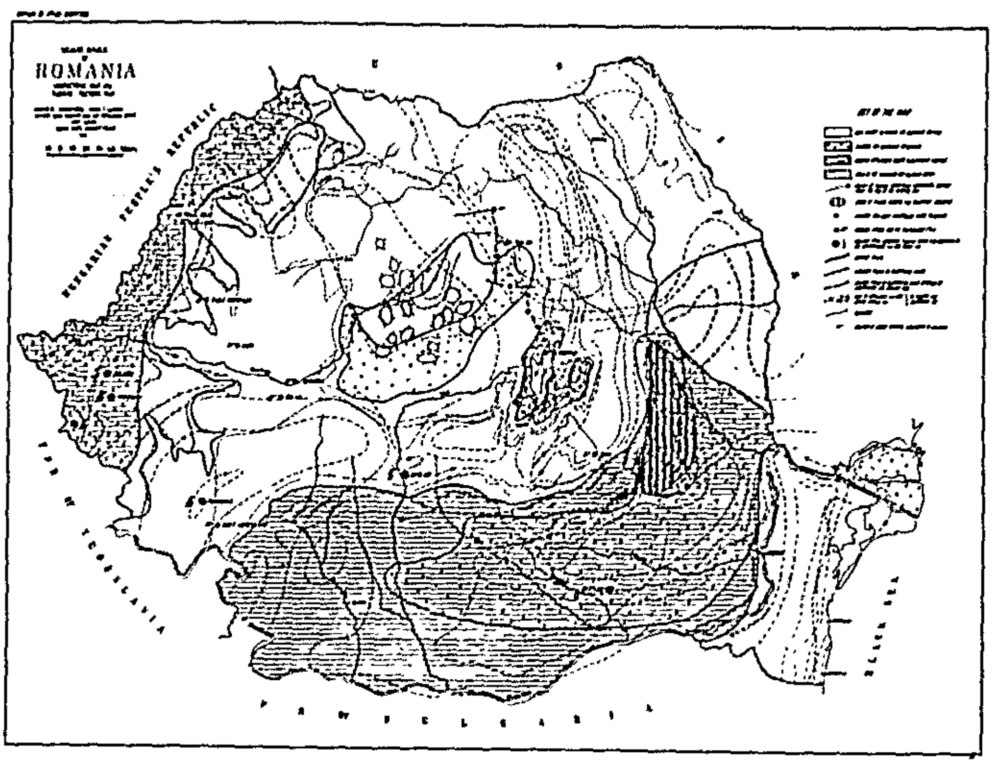


Fig. 2.4 Neotectonic Map and Tectonic Map of the Pliocena Period.

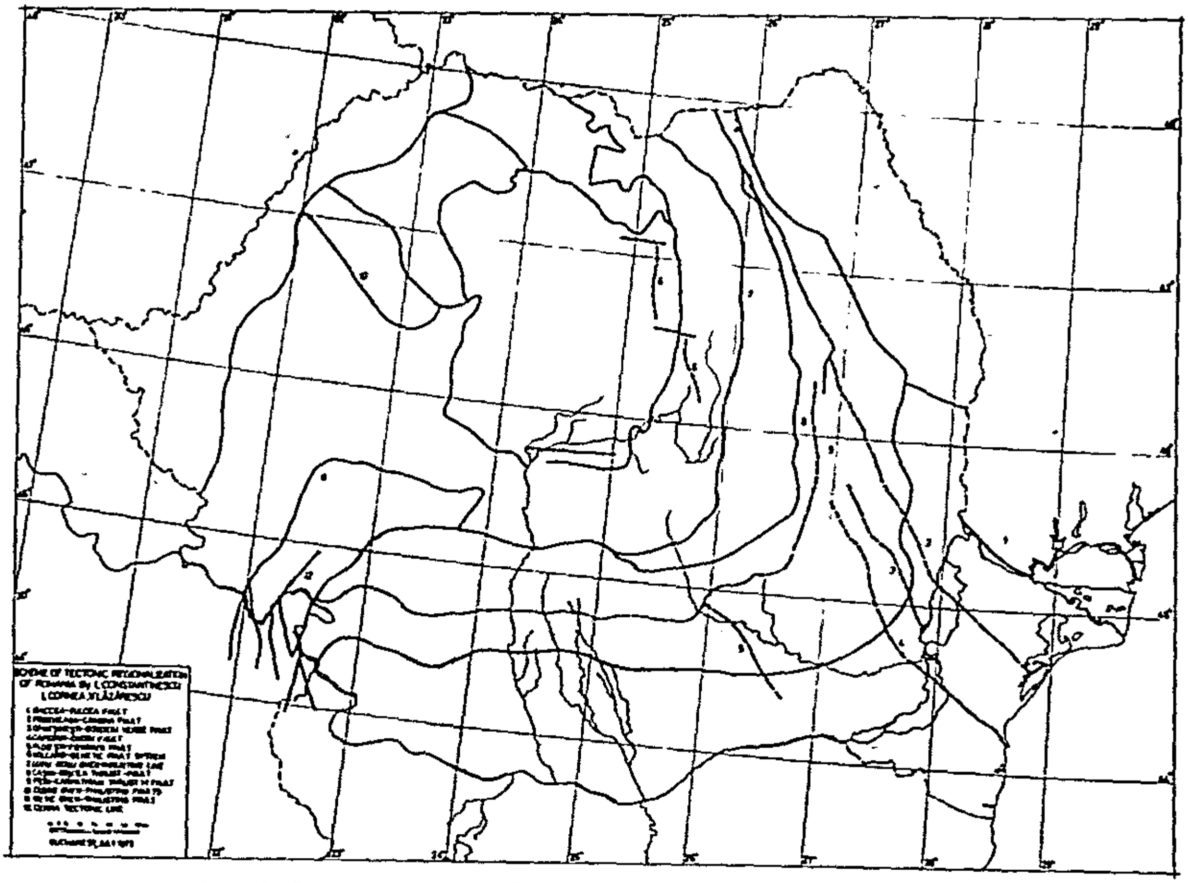


Fig. 2.5 Division of Tectonic Movements in Romania.

2.2 Seismicity of Romania

Earthquakes in Romania are roughly classified into two types: moderately deep focus earthquakes occuring in the Vrancea Region and shallow focus earthquakes common in the other districts of Romania. Each of these two types of earthquakes has its own important significance.

First, moderately deep focus earthquakes, as shown in Fig. 2.2, belong to the group large magnitude quakes in Romania. Hence, as Fig. 2.2 shows, these moderately deep shocks cause the largest seismic intensities in this country.

Figure 2.6 indicates the epicenters of earthquakes which occured during the period 1964 to 1976. The epicenters are clustered in an area between 45° and 46° North and between 26° and 27° East. They are all of the moderately deep earthquake type. The other epicenters are of the shallow focus earthquake type. The number of the former is far greater than that of the latter.

The vertical distribution of the earthquakes in Fig. 2.6 projected along the dotted line is as shown in Fig. 2.7.

Note that the epicenters are concentrated in a limited area and at depths a little deeper than 150 km.

Earthquakes shown in Fig. 2.7 are all considered to be greater than Magnitude 4. However, as shown in Fig. 2.6 and Fig. 2.7, a large number of earthquakes of less Magnitude 4 were also recorded. Records at both the Cheia and Vrancea Seismological Observation Stations also testify to this fact. Both stations have been equipped with seismographs of 2 ∿ 5 x 10^4 magnification since before March 1977. These seismometers have recorded 150 ∿ 200 minor tremors lasting from 2 ∿ 3 seconds to about 15 seconds in terms of S-P time.

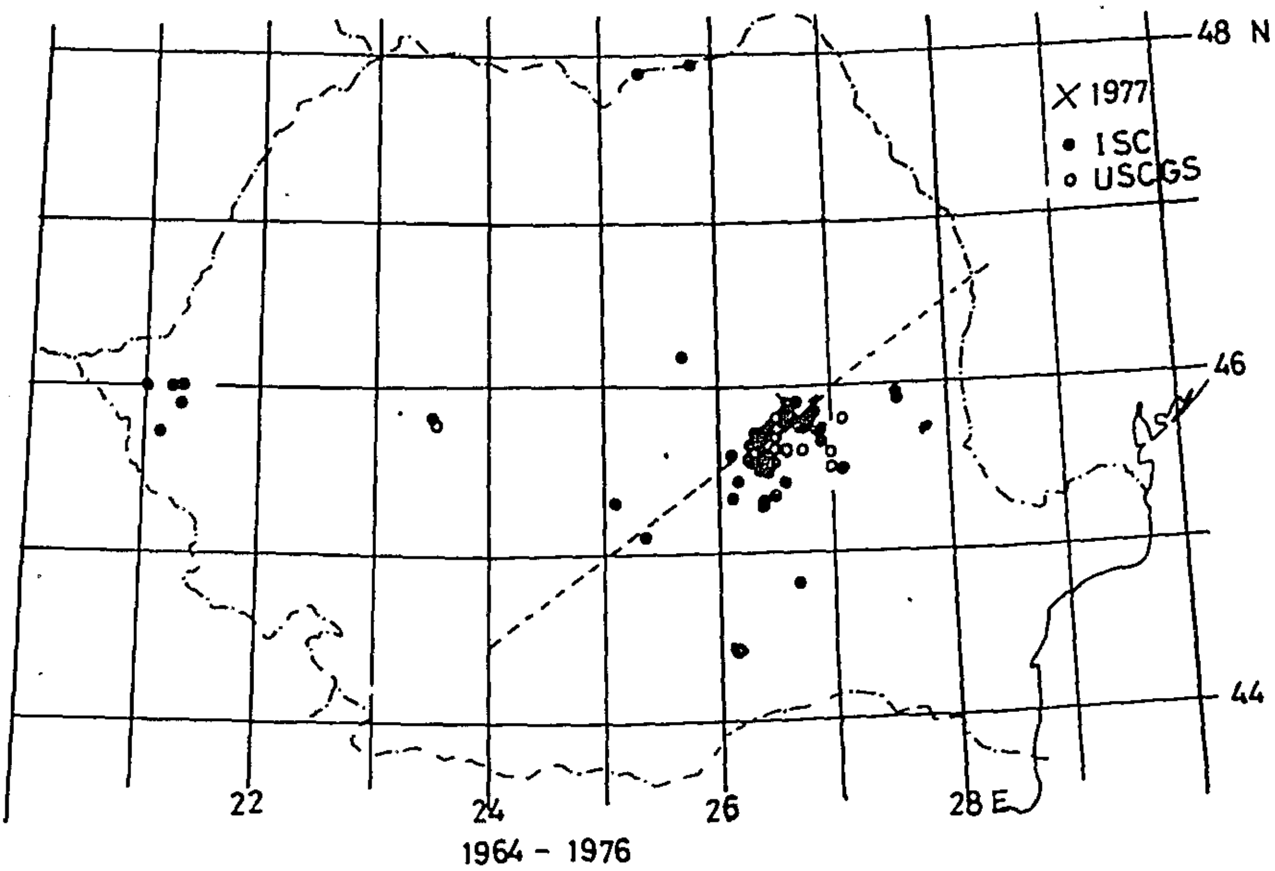


Fig. 2.6 Distribution of M≥4 Earthquakes in Romania (1964 ∿ 1976)

(After Meteorological Agency, Japan)

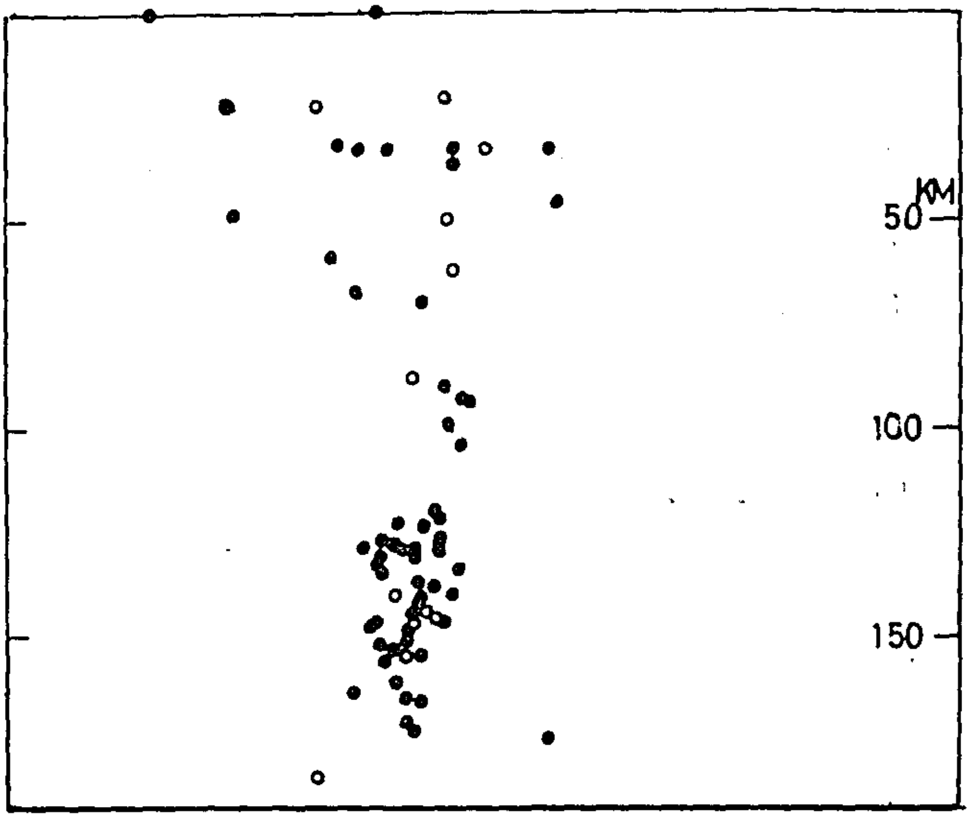


Fig. 2.7 Vertical Distribution of $M \geq 4$ Earthquakes projected along the dotted line of Fig. 2.6. (1964 ∿ 1976)

(After Meterological Agency, Japan)

As these earthquakes are small in scale, it is quite difficult to pinpoint the exact positions of the hypocenters. But from the S-P distribution, these earthquakes obviously occupy about the same space distribution as $M \geq 4$ earthquakes. In regard to seismic observation stations, refer to Fig. 2.13.

In regard to shallow focus earthquakes occurring in Romania, Fig. 2.1 shows that they are frequent in a limited area. Almost all of these shallow focus earthquakes exceed Magnitude 5.5. Figure 2.2 indicates that the seismic intensities of these shallow earthquakes at the epicenters exceed 7. (MM)

Although shallow focus earthquakes do not occur frequently, there is no guarantee that shallow focus earthquakes will not occur outside the areas shown in Fig. 2.1. Actually, on April 20th, a perceptible earthquake was recorded in Bucharest with the hypocenter roughly 30 km north of the city. This type of an earthquake was the first recorded by the surrounding network of observation stations since their establishment.

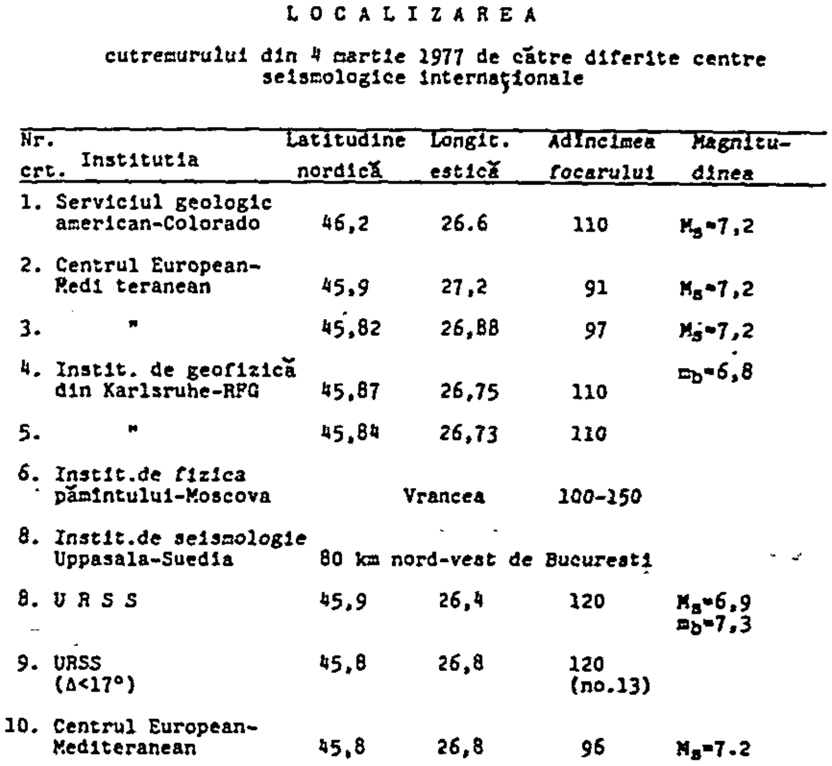
Even in this earthquake-phone nation of Japan, there are many inland and coastal areas where devastating earthquakes have never occurred. And there are many areas in Japan where disastrous earthquakes have occurred only once in history. From these facts, it may be hasty to conclude that shallow focus earthquakes that are frequent in inland Romania always occur in limited areas.

2.3 The March 4, 1977 Romanian Earthquake

2.3.1 General Condition

On March 4, 1977, at 21:22 hours Local Standard Time, a strong tremor was felt in an extensive area centered in Romania. The epicenter and magnitude of the earthquake were as listed in Table 1.

Table 1: The Epicenter, Depth and Magnitude of the March 4, 1977 Romanian Earthquake Determined by a Network of Stations.



LOCALIZAREA

cutremurului din 4 martie 1977 de către diferite centre seismologice internaţionale

Nr. crt.	Institutia	Latitudine nordică	Longit. estică	Adîncimea focarului	Magnitudinea
1.	Serviciul geologic american-Colorado	46,2	26.6	110	M_s=7,2
2.	Centrul European-Medi teranean	45,9	27,2	91	M_s=7,2
3.	"	45,82	26,88	97	M_s=7,2
4.	Instit. de geofizică din Karlsruhe-RFG	45,87	26,75	110	m_b=6,8
5.	"	45,84	26,73	110	
6.	Instit.de fizica pămîntului-Moscova		Vrancea	100-150	
8.	Instit.de seismologie Uppasala-Suedia	80 km nord-vest de Bucureşti			
8.	U R S S	45,9	26,4	120	M_s=6,9 m_b=7,3
9.	URSS (Δ<17°)	45,8	26,8	120 (no.13)	
10.	Centrul European-Mediteranean	45,8	26,8	96	M_s=7.2

As shown by this Table, seismic observatory stations in the United States, Europe, West Germany, and the Soviet Union have each determined the epicenter factors of the subject earthquake.

However, the factors listed in item No.5 of the Table as 26.73° East, 45.84° North, depth 110 km and magnitude 7.2 are the most reliable because they are the results of abundant data collected from the network of stations in Romania.

As will be explained later, there is no system in Romania today for the prompt colection and analysis of seismic data. The country relies on other networks of stations in determining seismic epicenters. Therefore, it is extremely confusing when a large earthquake occurs in the country. Actually, this March 4th Romanian, Earthquake did confuse seismologists in Romania, delaying them in the determination of the epicenter until the following morning.

As the determination of the location and depth of an epicenter is extremely important in predicting aftershocks and magnitudes, steps must be taken immediately to realize a system for the prompt determination of the epicenters of earthquakes.

2.3.2 The Characteristics of the 1977 Romanian Earthquake

This Romanian Earthquake occured on the surface of a depressing plate at a depth 110 km underground with intensity of Magnitude 7.2.

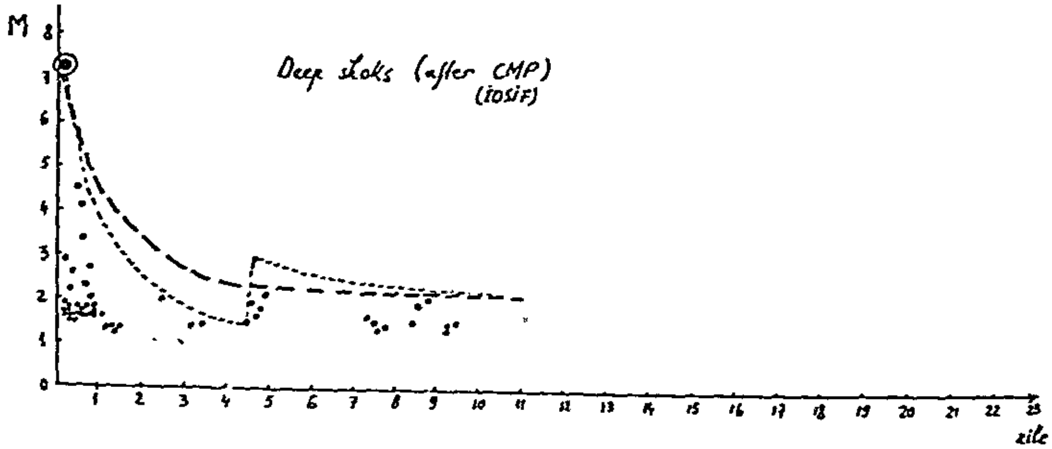


Fig. 2.8 Aftershocks of the March 4, 1977 Romanian Earthquake Observed at the Camplung Station.

As observed in the studies of Romanian seismologists, the earthquake mechanism on the surface of these moderate depth shocks is characterized by the existence of a down-dip compression force. The amplitudes of the corresponding P wave and S wave have directionality.

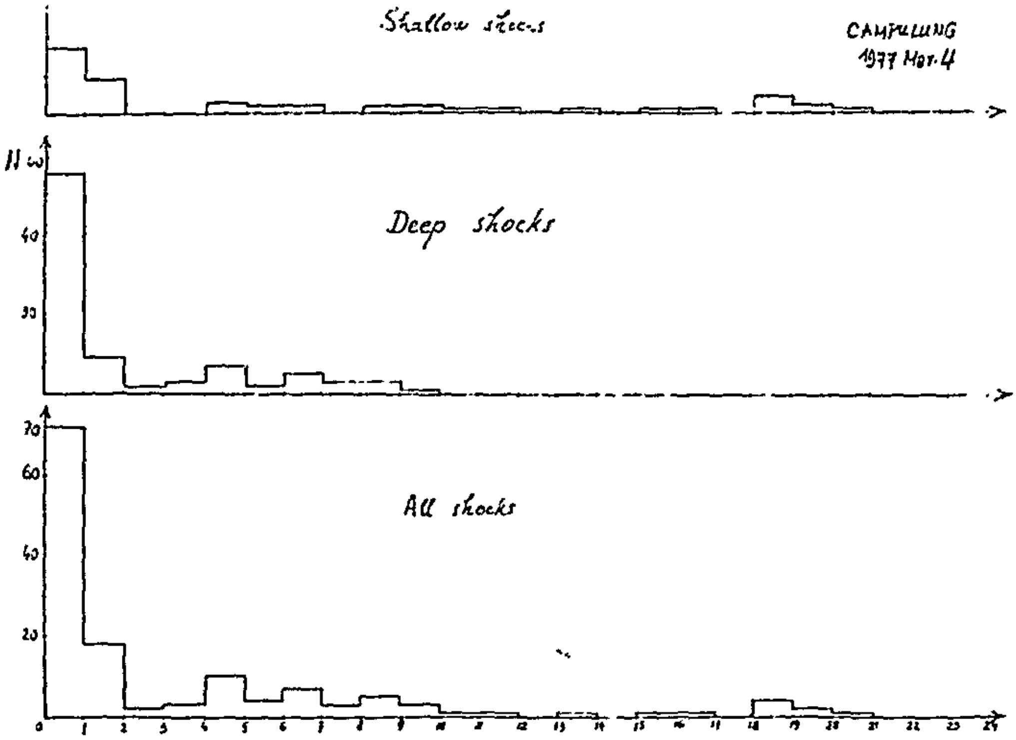
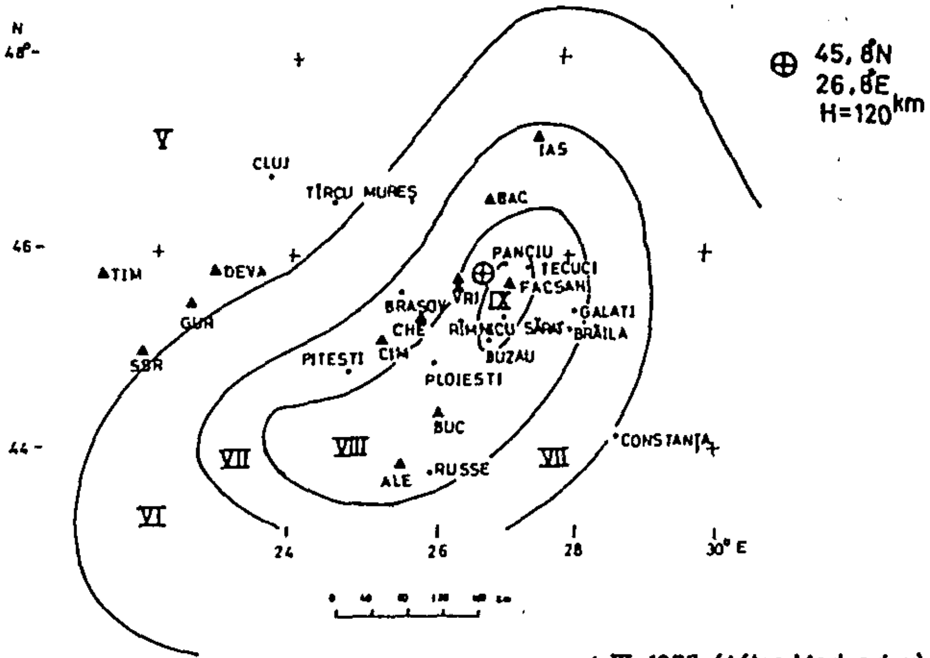


Fig. 2.9 Aftershocks of the March 4, 1977 Romanian Earthquake (Moderate depth shock and shallow focus earthquake) observed by CMP

Figure 2.10 and Fig. 2.11 respectively show the isoseismal distributions of earthquakes in 1977 and in 1940 indicating that the distribution of seismic intensities bears a directional characteristic towards the southwest from the northeast.



4 III 1977 (After Medvedev)

Fig. 2.10 Aftershock Distribution of the March 4, 1977 Romanian Earthquake Observed from Medvedev.

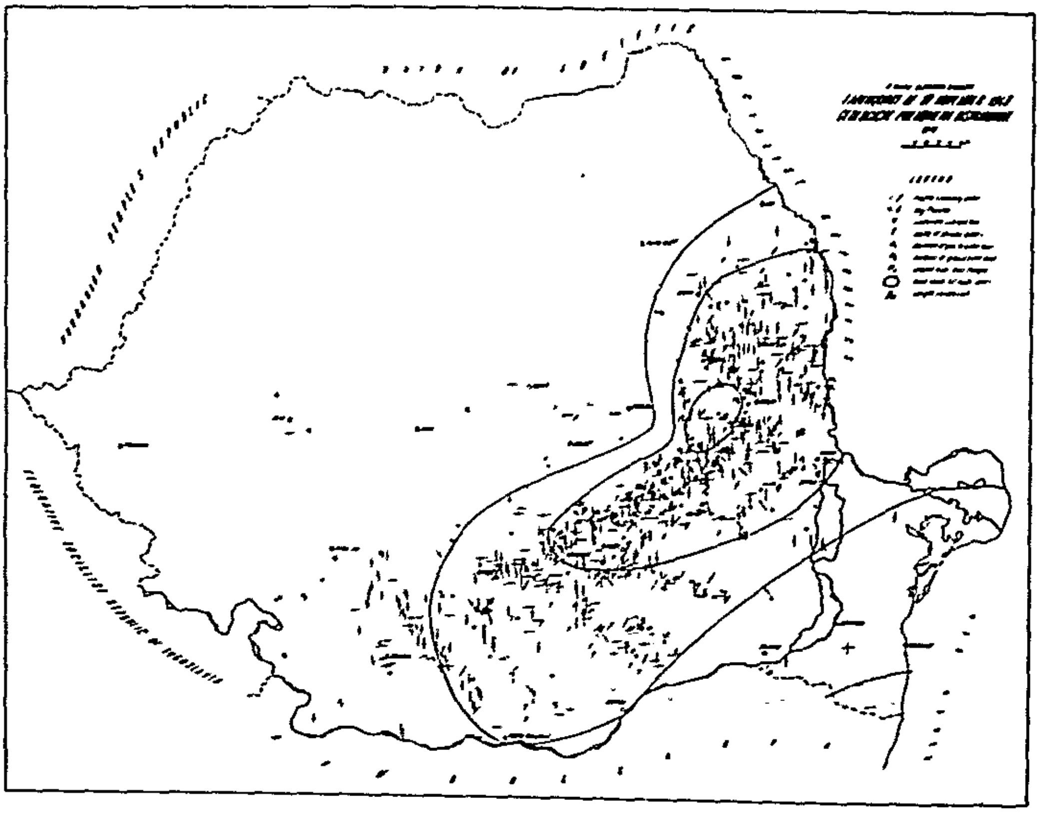


Fig. 2.11 Seismic Intensity Distribution of 1940 Romanian Earthquake.

This characteristic corresponds closely with the S wave amplitude direction considering down-dip compression force activated on the surface of the depressing plate.

Actually, in Bucharest, the accelerometer record shows an excessively large S wave amplitude in relation to that of the P wave (about 200 gal.).

2.3.3 Foreshocks and the subject Earthquake

Until February, or immediately before the occurrence of the subject earthquake, reports say that seismic activity drastically declined in the Vrancea Region. Statistical analysis in the near future may determine the reasons.

Figure 2.8 and Fig. 2.9 indicate aftershocks activity. Figure 2.9 shows the seismic activities, including the shallow focus earthquakes, after the subject earthquake. Figure 2.9 illustrates that the characteristic aftershock activities, unlike those in shallow focus earthquakes do not last long and resemble with those in the case of a deep earthquake.

Furthermore, after the subject earthquake, the shallow earthquake zone. We must wait for further studies to disclose the relationship between this phenomenon and the subject earthquake.

2.3.4 Others

Presently questionaires are being distributed to all those concerned in regard to the study of precursory phenomenon and observation of surface abnormalities of surface phenomena after the subject quake.

The sand blowing phenomenon reported in 1944 was also confirmed near Bucharest in 1977.

2.4 Recurrence Time of the Romanian Earthquake

It is commonly thought that earthquakes in general occur repeatedly in the same area. The interval between earthquakes is called "recurrence time". However, we must note here that "recurrence time" is not synonymous with "period".

As explained in Section 2.2, devastating earthquakes in Romania only occur in the Vrancea Region and the epicenters are located at depths of between 20 and 120 km. Thus, they are moderately deep shocks.

Records of earthquakes in this category date back to the 15th century in Romania. According to these records, the predominant periods of all these seismic activities are longer than one second, which indicates that they were all moderately deep shocks in the Vrancea Region.

Table II lists the dates and maximum intensities (MM) of devastating earthquakes that occured in the past in Romania. In 450 years, 29 major earthquakes were recorded in that country.

Maximum intensity of IX corresponds to a little over Magnitude 7. Hence, there were 7 earthquakes during this period that were recorded as over 7 or near 7 (Seismic intensitites VIII ∿ IX) in Magnitude.

Table II: Earthquakes of Intensity or More VII in Magnitude in the Vrancea Region Since 1491.

TABLE I

	INTENSITY	NUMBER
1491	VIII	1
1516	IX	1
1543-1545	VIII	2
1569	VIII	1
1590	VIII-IX	1
1604-1606	VIII VII-VIII	2 1
1620	VII-VIII	1
1637	VII-VIII	1
1679-1681	VIII	2
1701	VII-VIII	1
1738	VIII-IX	1
1778-1793	VIII VII	1 3
1802	IX	1
1892	VIII-IX	1
1868	VII-VIII	1
1893-1896	VII	4
1908	IX	1
1940-1945	IX VII-VIII	1 1

Careful study of this Table also reveals that earthquakes of Magnitude 6 class tend to occur in pairs. In some instances, three or four such earthquakes occured in two to three years. However, earthquakes more than 7 in magnitude seem to occur alone.

In any case, when a moderate deep focus earthquake occurs, preparations must be made in the expectation that other earthquakes to follow.

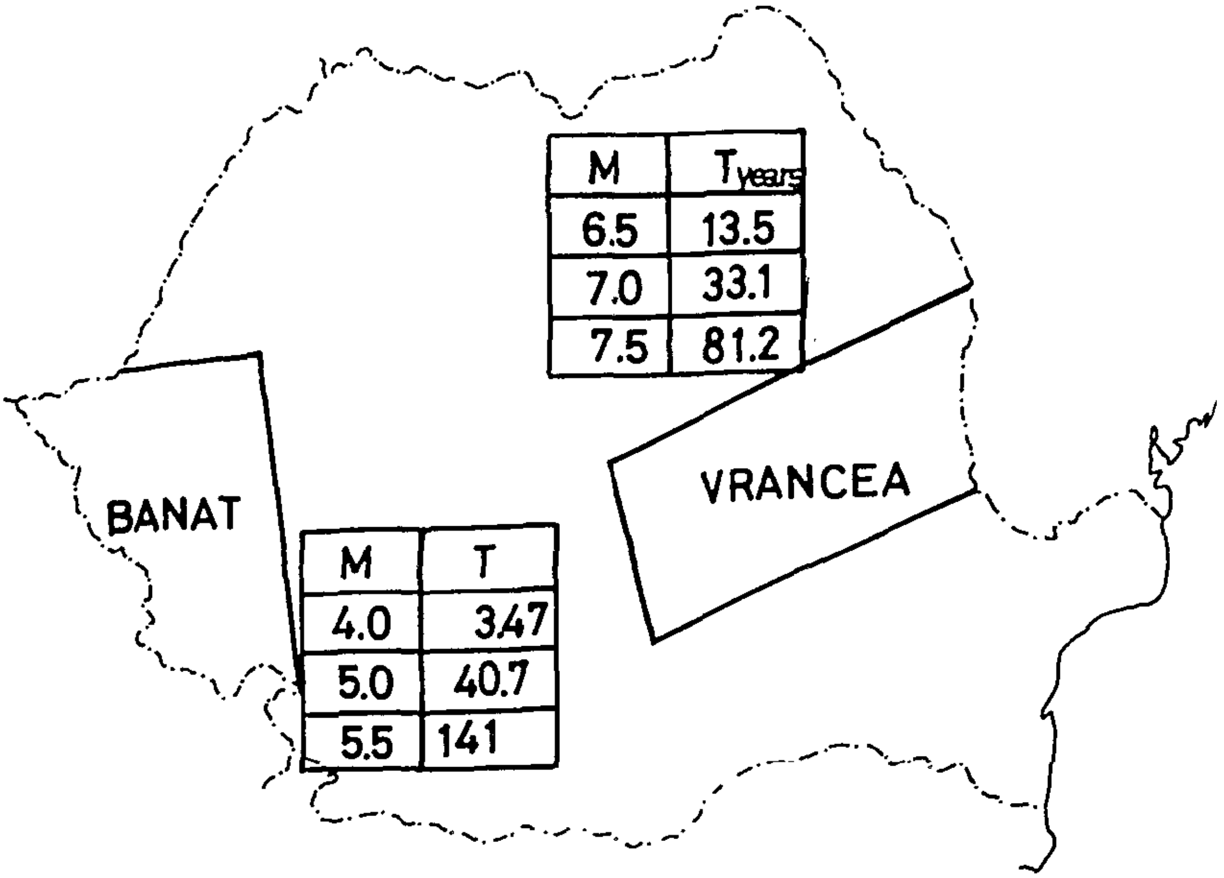


Fig. 2.12 Recurrence Time in the Vrancea and the Banat Regions in Romania.

According to statistical observations made by seismologists in Romania, the recurrence time of Magnitude 7 class earthquakes in the Vrancea Region is 30 years.

Of course, it must be noted that "30 years is only significant as a probability. Generally, seismologists in Romania believe that a devastating earthquake occurs two to three times in every 100 years. If the meaning of 'devastating' is to be defined in a stricter sense, a devastating earthquake occurs once or twice in a century.

According to another study of shallow depth focus earthquakes in the Banat Region, Magnitude 5 class earthquakes occur once in every 40 years. If this rate is extrapolated, it means Magnitude 6 class earthquakes would occur once in every 300 ∿ 400 years.

Although this kind of extrapolation poses some problems, it is prudent to expect large scale shallow focus earthquakes of Magnitude 6 or more to occur in the future.

Fig. 2.13 Distribution of Seismic Observation Stations and Temporary Observation Points.

CHAPTER 3 SEISMOLOGICAL RESEARCH ACTIVITIES IN ROMANIA

3.1 Organization of Seismological Research

Table 3.1 shows the organization of seismological and related geophysical research acitivities in Romania. The organization underwent a large-scale change recently.

Table 3.1 Organization I

STATE COMMITTEE FOR NUCLEAR ENERGY (CSEN)

Central Institute of Physics

1

2

3

4 Institute of Earth Physics and Seismology
(12 seismological stations)

Director Corner Ion

- a) Seismological Laboratory:
  Chief: Dr. Radu Cornelius
- b) Geodynamics and Earth Tide Laboratory:
  Chief: Mr. Zogravescu Dorel
- c) Data Processing Laboratory
  Chief: Mr. Popescu Miron

MINISTRY OF MINES, PETROLEUM AND GEOLOGY

Institute of Geology and Geophysics

The Institute of Earth Physics and Seismology belonging to the Central Institute of Physics was inaugurated only two months prior to the subject earthquake.

Table 3.2 Organization II

Before 1970	The Center of Geophysical Research with 4 laboratories. The Director was Prof. C. Constantinescu. The seismological laboratory was composed of two sections headed by Dr. Radu and Dr. Iosif respectively.
1970	Institute of Applied Geopjusics Dr. Cornea served as Vice-Director. There were 6 laboratories. The Seismology Laboratory was headed by Dr. Enescu until 1972. After 1972, Dr. Cornea became the head. (Actually Dr. Radu was in charge.)
1974	Institute of Geology and Geophysics had 8 laboratories, including the Seismology Laboratory headed by Dr. Cornea.
1977	The Seismology Laboratory, elevated to the Institute of Earth's Physics and Seismology. The Director is Dr. Cornea.

Table 3.2 shows in detail the history of research organization. Similar to the earlier days of the seismology research organization in Japan and other countries, Romania, too, grouped seismology with geophysics, applied geophysics and geology to function as one. Furthermore, the number of seismological researchers was small.

In 1977, in conformity with the development of earth science, an independent seismological research institution was inaugurated.

This institution included a seismological laboratory, geodynamics and earth-tide laboratory and a data processing laboratory.

This institution was formed after thoroughly recognizing the significance of having an important research field inside the country after detecting a depressing plate in the Vrancea Region. The subject earthquake, serving as a turning point, is expected to prompt the advance of future seismological studies in the nation.

However, as shown in Table 3.3, there were only ten specialists at this Seismological Laboratory which has a long history. Other related laboratories have adequate room for more equipment and personnel.

It is most urgent to train specialists in that country to reinforce seismological studies.

Table 3.3 Current Organization of Earth Physics and Seismology Laboratories in Romania

Institute of Earth Physics and Seismology

Director: Dr. Ion Cornea

1) Seismological Laboratory

Chief : Dr. Radu Cornelins

Members: Dr. Losif Traian
Dr. Enescu D.
Mr. Jianu Dumitri
Mrs. Iosif Sieglinde
Mr. Marza Vasile
Mrs. Apopei Ioana
Mr. Pantea
Mr. Voiculescu Dan
(Electronics Engineer)

Cheia Seismic Observation
Station Chief:
Dr. Fânta nâ constantin

2) Geodynamics and Earth Tide

Mr. Zogranescu Doral

3) Data Processing, etc.

Mr. Popescu Miron

As shown in Table 3.1 in the field of seismology, the Institute of Geology and Geophysics (The Ministry of Mines, Petroleum and Geology) corresponds to the Geological Survey in Japan. This institute is grapping with the task of developing underground (natural) resources through studies of the earth's crustal structure, etc. In this institute, there are about 70 geologists, 20 geochemists and about 60 physicists and computer engineers engaged in the study of geophysics fields. There are about 150 people, chiefly geologists, who are conducting research to develop energy resources, including prospecting of oil deposits. They are also exporting some of their technical know-how abroad.

It was interesting to learn that the geologists were engaged in a national project of boring an 8,000 m deep well.

As previously mentioned, both the Institute of Earth Physics and Seismology and the Institute of Geology and Geophysics have departments to conduct basic research similar in nature.

These departments can serve important roles in developing studies of earthquakes and related subjects.

3.2 Seismic Observation Network

The history of seismic observation in Romania dates to the Year 1902 when the first observation station was established in Bucharest as shown in Table 3.4.

Over the years, more stations were established around the Vrancea Region to conduct seismic observation.

Table 3.4 History of Seismic Observation Network in Romania

(Walachia and Moldavia)

1902	Bucharest Seismic Observation Station was established by astronomer Prof. Cioculescu.
1916	The station introduced Galitzin seismometers.
1933	Physicist Prof. Demetrescu was appointed director of the station.
1940	New observation stations were completed in Iasi, Cimplung and Focsani.
1965	A new station was built in Vrincioaia.
1970	A new station was built in Deva.
1973	A fully modernized station was completed in Cheia.
(Transylvania)	
1930	A new station was built in Cluj-Napoca.
(Banat Region)	
1940	A new station was completed in Timisoara.
1960	A new station was completed in Susara.

The Cluj-Napoca Observation Station constructed in 1930 to observe seismic activities in Transylvania was moved to Timisoara in the Banat Region in 1940 to continue observation.

Presently, as shown in Fig. 14, there are twelve major seismic observation stations in Romania.

However, the March 4, 1977 Romanian Earthquake prompted the construction of many temperorary observation points that are still continuing observation work.

Professor Fuchs of West Germany had been conducting seismic observations at three dam sites to study inducted earthquakes caused by water level changes. However, after the subject 1977 Earthquake, he promptly established 10 temporary observation points including some employing simple wireless telemeter methods. His group is cooperating closely with local specialists for aftershock observation.

While donating four sets of three-component seismometers to Romania, China is continuing observation in the country from its previously established station and temporary observation points.

The Soviet Union, too, is also helping Romania by sending technicians for maintenance of Soviet made seismometers installed in the country.

The Japanese specialists group also recorded micro-earthquakes for 8 days. University of Tokyo-Faculty of Science-Type Seismometers (converting ocean bottom seismometers into land type) at points indicated in Fig. 2.13. We are now in the process of playing back our recordings.

Table 3.5 and Table 3.6 show the list of seismometers employed in each station.

Table 3.5 List of Seismometers at Each Earthquake Observation Station in Romania.

Station	Vegik-M	Mainka Modif.	Galitzin	Kirnos SKD	Hiller	DD1	SKM-3	Sprengnether	Geotech	Acceleration Seismograph
1)Bacau	3	2								
2)Bucurest		2	2	3						
3)Campulung		2			3					
4)Deva	3			3						
5)Pocsani	2	2			1					
6)Iasi	3	2		1						
7)Vrincioaia	3	2				3				
8)Cheia				3		3	6	3		6
9)Susara	3									
10)Timisoara		4		3						
11)Gurazlata						3				
12)Alexandria										3
13)Magurele						3				
14)Arges									1	
15)Bicaz									1	
16)Lotru									1	

Table 3.6 List of Seismic Observation Stations in Romania

STATION	SEISMOGRAPH		Ts	Tg	MAGNIFICATION	REMARK
LOCATION						
1) BACAU (BAC)						
46°34'N	VEGIK-M	Z	1.5	0.4	1,000	
26°54'E	VEGIK-M	E	1.5	0.4	1,000	1965
167.5M	VEGIK-M	N	1.5	0.4	1,000	
ALUVIUM	MAINKA MODIF.	E	3.5	-	58	1942
	MAINKA MODIF.	N	3.5	-	58	(1958)
2) BUCURESTI (BUC)						
44°24.5'N	MAINKA MODIF.	E	10.0	-	226	1935
26°05.8'E	MAINKA MODIF.	N	10.0	-	226	
82.5M						
ALUVIUM	GALITZIN	E	12.0	12.0	1,000	1937
	GALITZIN	N	12.0	12.0	1,000	
	KIRNOS-SKD	Z	12.5	3.0	410	1964
3) CIMPULUNG (CMP)						
45°16.1'	HILLER	Z	1.5	1.5	2,000	1965
25°02.3'	HILLER	E	1.5	1.5	2,000	1969
598M	HILLER	N	1.5	1.5	2,000	
ALUVIUM						
	MAINKA MODIF.	E	3.5	-	58	1943
	MAINKA MODIF.	N	3.5	-	58	
4) DEVA (DEV)						
45°53'N	VEGIK-M	Z	1.0	0.4	15,000	1971
22°54.2'	VEGIK-M	E	1.1	0.4	15,000	1972
250M	VEGIK-M	N	1.1	0.4	15,000	
ANDESITE						
	KIRNOS-SKD	Z	25.0	1.2	1,000	
	KIRNOS-SKD	N	25.0	1.2	1,000	
	KIRNOS-SKD	E	25.0	1.2	1,000	
5) FOCSANI (FOC)						
45°41.7'N	HILLER	Z	1.5	1.5	1,800	1964
27°11' E	VEGIK-M	Z	1.0	0.4	550	1975
61M	VEGIK-M	N	1.0	0.4	1,000	1971
ALUVIUM						
	MAINKA MODIF.	E	3.5	-	58	1942
	MAINKA MODIF.	N	3.5	-	58	1952
6) IASI (IAS)						
47°11.6'N	VEGIK-M	Z	1.5	0.4	1,000	
27°33.7'E	VEGIK-M	E	1.0	0.4	1,000	1964
400M	VEGIK-M	N	1.0	0.4	1,000	
ALUVIUM						
	MAINKA MODIF.	E	4.8	-	170	1951
	MAINKA MODIF.	N	4.8	-	170	
	KIRNOS-SKD	Z	25.0	1.2	1,000	1972
7) VRINCIOAIA (VRI)						
45°52.2'N	VEGIK-M	Z	1.0	0.4	25,000	1967
26°43.5'E	VEGIK-M	E	1.0	0.4	21,000	1975
400M	VEGIK-M	N	1.0	0.4	15,000	1969
ALUVIUM						
	MAINKA MODIF.	E	3.5	-	58	1952
	MAINKA MODIF.	N	3.5	-	58	1964
	DD1	Z			100,000	1977
	DD1	E			100,000	1977
	DD1	N			100,000	1977
8) CHEIA (CHE)						
45°29.5'N	SKM-3	Z	2.0	0.7	50,000	1974
25°56.6'E	SKM-3	E	2.0	0.7	25,000	
1360M	SKM-3	N	2.0	0.7	28,000	
LIMESTONE	SKM-3	Z	1.0	0.5	55,000	1975
	SKM-3	E	1.0	0.5	62,000	
	SKM-3	N	1.0	0.5	61,000	
	SPRENGNETHER	Z	1.5	90.0	1,600	1975
	SPRENGNETHER	E	1.5	90.0	1,600	
	SPRENGNETHER	N	1.5	90.0	1,600	

Table 3.6 (conti.) List of Seismic Observation Stations in Romania

STATION	SEISMOGRAPH		Ts	Tg	MAGNIFICATION	REMARK
	SKD	Z	25.0	1.2	1,000	1975
	SKD	E	25.0	1.2	1,000	
	SKD	N	25.0	1.2	1,000	
	ACCELERATION SEISMOGRAPH		(USSR)			
	ACCELERATION SEISMOGRAPH		(USA)			
	DD1	Z			200,000	1977
	DD1	E			200,000	
	DD1	N			200,000	
9) SUSARA (SSR)						
44°51.1'N	VEGIK-M	Z	1.5	0.2	5,690	1969
21°44.6'E	VEGIK-M	E	1.5	0.2	5,690	
400M	VEGIK-M	N	1.5	0.2	5,400	
ORESIL						
10) TIMISOARA (TIM)						
45°44.2'N	MAINKA MODIF.	E	8.0	-	197	1943
21°13.3'E	MAINKA MODIF.	N	8.0	-	197	1951
88M	MAINKA	NE	4.2	-	86	1964
ALUVIUM	MAINKA	NW	4.2	-	86	
	SKD	Z	25.0	1.2	500	1968
	SKD	E	25.0	1.2	500	
	SKD	N	25.0	1.2	500	
11) GURAZLATA						
	DD1	Z			100,000	1977
	DD1	E			100,000	
	DD1	N			100,000	
12) ALEXANDRIA						
	ACCELERATION SEISMOGRAPH					
13) MAGURELE						
	DD1	Z			2,000	1977
	DD1	E			2,000	
	DD1	N			2,000	
14) ARGES (ARS)						
45°22.1'N	GEOTECH S-13	Z	1.0		100,000	1975
24°38' E						
868M						
GENEISES						
15) BICAZ (BIC)						
46°56.3'N	GEOTECH S-13	Z	1.0		130,000	1975
26°06.2'E						
410M						
SEDIMENT						
16) LOTRU (LOT)						
(VIDRA)	GEOTECH S-13	Z	1.0		75,000	1975
45°26.9'N						
23°46.2'E						
1240M						
GNEISES						

As shown in these tables, the history of seismic observation in Romania is long. Therefore, the seismometers used in that country are varied and many are old-fashioned mechanical types that are more labor consuming than the self-recording types. It is desirable that efforts be exerted to modernize these instruments, including seismometers, recorders, etc.

Figure 2.13 shows tha present network of stations in Romania. Despite the large number of seismic observation stations, they are overly concentrated along the Carpathian Arc, centering around the Vrancea Region.

The devastating March 4, 1977 Romania Earthquake is of the moderate depth shock type, which is peculiar to the Vrancea Region. However, in order to investigate this type of earthquake in detail, it is absolutely necessary to precisely pinpoint the location of the ipicenter, especially the depth.

To solve this problem, we believe it is urgent to construct new seismic observation stations in the Transylvania Region and in the southeast region of Romania to reinforce studies of earthquakes in that country.

3.3 Geodetic Projects in Romania

We were unable to visit the official governmental organ in charge of geodetic works during our stay in Romania. Therefore, a summary of discussions with those concerned is described below.

First, the Romanian Army is responsible for national geodetic survey work. Within the organization of the Army are the Geodetic Institute run by civilians and the Topographic Division operated by the military. These two institutions work in close cooperation.

Triangulation and levelling are employed as the major methods of surveying the land. We were not informed of the densith and periods of repetition of surveying.

However, repeated levelling work must have been conducted to obtain the figures of vertical motion in Fig. 2.1.

We were told that levelling is conducted once every five years in areas where vertical motion is great, but this may have been a goal.

In regard to levelling routes, railroads are frequently used, in addition to highways. In flat lands, we often came across triangulation towers which were quite imposing.

Although it is within the limits of conjecture, it is unlikely that triangulation is repeated to survey the horizontal crustal movements.

At the previously mentioned Institute of Earth Physics and Seismology, there are also specialists in geodesics. These geodetic experts conduct levelling survey for seismological research especially to study in detail the vertical movements in the Vrancea Region. They are eager to establish a new tranverse levelling route across the center of the mountains. They also showed great interest in laser range finding.

Although lightwave or electro magnetic wave range finders are not employed for nationwide geodetic surveying, electro magnetic range finders are already in use in dam construction surveying by the Water Resource Corporation.

The nationwide surveying of gravity and magnetism is conducted by the Institute of Geology and Geophysics of the Ministry of Mines, Petroleum and Geology. The Institute also compiles data indicating abnormalities of all kinds which are not otherwise disclosed.

The survey of crustal movements by repeated levelling is essential for earthquake prediction. It is hoped that studies of earthquake prediction are advanced by exchanging data between the institutes concerned in close cooperation.

Supplement: Cheia Seismic Observation Station

The Cheia Seismic Observation Station was completed in 1973 as Romania's most advanced observation station, equipped with up-to-date facilities comparable to any in the world.

The station is situated in the Vrancea seismic zone, 120 km north of Bucharest and 30 km southeast of Brasov at an altitude of 1,500 m, and commands a majectic view of the surrounding areas.

The L-shaped observation tunnel is situated about 150 m from the station building.

The station has all kinds of seismographs as introduced in Table 3.2-1. Observation is conducted by employing the world's most advanced seismometers including the short-period, highly sensitive, long-cycle seismometers, etc.

The four staff members including the station chief and his wife conduct daily observations of 17 different components. They plan to include continuous observation of crustal movements in the future.

Photos 1 ∿ 6 show views of the station building, the interior of the station and a part of the L-shaped tunnel, etc. Here, highly advanced seismological observations are conducted daily under the leadership of the energetic director.

We hope that other seismic observation stations in Romania will be upgraded to the standard of the Cheia Seismic Observation Station to reinforce seismic observation network in Romania.

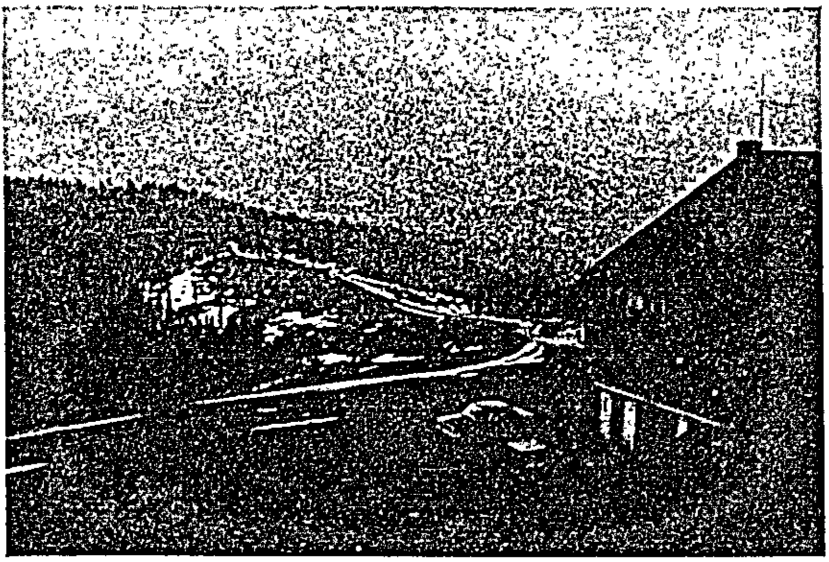


Photo 1 Cheia Station Viewed From the Entrance to the Observation Station

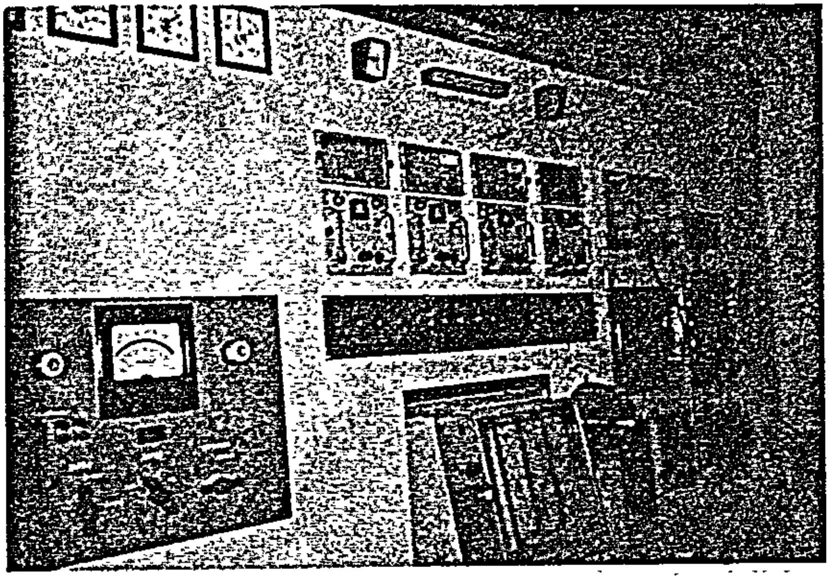


Photo 2 Time Pieces Indicating Romanian Standard Time Power Supply

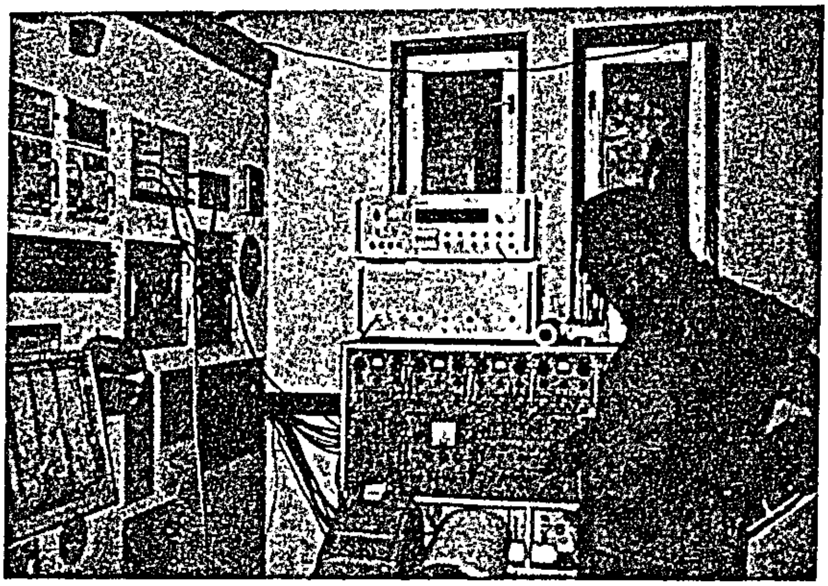


Photo 3 Crystal Time Piece & Seismic Wave Recorders

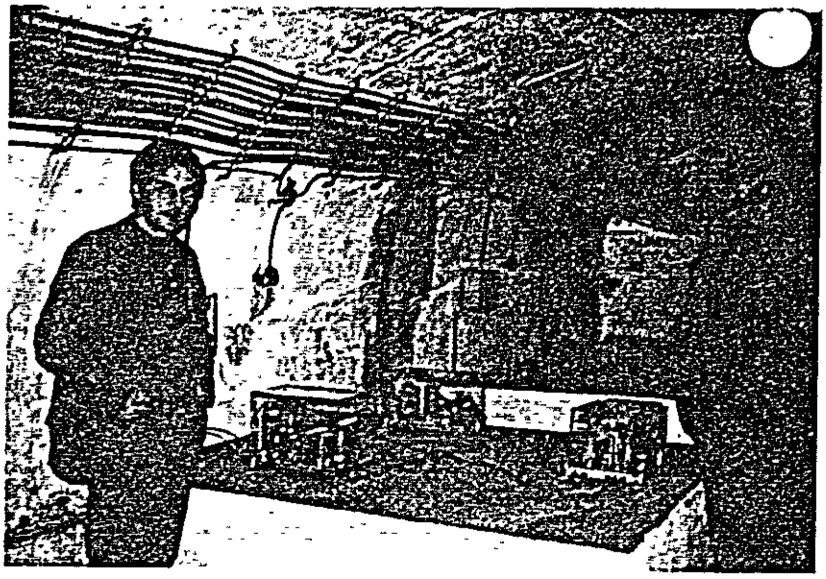


Photo 4 DDI (Made in China)

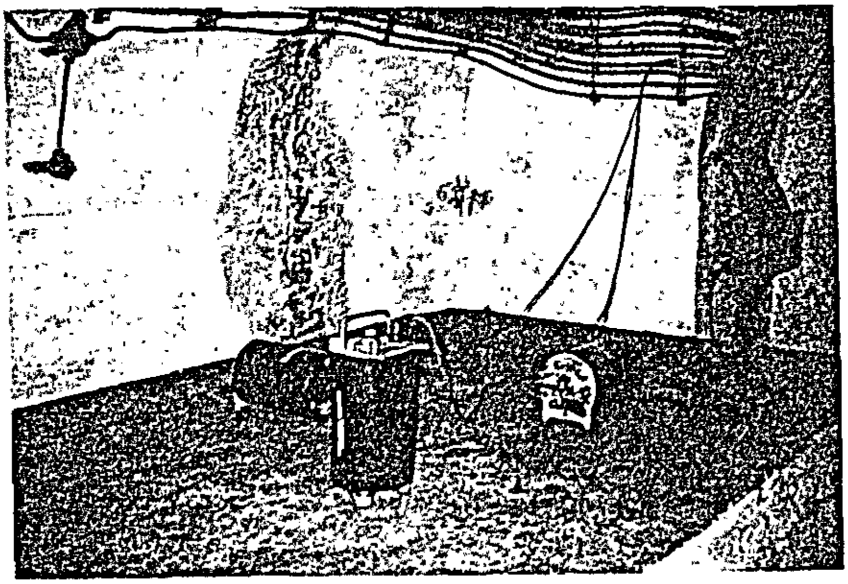


Photo 5 GEOTECH (Made in West Germany)

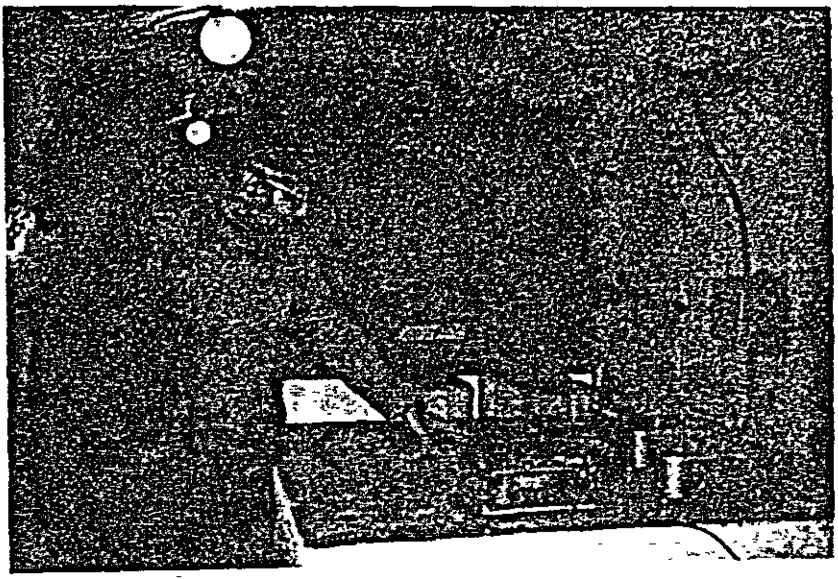


Photo 6 SKM (Made in the Soviet Union)

CHAPTER 4 THE PRESENT STATE OF ROMANIAN BUILDINGS

4.1 Outline of Romanian Buildings

Romanian buildings can be roughly classified into brick, reinforced brick and reinforced concrete structures. In the field of artistic design of buildings, architectural activities flourished from around the 14th century, centering on the construction of palaces and churches.

Current, architectural efforts are focused on large numbers of private houses, public facilities, cultural facilities, industrial plants, etc.

However, it was only recently that are among the many prominent architects, quakeproofing became an importatant consideration in Romanian architecture. In terms of quake-resistance, Romanian buildings can be broken down into the following four time categories.

1) Those built before 1940
2) Those built between 1941 and 1952
3) Those built between 1953 and 1962
4) Those built after 1963.

Buildings in the first category are mainly brick or reinforced brick structures and are medium in height, ranging from five to ten stories. These buildings were built with the main stress being given to their architectural design rather than structural planning. Aseismic considerations were practically non-existent.

The structural characteristics of these buildings can be summarized as follows.

(i) The arrangement of structural elements is extremely irregular. There are many cases in which reinforced concrete columns and beams, used to strengthen brick walls, were not joined together and do not form structural frames.

(ii) Some buildings have walls that can be regarded as aseismatic walls, but they were mostly placed not in the orthogonal disposition but in one direction only.

(iii) An earthquake in 1940 was felt strongly in Bucharest. The ground acceleration in this quake is estimated to have been 140 gal. Very few buildings that collapsed in the quake, but many buildings were cracked in such places as walls and lintels over the openings. These cracks were repaired temporarily and the buildings have been used up to now almost as they were.

For those buildings belonging to the second category, aseismic design was attempted due to the 1940 tremor. In areas with a high risk of earthquakes, including Bucharest, the horizontal seismic intensity used for design purposes was 0.1 against 0.05 for less risky zones.

However, the first half of this period overlapped the years of World War II so design standards were inadequate and construction activity was at a low point.

After 1945, construction activity began to boom, leading to standardization and industrial production of structural skeltons. Given below are the industrialized construction methods representative of this period.

(i) Five-storied large panel construction

(ii) Ten-storied large panel construction (Cast-in-place reinforced aseismic concrete walls were used in this method.)

(iii) Reinforced concrete construction by the sliding form construction method.

(iv) Field-cast reinforced concrete construction by metal form.

For those buildings in the third category, standardization of building construction and industrial production of materials since 1945 were extended further. But in this period there was some confusion over design values of seismic intensity.

The fourth and last period began in 1963 when the country's anti-quake regulations were promulgated. Contents of the regulations will be given in the next chapter. But under the regulations, the design horizontal seismic coefficient for a 10 storied apartment building was set at about 0.06, a value lower than that observed for buildings in the second time category.

Buildings constructed after World War Two generally have similar structural characteristics. Common problem areas in terms of aseismic characteristics are as follows.

(i) Many of those having aseismic walls lacked adequate joints between the walls and the frames.

(ii) Many buildings were designed to house shops in the first story with fewer aseismic walls than upstairs. Damage in this tremor was especially heavy in these parts of buildings.

(iii) Ample consideration was not given to the deformation of structural members at the time of an earthquake. Extensive use of bricks, concrete blocks and Siporex boards for outer walls, spandrels and partition walls tended to lead to damage to non-structural members.

In the fourth period, many industrial plants were constructed. Most of them are reinforced concrete or prestressed concrete structures. Precast elements were used widely in building the plants, e.g., precast-prestressed concrete beams for 12 to 16m-long beams and for the floor system, prestressed channel-shaped concrete slabs that can also serve as sub-beams. (See Photo 4.1)

These industrial plants, in many cases, are multi-storied to save space and buildings of six stories are not rare. Their floor load exceeds 1 ton for the installation of machine tools.

Photo 4.1 Industrial plant employing precast construction.

The above is an outline of Romanian architectural structures in terms of time periods.

The Romanian Government Architectural Research Institute (INCERC) is conducting a survey of building damage in Bucharest and making pattern classifications of residences for statistical processing of the survey results. Following are the survey method and some trends in damage found through the interim tabulation. Mr. Zorpepel of INERC is in charge of this survey.

(1) Survey Method

1) Zoning the city

In this survey, Bucharest was divided into small zones of 1 km^2 each. 54 such zones where damage occurred were surveyed. One zone included an average of 300 buildings.

2) Buildings surveyed and survey items

Buildings in this survey were limited to houses, which were classified into the following five categories.

- Old buildings made of poor materials.
- Brick-walled buildings with wooden floors.
- Brick-walled buildings with reinforced concrete floors or with floor framing employing bricks.
- Buildings of reinforced concrete rigid frame construction.
- Buildings of wall-panneled reinforced concrete construction.

Building factors covered by the survey are as follows.

- Years since construction
- Number of stories
- Type of structure (by five categories above-mentioned)
- Type of foundation
- Direction
- Relation with adjacent buildings
- Degree of damage

Degree of damage is expressed by the following guidelines.

- Building elements are divided into three categories -- structural elements, secondary elements, gables and chimneys.
- The building elements were further subdivided into columns, beams, floors, installed walls, window sashes, shear walls, lintels and elevator rooms.
- Degree of damage is expressed in 6 stages, from 0 for no damage to 5 for collapse.

° Buildings' natural periods obtained by a conventional formula using number of stories, type of structure, age of building, and directions as parameters are given in 9 grades from zero to eight.

3) Results of interim tabulation

° Damage was concentrated in the first two structural categories -- "old buildings made of poor materials" and "brick buildings with wooden flooring". These buildings' natural periods were 0.5 seconds or less.

° Regionally, the city's south-west area was severely damaged. Many buildings in this area were built in the 1930's and their brick walls were mostly single-laid (28cm), while those buildings in the northeast area generally had thicker walls with a depth of one and a half bricks.

° Structurally, "brick-built houses with wooden floors" tended to sustain heavier damage than those classified as "old houses made of poor materials".

° Damage distribution showed that heavy damage was localized in certain specific areas. This is taken to indicate a relationship between damage and features of the city's ground surface.

° No relationship was found between ground-water levels and damage.

° Damage and buildings' natural periods were found to be correlated positively.

4.2 Ground Features of Bucharest

The survey team was briefed on ground conditions under Bucharest by a geological expert, Mr. Tomiscu, at Rumania Bucharest Region Public Corporation for Construction (IPB). The following are the main points.

(1) General Conditions

As illustrated in Fig. 4.1, the central part of Bucharest is situated between two river systems, one in the north and one in the south. Its terrain descends gently from northwest to southeast. Geologically, the region can be divided roughly into three areas with specific features; the first, the central area lying between the two river systems (Area-A in Fig. 4.1), second, the river bank areas (Area-B in Fig. 4.1, popularly called the "meadowlands") and third, the southern and northern end areas (Area-C in Fig. 4.1).

Geological features:

Area A

° 0 ∿ 4 or 5m: silt and clay,

° ∿ 7 or 8m: sand and gravel layers,

° constant water levels

2 ∿ 4m in the northwest part,

5 ∿ 6m in the central part,

7 ∿ 8m in the southeast part.

Area B

This area has soft ground up to 8 or 9 meters deep. The groundwater levels fluctuate in a range of from zero to 6 meters.

Area C

- ° 0 ∿ 2 or 3m: loess layer
- ° ∿ 11m: silt layer
- ° Constant water levels

  10 ∿ 12m in the northern part,

  8m in the southern part.

(2) Land Subsidence

In Area A, buildings sometimes sink 2 to 3cm after completion. In Area B, the nature of the soil differs greatly from place to place. Buildings on alluvial soil do not sink at all, but those on silt tend to sink by 10 to 15 centimeters after completion. In Area C, buildings sink by 15 to 20 centimeters and often their construction is preceded by ground solidification. After this work, subsidence is usually reduced to 3 to 5 centimeters.

(3) Conditions of foundation

In Area A, a direct foundation is common with depths usually ranging from 2 to 4 meters. For high buildings, the foundation mostly goes down to 6 meters.

In Area B, a direct foundation is prevalent for buildings of up to five stories with the occational use of mat-foundation depending on location. For higher buildings, a pile foundation is sometimes a substitute for a direct foundation. In Area C, a direct foundation is adopted for buildings of up to five stories. For higher buildings (apartment buildings of up to around eleven stories) a pile foundation had been widely used. But about nine months before the survey team visited Romania, this method was replaced with direct foundation on solidified ground. Drop hammers are used to strengthen the soil with gravel.

(4) Soil Strength for Design Use

Area A : 20 to 40t/m^2

Area B and C : 10 to 20t/m^2

(5) Other

Boring data is still not obtainable. But it was confirmed that such data exists in about 60 cases (up to the depths of around 20m). According to the officials concerned, a thick marl layer 30 to 35 meters deep exists under the surface soil and this layer serves as the bedrock of Bucharest.

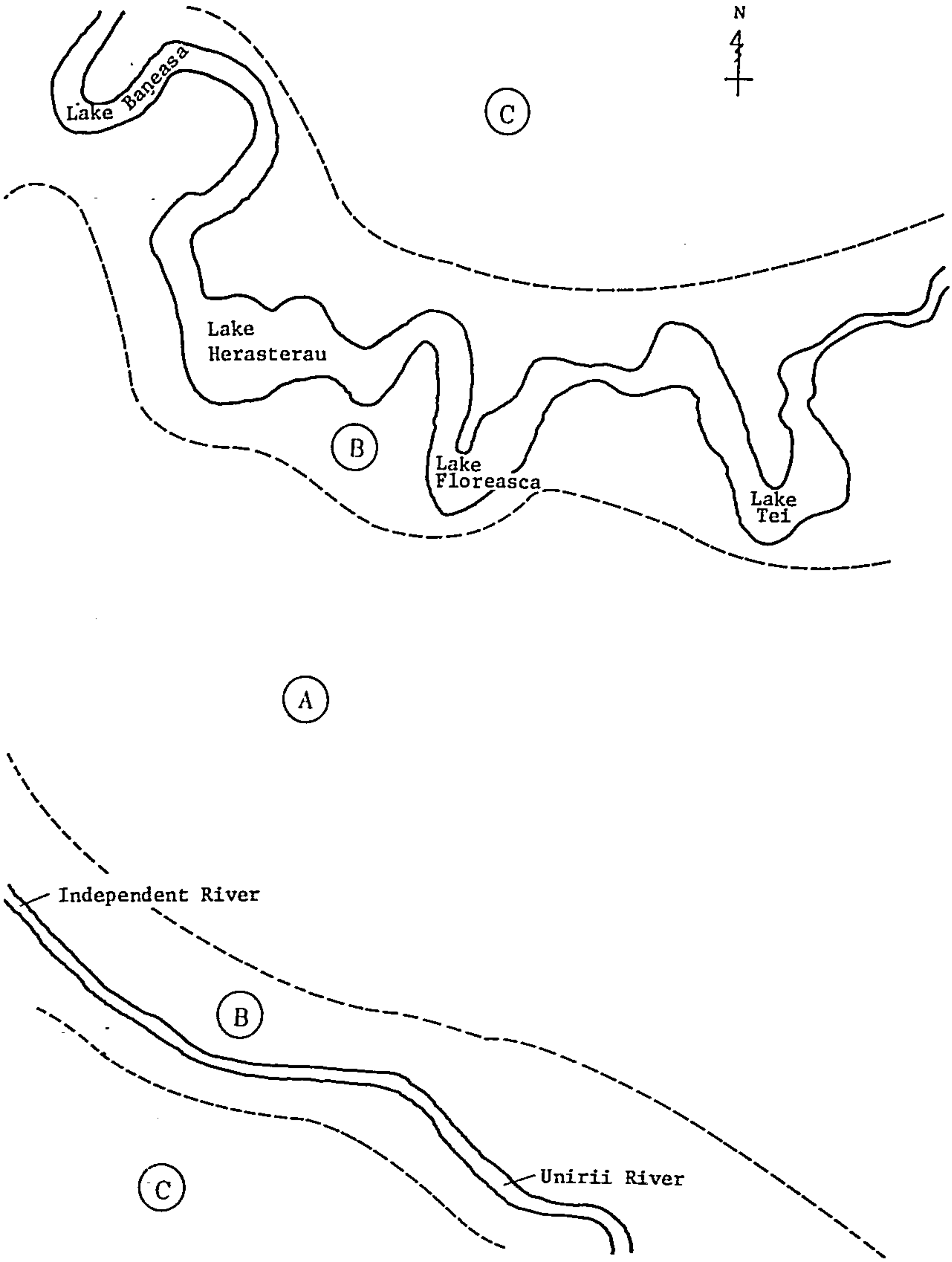


Fig. 4.1 Ground Conditions under Bucharest

4.3 Aseismic Building Regulations in Romania

The present regulations for quake-proof buildings, established in 1963, consist of six chapters with a supplement explaining a simple dynamic design method, etc.

These regulations detail the method for calculating seismic loads. For calculation on reinforced concrete and other structures, there is a separate set of detailed standards available.

An outline of these seismic load provisions is given below.

Design story shear force may be obtained by the following equation.

$$S_K = C.Q_K, \quad .... \quad (1)$$

where, S_K = design story shear force in k-th story

Q_K = weight of the k-th story

C = seismic intensity

Values for C, by which the weight of every story is multiplied, may be obtained by the following equation.

$$c = k_s \cdot \beta \cdot \rho \cdot \eta \quad .... \quad (2)$$

where k_s = Basic seismic intensity determined by a combination of the regional and importance coefficients. (See Table 4.1)

β = spectral coefficient determined by the primary natural period. (See Fig. 4.2)

ρ = Coefficient of type of structure determined by damping of building. (See Table 4.2)

η = Coefficient of distribution in the height direction (by Eq 3)

Distribution coefficeints may be obtained from the following equation.

$$\eta_k = U_k \cdot \frac{\sum_1^n Q_k \cdot U_k}{\sum_1^n Q_k \cdot U_k^2}, \;\ldots\ldots\ldots\ldots \;(3)$$

where, U_k - mode of kth story

When using Eq. (1), the base shear coefficient should not be lower than 0.02 and distribution coefficients should be obtained separately for the first, second and third modes. The design stress is the resultant stress which is obtained by substituting the building stress corresponding to these modes into the following equation.

$$N = \sqrt{N_1^2 + N_1^2 + N_3^2}, \;\ldots\ldots\ldots\ldots\ldots \;(4)$$

where, N = design stress

N_1= stress due to the seismic load using the distribution coefficients based on the primary natural period.

N_2, N_3 = stresses corresponding to secondary and tertiary natural periods.

Furthermore, the following three points require special attention.

1) In the presence of eccentricity, S_k must, of course, be increased. But moreover, 5% of the width of a structure perpendicular to the direction of horizontal force must be considered as additional eccentricity. Accordingly, the eccentricity obtained by the equation below is used.

$$e = e_1 + 0.05B,$$

where, e_1 = eccentricity

B = building width -

2) For corner columns, two-directional force must be considered. In this case, the seismic forces are both 1/1.4 time one directional forces.

3) Local intensity is obtained from the basic intensity multiplied by the following coefficients.

Parapets	3
Projections	10
Connections of shear walls	1.5
Anchor bolts	5
Highly stressed joints	3
For checking axial capacity of columns	4
For checking shear capacity of beams	4
Large-spanned slab without beam	6
Cantilever beam	6
Large-spanned beams	4

The points mentioned above are the essentials of the 1963 anti-quake regulations.

Table 4.1 Standard Seismic Intensity

Importance (coeffient)	Use	Regional (coefficient)			
		7	8	9	6
I	Memorial Buildings	0.05	0.08	0.12	0.03
II	General Buildings	0.03	0.05	0.08	-
III	One-Story Industrial Plant	0.02	0.03	0.05	-
IV	One-Story General Buildings	-	-	0.03	-

Fig. 4.2 Spectral Coefficient

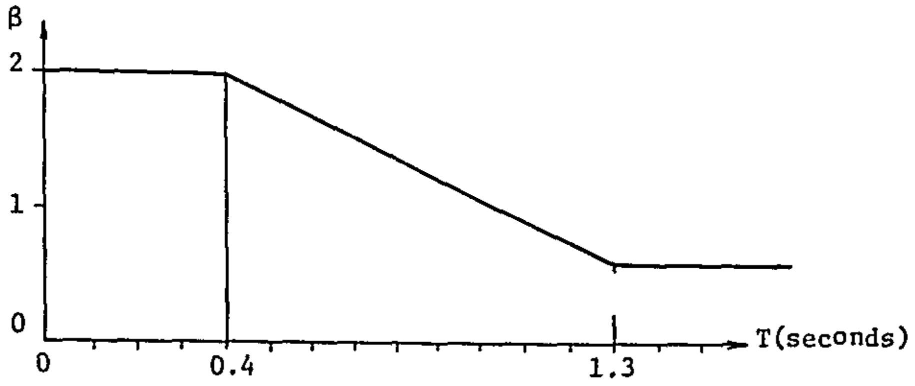


Table 4.2 Structural Coefficient

Type of Structure	Coefficient
Reinforced Concrete Rigid Frame Structure	1.0
Wall-Panelled Reinforced Concrete Structure	1.2
Reinforced Stone Building	1.3
Chimney	1.8
Water Tank	2.0

CHAPTER 5 DAMAGE TO BUILDINGS AND CHARACTERISTICS

5.1 Outline of Damage to Buildings Caused by Romanian Earthquake

5.1.1 General State of Damage and Characteristics of the Earthquake

This earthquake, as illustrated in Fig. 5.1, brought about considerable damage, mainly to buildings, in wide areas of Bucharest, located about 160 km south-south-west of the epicenter.

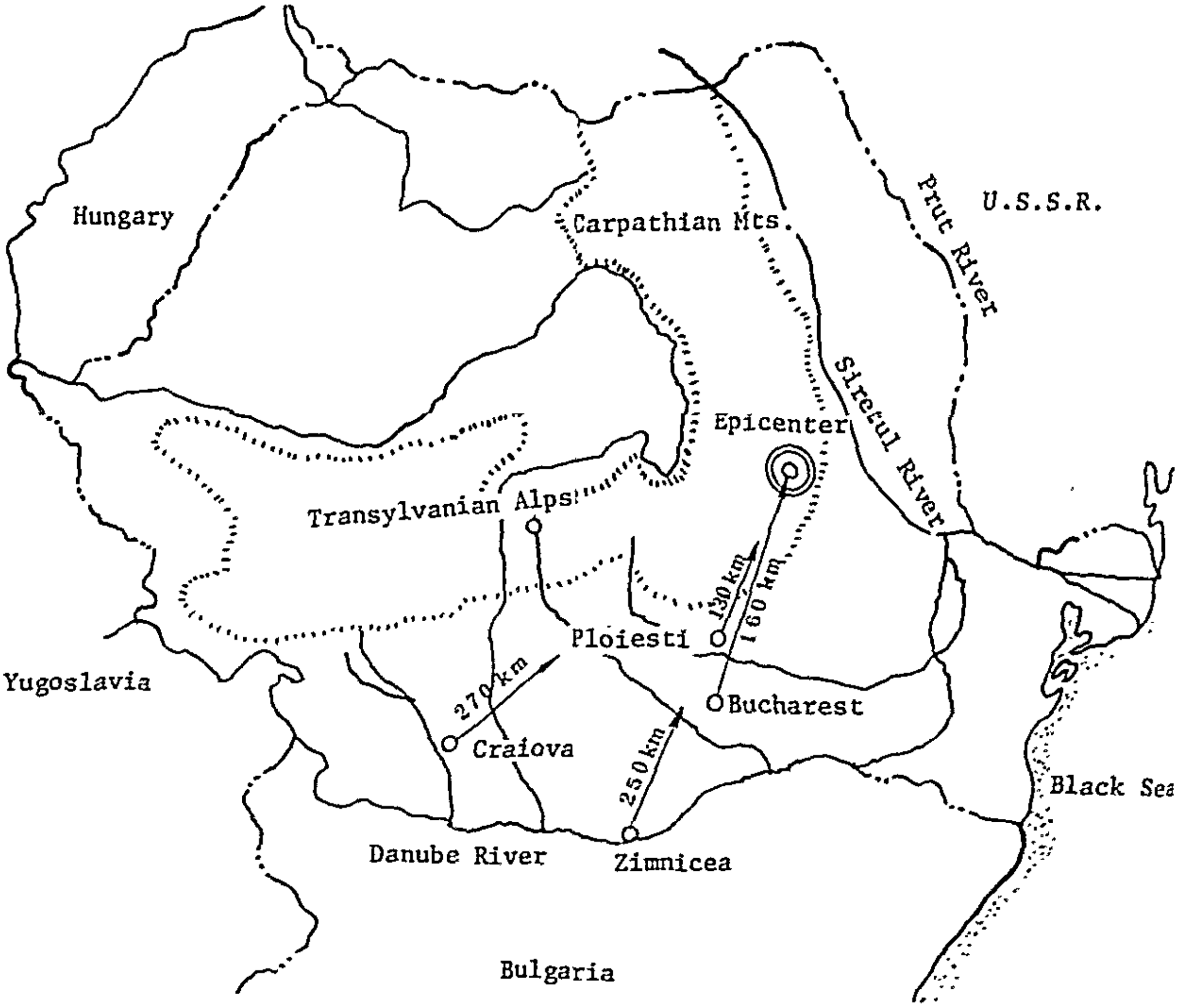


Fig. 5.1 Epicenter of the March, 1977 Romanian Earthquake and Distances of Major Affected Cities from the Epicenter

As described in Chapter 3, which dealt with various factors of the shock, the earthquake was an intermediate deep earthquake. A quake of this magnitude is not rare. But this Romanian earthquake is unusual in that destroyed a large number of buildings at places several hundred kilometers from the epicenter. (For example, a very different case is the Fukui earthquake in Japan in 1948. The magnitude of the shock was 7.3 and its hypocenter was about 20 km deep. But the area severely hit was limited to the Fukui Plains extending about 20 km from east to west and about 40 km from north to south. In Kanazawa City, about 65 km away from Fukui, damage by the quake were relatively slight.)

Another feature of the Romanian quake that distinguishes it from usual tremors, was that damage in villages closer to the epicenter was slight, when compared to heavy damage in Bucharest, Ploiesti, Craiova, Zimnicea and several other other urban areas situated like stepping stones about 130 to 270 km to the south-southwest or southwest of the epicenter. This is shown in Fig. 5.1.

However, according to accounts by officials concerned, which will be described later, there are indications that the peculiar pattern of damage distribution in this quake is not necessarily due to the so-called abnormal region of seismic intensity. The differences in buildings" capacity can also be considered as responsible for it.

For example, many of buildings in the vicinity of the quake center were built after the destruction of the 1940 earthquake. But those in Bucharest were not destroyed by the quake. At that time they were partially reinforced for continued use. Moreover, the damaged area in the 1940 quake was not so extensive as to affect Craiova or Zimnicea. So, in the two cities, many buildings without aseismic design existed at the time of this earthquake.

The degree of earthquake risk in Romania was detailed in Chapter 3. But, in short, major quakes so far recorded almost all had their epicenters in areas very close to the epicenter of this tremor. Also, their intervals of recurrence are relatively short.

As stated previously, the 1940 tremor inflicted damage mainly in the vicinity of the epicenter. The maximum acceleration in Bucharest in the quake is said to have been around 140 gals. And, in fact, evidence of reinforcement made at that time to damaged buildings were discovered during the survey this time.

Apart from these relatively deep quakes, so-called shallow quakes have been recorded in much wider areas in Romania. Accordingly, the risk of earthquakes can be considered to exist almost nationwide. However, judging from records of past damage, Romanian quakes can be regarded as smaller than those in Japan in terms of intensity.

5.1.2 Aseismic Design of Buildings

The Romanian aseismic regulations, an outline of which was given in Chapter 4, provide basic rules for various structures. Besides the seismic forces for aseismic design, they include a rule that the spacing between stirrups in reinforced concrete columns shall be 10 cm or below.

As stated previously, the seismic force for design use is determined by importance, regional, and structural coefficients, vibration modes, etc. For example, the seismic coefficient is 0.12 for reinforced concrete framed apartment building of up to 10 stories in the most risky area.

An outstanding feature of the regulations is a clear provision giving stress to economy in aseismic design. In fact, the designs for modern buildings, such as industrial plants and apartment buildings are drawn up mostly by public organizations apparently to ensure thorough rationalization in this field of work.

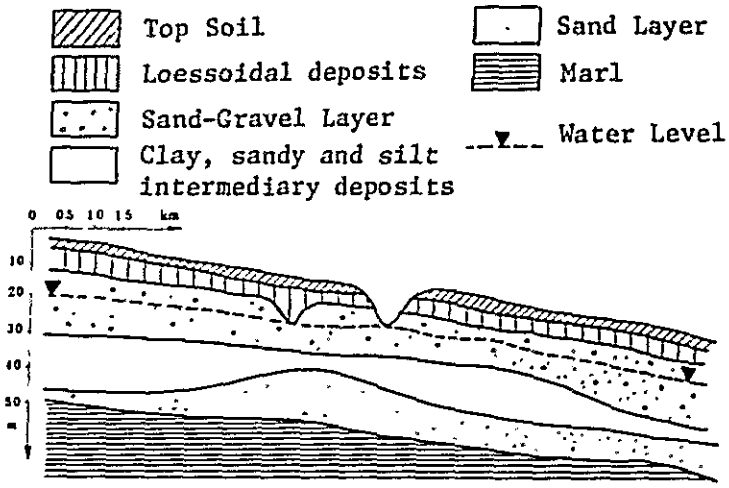
There are also complete practical design standards like the "Design Standard for Reinforced Concrete Structures" published by the Architectural Institute of Japan. These standards are utilized by the above-mentioned public organizations.

Different from Japan's method based on the allowable stress, the Romanian one is an ultimate strength design method. And the design concrete strength and the yield point strength of steel materials are set low at 50 % and 65 % respectively for practical design.

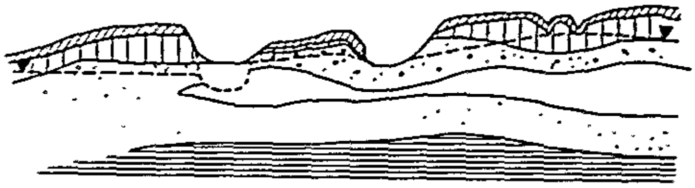
5.1.3 Ground of Bucharest and Earthquake Record

The schematic diagram of a cross section of Bucharest ground, shown in Fig. 5.2, indicates that the city's ground structure is more or less the same at all points, although there are differences in the depth of each strata. And most buildings, even 15-story reinforced concrete buildings, are directly supported by a sand-gravel layer or a consolidated sand layer rather than pile foundation. The ultimate bearing capacity of the ground is said to range from about 35 to $50 t/m^2$.

In Romania, the first strong motion record was obtained in this tremer. The record was obtained by Japanese-made strong motion accellerograph--SMAC-B-- installed in the semi-basement of the Architectural Research Institute (INCERE, one-story reinforced concrete building), located in the eastern part of Bucharest.



a) West Northwest to East Southeast Cross Section



b) South to North Cross Section

Fig. 5.2 Cross Section of Strata Under Bucharest

The main features of the record, shown in Fig. 5.3, are as follows.

(1) Out of the acceleration records, obtained the horizontal motion in the north-south direction corresponding to the direction of the epicenter was large, as against the relatively small vertical motion.

(2) The maximum acceleration in the north-south horizontal motion was about 200 gals. (The value is a little larger than that recorded in Hachinohe Port in Japan -- 185 gals -- at the time of the 1968 Tokachioki Earthquake that occurred off the coast of Tokachi, Hokkaido.

(3) Most significant in the north-south horizontal acceleration record was its fairly long period, lasting about 1.5 seconds. One cycle was particularly outstanding.

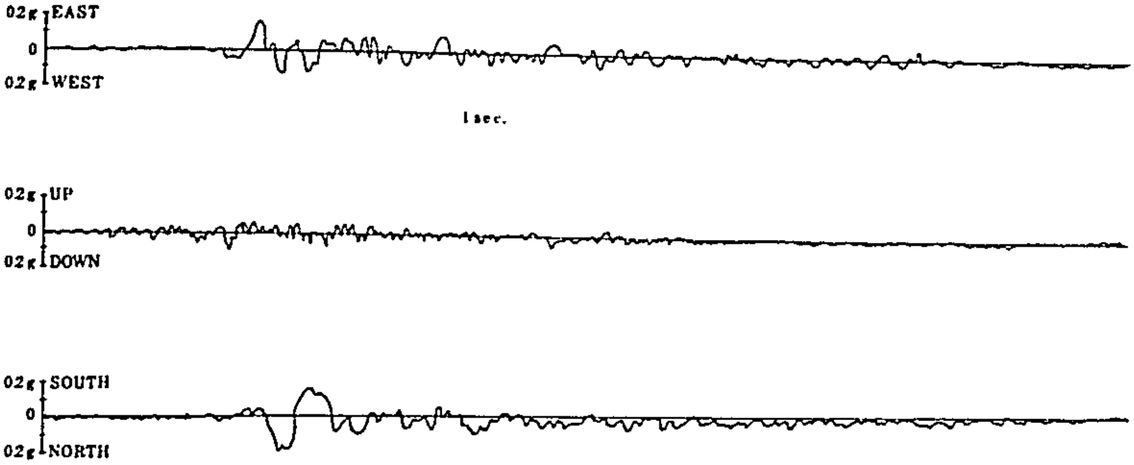


Fig. 5.3 Strong Motion Record of Romanian Earthquake

Never before was a record of such acceleration in a long period of 1.5 seconds registered in rigid ground, almost equivalent to Class-II ground in Japan. This aspect requires full study.

In Romania, especially in Bucharest, a regional coefficient had been established for each of fairly finely divided areas on the basis of the experience of destruction in the 1940 earthquake and the ground constitution. (see Fig. 5.4)

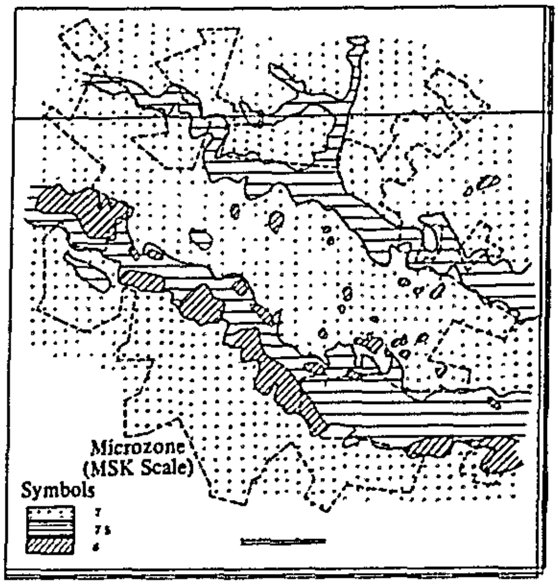


Fig. 5.4 Seismic Microzoning of Bucharest

The regional coefficients were in practical use. However, the distribution of damage this time differed considerably from the distribution of these regional factors. Also, there appears to be very little artifically-developed building land. However, heavy damage to buildings in cliff edge areas on natural river terraces can be cited as a possible corelation between ground conditions and building damage. Figures 5.15 to 5.18 show response spectra on acceleration, velocity and displacement of the strong motion records noted above, which were analyized by the Strong Earthquake Observation Committee in the Building Research Institute, Ministry of Construction, Japan.

5.1.4 Outline of Building Damage

As mentioned above, buildings of wood and steel construction are almost non-existent in Romania. Most buildings there are of brick construction or of reinforced concrete construction and many medium-height brick buildings are strengthened partially with reinforced concrete columns and beams. And very roughly speaking, almost all brick buildings lack aseismic design. It is assumed that many of the reinforced concrete buildings were constructed after the aseismic regulations went into force. However, even now in Bucharest, bricks can be used for the construction of buildings with heights of five or fewer stories, on condition that they are partially strengthened with reinforcing bars.

This survey, as explained in Chapter 1, could not cover many damaged buildings on the spot, since much time was spent for the exchange of opinions with Romanian scholars and technical experts. At the time of our arrival (about 40 days after the occurrence of the earthquake), many of buildings were already in a different state from that immediately after the earthquake. Dismantling and removal of buildings were in progress and repair of damaged buildings was under way.

Moreover, data on damage, including results of a survey on the causes and various documents involved, were only obtainable after approval by the many organizations responsible. And the procedure barred us from getting many such hoped-for materials. Also, Romanian authorities concerned were too busy and tired out to support us fully.

Therefore, it is impossible to give detailed data on each case of damage surveyed. But construction methods viewed in terms of structures and characteristics of damage are described in the following paragraph - 5.2.

In addition, a list of damaged buildings examined closely both from the outside and inside is given in Table 5.1. In regard to those in Bucharest in particular, their location and degrees of damage are shown in Fig. 5.5.

(1) Damage in Bucharest

Bucharest is the nation's capital with a population of about 1,590,000.

A large proportion of the buildings in old blocks in the central area of the city are public buildings, apartment buildings with shops and private houses either of brick or reinforced brick construction. They are of low to medium height. In the outer circle area around the old blocks exist groups of 9 to 14-story reinforced concrete apartment buildings both with and without shops, which were built at an annual rate of approximately 30,000 units in recent years.

The number of totally destroyed buildings in this tremor is said to be 35. Many of them were reinforded brick buildings about 10 stories high in the old blocks. Only 3 of them were new type buildings.

However, there also were many more buildings badly damaged, though not completely destroyed. Approximately 20,300 houses, for example, were damaged, half of them heavily. A large number of shops, schools, cultural facilities and industrial plants were affected by the quake.

Table 5.1 List of Surveyed Buildings (No. 1)

No.	Name and Use of Building	Structural Outline *1	Story No.	Location	Year of Construction *2	Damage*3		Note	Photos and Documents*4	
						Super Structure	Secondary Element		Photographs	Figures
1	City Hall	B	2	Craiova	O	L	L	An old building with slight damage.	-	
2	District Hall	B	2	"	O	S	S	Fall of a brick dome-shaped ceiling.	4,5	
3	Art Museum	B	2	"	1899∿1907	S	S	Fall of the ceiling, interior seriously damaged.	6,7	
4	High School	B	3(1B)	"	1826	S	S	Fall of the floor, walls badly broken.	10,11,12	
5	Museum of History	B	2	"	1915	S	S	Walls and the ceiling seriously damaged.	8, 9	
6	Private House	B	1,2	"	ON	C	C	Collapsed clay-joints.	1,2,3	
7	Apartment House	B	5	"	N	M	L	Moderate damage to recently-built non-reinforced brick walls.	83	
8	Industrial Plant	RC(Column), PC(Beams and slabs)	1	Ploiesti	1973	L	M	A block-built chimney broken, walls heavily damaged.	81	
9	Apartment House	B	5	"	1962	S	L	The 1st story heavily destroyed, but glass panes mostly intact.	17,18	
10	Church	B	2	"	1834	C	C	The collapse of a pinnacle	13,14	
11	Apartment building with shops	RCF	5	"	1960	S	S	Extensive damage to columns.	62,63,64,65	
12	Apartment House	RCF	4	"	N	C	(C)	The 1st story totally flattened.	60,61	
13	Computer Center	RCF	3	Bucharest	N	C	C	Totally destroyed.	-	
14	Apartment Building	BRC	11	"	O	S	S	Extensive damage to columns. Reinforced after the 1940 quake.	28,30,31,32 84	7
15	Apartment-Shop Building	RCF	10	"	1960	S	M	Shear failures in 1st story columns and in brick walls.	44	
16	Apartment-Shop Building	RCF	10(B1)	"	1964	(C)	(C)	Three spans of the building collapsed.	43	

Table 5.1 List of Surveyed Buildings (No. 2)

No.	Name and Use of Building	Structural Outline *1	Story No.	Location	Year of Construction *2	Damage *3		Note	Photos and Documents *4	
						Super Structure	Secondary Element		Photographs	Figures
17	Apartment Building	RCW	11	Bucharest	1974	S	M	Breakdown of walls and columns by poor execution of work.	69,70,71	
18	Apartment Building	RCW	11	"	1974	(S)	(M)	Collapse of wall columns in the first story.	68	
19	Apartment-Shop Building	RCF	12	"	1975	(M)	(L)	Collapse in the capital of a 2nd story column.	45,46,47	
20	Apartment-Shop Building	RCF	12	"	1975	S	S	Shear cracks in beams in all stories.	-	
21	Apartment-Shop Building	RCF	9	"	1976	M	S	Buckling of main reinforcing bars in a 5th story column, interior and exterior damaged.	35,36,37,38	
22	Apartment-Shop Building	RCW	11	"	1976	L	L	Shear cracks similar to the second vibration modes in a shorter side wall.	-	
23	The Ambassador's Official Residence	B	2(B1)	"	O	(S)	L	Brick walls heavily damaged in part.	15,16	6
24	Small Apartment House	BRC	4	"	O	M	M	Shear cracks in a column and interiors damaged.	-	
25	Small Apartment House	BRC	5	"	O	M	L	Shear cracks in block walls.	-	
26	Management Building	RCF	11	"	N	M	S	Shear cracks in beams, interiors shattered.	-	
27	Pump-Manufacturing Plant	RCF,PC(Floor)	5	"	N	S	L	Failure of column capital by poor execution of work.	66,67,82,86	
28	Apartment Building	RCW	12(B1)	"	N	L	L	Shear cracks in a boundary beam by bending force.	76,77	
29	Apartment Building	RCW	11(B1)	"	1975	C	C	One of six units of collapsed buildings. 90 people perished.	72∿75,87∿91	
30	Apartment Building	RCW	11	"	N	L	L	Shear cracks in the border beam.	-	13

Table 5.1 List of Surveyed Buildings (No. 3)

No.	Name and Use of Building	Structural Outline *1	Story No.	Location	Year of Construction *2	Damage *3		Note	Photos and Documents *4	
						Super Structure	Secondary Element		Photographs	Figures
31	Office Building	RCF	14	Bucharest	1967	S	S	Buckling of columns, shear cracks in beams, interiors heavily damaged	53~58,85	8, 9
32	Japanese Embassy building	B	2(B1)	"	O	L	L	Almost no cracks	-	
33	Optical Industry Plant	RC(Column), PC(Floor,Beam)	5	"	N	S	M	Serious damage to a core RC which was not in the original design.	X	
34	Special Machinery Plant	RCF	5	"	N	(S)	M	Failure of a column capital due to poor execution of work.	X	
35	Management Building of the Plant	RCF	4	"	1964	(S)	(S)	Wrecking of a short column made up of non-structural and block walls.	50,51,52	
36	Calculator Parts Manufacturing Plant	RC(Column), PC(Floor), PS(Beam)	1	"	1971	N	N	Almost no damage	80	
37	"	RC Core plus flat slab	5(B1)	"	1971	L	N	Core broken partially	-	
38	"	RC(Column, Core) PC(Floor,Beam)	5(B1)	"	1971	M	S	Core and some columns heavily damaged; reinforcement already completed	X	
39	Apartment Building	BRC	10	"	N	S	S	Cashing with an adjacent building combined with joints, interior badly damaged	-	
40	Apartment Building	RCF	9	"	ON	L	L	Well-erected columns, slight damage.	-	
41	Apartment Building	RCW	11	"	1976	N	L	Slight damage	-	

Note: *1 Classification by type of construction

B : Brick Structure
BRC : RC Reinforced Brick Construction
RCF : Rigid Frame Reinforced Concrete Construction
RCW : Wall Type Reinforced Concrete Construction
PC : Precast Construction
PS : Pre-stressed Construction

*2 Year of Construction

O : Before 1940
ON : 1940 - 1963
N : 1963 and after

*3 Degree of Damage

C : Collapse
S : Heavy Damage
M : Medium Damage
L : Light Damage
N : No Damage
Partially damaged buildings are in parentheses.

*4 Photos and Figures

Those numbered are all in Chapter Five.
X indicates photographs were not permitted.

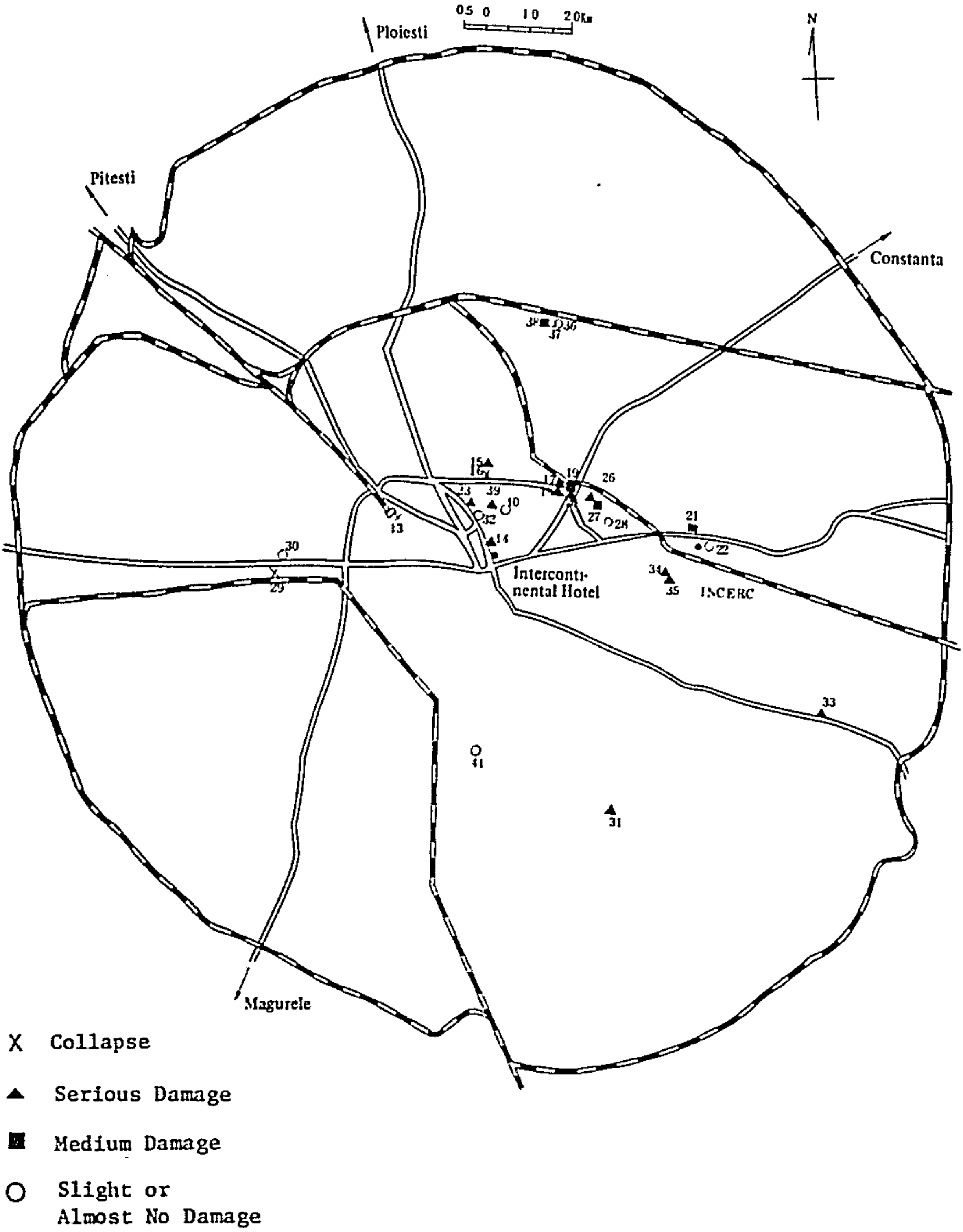


Fig. 5.5 Buildings Surveyed in Bucharest
(Numbers: Building numbers in Table 5.1)

Many damaged buildings are relatively high buildings of brick construction. But even among new reinforced concrete buildings, many apartment buildings of rigid frame structure with relatively small wall ratios, sustained damage to inner and outer walls and finishings.

(2) Damage in Ploiesti

Ploiesti is the second largest city in the country, located about 130 km south-southwest of the epicenter. Most buildings in the city center are brick buildings, though there are a certain number of reinforced concrete apartment buildings, both with and without shops, in the vicinity of the railway station. In the city's outskirts, there are a number of large-scale industrial plants.

Private houses are one and two-story brick buildings. Their quality does not appear to be especially good, but damage to them was generally slight.

In contrast, heavy damage was witnessed in relatively large buildings, including a church of brick construction, reinforced concrete apartment buildings and industrial plants. As shown on Table 5.1, the first story section of a four-storied reinforced concrete building was totally destroyed.

(3) Damage in Craiova

Craiova, capital of Dolj district, is on the east bank of the Jiu River and has a population of 200,000. The city is situated about 270 km southwest of the epicenter. The city's central area consists of mostly brick buildings and a small number of reinforced concrete buildings.

About 500 of the city's buildings were either totally destroyed or heavily damaged, resulting in the death of 50 people. In terms of types of buildings, private houses of low-quality brick construction along the bank of the

Jiu River were most heavily damaged. Damage was very conspicuous in old brick buildings, including schools and museums. Damage was slight in new buildings and the lightweight concrete industrial plants built in the suburbs.

(4) Damage in Zimnicea

Zimnicea is a city with a population of about 15,000, located on the northern bank of the Danube River, about 260 km from the epicenter. Damage to the city was very heavy with 2,552 houses, about 80% of all buildings destroyed. Most of them were brick buildings. There were five fatalities. A large proportion of broken buildings had already been demolished and cleared up late in April when new city construction was beginning on a large scale. Emphasis was on construction of apartment buildings with basements, a type of building that sustained relatively slight damage in the quake.

5.2 Structural Damage to Buildings and Characteristics

5.2.1 Brick Buildings

Brick buildings can be classified into the following three types.

(1) Those of low-quality fillers and bricks.

(2) Those of relatively good quality with wooden floors.

(3) Those of high quality with reinforced concrete floors and reinforced concrete columns and beams at key places.

The brick structure, having both low-quality joints and bricks, was used widely for houses in the outskirts of Bucharest and in provincial cities and rural areas. These houses are mostly one or two story buildings with wooden floors and roof truss. The floor material is not heavy. The brick wall, on the other hand, is extremely heavy, being about 40 cm thick. Bricks are not hard and more clay or lime mortar is often used for joint filler. Generally openings are rather small and the wall ratio is large. The average weight of these houses often reaches $1.5t/m^2$. Their foundation is usually made of bricks.

Buildings of this type are very common in Romania. But those which were heavily damaged are concentrated in Zimnicea and Craiova. One reason may be the ground conditions of the two cities.

A close examination of damage to these buildings revealed two different types of collapse. One is the collapse of brick walls by in-plane shear force that caused diagonal shear cracks running mainly along joint lines. The other is the falling down of walls toward the outside. The latter occurred in walls not restrained horizontally by roofs or floor materials. Many of the walls were on the northern side of houses and they fell in the northern direction, toward the epicenter. (See photos 5.1, 5.2, and 5.3)

Photo 5.1

A Destroyed Brick House in Craiova

Photo 5.2 A destroyed brick house in Craiova

Photo 5.3 A crumbled brick wall. (clay-bonded; Craiova)

Brick buildings of the second type are mostly rather old and include those for public use such as schools, churches and an art museum and also high-class private houses. Because of their uses, rooms are generally large and the buildings often have large, heavy decorations on their walls and roofs.

Walls are very thick, sometimes as thick as 50 to 60 cm, and the buildings are frequently many stories tall. Therefore, the unit weight of these buildings is much greater than that of ordinary private houses.

As an example of buildings of the second type, the plan of the Japanese Ambassador's official residence in Bucharest is shown in Fig. 5.6. The unit weight of this two-story building is very heavy, about $4.0t/m^2$, but the average axial unit stress is only about 3.5 to $5.3\ kg/cm^2$.

This building had some damage, including a 6 mm shift to the north of a part of a projection on the northern side of the second story and conspicuous cracks on the heads of arched windows.

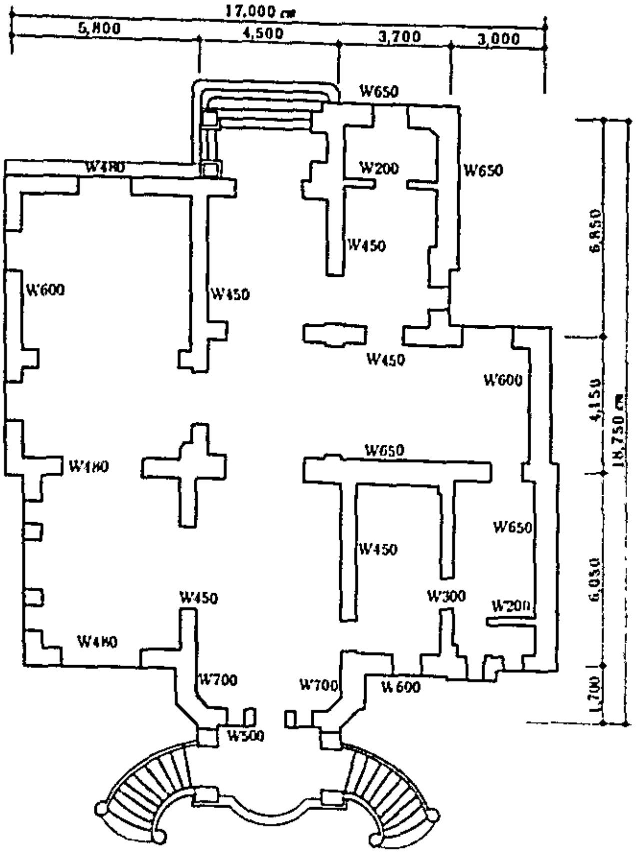


Fig. 5.6 Plan of the First Story Walls of the Japanese Ambassador's Residence, a Brick Building, Bucharest

Damage to this type of building was seen in every city. Photos 5.4 - 5.16 show exteriors of some of these buildings and scenes of desruction inside.

The main features of damage to these buildings are:

(1) Collapse of building corners.

(2) Collapse of projections such as pinnacles of churches.

(3) Collapse of thin, brick-built dome-shaped ceilings inside buildings.

Photo 5.4 The district hall (Brick structure; the exterior looks sound with slight damage but the interior was badly damaged. Craiova)

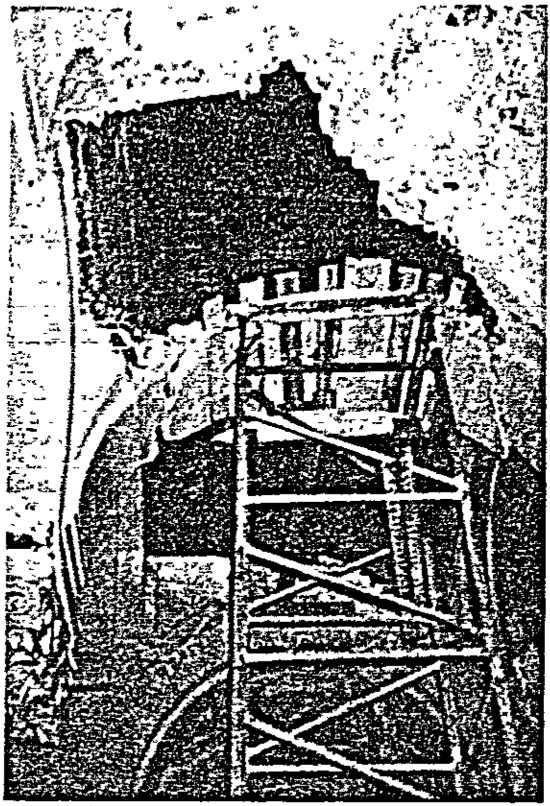


Photo 5.5

A broken shell-shaped brick ceiling in the hall

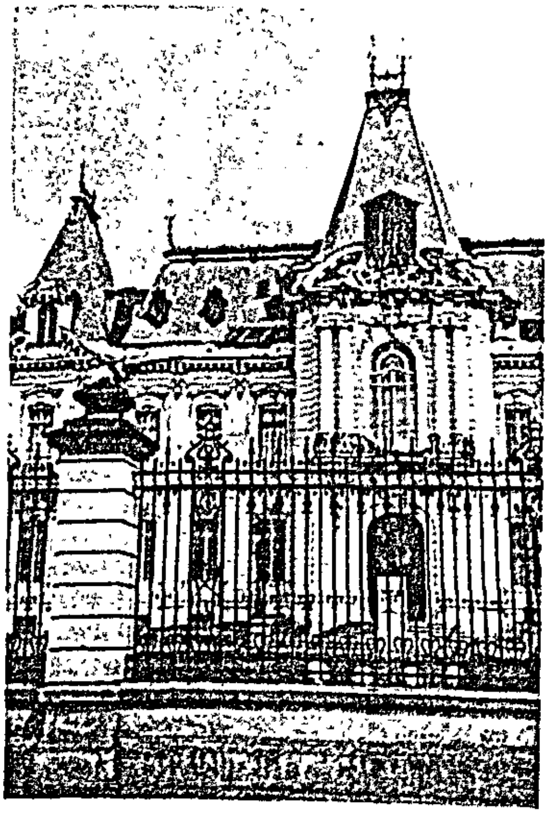


Photo 5.6

The Art Museum of Craiova
(Brick work, 1899 - 1907)

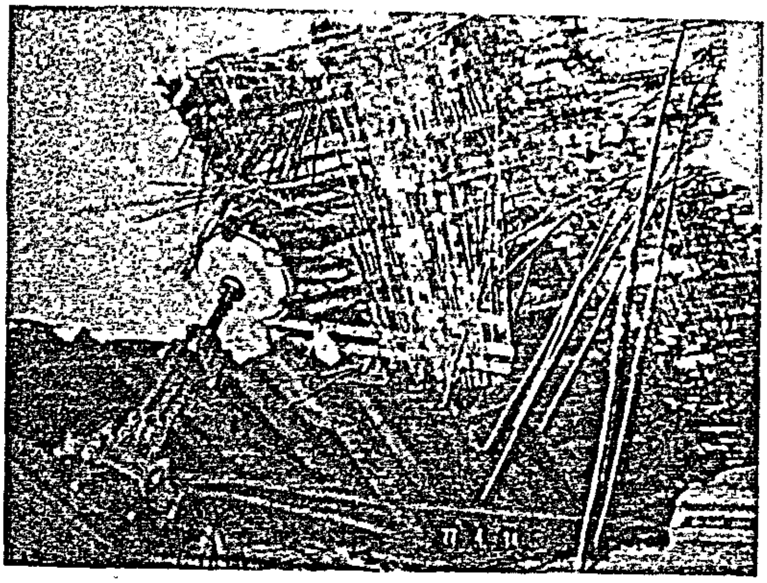


Photo 5.7 The fallen second story floor of the museum. (Below the wooden beams are remnants of plaster ceiling on marsh reed-wood lathing.)

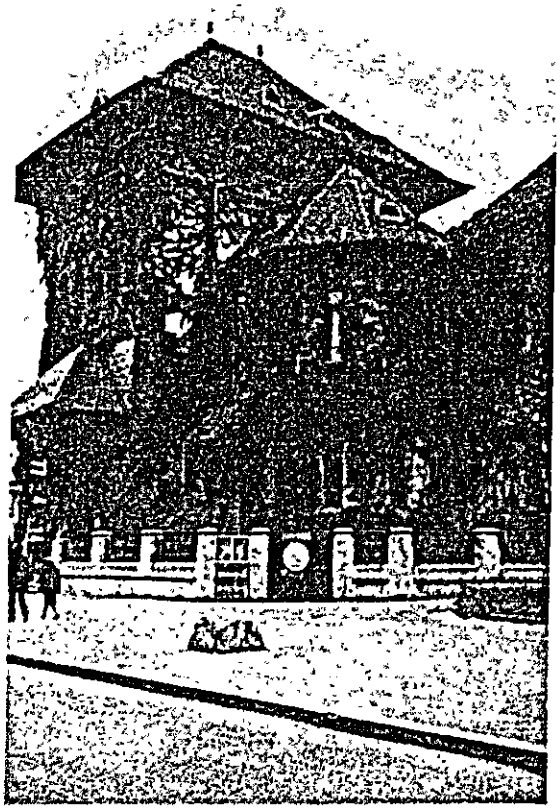


Photo 5.8

The Museum of History in Craiova

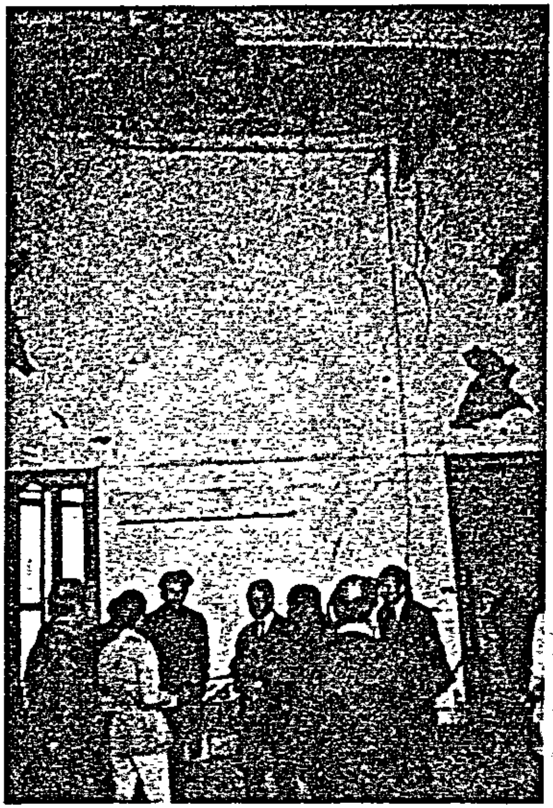


Photo 5.9

Wrecked interior of the Museum of History

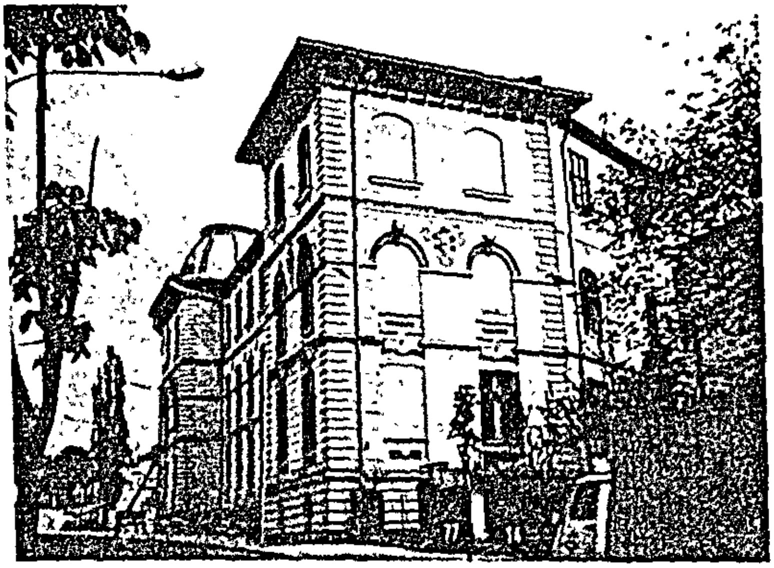


Photo 5.10 A high school in Craiova (Heavy damage inside)

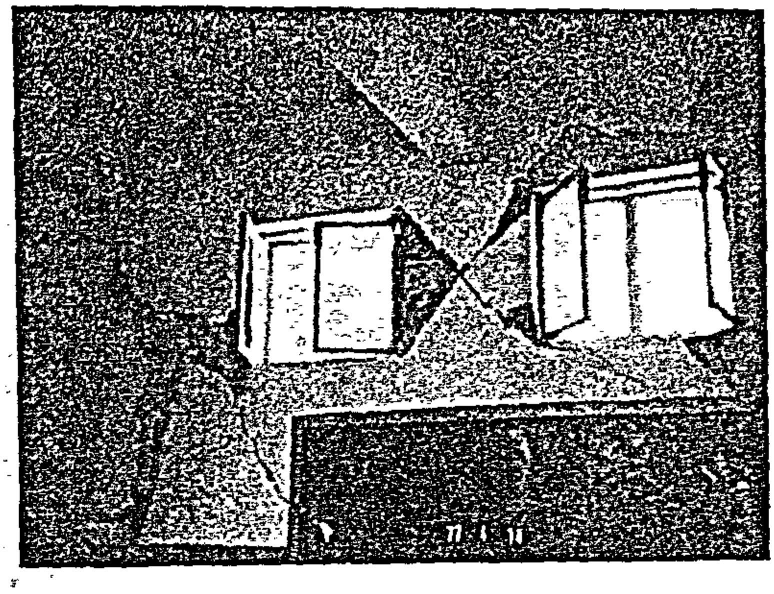


Photo 5.11 A brick wall of the high school with shear cracks.

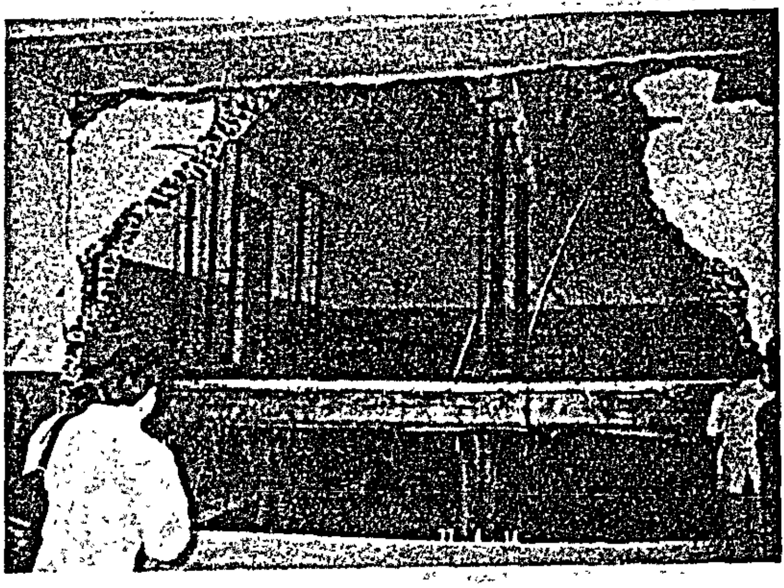


Photo 5.12 A fallen brick wall in the high school

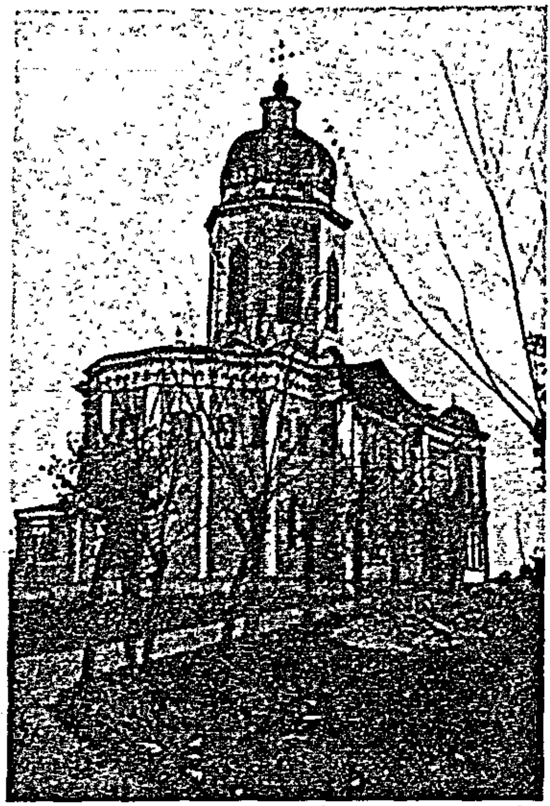


Photo 5.13
A damaged brick church in Ploiesti

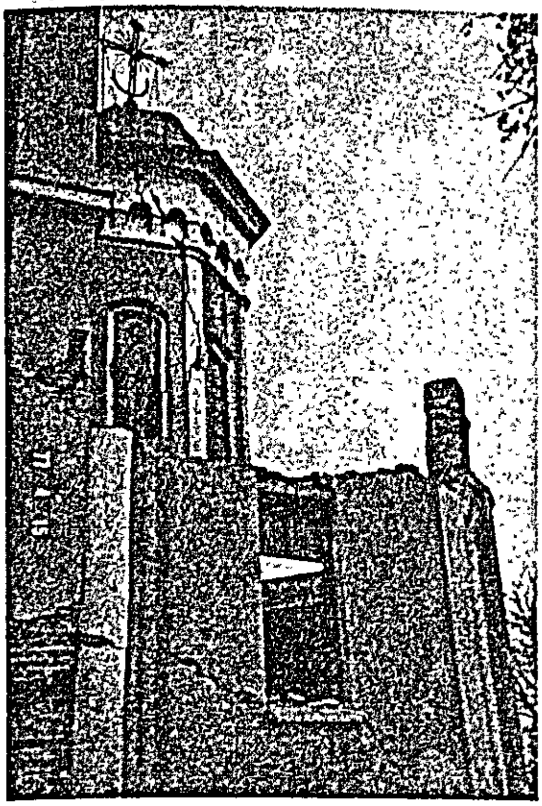


Photo 5.14

Close-up of damage to the church

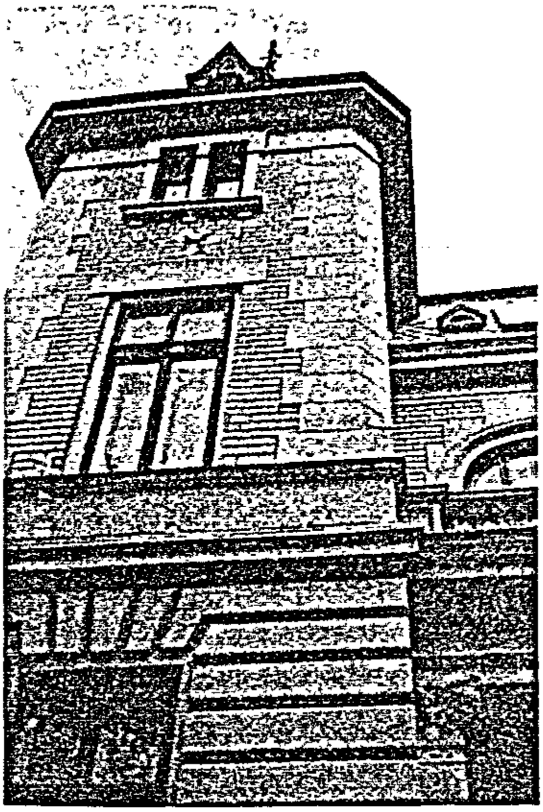


Photo 5.15

The Japanese Ambassador's official residence in Bucharest. (An old brick two story building with a basement; conspicuous cracks developed in the spandrel beams and the top of the arch)

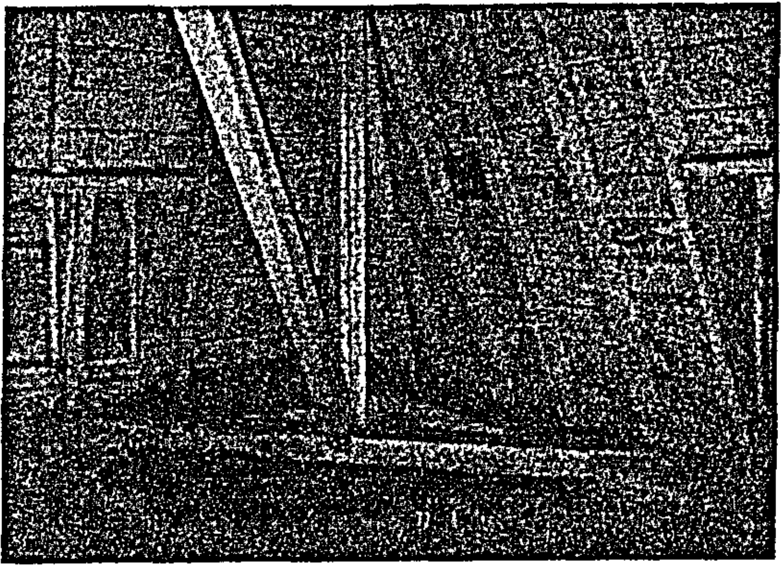


Photo 5.16 The inside of a garret of the Ambassador's residence. (wooden roof truss on the brick beams.)

(4) Collapse of floors and ceilings

Among causes of the damage are fragility of brick construction, distance from wall to wall and weakness to out-of-plane force because of the almost total absence of effective joints between wall planes and floors and ceilings.

As mentioned above, the construction of brick buildings is allowed even now if the height is five stories or fewer. But the regulations provide that brick walls must be reinforced horizontally with 9 mm bars placed doubly and in at least three layers.

However, several buildings were among those damaged as shown in Photos 5.17 and 5.18. Destruction occurred mostly at the corners of these buildings. But, generally, buildings with relatively small living space, such as apartment buildings, escaped heavy damage.

5.2.2 Brick Buildings Strengthened by Reinforced Concrete

Brick buildings of the third type, as already noted, have reinforced concrete construction, for floors, columns and beams. But the reinforcement is partial. For example, beams are used to strengthen large openings and columns for places where axial force is especially big. The beams and columns are ofter not continuous, in contrast to ordinary frame structures, because the reinforcements are intended only to withstand long-time load.

This construction method was used for a large number of tall apartment buildings of ten stories or more, especially in the old blocks of Bucharest. These buildings are generally old and do not have aseismic designs. Many of them had been damaged in the 1940 earthquake.

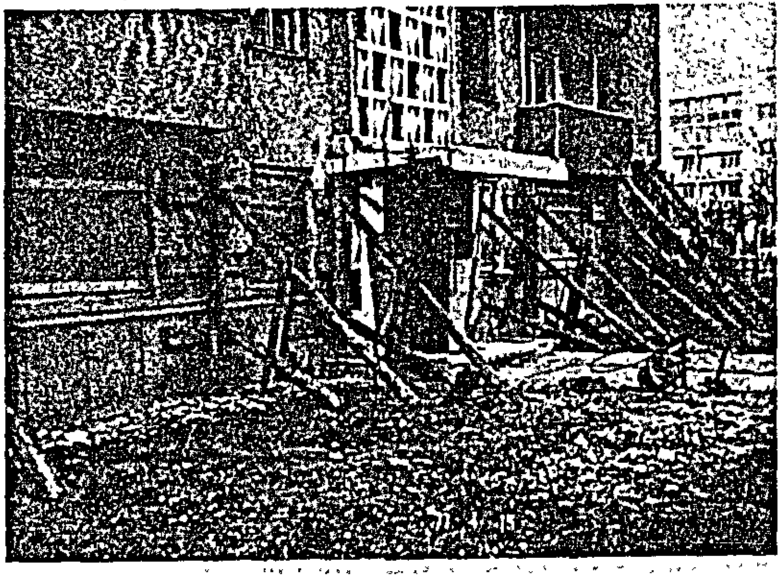


Photo 5.17 A collapsed five-storied brick apartment house. (1962, Ploiesti)

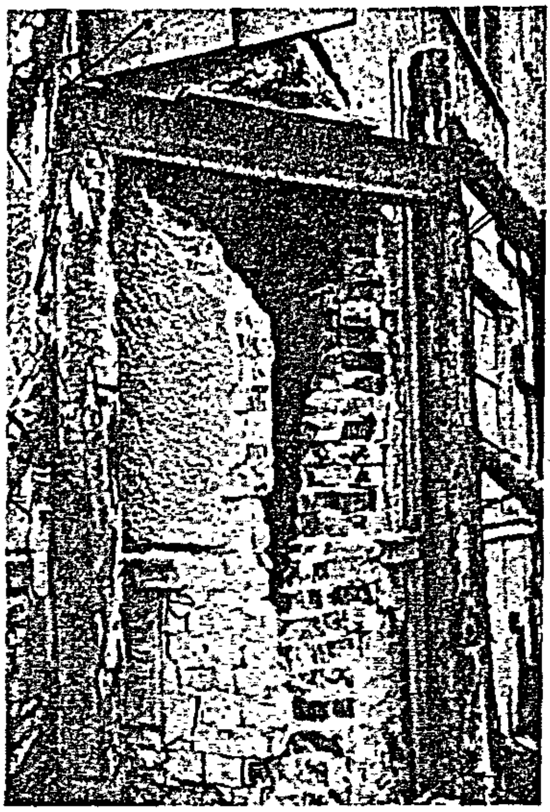


Photo 5.18

Close-up of damage to the apartment building. (Lime-mortar joint)

This type of building sustained the heaviest damage in Bucharest this time and scenes of destruction are shown in Photos from 5.19 to 5.32.

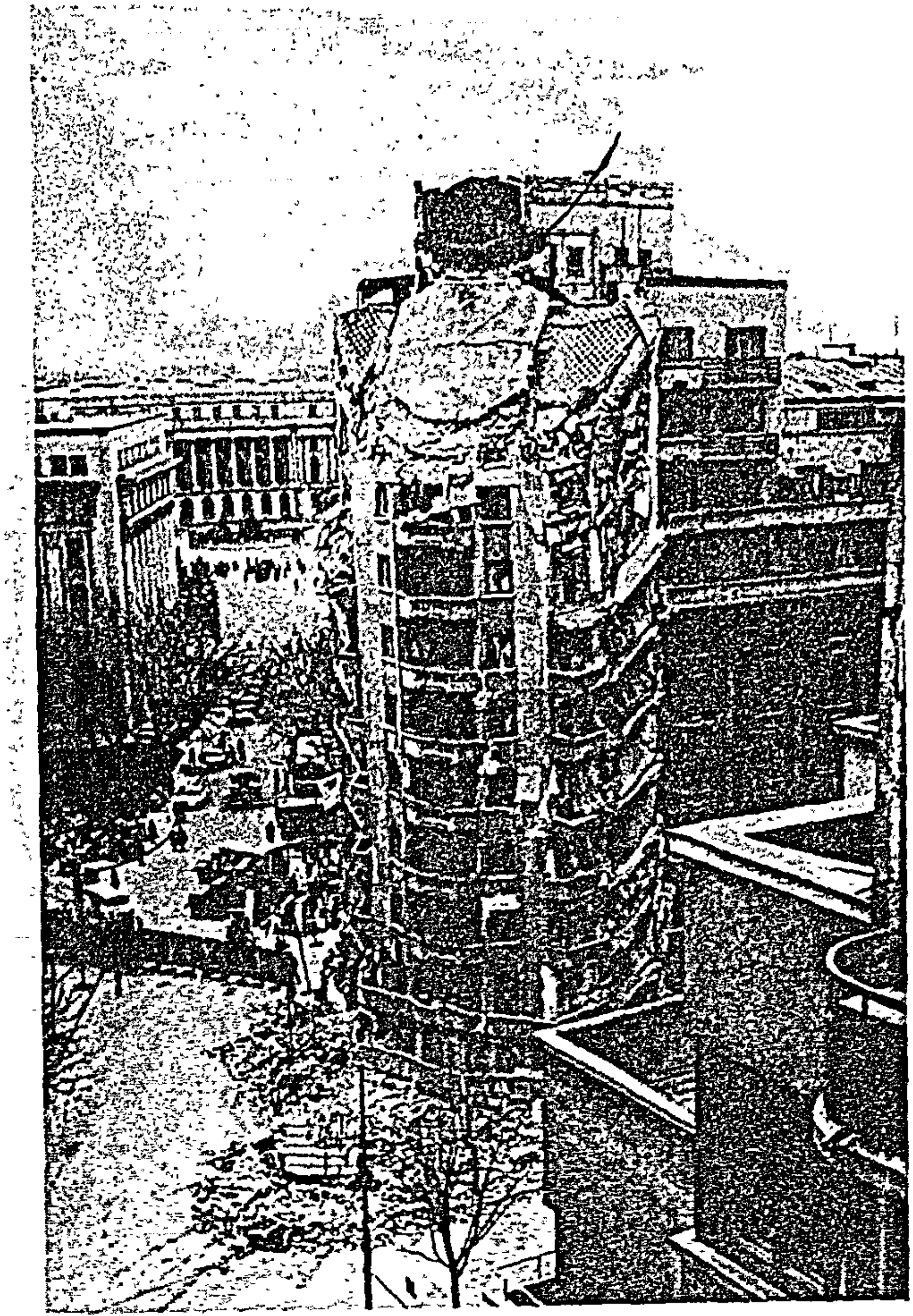


Photo 5.19 A crushed building of reinforced brick construction No. 1, Bucharest

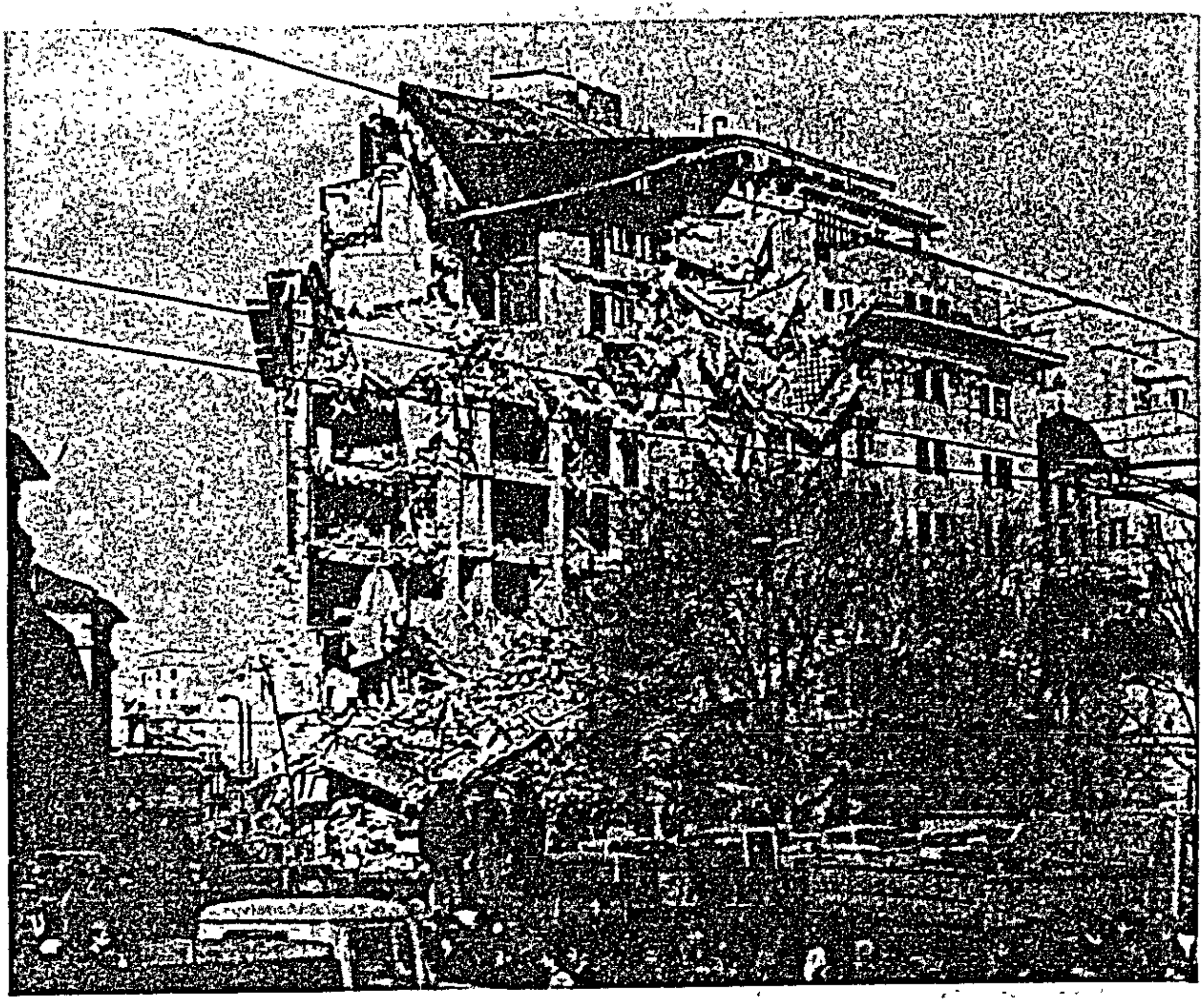


Photo 5.20 A destroyed building of reinforced brick construction No. 2, Bucharest

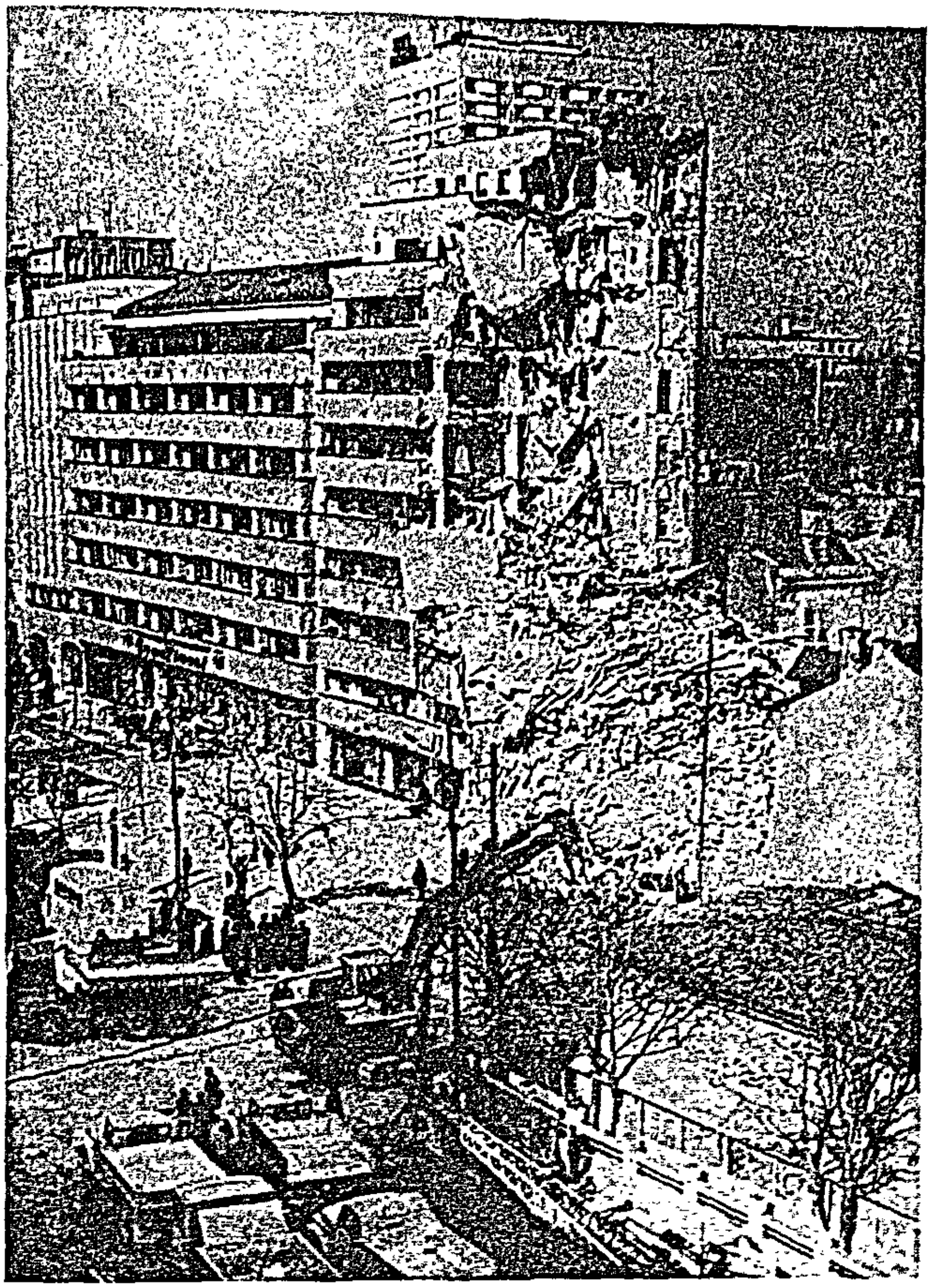


Photo 5.21 A destroyed building of reinforced brick construction No. 3, Bucharest.

Photo 5.22 A destroyed building of reinforced brick construction No. 4, Bucharest.

Photo 5.23 A collapsed building of reinforced brick construction No. 5, Bucharest.

Photo 5.24 A fallen building of reinforced brick construction No. 6, Bucharest.

Photo 5.25 A destroyed building of reinforced brick construction No. 7, Bucharest.

Photo 5.26 A destroyed building of reinforced brick construction No. 8, Bucharest.

Photo 5.27 A destroyed building of brick construction No. 9, Bucharest.

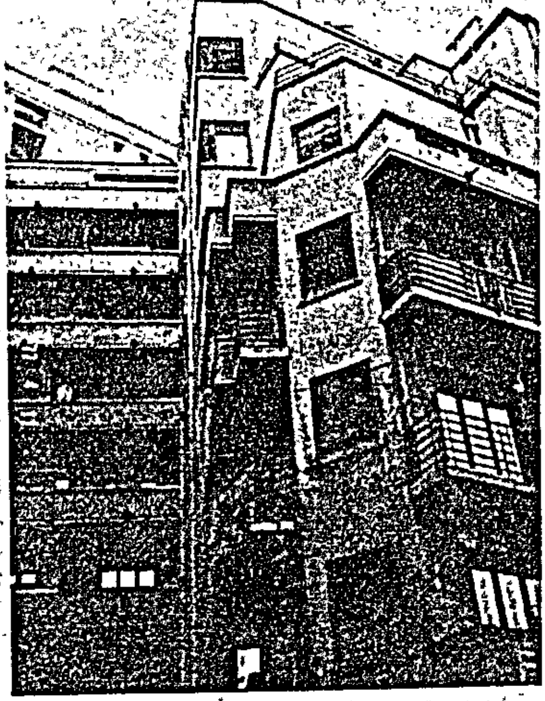


Photo 5.28

An 11-story reinforced concrete-strengthened brick apartment house built before 1940.

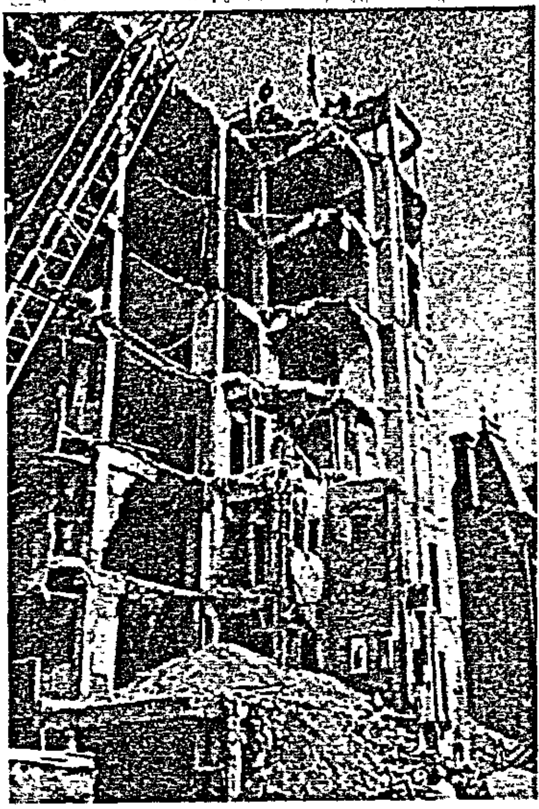


Photo 5.29

A destroyed apartment building of the same type as in Photo 5.28. (This is the building shown in Photo 5.21. Demolition in progress)

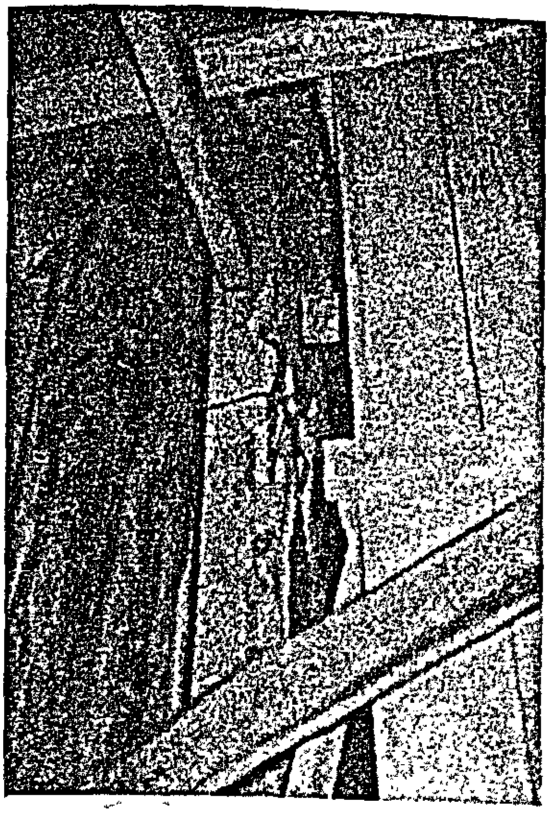


Photo 5.30

Buckling of main reinforcing bars in a first story concrete column of the apartment house shown in Photo 5.28.

Photo 5.31

Log-support to prevent the collapse of the apartment house in Photo 5.28.

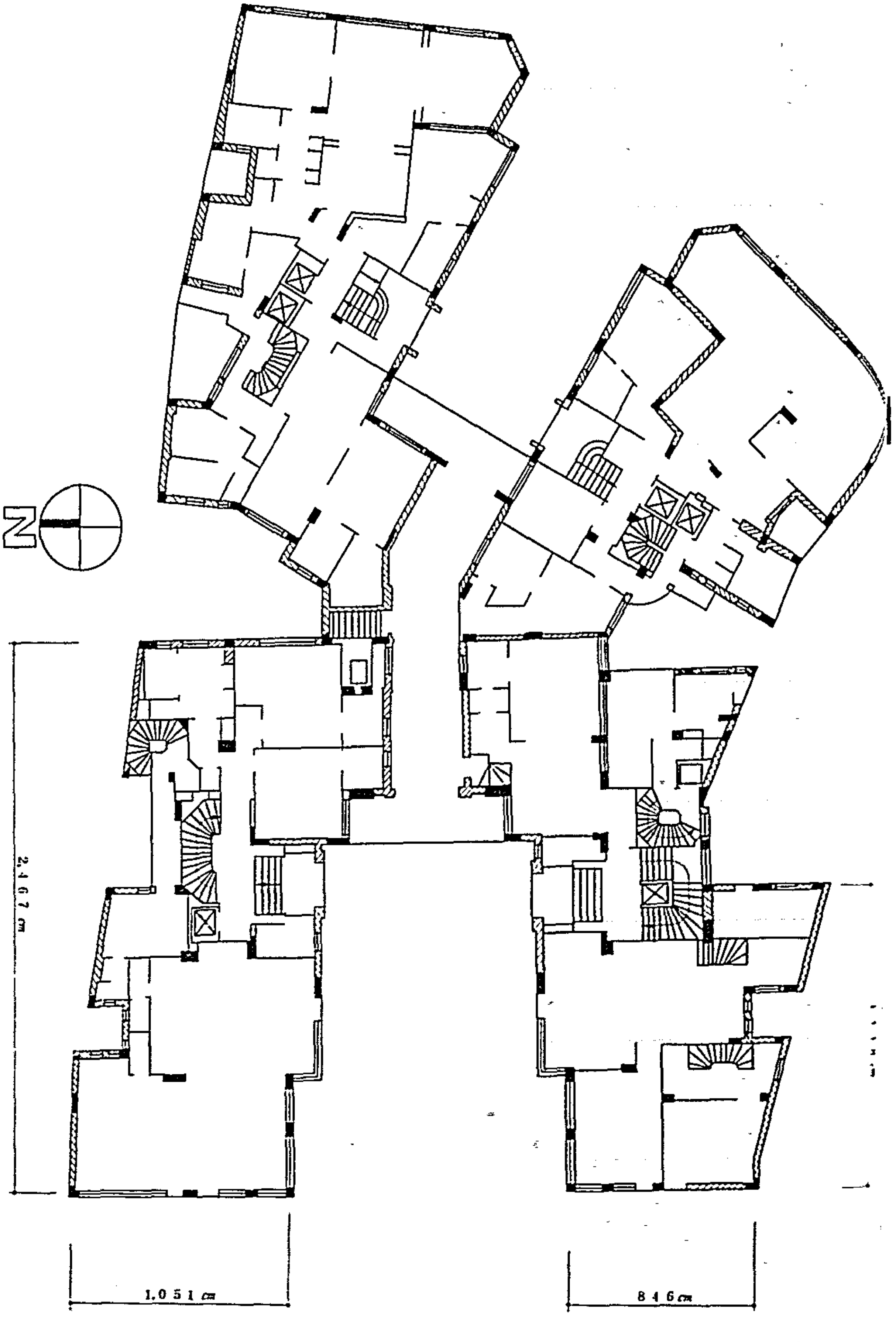


Fig. 5.7 Plan of the 1st story of a 11-story RC-brick apartment house.

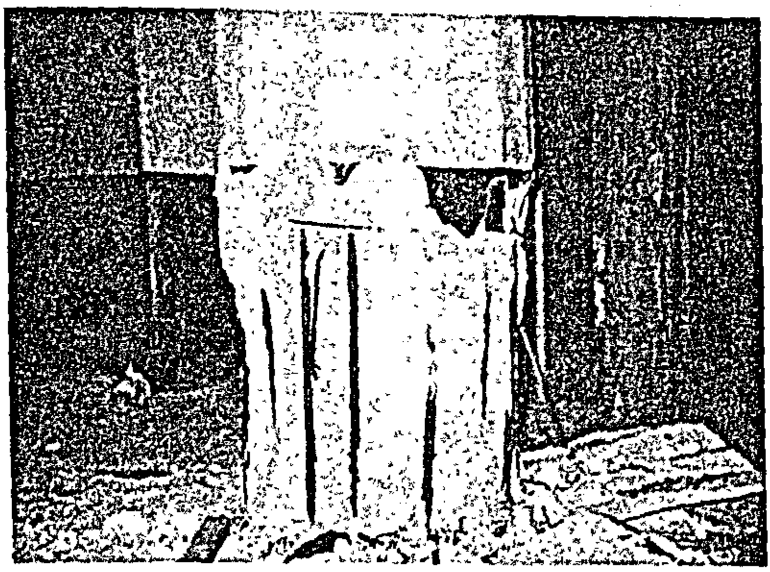


Photo 5.32 Decayed reinforcing bars in a basement column of the building in Photo 5.29.

Photographs from 5.19 to 5.25, taken immediately after the quake, were supplied to us by the Romanian authorities. When the survey team visited the city 40 days after the quake, demolition of the destroyed or heavily damaged buildings was already in progress. The results of post-quake activities may be seen by comparing Photo 5.29 and 5.21.

As shown in the plan in Fig. 5.7, some of these buildings are structurally very complex. According to officially published figures, totally or almost totally destroyed buildings in Bucharest, as shown in these photographs, numbered 35. Of these, 32 are buildings constructed by the method described above. They are all tall, from 7 to 14 stories.

The announced total of earthquake fatalities is 1,570. Most apparently died in the collapse of this type of building in Bucharest.

There are also many buildings, which, though not listed as destroyed, sustained almost irrepairable damage, such as the collapse of reinforced concrete columns or the breakdown of brick walls as shown in Photos 5.30 and 5.31. These buildings are estimated to number about 10,000.

The main features of this damage are given below.

(1) Damage was especially severe in buildings located on the corners of blocks or in those independently situated away from other buildings.

(2) Damage to buildings was more noticeable in corners of upper stories and brick sections of outer walls than in other places.

(3) Severely damaged buildings were located mostly in the center of old city blocks.

(4) All of the buildings were built before the 1940 quake.

A list of probable causes of this damage is given below. The collapse of these buildings is apparently due to a combination of several of these factors.

(1) Structural design for long-term stress only and without precautions for seismic forces.

(2) Reduction of Strength due to the 1940 quake.

(3) Deterioration of structural strength due to the passage of time. (As shown in Photo 5.32, main vertical bars inside the base of a supporting column of reinforced concrete were totally decayed.)

(4) Low concrete strength and large axial unit stress.

(5) Inadequate axial bars in columns ($p_g \fallingdotseq$ approx. 0.5%), wide spacing between hoops ($S \geqq 25$ cm); hooks were 90°.

(6) Discontinuous columns and beams without transversely reinforced joints.

(7) Major alterations after construction involving the removal of structural elements.

Buildings of this type were constructed in large numbers after 1940. Those built before the 1963 establishment of seismic regulations were badly damaged because they had some of the defects noted above. (Survey number 39)

5.2.3 Reinforced Concrete Frame Buildings

Photo 5.33 depicts multi-story reinforced concrete apartment buildings in Bucharest's suburbs viewed from the city center. Those in the foreground are brick and reinforced brick buildings.

Twelve medium and tall apartment blocks on the outskirts of Bucharest are shown in this photograph. A majority of these buildings are reinforced concrete buildings of rigid frame construction.

Exteriers of these buildings and scenes of damage are shown in Photos 5.34 to 5.67. As shown in the photographs, these buildings can be divided into the above mentioned apartment buildings and others. The apartment buildings may be sub-divided into those with and without shops on the 1st and 2nd floors.

The following are some of the most noticeable cases of damage done to this type of buildings.

Photo 5.33 Panoramic view of Bucharest from the city center. (Buildings of brick or reinforced brick structures are in the foreground. Middle and high-story apartment houses in the distance are reinforced concrete buildings on the city's outskirts.)

Photo 5.34

A 13-story apartment building of reinforced concrete rigid frame construction, Bucharest. (Non-structural walls are non-reinforced brick or block walls.)

Photo 5.35

A 14-story apartment building of reinforced concrete rigid frame construction, Bucharest.

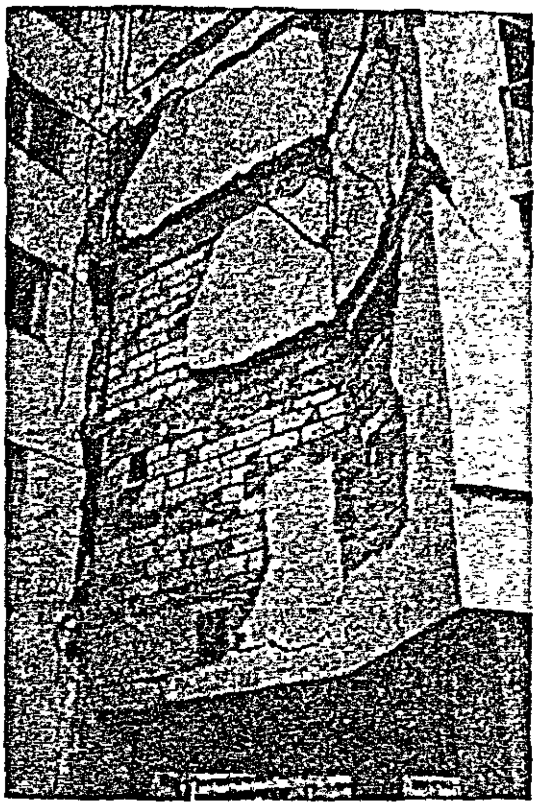


Photo 5.36

A badly damaged outer wall of the same building, Bucharest.

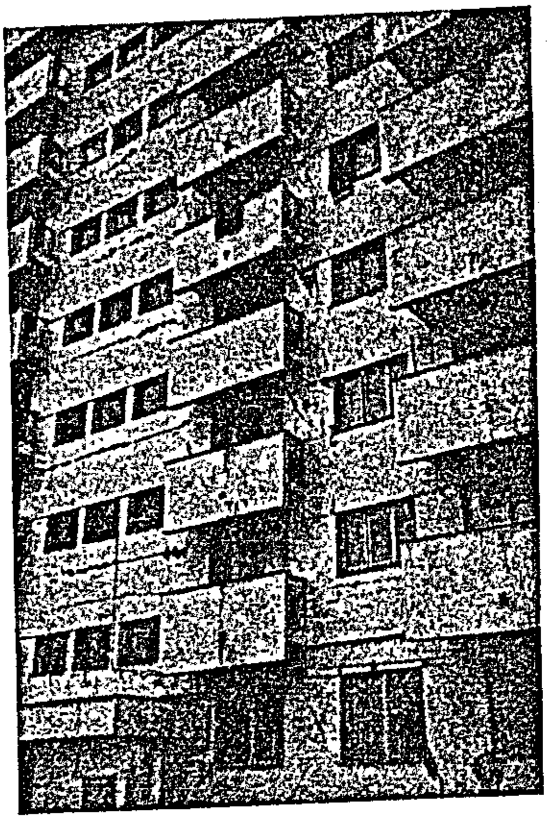


Photo 5.37

Damaged exterior of the same building, Bucharest.

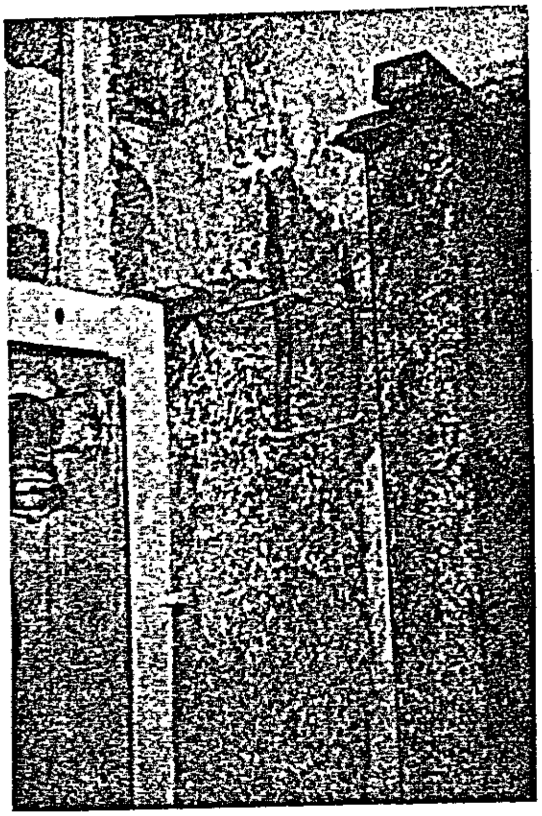


Photo 5.38

Buckling of main vertical bars in a fifth story column of the same building.

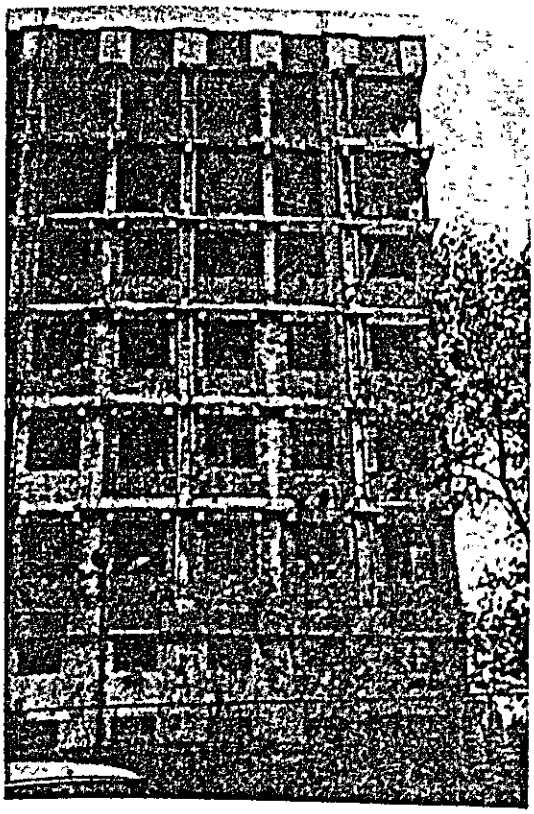


Photo 5.39

An 8-story hospital of reinforced concrete rigid frame construction, Bucharest (Repairs to fallen non-structural walls in progress.)

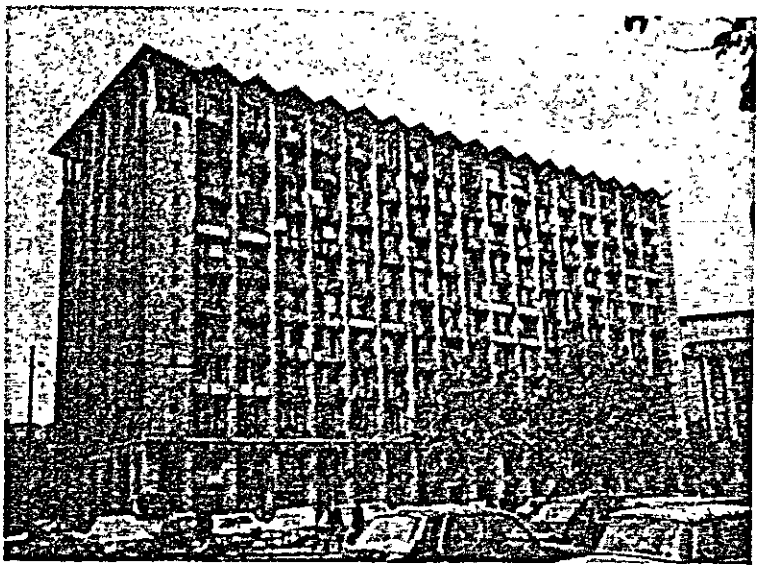


Photo 5.40 A 10-story reinforced concrete rigid frame apartment building with shops, Bucharest.

Photo 5.41

Falldown of concrete on a 1st story column base of the same building.

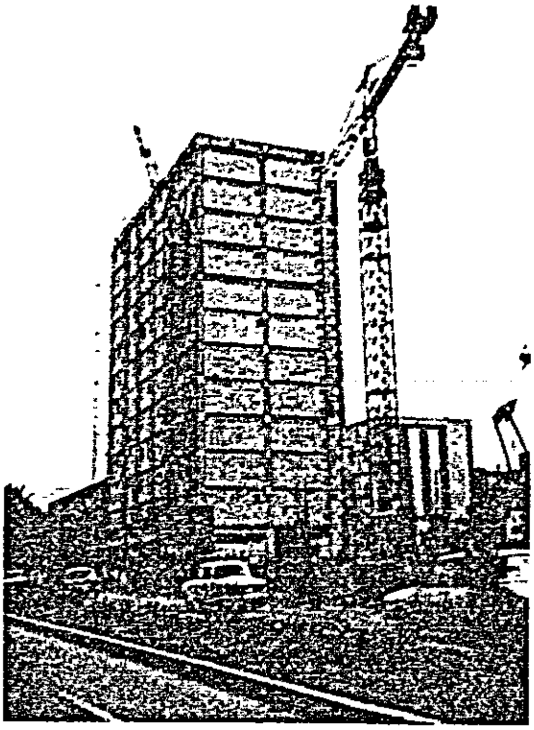


Photo 5.42

A new-type apartment building of reinforced concrete rigid frame construction with block walls as non-structural walls, Bucharest.

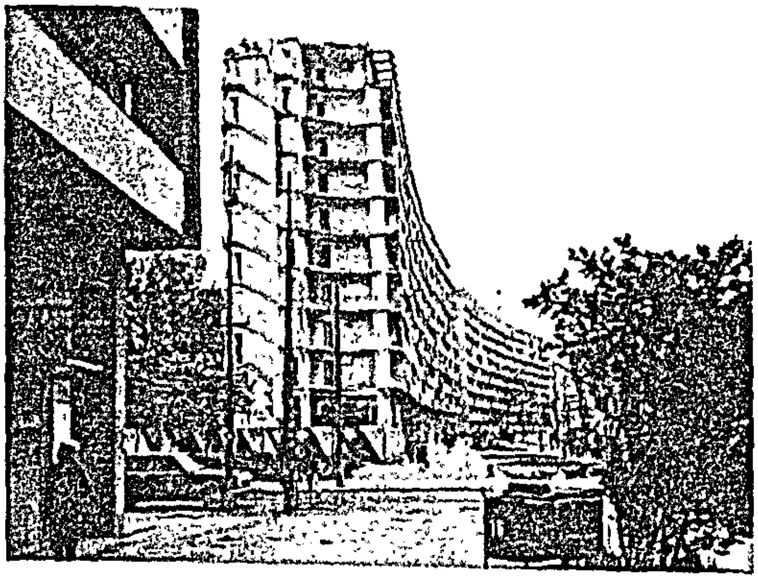


Photo 5.43 A new-type apartment building of reinforced concrete structure. The first story is high and has no block walls. (A section of the building in the foreground - 3 spans - collapsed and was removed.)

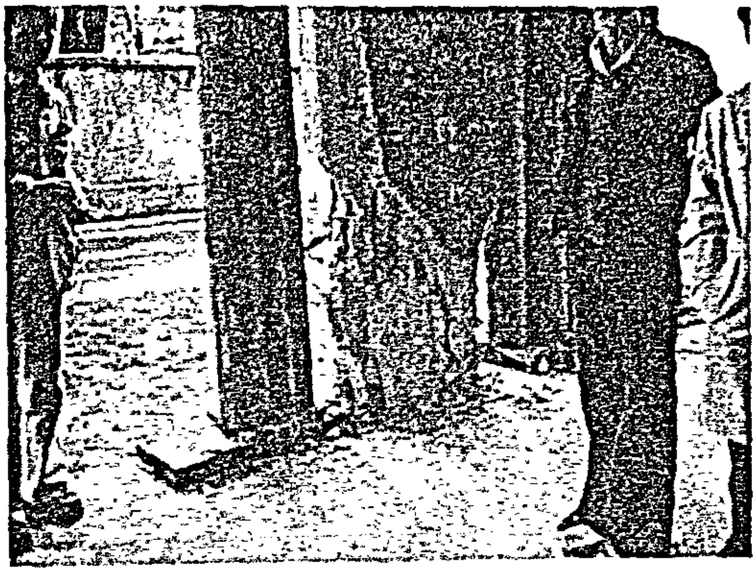


Photo 5.44 A shear failure in the 1st story column of an adjacent building of the same type as in Photo 5.43 (Hoop, 9ϕ about 30 cm spacing)

Photo 5.45 Damage to exterior of a 12-story reinforced concrete rigid frame apartment building with a department store on the 1st and 2nd floors, Bucharest.

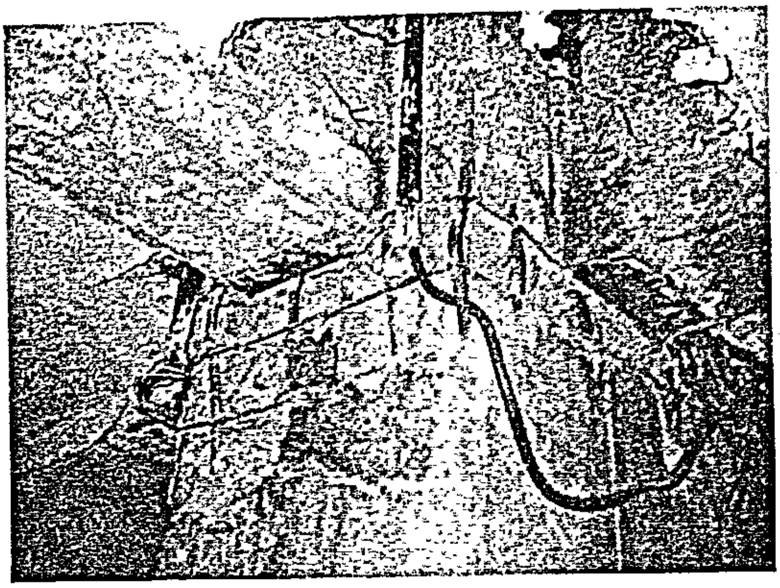


Photo 5.46 An exceptional failure in the 2nd story column capital in the same building, Bucharest.

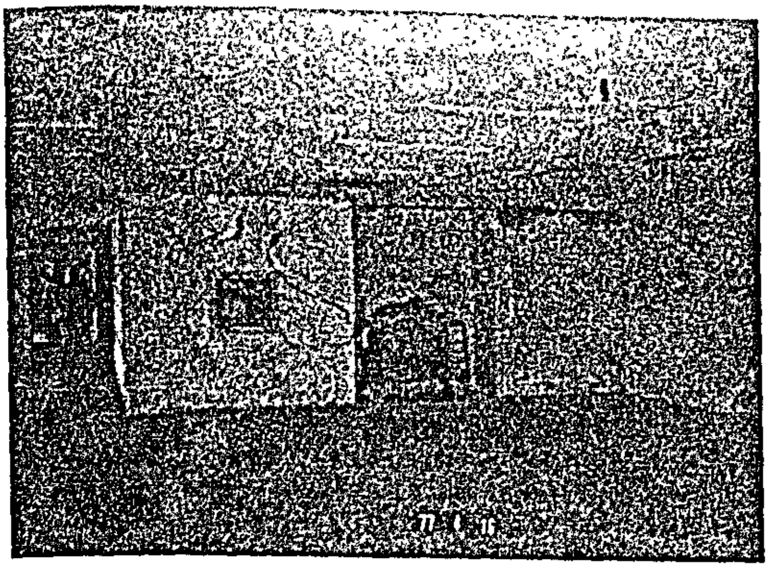


Photo 5.47 Shear cracks in a brick partition wall in the 2nd story of the same building, Bucharest.

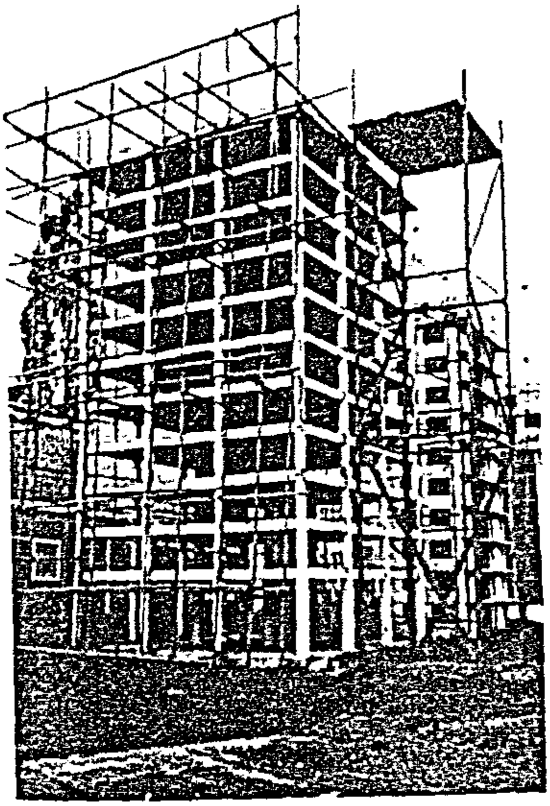


Photo 5.48

A skellton model for vibration tests of a frame construction apartment building with shop space. The experimental model is located in the compound of the architectural research institute - INCERC -, Bucharest.

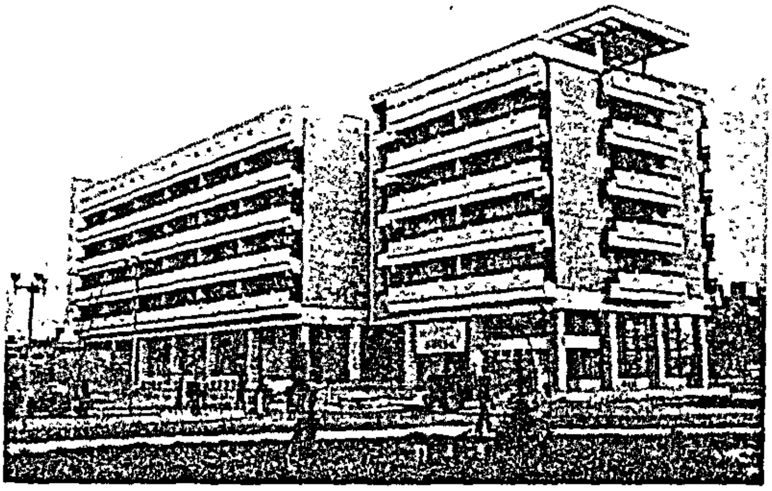


Photo 5.49 A five-story hotel of reinforced concrete rigid frame construction in the compound of the National Physical Science Center, Magurele, southwest of Bucharest. (Two 1st story columns were heavily damaged in the hotel which accomodated the survey team.)

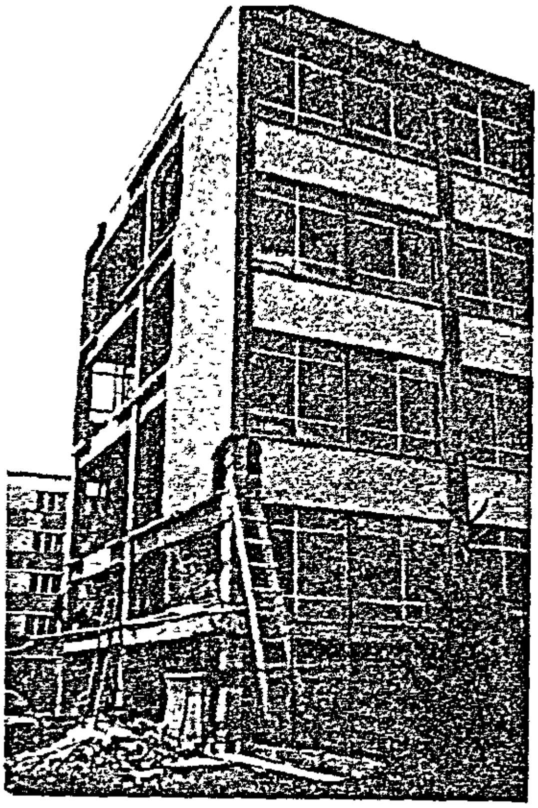


Photo 5.50

A 4-story office building of reinforced concrete rigid frame construction, Bucharest. (The lowest beam is a non-structural beam.)

Photo 5.51

A shear failure in a short column consisting of a non-structural beam and brick walls of the same building, Bucharest.

Photo 5.52

Buckling of main reinforcing column bars caused by a shear failure of the same building, Bucharest. (Hoops 8φ , 20 cm spacing)

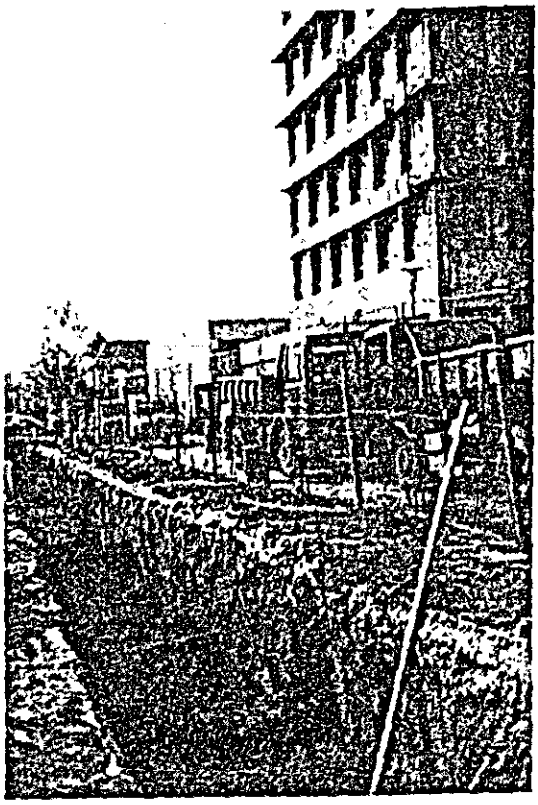


Photo 5.53

A 14-story office building of reinforced concrete rigid frame construction, Bucharest. Inner brick walls and glass panes were almost all broken. (Figures 8 and 9 show the building plan and skellton diagram.)

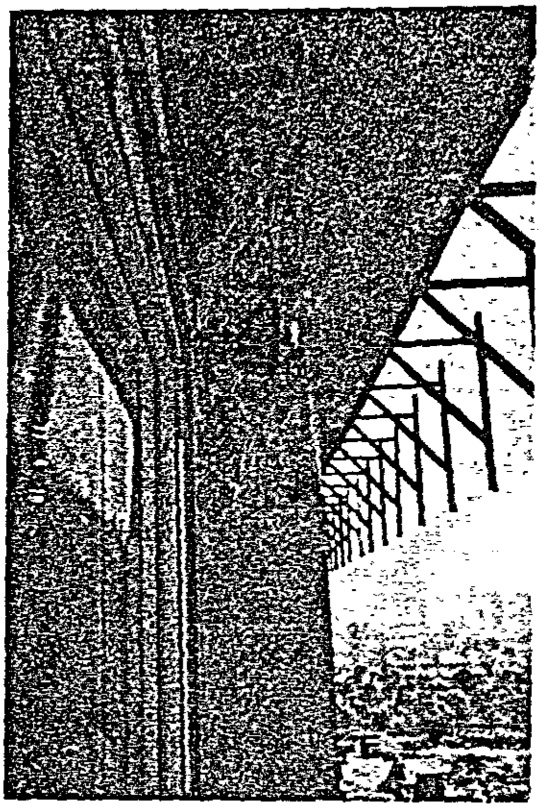


Photo 5.54

Main reinforcing bars' buckling in a 6th story column head of the same building, Bucharest.

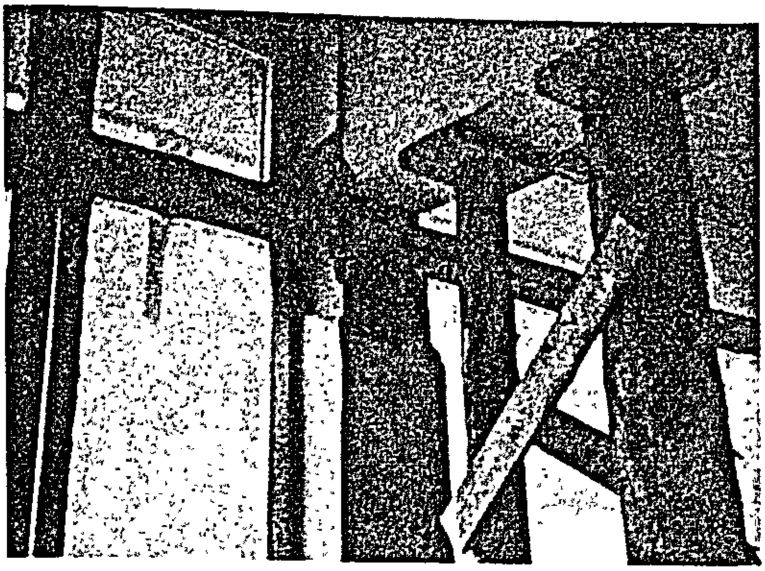


Photo 5.55 A scene of the building's interior, Bucharest. (the beams in the ridge direction are inverted beams.)

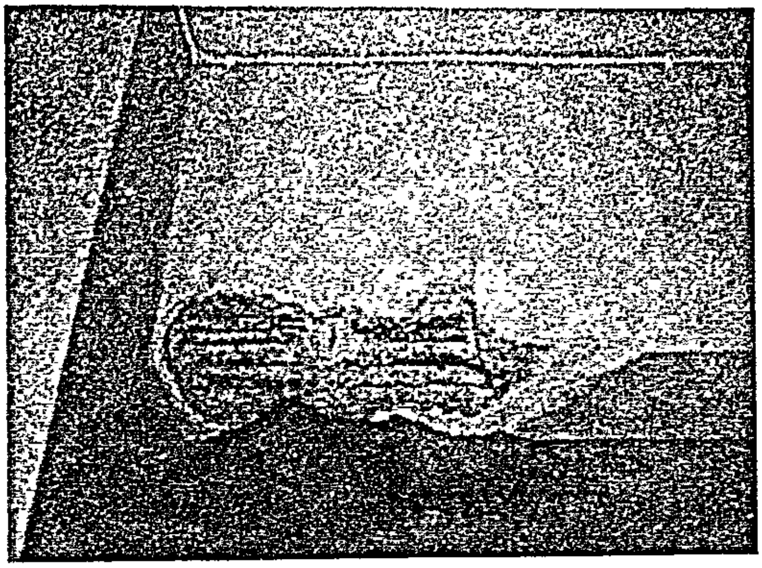


Photo 5.56 A fall of concrete from the bottom of a beam of the same building, Bucharest.

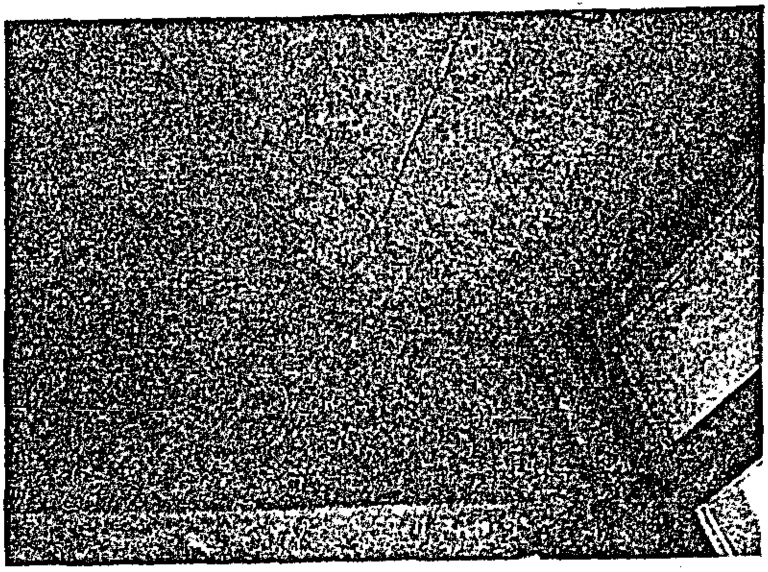


Photo 5.57 Rupture of a column capital and a shear crack extending to the floor slab of the same building, Bucharest.

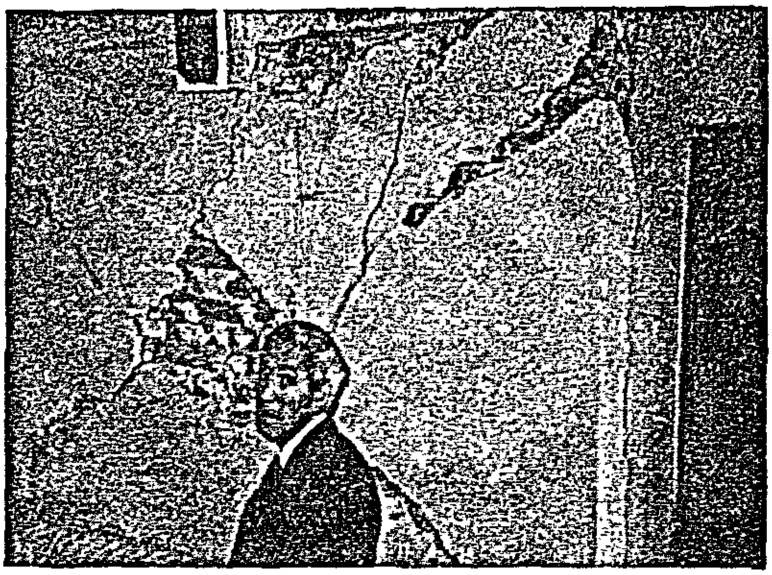


Photo 5.58 Shear failures in a non-reinforced brick partition wall inside the building, Bucharest.

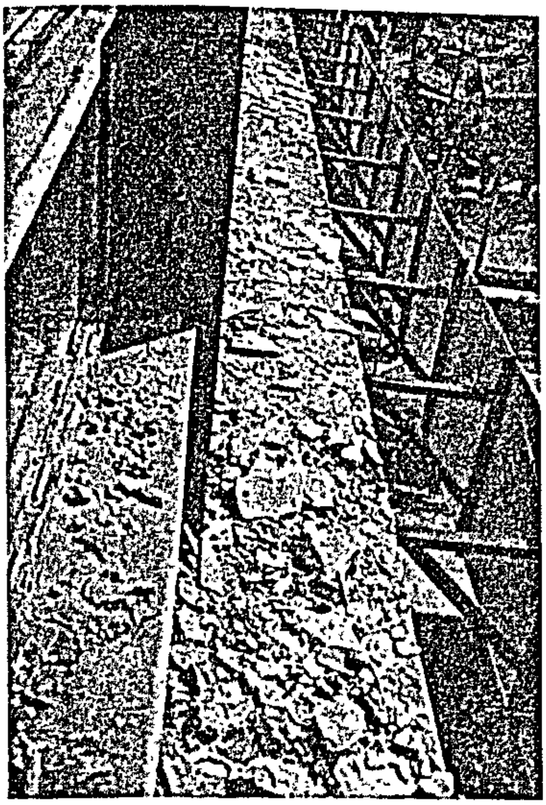


Photo 5.59

Fragments of fallen glass and concrete littered on the eaves of the building, Bucharest.

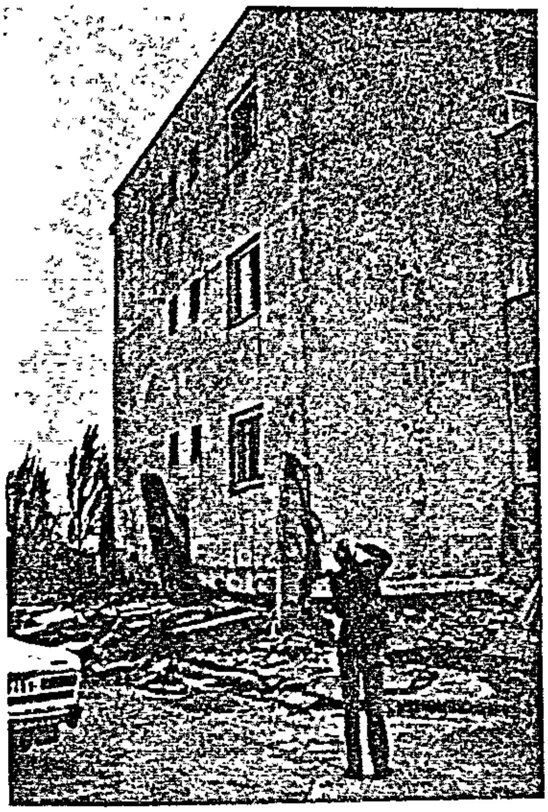


Photo 5.60

A 4-story apartment house with its first story totally flattened, Poiesti. (The first story was of a pilotty structure.)

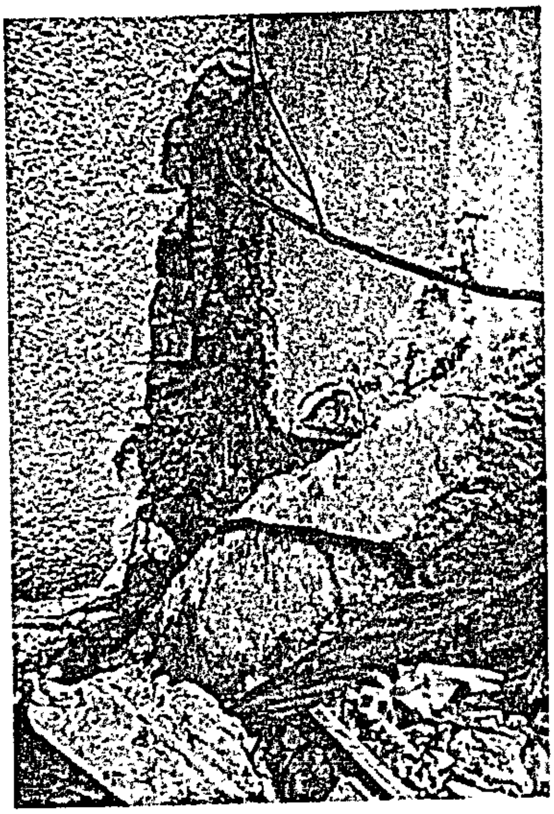


Photo 5.61

A 1st story column of the building in Photo 5.60. (Hoops, 6ϕ 150 mm spacing)

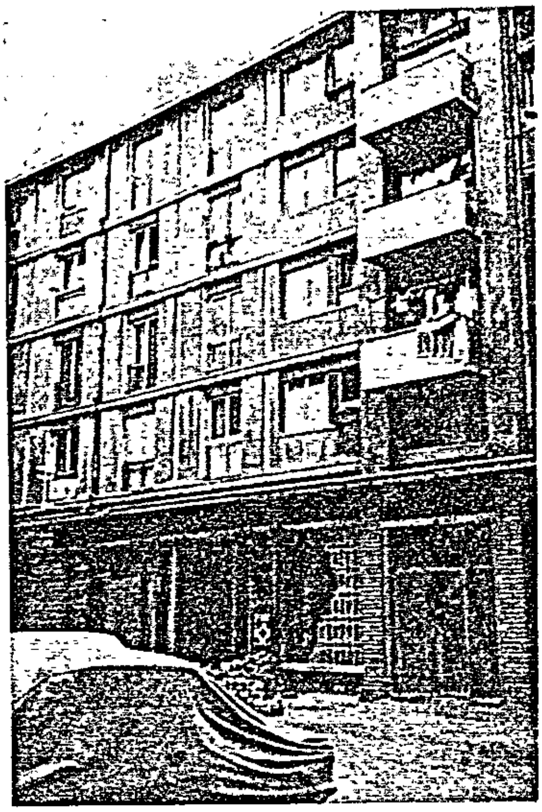


Photo 5.62

A damaged five-story apartment-shop building of reinforced concrete rigid frame construction, Ploiesti.

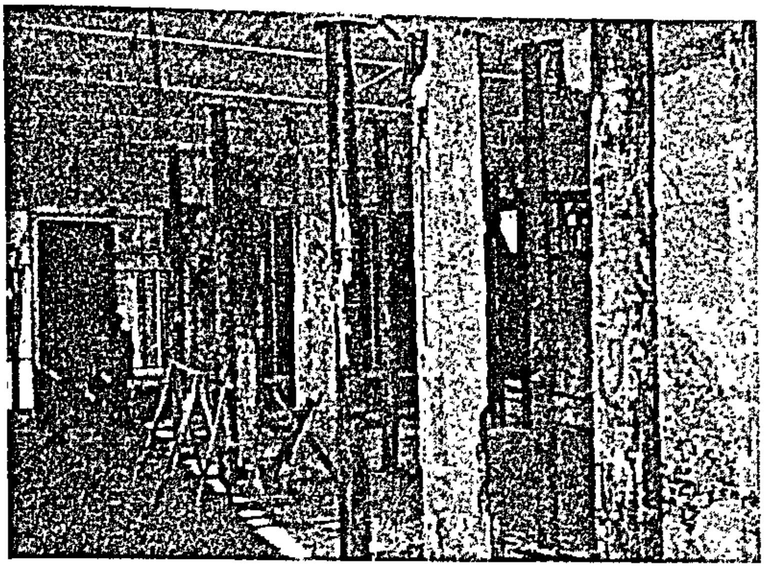


Photo 5.63 The interion of the 1st story of the same building, Ploiesti.

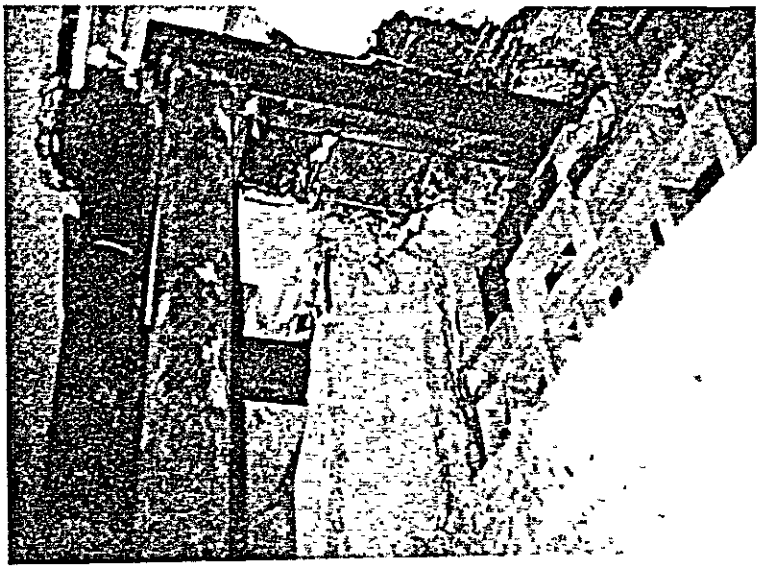


Photo 5.64 Buckling of main reinforcing bars in a column capital in 1st story of the same building, Ploiesti.

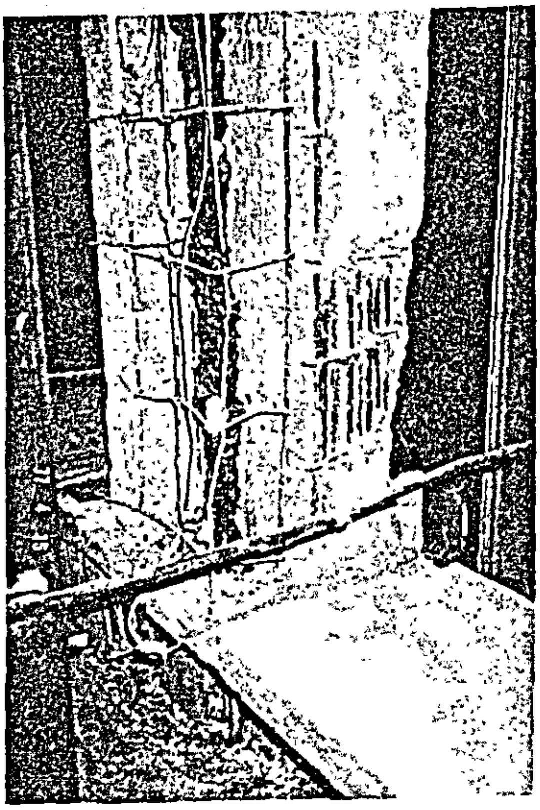


Photo 5.65

Splintered concrete surface of a 1st story column base caused by overly arranged bars in the same building, Ploiesti.

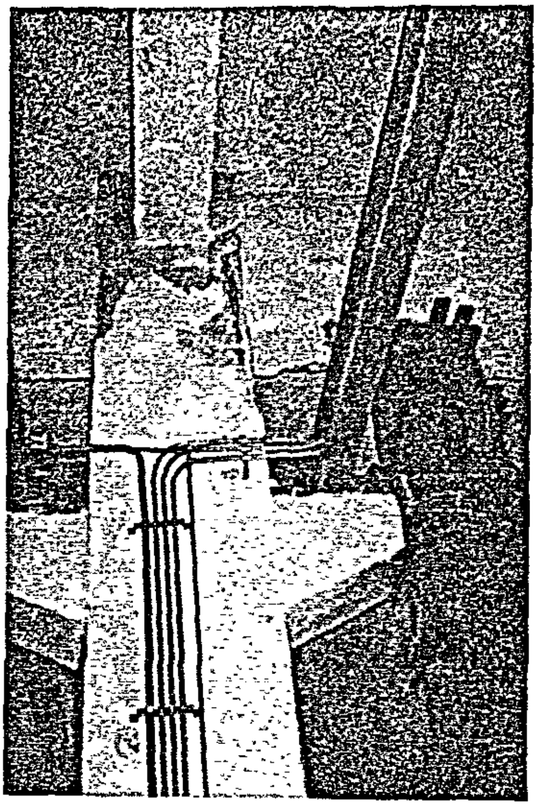


Photo 5.66

Separated concrete surface and buckling of main vertical bars in a column capital. A 5-story industrial plant of reinforced concrete rigid frame structure, Bucharest.

Photo 5.67 Failure of a construction joint in a column of the same building, Bucharest.

(1) Computer Center (Survey number 13, Bucharest)

This 3-story reinforced concrete building that had been located near Bucharest's North Station was totally flattened by the collapse of columns in every story. The building consisted of 24 m x 24 m plane shapes with double floor structure. They were supported by nine columns with threemeter-wide cantilever all around.

When the survey team visited the site, the building had already been demolished to take out the computers; the exact cause of collapse could not be determined. Judging from explanations of the officials concerned, however, half the main reinforcing bars in the columns were cut-off bars at column capitals. Reinforcement against shear force was also inadequate and connecting bars between slabs and frames were relatively weak being 4-20ϕ in all stories. It is estimated that, even though it incorporated an aseismic design, the building's horizontal capacity was too small in proportion to its weight and that ductility was also insufficient.

(2) Medium Height Apartment Building with Shops (Survey number 16, Bucharest, cf. Photos 5.43, 5.44)

This is a typical example of an apartment building which includes a shop in Bucharest. It was constructed immediately after the 1963 establishment of seismic regulations. Its upper part leaned significantly to one side because of the collapse of columns on the first floor. The building along with its basement was demolished and removed.

Officials cited the underpinning in progress at the time of the quake as a possible cause. However, a look at similar adjacent buildings revealed evident shear failure in columns (hoop bar ratio was approx. 0.1%; see Photo 5.44). Therefore one reason is thought to be the inadequacy of shear strength.

Furthermore, the building"s first story, used for shops, lacked brick walls such as were erected in upper stories. The height of the first story itself was much greater than those upstairs. These structural features, making the first story prone to deformation by vibration, are considered to be factors the collapse of this building.

(3) Pilotty-Style 4-Story Apartment Building (Ploiesti; see Photos 5.60, 5.61)

This is an apartment building in the suburbs of Ploiesti, some 40 km north of Bucharest. As shown in Photo 5.60, the first story of the building collapased completely. The first story consisted pilotty space with almost no brick partition walls as erected at many places of the upper stories.

The pitch of the 6 mm hoop bars in the columns was 15 cm or more in the second story but only 30 cm (Pw - 0.05%) in the first story. Main vertical bars in the columns were clearly inadequate since only 4 or 6 D-22 bars were used.

As a result it is estimated that the inadequate strength and deformation capacity of the first story was the main cause of the damage.

(4) Pure Rigid Frame 14-Story Office Building (Bucharest, photos 5.53 - 5.58, 5.80)

Figs. 5.8 and 5.9 show the building's plan and its skelton diagram, respectively. The building's structure is a pure rigid frame, although it has reinforced concrete walls for the stairway, which is disconnected from the main framed portion structurally.

The building was not destroyed. But there was damage to some of the main structural parts, e.g., column rupture accompanied by buckling of main reinforcing bars on the 2nd, 3rd and 7th floors, numerous shear cracks in wall beams and a shear failure of an inner column. In addition, non-reinforced brick walls inside were badly damaged everywhere and many window panes were broken.

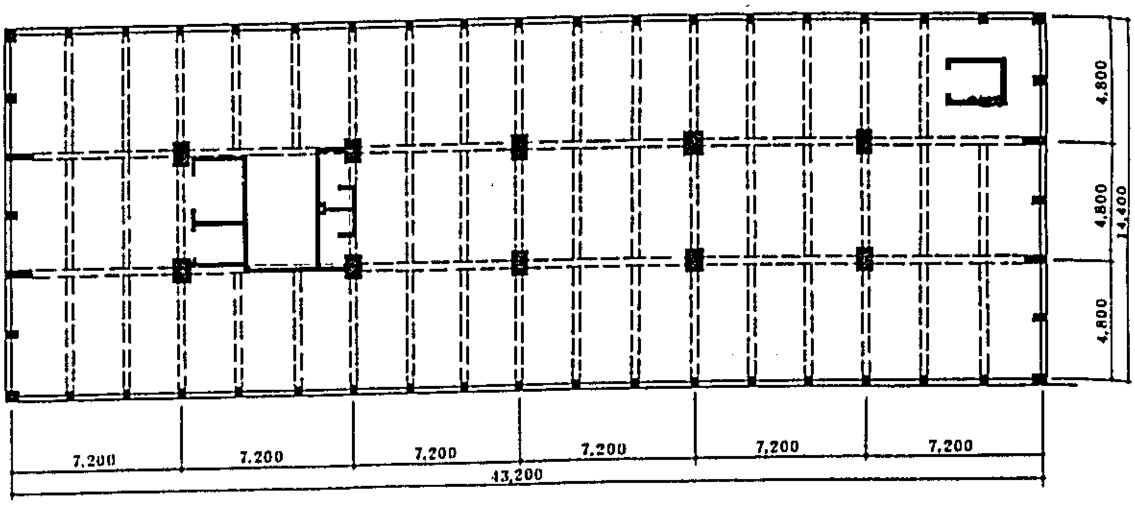


Fig. 5.8 Plan of a 14-story office building of reinforced concrete rigid frame construction, Bucharest, Romania.

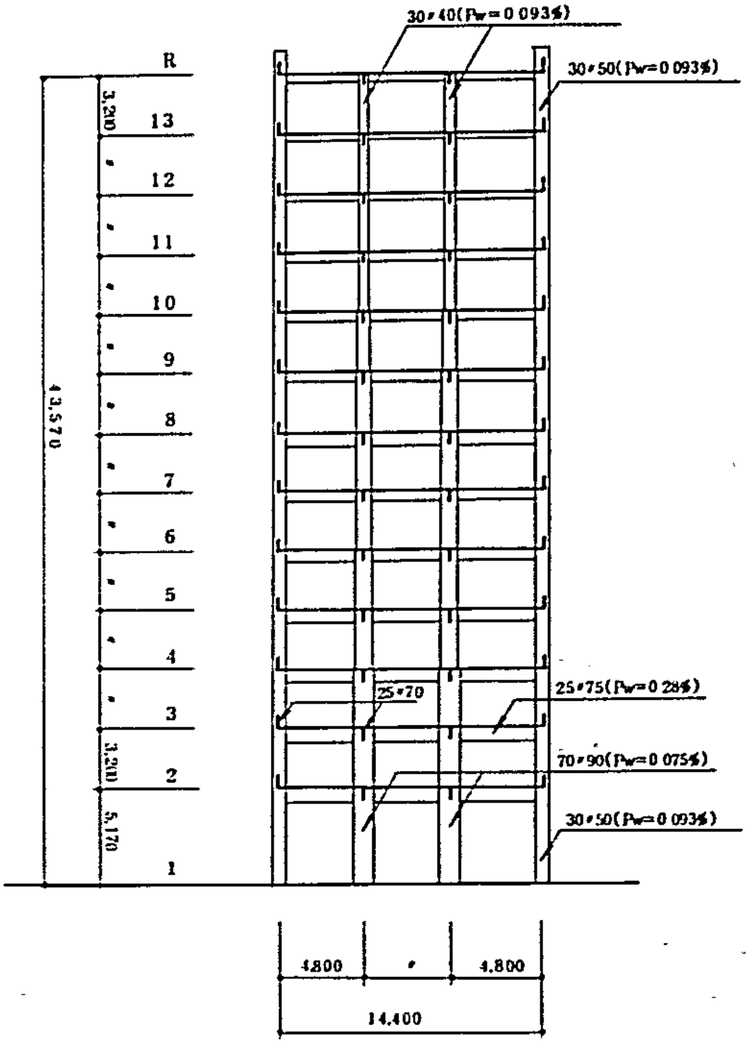


Fig. 5.9 Sectional skeleton diagram of the building in Fig. 5.8.

Officials explained that the building was designed with a base shear coefficient of 0.025 and the calculated values of its primary natural periods is about 2.5 seconds both directions.

The structural documents of this building made available to us, allowed comparison of its structural capacity to that of a Japanese building of comparable size by approximate estimation. Results of the study are shown in Table 5.2. (See Figs. 5.10 - 5.12 with regard to the Japanese building)

According to this table, the building's bearing capacity in the span direction is governed by the bending strength of the outer columns and the bending strength of beams in relation to inner columns. Therefore, shear failures of columns are not a problem. The reserved yield shear force coefficient at ultimate is about 0.08, almost triple the design value but still about one third of an equivalent Japanese building, the value of which is almost 0.26.

Accordingly, the main cause of damage is considered to be inadequate bearing capacity of the building as a whole resulting from the insufficient strength of outer columns and long beams.

Ground conditions under the building are not known. Judging from the response spectra of acceleration of the strong motion record shown below (see Fig. 5.16), acceleration applied to it would have been somewhere around 200 gals, assuming about 5% damping.

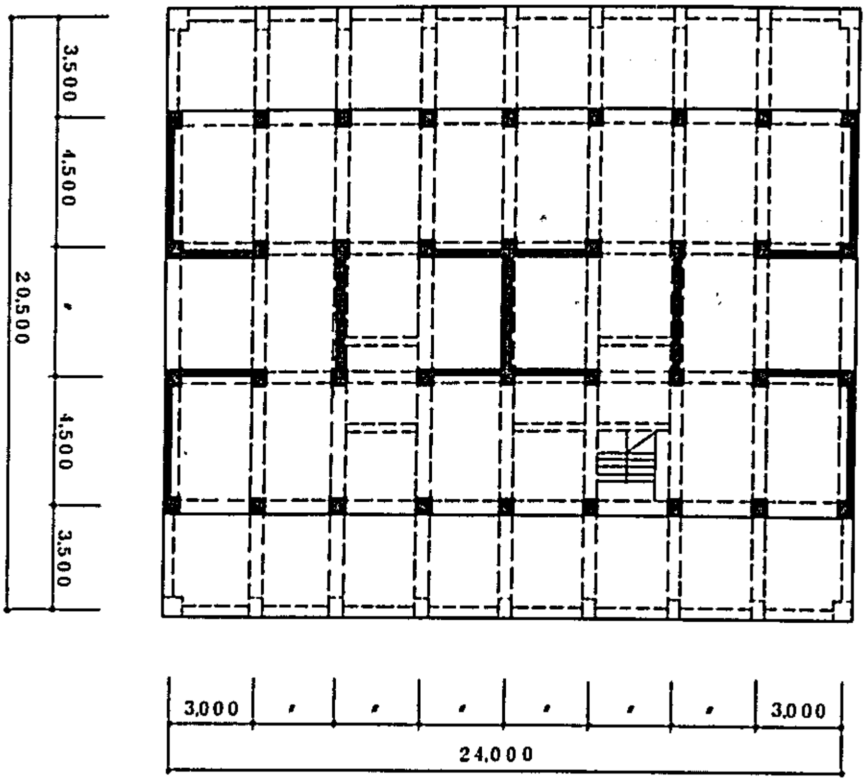


Fig. 5.10 Plan of a typical story of 18-story apartment building of reinforced concrete frame construction, Japan. (in mm)

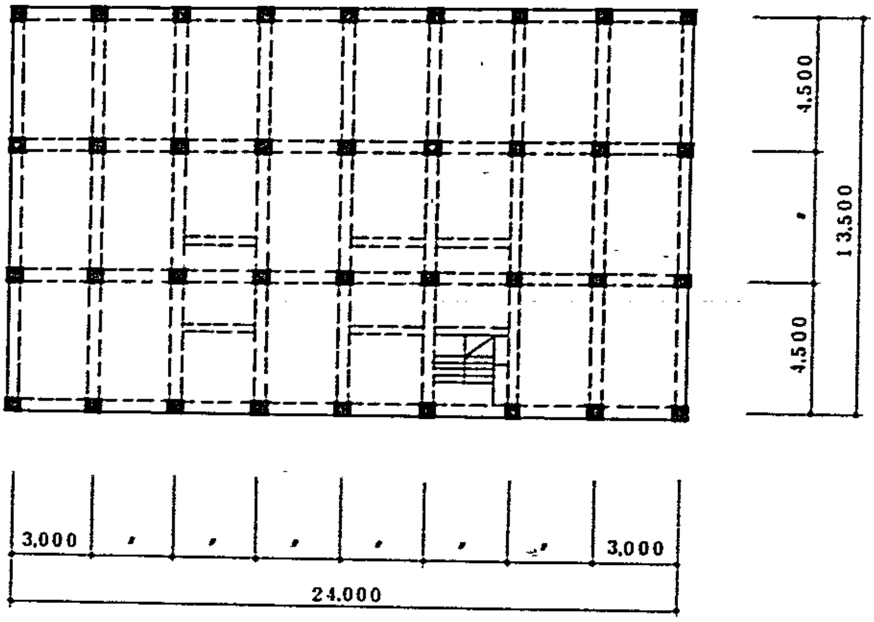


Fig. 5.11 Plan of the 1st story of the building in Fig. 5.10. (in mm)

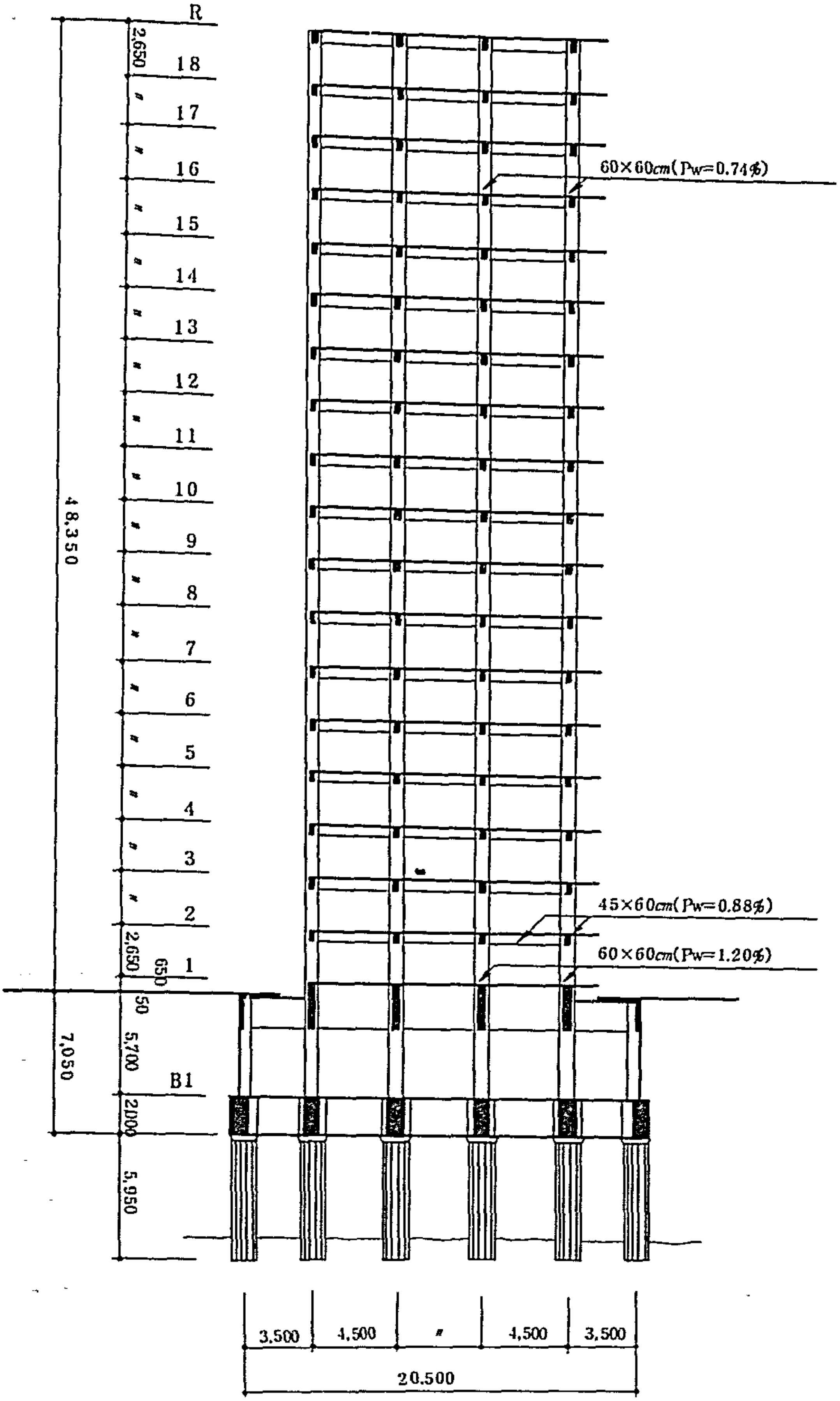
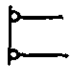
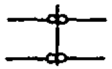


Fig. 5.12 Sectional skeleton diagram of the building in Fig. 5.10. (in mm)

Table 5.2 Comparison of Structural Factors of Multi-story Frame Reinforced Concrete Buildings

	Story	Story Height h (cm)	Column Location	Column Width x Column Depth BxD(cm)	Allocated Floor Space AF(m^2)	Axial Force N (ton)	Axial Unit Stress (kg/cm^2)	Tensile Reinforcement Ratio Pt(%)	Hoop Bar Ratio Pw(%)	Column Ratio $\Sigma BD/\Sigma A_F$ (cm^2/m^2)	Remarks
Japan	18	265	Outer Column	60x60	3x2.25	139.5	38.8	1.27	1.20	22.2	Design Strength for Concrete $Fc=300kg/cm^2$ Yielding Point of Steel Bar $fy=4000kg/cm^2$
			Inner Column	60x60	3x4.50	227.3	63.1	0.75	1.20		
Romania	14	320	Outer Column	30x50	2.4x2.4	81.2	54.1	0.27	0.093	14.8	$Fc=180kg/cm^2$ $fy=4000kg/cm^2$
			Inner Column	70x90	4.8x7.2	449.8	71.4	0.32	0.075		

Horizontal Strength of the Second Story

	Column Location	Axial Force N* (ton)	Bending Strength Q_B (ton)	$\frac{Q_B}{N}$	Shear Strength Qs (ton)	$\frac{Q_S}{N}$	Failure Mechanism	Strength of the Mechanism Qm (ton)	$\frac{Qm}{N}$	$\frac{\Sigma Qm}{\Sigma N}$	Design Shear Force Coefficient
Japan	Outer Column	139.5	121.0	0.87	97.1	0.70		28.6	0.23	0.264 (1.0)	0.20
	Inner Column	227.3	102.9	0.45	99.6	0.44		57.2	0.28		
Romania	Outer Column	81.2	15.7	0.19	17.4	0.21		15.7	0.19	0.076 (0.29)	0.025
	Inner Column	449.8	149.5	0.33	87.6	0.19		24.3	0.054		

Asterisk; axial forces of the first story columns were used as substitutes.

The examples of damage listed above are the most outstanding ones. The following are the main features of damage done to buildings of rigid-frame reinforcement concrete construction, including those above.

(1) Among medium and tall buildings, there was only one case of superstructure collapse. However, damage to non-structural elements was severe even in buildings that sustained only slight structural damage. This, along with the prevalent standardization of building designs, increased the total value of losses.

(2) Low buildings appear to have sustained less severe damage than medium and high buildings. But as noted above, did exceptional collapse due to inadequate strength.

(3) In general, structural damage was more visible in columns than in beams. There were many cases of shear failures and buckling of main vertical bars.

(4) Since a large majority of buildings have relatively small bearing capacity, collapse or rupture occurred at many places where execution of work was defective. These defects included poor casting of concrete, poorly finished concrete jointing, maladustment of steel bars, and locally excessive planting of main reinforcing bars.

Therefore, it can be pointed out that the destruction of these buildings was mainly caused by the insufficient strength and rigidity of structure as well as by the imbalanced distribution of rigidity.

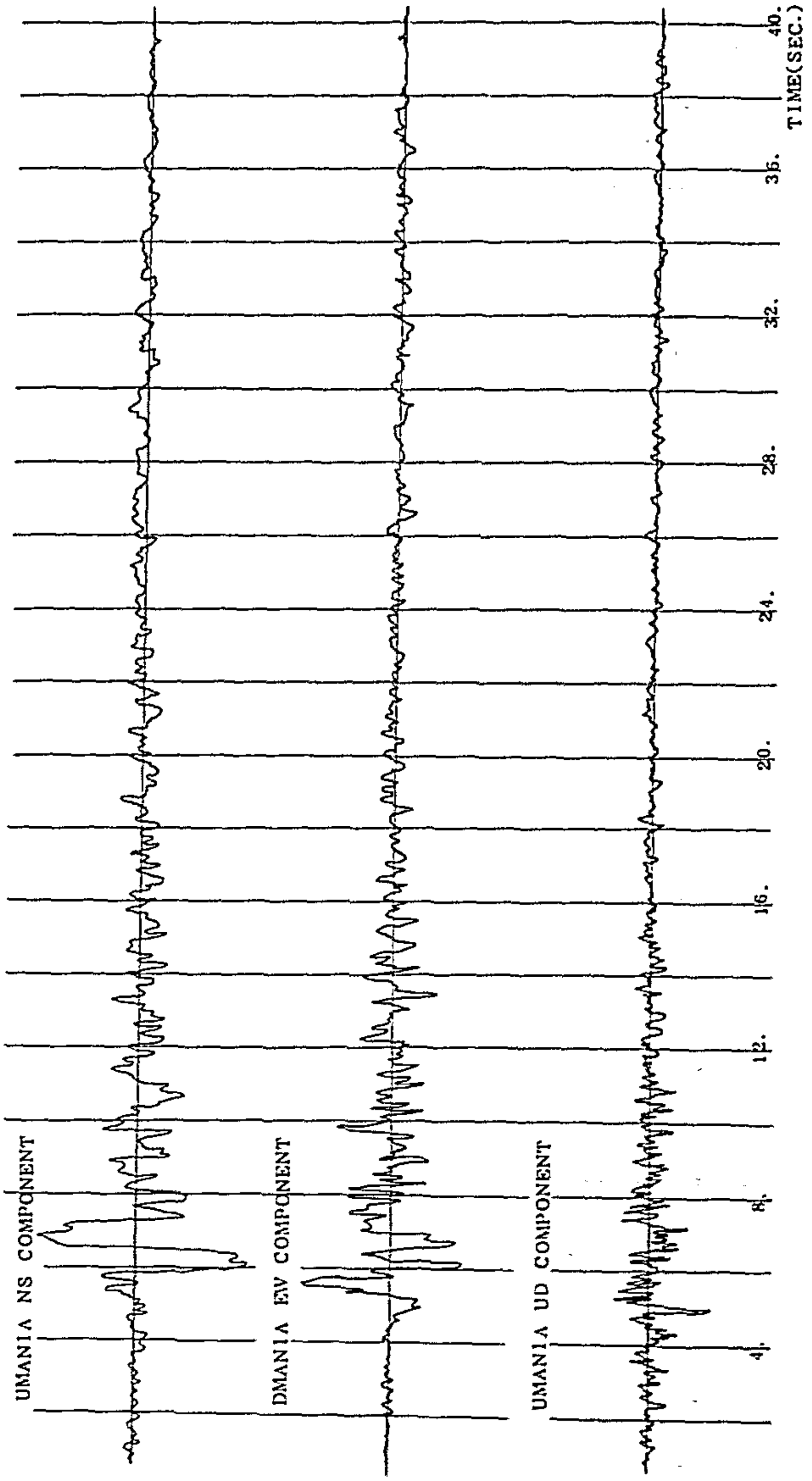


Fig. 5.15 Corrected Accelerogram of Romanian Earthquake

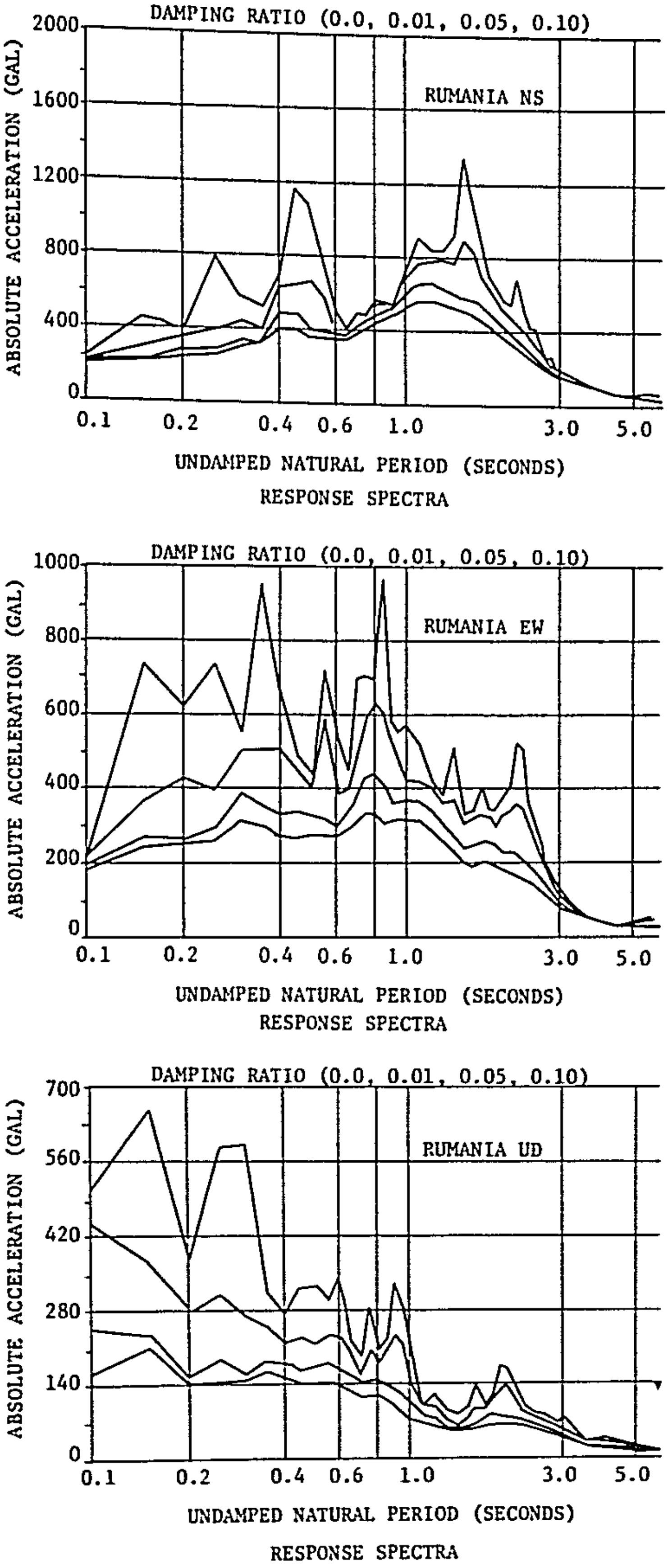
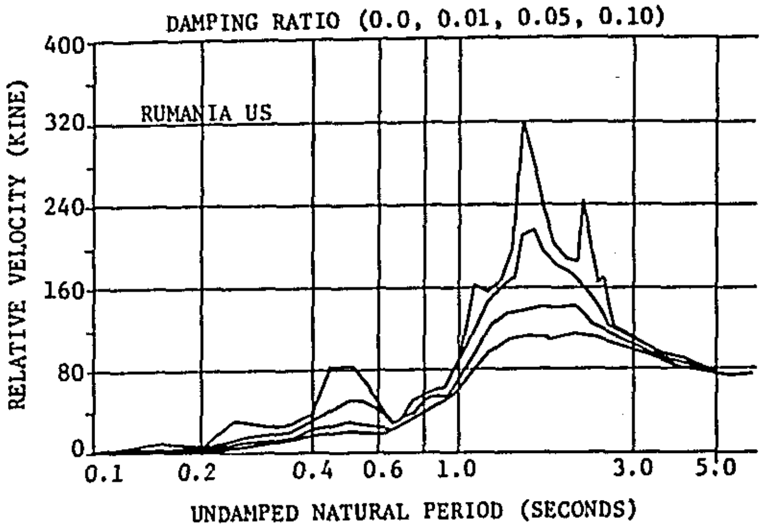
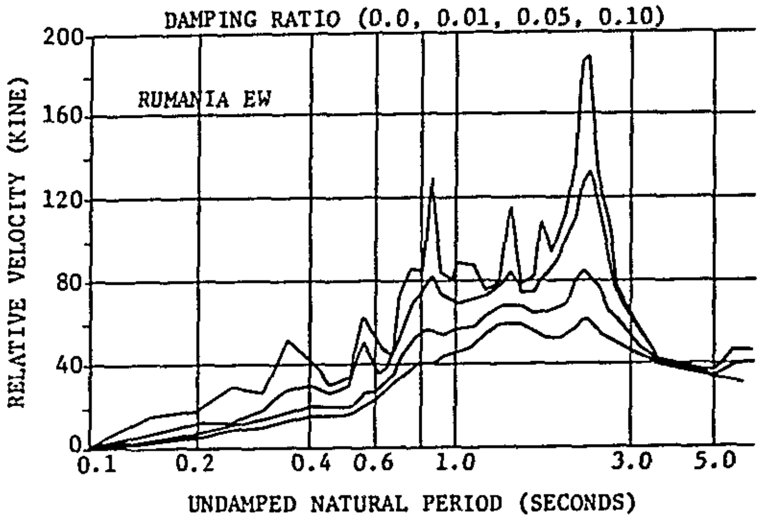


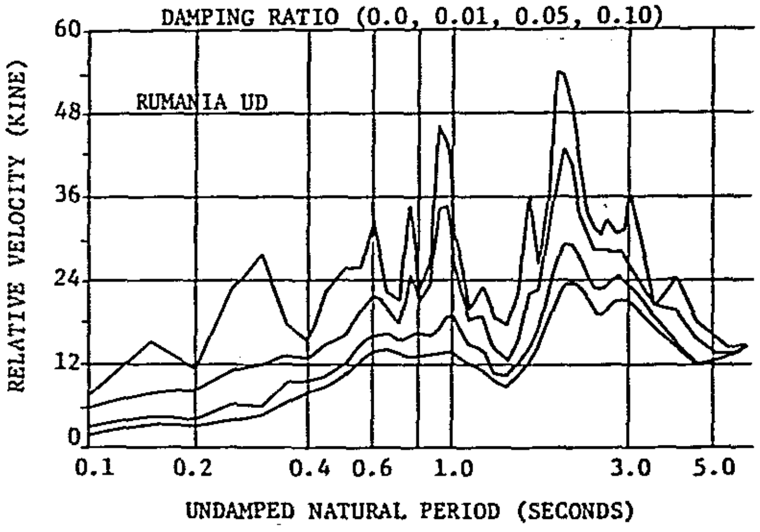
Fig. 5.16 Acceleration Spectra of Romanian Earthquake



RESPONSE SPECTRA



RESPONSE SPECTRA



RESPONSE SPECTRA

Fig. 5.17 Velocity Spectra of Romanian Earthquake

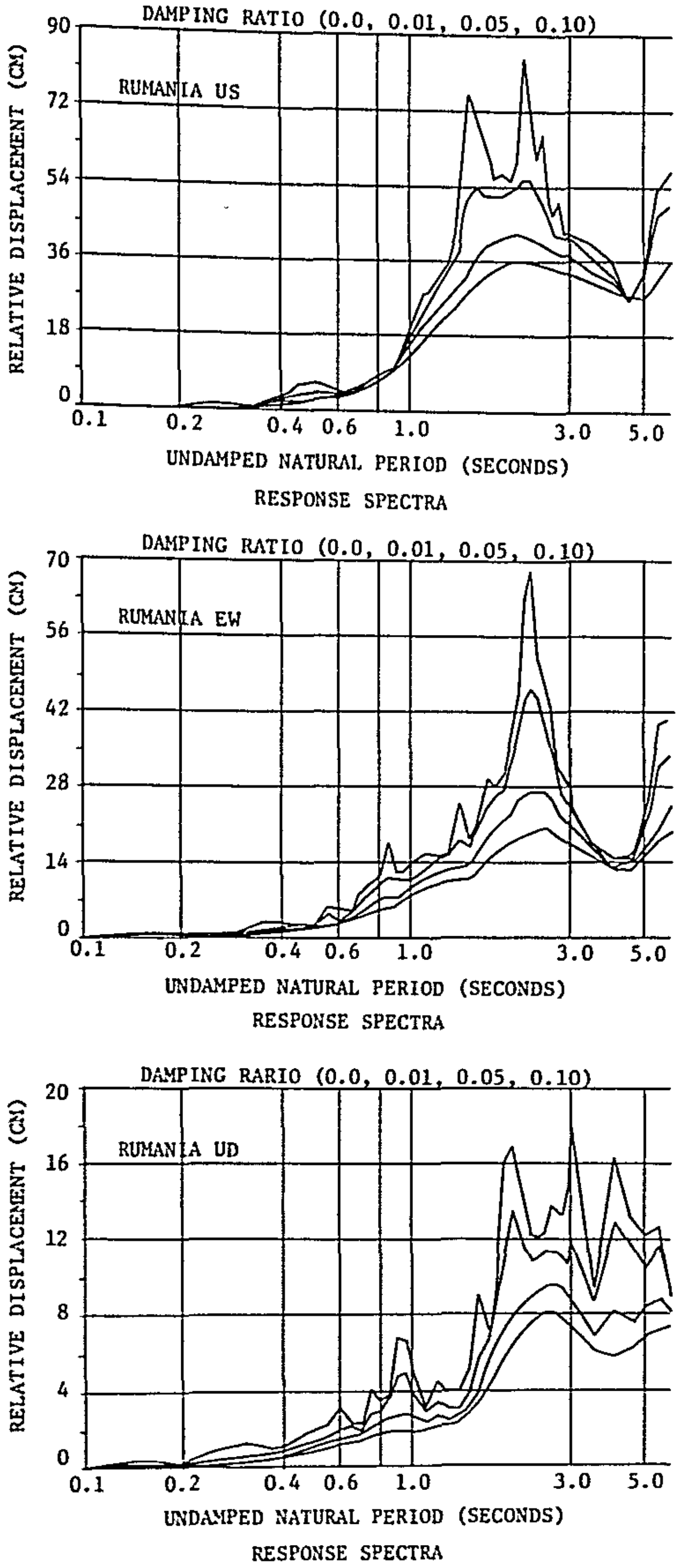


Fig. 5.18 Displacement Spectra of Romanian Earthquake

5.2.4 Reinforced Concrete Wall Buildings (See Photos 5.68 - 5.75)

The reinforced concrete wall structure was found to be used mainly for 10 to 14 story apartment buildings. However, as shown in the typical plan of such an apartment building (see Fig. 5.13), one characteristic of Romanian apartment buildings of this construction is that the reinforced concrete wall in the ridge direction runs only down the middle of such a building.

Accordingly, walls in the span direction have no crossing walls at their ends where only small columns (about 25 cm x 30 cm columns with vertical reinforcing bars of 6-12ϕ) are standing.

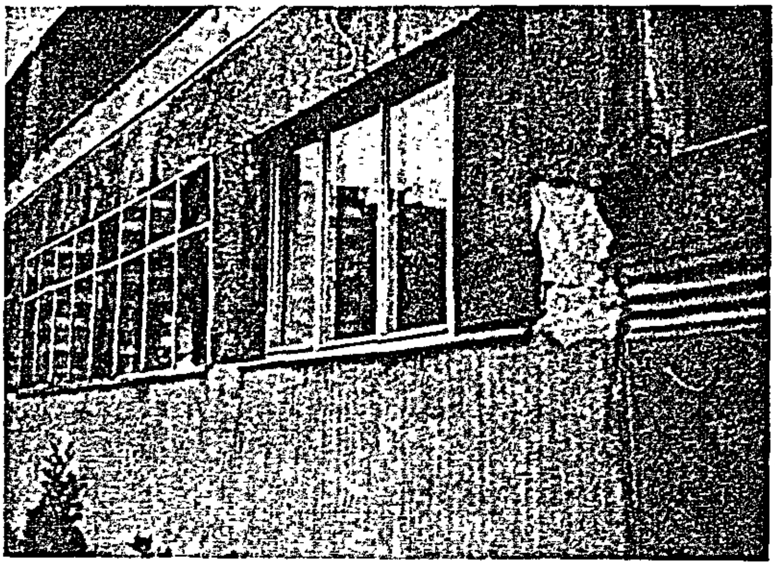


Photo 5.68 Failure of the wall-end column and broken glass panes of an 11-story apartment building of reinforced concrete wall apartment building, Bucharest. (In the ridge direction, the wall runs only to the midpoint.)

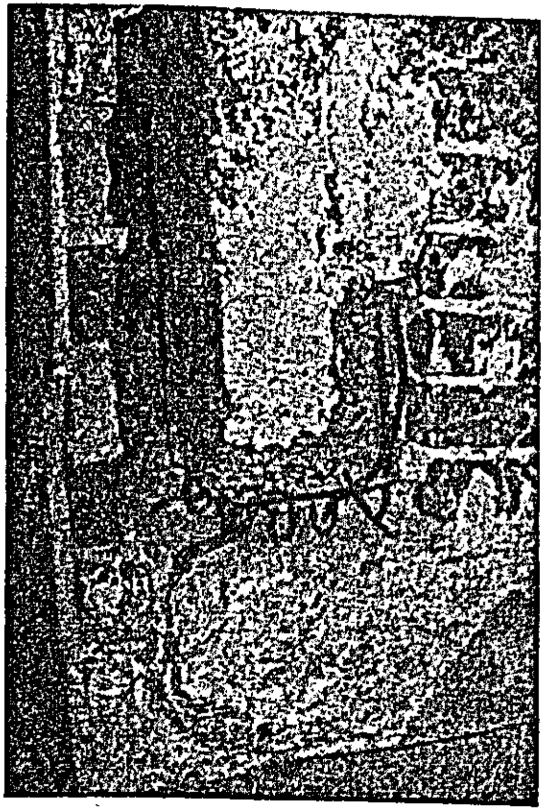


Photo 5.69

Failure of a 1st story wall-end column of a building of a similar type, Bucharest. (Visible signs of maladjusted main reinforcing bars on the four corners.)

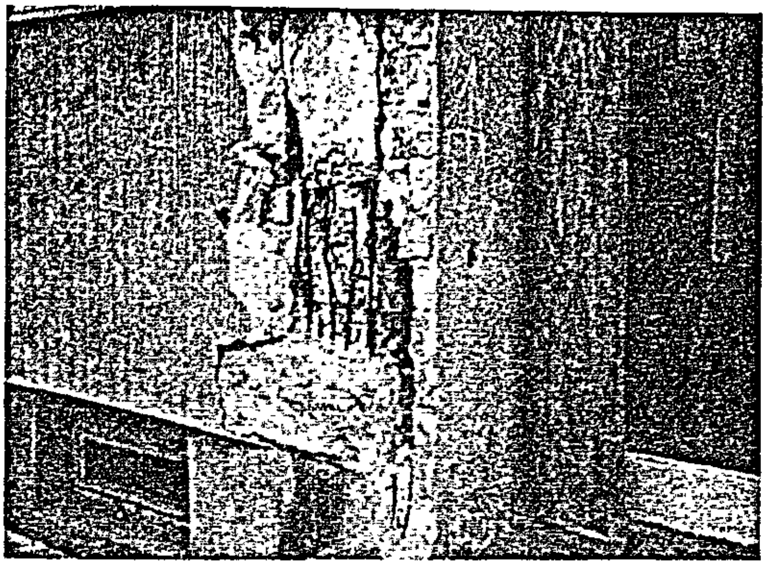


Photo 5.70 Failure of a 1st story wall-corner column of a building of similar type, Bucharest. (Malcasting of concrete)

Photo 5.71 Failure of a 1st story wall in the span direction and buckling of reinforcing bars of a building of similar type, Bucharest.

Photo 5.72

An 11-story reinforced concrete wall apartment building with a basement, Bucharest. (An adjacent building of the same type totally collapsed, resulting in the death of 90 people)

Photo 5.73

Failure of a 1st story wall-end column of the same building, Bucharest. (The exterior wall in the ridge direction in this photo is a weak non-reinforced brick wall. The structural wall runs only in the midway of the building; measured natural periods were 0.5 seconds for the ridge direction, 0.7 seconds for the span direction.)

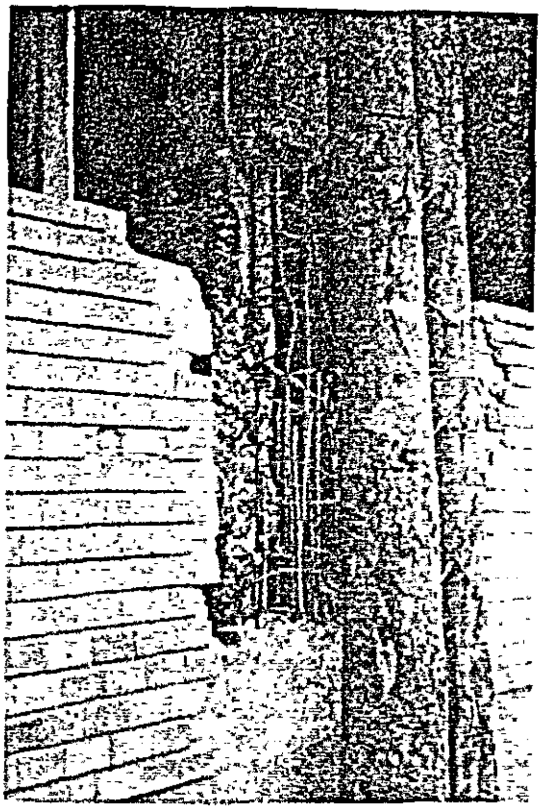


Photo 5.74

Failure of a 1st story wall-end column of the same building just before reinforcement, Bucharest. (Buckling of column main reinforcing bars is exposed.)

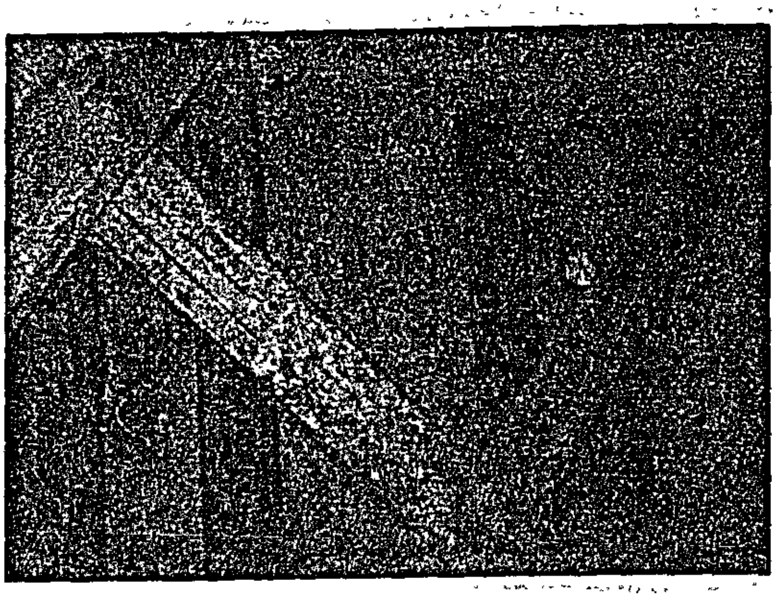


Photo 5.75 Failure of the 1st story wall in the span direction and buckling of reinforcing bars, Bucharest.

For the outer walls in the ridge direction, non-reinforced brick walls are used. When finished, concrete and brick sections are hardly distinguishable from the outside, so that the building appears solid. (See Photos 5.72, 5.73) Wall thickness is approximately 14 cm on each floor and 6 mm reinforcing bars are doubly set in the walls with a 30 cm pitch.

Below are examples of reinforced concrete wall buildings which were destroyed.

(1) 11-story apartment buildings (Survey number 29, see Photos 5.72 - 5.75)

These new apartment houses built in 1975 were six structurally independent buildings standing closely together with virtually no width in their expansion joints. Each building has two apartments per floor with a stairway in between. The westernmost building feld to the northern side (in the span direction) and was totally destroyed. As a result approximately 90 of the 150 occupants died. The building's plane shape is almost identical to that shown on Fig. 5.13.

The remaining five buildings were also damaged in different degrees; the further west, the heavier the damage. The state of damage is shown in Photos 5.73 and 5.74. As shown in the photographs, major damage occurred in the south-north (span side) direction, corresponding to the direction of the epicenter. Not only wall-end columns but also earthquake-reistant walls were destroyed. Main reinforcing bars also buckled.i.

However, buildings of the same type standing across a street suffered no structural damage, although their longer direction with smaller walls were in the south-north direction. Causes of these contracdictory phenomena are not clear. But defective execution of construction and ground conditions and are suspected to be factors responsible (these damaged buildings are closer to what we assume was a river bank area than the un-damaged is).

(2) 11-story apartment building (Survey number 17, Photos 5.69 - 5.71)

This building is almost the same type as those noted above. It did not collapse, but its first story was badly damaged. Possible causes for this, as shown in Photos 5.69 and 5.70, are malcasting of concrete in wall columns and extreme maladjustment of main vertical bars in the other wall columns. Photo 5.71 shows that collapse and buckling extended to earthquake-resistant walls inside.

The examples given above are of heavily damaged buildings. Generally, the behavior of wall-systemed apartment buildings is regarded as fairly satisfactory when compaired to that of frame-structured reinforced concrete apartment buildings of similar heights. The high rigidity of the wall-system structure helped minimize the breakdown of inner and outer non-structural elements which was frequently seen in frame-structured buildings.

Figure 5.14 is a plan of a Japanese building similar in size and type to the Romanian wall-systemed apartment house shown in Fig. 5.13. Structural factors are compared in Table 5.3.

The following observations can be made from this table.

1) The Romanian apartment building is imbalanced in wall ratioes in the span and ridge directions. In the ridge direction the wall runs on a single structural plane only and the total wall ratio in this direction is only about one-third of that in the span direction.

2) Judging from the data obtained in Japan by experimental destruction of full-sized buildings, estimated maximum shear force coefficients are from 0.16 to 0.47 for the Romanian building against from 0.95 to 1.17 for the Japanese building, assuming the wall's unit shear strength is $20kg/cm^2$.

3) Hoop bar ratios of the walls are 0.13 % for the Romanian building and from 0.39 to 0.53 % for the Japanese building.

4) Accordingly, in the case of the Romanian building, one important problem is the lack of surplus strength and favorable deformation capacity. Because, it lacks sufficient strength due to the inadequate wall quantity in the ridge direction, and also due to the absense of walls to match those in the span direction orthoqoually.

5.2.5 Buildings of Other Structures

There are some other types of buildings in Romania, especially in Bucharest, which were observed. Their construction methods and a summary of damage are given below.

(1) It appeared that middle and high-story buildings with precast walls mostly escaped damage. The method has been used for some apartment buildings.

(2) Industrial plants in urban areas are middle-story buildings of reinforced concrete, while those in the suburbs and provincial cities are generally one-story buildings of precast concrete.

The plants in urban areas were built either by the cast-in-place method or by the partial use of precast elements. Their live loads are relatively large and their columns and beams were found, in many cases, to have much greater sectional areas than those used in apartment buildings.

These buildings do not appear to have sustained serious damage except for partial collapse due to defective construction work.

The one-story industrial plants using precast members also escaped serious damage both to structural and non-structural elements, despite the fact that they were built by standardized methods and had low rigidity because of their high story height. This apparently reflects better administration of construction materials production and work execution itself than provided for other buildings. (See Photos 5.80 - 5.82)

(3) Some middle-or high-story buildings of reinforced concrete frame construction combined with earthquake-resistant walls were observed (See Photos 5.76 - 5.79).

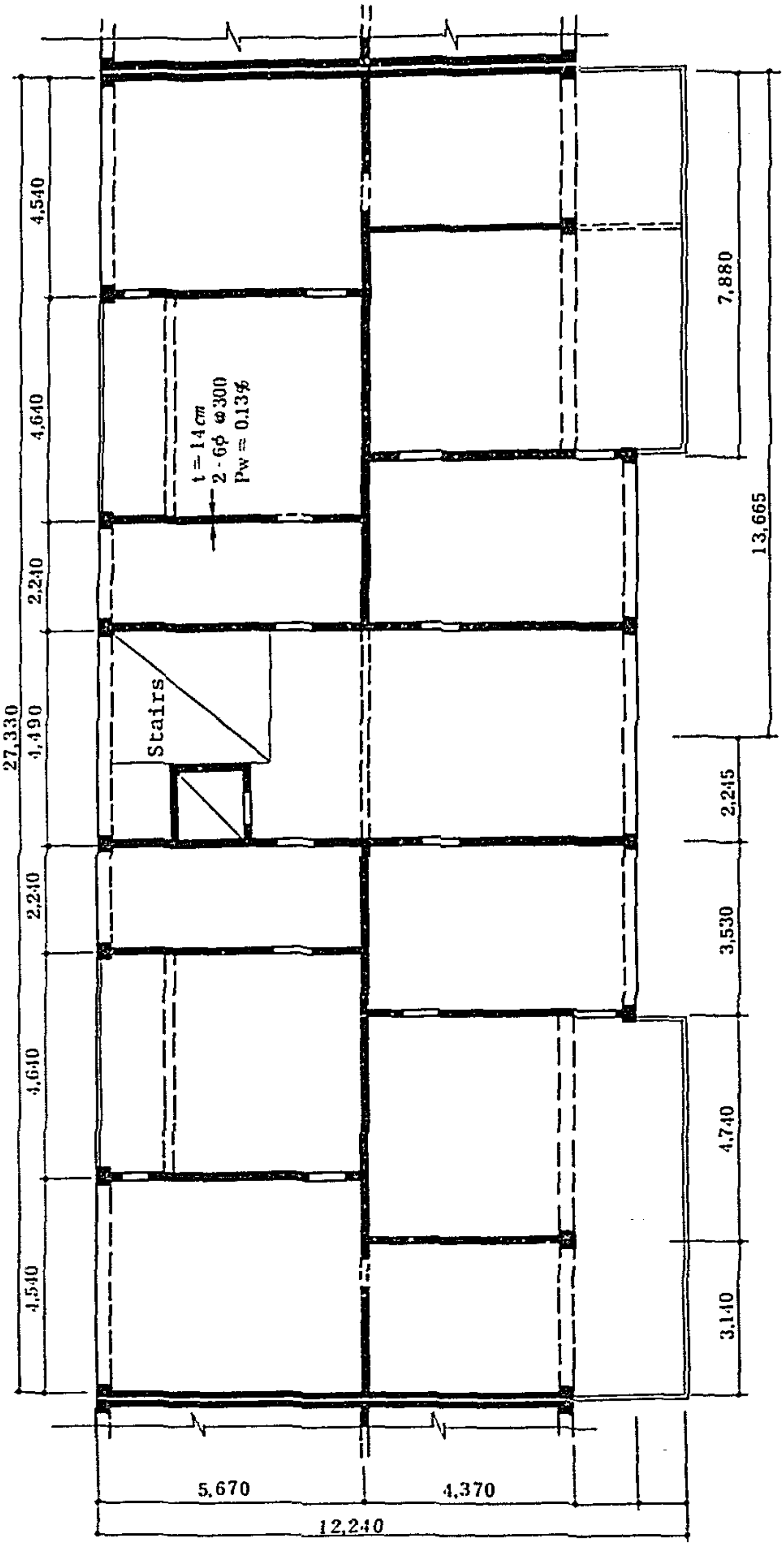


Fig. 5.13 Plan of a 11-story apartment building of wall construction, Bucharest, Romania

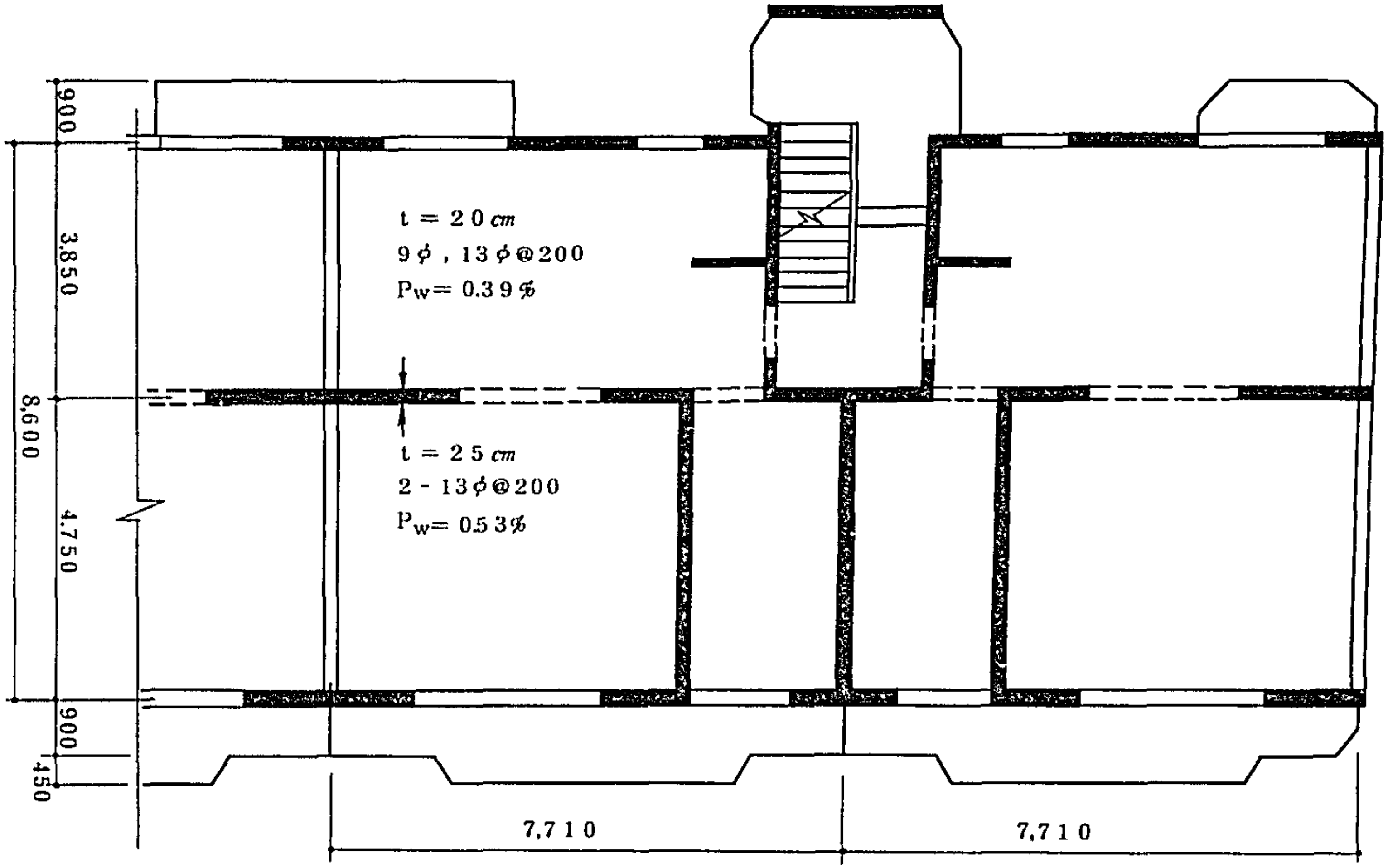


Fig. 5.14 Plan of a 8-story apartment building of wall construction. (Japan Housing Cooperation)

Table 5.3 Comparison of Structural Factors of Typical Apartment Buildings of Reinforced Concrete Wall Construction

	Story N	Direction	Thickness t (cm)	Wall Reinforcement	Shear Reinforcement Ratio Pw(%)	Wall Quantity lw (cm/m^2)	Wall Ratio txlw (cm^2/m^2)	Wall Ratio Against Total Floor Space $\bar{l}w = \frac{t.lw}{N}$ (cm^2/m^2)	*1 τ_{1G} (Kg/cm^2)	*2 k_U	$\frac{k_U}{0.16}$
Romania	11	Ridge Direction	14	2-6ϕ @ 300	0.13	6.4	89.4	8.1	135.8	0.16	1.0
		Span	14	2-6ϕ @ 300	0.13	22.3	312.2	23.4	47.0	0.47	2.94
Japan	8	Ridge Direction	25	2-13ϕ @ 200	0.53	15.3	382.5	47.8	23.0	0.95	5.94
		Span	20	2-13ϕ @ 200	0.39	23.4	468.0	58.5	18.8	1.17	7.31

*1 τ_{1G}: Average shear unit stress on wall by 1G of horizontal force

*2 k_U: Estimated maximum shear force coefficient

Photo 5.80 A one-story plant of precast, prestressed construction, Bucharest. (Cast-in-place columns; 6 m in story height; the natural period, about 1.5 seconds; slightly damaged)

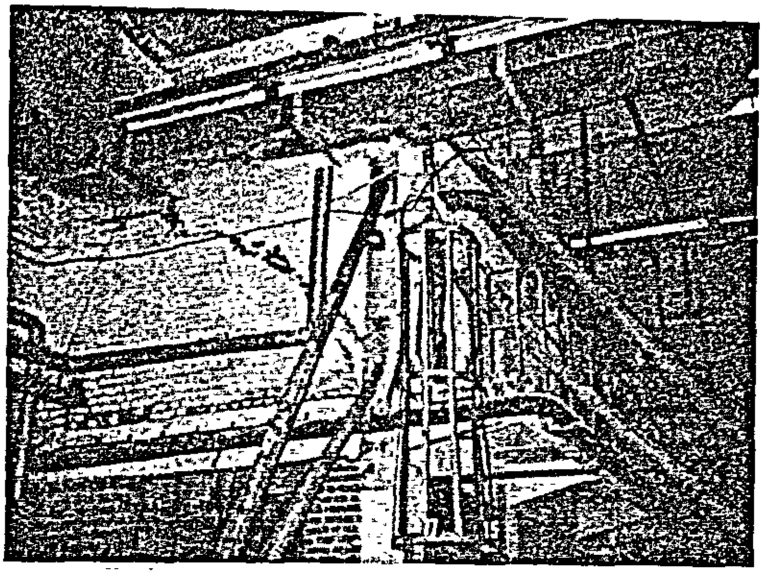


Photo 5.81 Cracks in a partition brick-build wall of a one-story plant, Ploiesti. (Cast-in-place columns, precast beams and floor slabs; 9 m tall.)

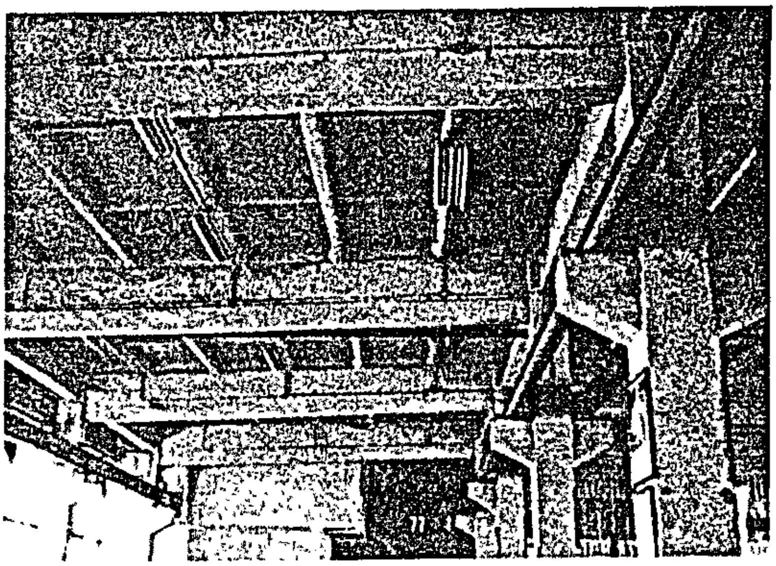


Photo 5.82 A five-story plant with cast-in-place rigid frame and precast floor slabs, Bucharest. (Slight damage to the structure)

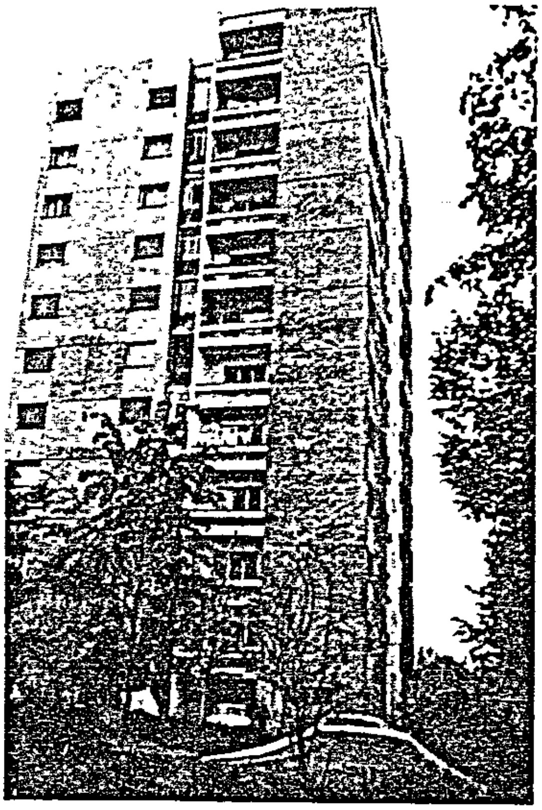


Photo 5.76

A 12-story apartment building with a basement. The reinforced concrete structure combines a rigid frame and earthquake resistant walls, Bucharest. (Measured natural period was about 0.7 seconds; slightly damaged.)

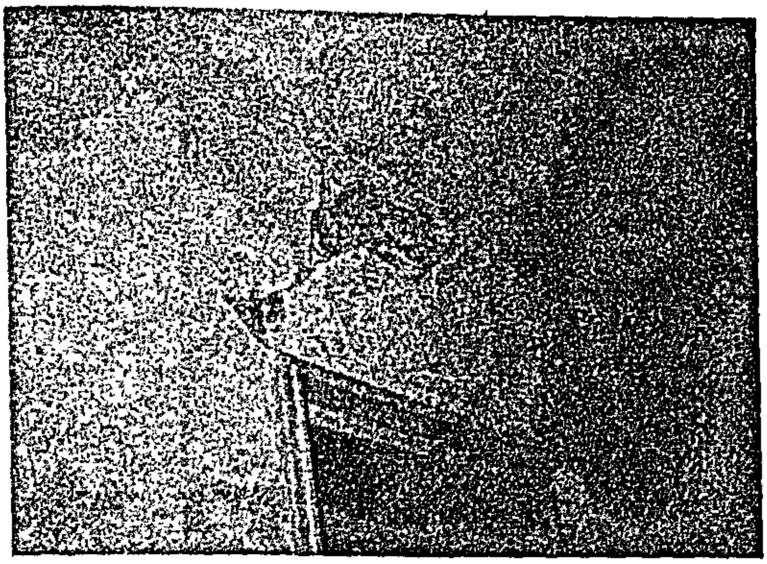


Photo 5.77 Shear cracks in the building's boundary beam

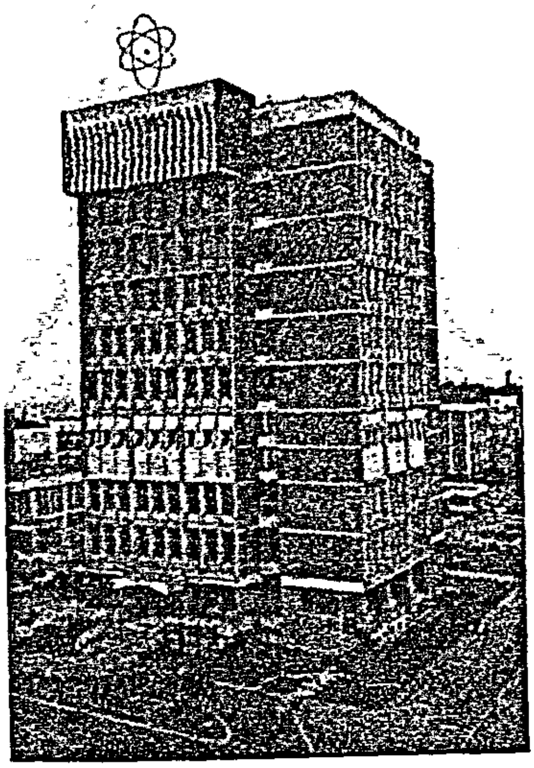


Photo 5.78

An 11-story building with a basement of the National Geophysical Research Center; reinforced concrete structure combines a rigid frame and shear wall, Magurele. (Slightly damaged)

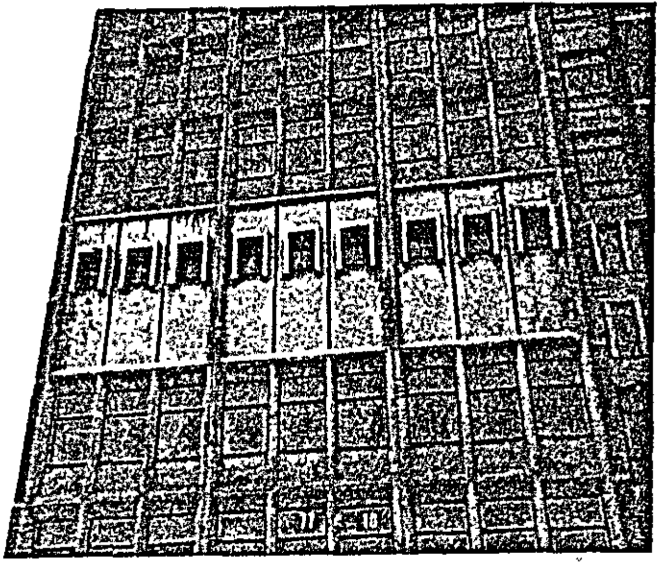


Photo 5.79 Cracks in curtain walls of the same building.

These buildings generally withstood the tremor. Damage to these buildings was slight, being limited to certain parts of structural members and exteriors.

5.3 Reinforcement of Damaged Structures

The survey team visited Romania about one month after the occurrence of the earthquake and stayed there for some 20 days. During the time, demolition and reinforcing of damaged buildings were in progress. The Romanian Government laid down the guideline that damaged buildings should be repaired rather the demolished if the cost of repair fell below 80% of the cost required for building a new one.

As a result, those being repaired include even such old buildings lacking aseismic designs that had been damaged in the earthquake in 1940 and again this time. Some of these are seen in Photo 5.28 and Fig. 5.7.

According to officials, a main objective of the repair program is that fallen brick walls will be removed and replaced with reinforced concrete walls. Some buildings will be structurally reinforced on the horizontal plane by steel beams in order to improve horizontal rigidity. (Some of the buildings, which were to be repaired this way showed the effects of tortional vibration received because of their rather complex plane shapes and eccentric distribution of high-rigidity members.

However, among private house being repaired, there were many examples of evident patch-up work. Photos 5.83 to 5.91 show the progress of the repairs.

Photo 5.83

Strengthening work for a reinforced brick five-story apartment house, Craiova.

Photo 5.84 Reinforcement of decayed bars in a basement column of an 11-story reinforced brick apartment building, Bucharest. (The same building as in Photo 5.28)

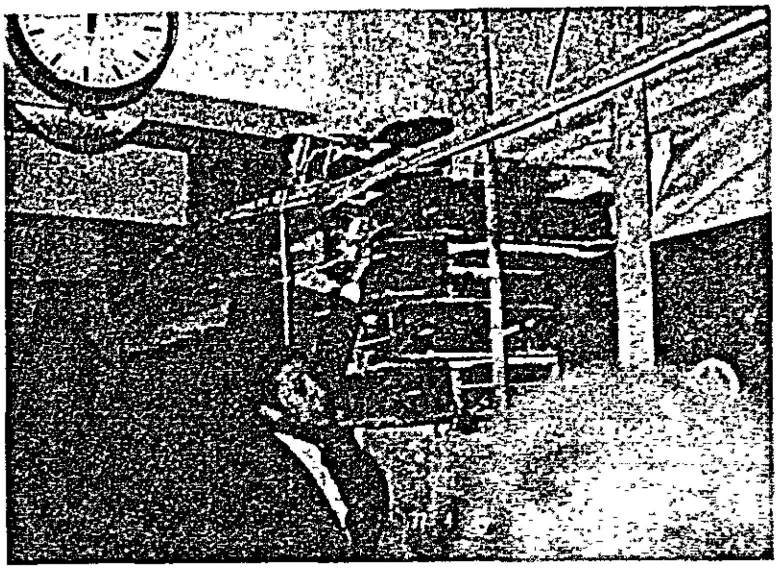


Photo 5.85 Reinforcement of a sheared 6th story column of a 14-story office building, the reinforced concrete rigid frame structure, Bucharest. (The same building as in Photo 5.53)

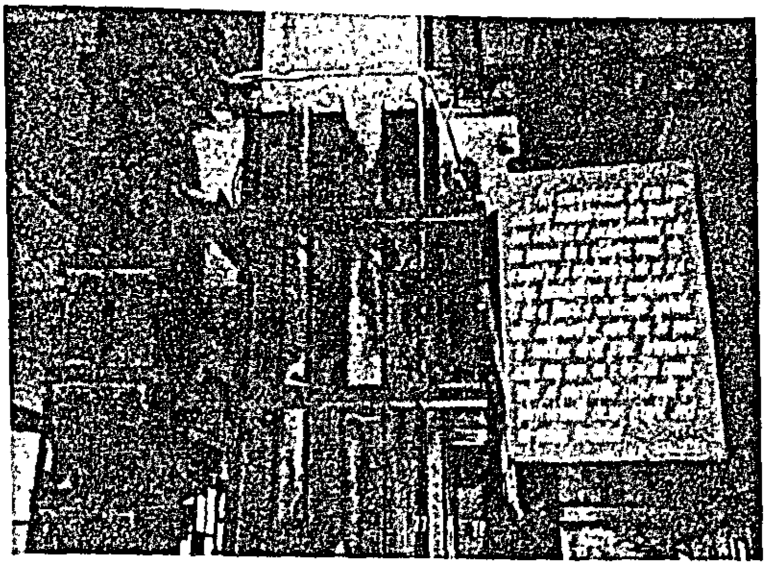


Photo 5.86 Strengthening of a sheared 3rd story column of a 5-story industrial plant of reinforced concrete rigid frame construction, Bucharest. (The same building as in Photo 5.66)

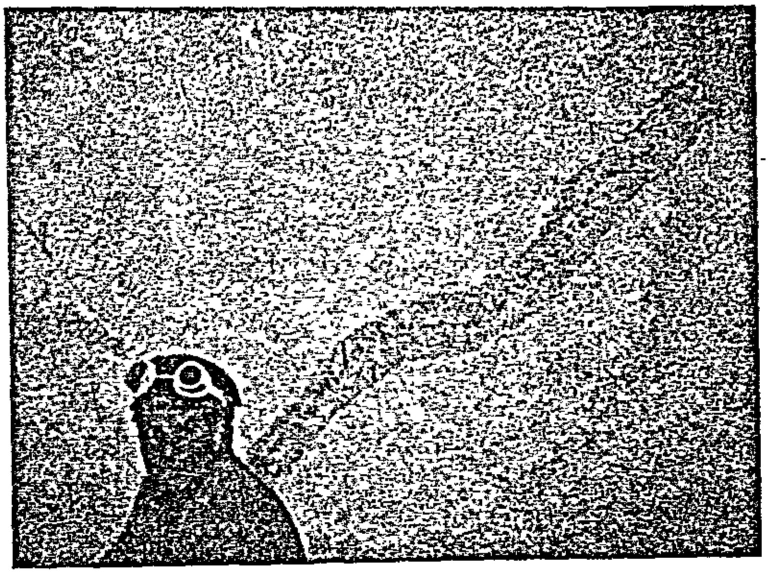


Photo 5.87 Filling of epoxy resin in shear cracks running in a wall of an 11-story apartment building of reinforced concrete wall construction, Bucharest. (The same building as in Photo 5.72)

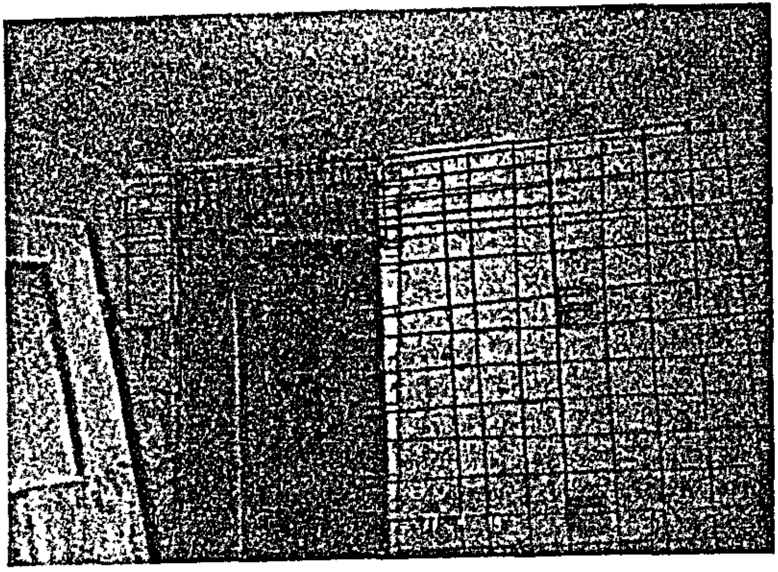


Photo 5.88 Reinforcement of a beam of the same building, Bucharest.

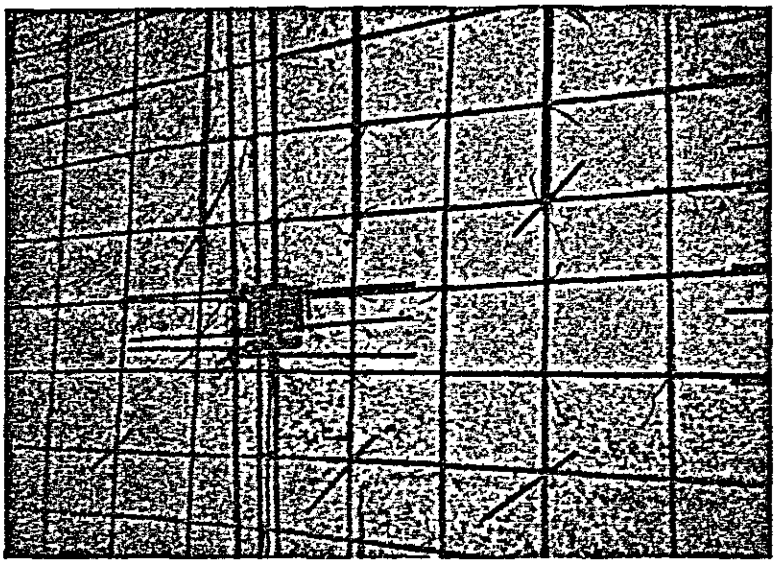


Photo 5.89 Reinforcement of a wall of the same building, Bucharest.

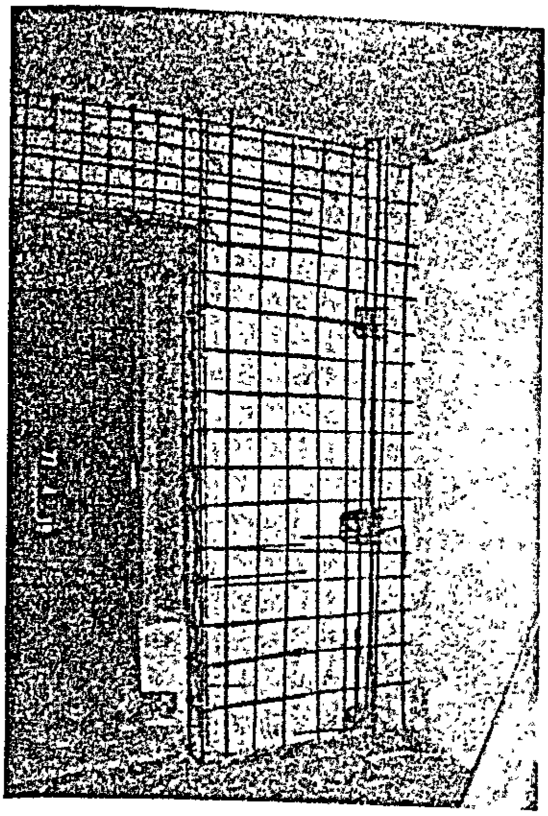


Photo 5.90

Reinforcement of a wall of the same building, Bucharest.

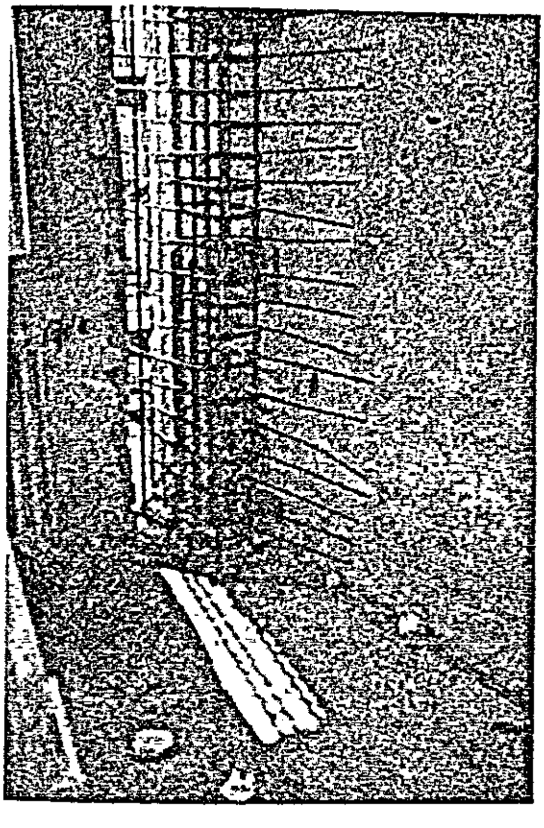


Photo 5.91

Reinforcement of a column of the same building, Bucharest.

CHAPTER 6 CIVIL ENGINEERING AND URBAN FACILITIES

6.1 An Outline of Civil Engineering Facilities in Romania

This section summarizes the situation of Romania's civil engineering facilities, such as rivers, ports and harbors, roads and railways as well as facilities for public utilies, including power plants.

(1) River, port and harbor facilities

As shown in Fig. 6.1, Romania consits of the northwestern region (Transylvania) and the northeastern region (Moldavia) separated by the Carpathian Mountains as well as the southern region (Wallachia). The Danube flows from west to east on the southern border of Romania to turns northward in the eastern part of the country and flows in to the Black Sea.

Rivers originating in Transylvania flow into Hungary and join the Danube in the Hungarian Basin. Most rivers originating in Moldavia and all of those originating in Wallachia join the Danube.

Gauging stations for these many rivers have been established at 1,500 points but Romania plans to inccrease the number of the stations to 5,000 to 6,000 and conduct automatic observation in the future.

Hydroelectric power which has been developed accounts for approximately 20 per cent of the hydroelectric power resoures. The number of dams completed between 1954 and 1974 totals 33 and it is planned to increase the number to 80 by 1980. As shown in Fig. 6.2, hydroelectric power stations were constructed at 39 locations between 1952 and 1974. The capacities of power plants on line in 1973 amounts to 2,300 MW (46 times that of 1950) and power output to 7,548 GWh (45 times that of 1950) as shown in Fig. 6.3.

Figure 6.4 shows the distribution of various hydroelectric facilities.

(2) Road and railway facilities

Roads in Romania are well developed with Bucharest at the center. As shown in Fig. 6.5, main roads form an adequate network in the inhabitable and arable areas, except for the mountainous regions. The major trunk roads constituting part of the European highway network are excellent, for superior to those in Japan. They are excellent in terms of environment, geonetry and structual design, as shown in Figs. 6.1 and 6.2.

Nine railway lines extend radially from Bucharest and, as shown in Fig. 6.6, all are connected with the European railway network, with the exception of one leading to Black Sea.

However, Romanian railways fypically have few circular lines and they branch off as they extend to remote areas.

(3) Electric power and other facilities

There are thermoelectric power plants in Bucharest and Ploiesti. It is believed that the plant in Bucharest is intended to supply electric power for industrial and non-industrial use and that in Ploiesti for an industrial complex to cover hydroelectric power shortages. The remaining heat obtained from the thermoelectric power plants and the industrial complex is supplied through pipe-lines for non-industrial purposes. It is necessary to learn from this state-run project from the viewpoint of conserving resources and disaster prevention.

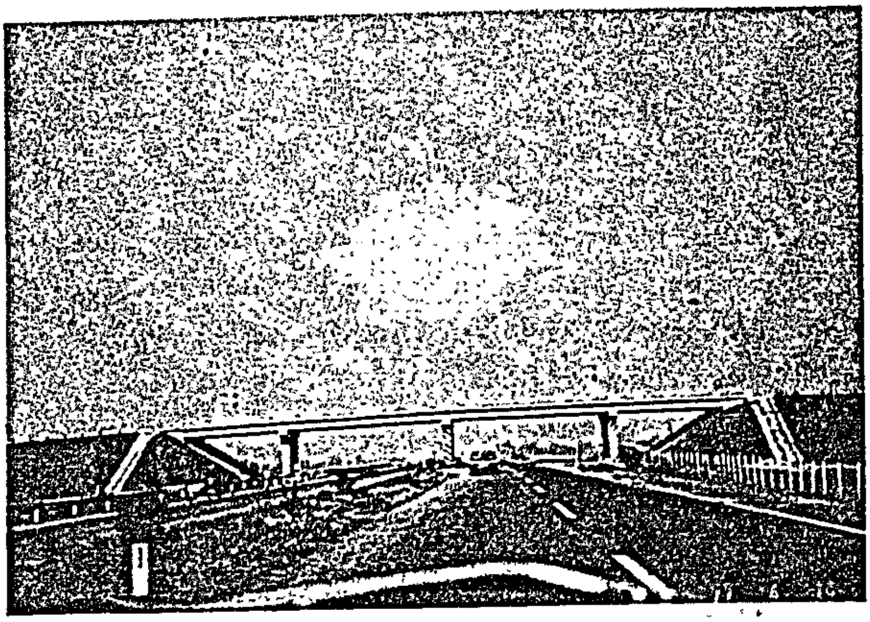


Photo 6.1 An expressway (Bucharest-Pitesti)

Photo 6.2 A national highway (Pitesti-Craiova)

6.2 An outline of urban facilities in Bucharest and other cities

Many green zones and areas with trees are located in the capital city of Bucharest, local cities and roads between cities. Three along the roads and cultivated fields are very well kept.

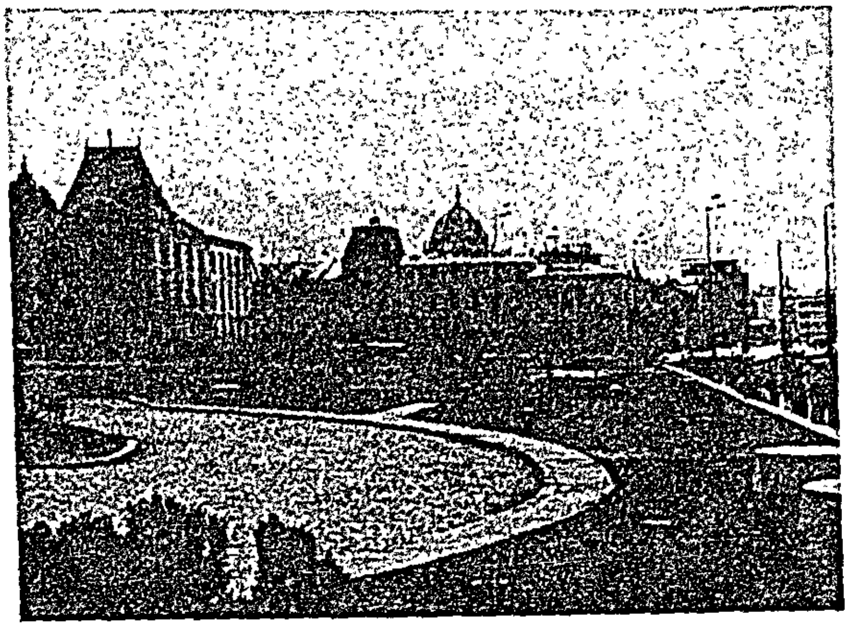


Photo 6.3 A spacious street with a green zone (Bucharest)

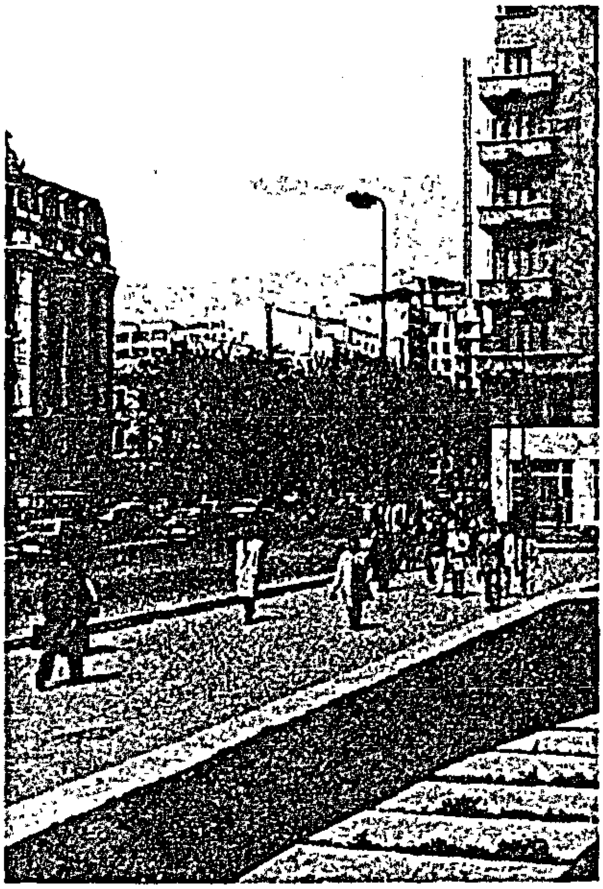


Photo 6.4 A well-laid out street (Bucharest)

For example, we observed many saplings planted or being planted where lines of trees ended on streets.

Basically, the space of green zones and water is neatly incorporated in Romanian cities to give them charm and disaster-preventive characteristics.

It is believed that through the process of destruction by foreign enemies and reconstruction of cities, the Romanian people constructed cities on the concept reverse to that or Japanese who built labyrinthian cities to cope with war.

As far as the capital city of Bucharest is concerned, such basic life-line systems as the water supply, electric power and gas supplies, telephone and sewer systems are laid under the ground in the city center. Although parts of the roads are used by street cars, traffic signals and traffic-control signs are conveniently provided for drivers and pedestrians.

A subway line is under construction to alleviate traffic congestion in the heart of the city.

6.3 Earthquake-resistant design methods for civil engineering facilities

Earthquake-resistant design methods with seismic loads taken into consideration have been enforced since 1952 under the Uniform Building Codes with regard to construction of dams and bridges.

The methods of earthquake-resistant design are based on those of Japan and the United States. Romania has not yet fully mastered the latest technology in terms of the consistency in its designing system.

The following are concrete examples.

In making a ground survey for bridge construction, only being logs and indes properties of the soil are sought, not the physical properties of soil itself.

In the construction of fill-type dams, they often adopt the rather steep lope of 1:1.5.

No attention is paid to giving earthquake-resistances to banks, dikes, ports and harbors and underground facilities.

The following is a question-and-answer session with Romanian technicians on "roads and railways" and "dams". At the end is a list of books for reference donated to Romania.

Supplement: Questions by the Romanian Government and Answers

(On Roads and Railways)

Q-1 The seismic intensity zoning in Japan varies for each of the seismic codes. Why?

A-1 Japan's seismic codes are based on the zoning established by Professor Kawazumi. The variation concerns the differences in the way the return period is applied to each structure.

Q-2 The design seismic intensity does not vary according to types or scales of bridges. Why?

A-2 There is no reason to change the design seismic intensity due to the differences in bridge types. However, bridges of different scales have their respective fundamental natural periods. Amplification factors differ depending on these periods and this changes the design seismic intensity.

Q-3 How long are the records of ground motions which are used for dynamic analyses?

A-3 Usually, the duration is up to 30 seconds, but in some rare cases it is one minute or more.

Q-4 Is the live load considered to be the mass in dynamic analyses?

A-4 No. (The possibility of an earthquake, while the live load is act working is very small.)

Q-5 What consideration is given to the earthquake-resistant design of bridge supports?

A-5 Dislodgments of bridge ends is prevented by the device shown in Document-9 (Eathquake Resistant Design For Civil Engineering Structures, Earth Structures and Foundation: In Japan, The Japan Society of Civil Engineers, 1977).

Q-6 What is the limit design?

A-6 The limit design will be adopted in the futre.

Q-7 Is the impact load considered for the super-structure of a bridge?

A-7 There is no need for such consideration. (The ground motion in nature is not an impact.)

Q-8 What is your recommendation for a earth quake-resistant design of a cable-stayed bridge?

A-8 Attention is required to stressed in the cable anchorage and the tower base.

Q-9 What data do you have regarding earthquake damage to dykes?

A-9 Examples of damage in the Niigata Earthquake (1964) and the San Fernando Earthquake (1971) were shown with the use of photo slides. (Those depicted circular sliding due to liquefaction of soil or decrease of soil strength.)

Q-10 What information do have regarding earthquake-resistant capability of bridges with flexible piers?

A-10 Rigid piers are used for piers of bridges of usual scales.

Q-11 What information do you have regarding earthquake-resistant capability of fixed-supported continuous bridges?

A-11 Theoretically, they have this capability. But the temperature stress must also be taken into account.

Q-12 How long are the predominant periods of stiff ground and soft ground?

A-12 About 0.3 seconds and 0.8 seconds respectively.

Q-13 What are structural details are important at the hinge in the center of a cantilever PC bridge?

A-13 Shear keys are installed in both the lateral and vertical directions of the longitudinal axis of the bridge.

Q-14 Is the inclined pile effective?

A-14 It's construction is expensive but is effective in increasing horizontal resistance.

(On Dams)

Q-15 Is the dynamic analysis method usually used for checking the earthquake-resistant capability of old dams?

A-15 The static analysis is primarily used.

Q-16 Are there any laws or regulations for post-earthquake disaster prevention?

A-16 There are no such rules, since there has been no case of earhquake damage to dams higher than 30 meters.

Q-17 Is there a warning system for the downstream areas of dams?

A-17 There is no such system as far as the dams themselves are concerned. But such system is used for dams in cases of flods and for railways.

Q-18 What degree of ground motion accelerations is considered for design? (in the maximum ground motion or normal ground motion.)

A-18 In the static design, about half the seismic coefficient for ordinary structures is used for designing dams, except for arch dams. However, the actual seismic coefficient should be much larger than the apparent value because the safety factor is very high in the cases of concrete dams.

Q-19 What method is used for checking in the static analysis and in the non-linear range?

A-19 The static analysis method, as stated previously, is already well-established. The dynamic analysis is used for quantitative evaluation only in the elastic range. More study of the dynamic analysis method is needed.

Q-20 What is the best way of dealing with the effects of joints in arch dams and buttress dams?

A-20 No consideration is given in the design to the effects of joints which are secondary in nature.

Q-21 Which method is used in the design of fill-type dams, the straight line sliding method, or the circuler sliding method?

A-21 Both methods (stability analysis) are in use. The seismic coefficients for application are sometimes employed through the dynamic analysis. In this case, the safety factor on the sliding plane is obtained by the static calculation.

Q-22 What is the safety factor of fill-type dams?

A-22 In th- static design with the use of the design seismic coefficient, the safety factor for the stability of the slope is 1.2.

Q-23 How is the effect of water and pore-water evaluated for fill-type dams.

A-23 The effect of water on fill-type dams is a subject of future research.

Q-24 Is there any stability analysis taking deformation during earthquakes into account?

A-24 No yet.

Q-25 What information do you have concerning the measurement of micro-tremors or explosions for the purpose of micro-zoning?

A-25 The measurement is conducted, but views of specialists remain in conflict.

Q-26 What are the characteristics of SHIRASU soil?

A-26 Its nature varies greatly depending on the water content. When dry, the soil shows satisfactory strength but when wet, the strength is diminished.

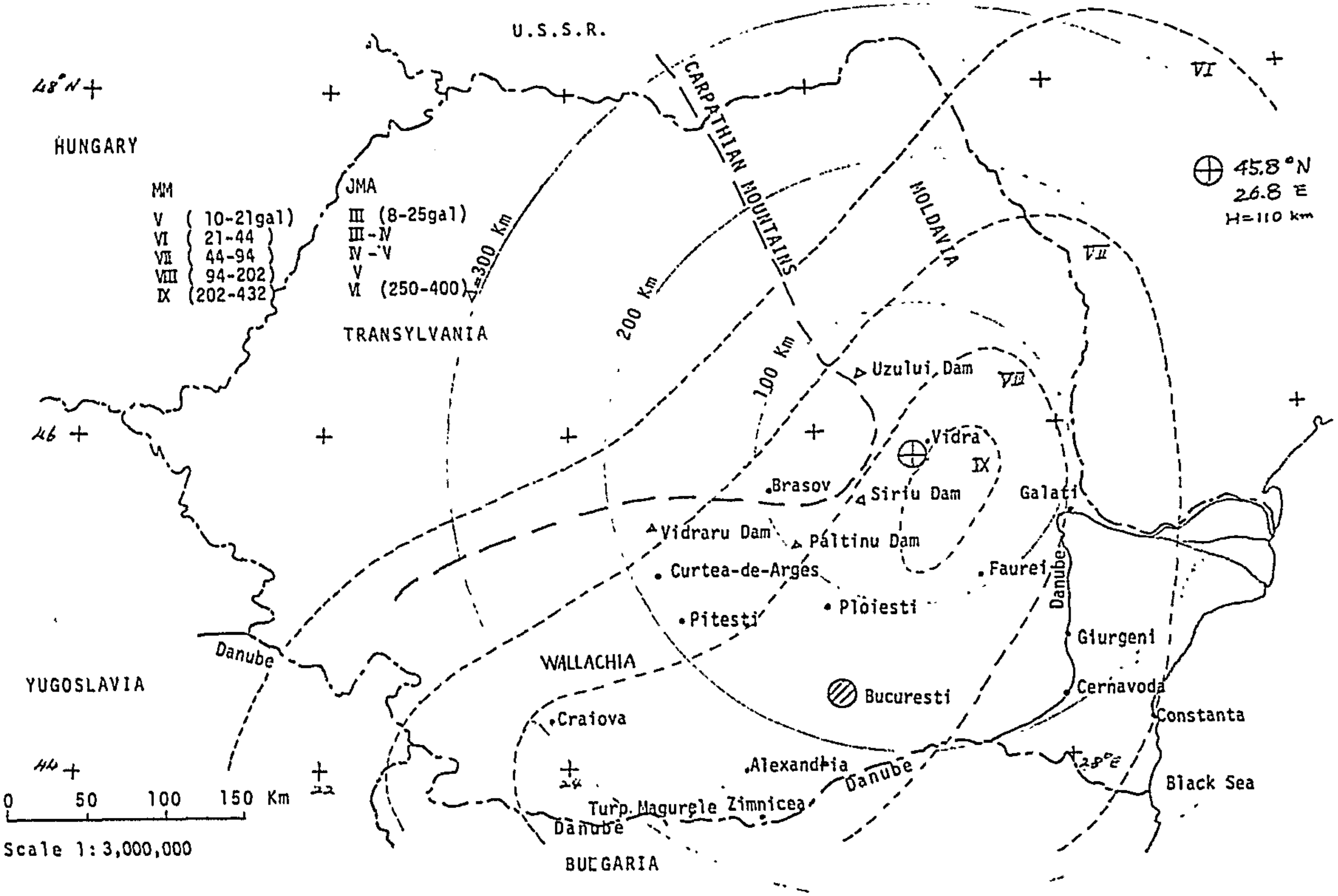


Fig. 6.1 A chart of Romania's topography and isoseismic lines of the 4 III 1977 earthquake by Prof. Medvedev.

1. Crăinicel
2. Moroieni
3 Aştileu I
4. Sadu
5. Bicaz
6. Roznov I
7. Roznov II
8. Pîngăraţi
9. Piatra Neamţ
10. Zăneşti
11. Costişa
12 Racova
13 Buhuşi
14 Gîrleni
15 Vaduri
16 Bacău I
17. Bacău II
18 Argeş
19. Oeşti
20. Albeşti
21. Strîmtori
22 Cerbureni
23. Cumpănita
24. Vilsan
25. Valea Iaşului
26. Timiş Trei Ape
27. Iron Gates I
28. Bascov
29. Paltinul
30. Curtea de Argeş
31. Piteşti
32. Clunget Lotru
33. Neoplex
34. Ziganeni
35. Băiculeşti
36. Minieeşti
37. Poiana Uzului
38. Rîmnicu Vîlcea
39 Tarniţa
40 Budeasa
41. Brădişor
42. Băbeni
43 Dăeşti
44. Gîlceag
45 Govora
46. Ioneşti
47. Jidoaia
48 Leşu
49. Lotru aval
50. Mărişelu
51. Merişani
52. Mălaia
53. Petrimanu
54. Riureni
55. Stînca Costeşti
56. Şugag
57. Vîlcele
58. Adjud
59. Aştileu II
60. Arceşti
61. Arpaş I
62. Avrig
63 Bereşti
64. Călimăneşti
65. Cernavodă
66. Ciocotiş
67. Crivaia
68. Clăbucet
69. Cinciş Teliuc
70 Clineni
71. Cerna
72. Clineşti
73. Drăgaşani
74. Drăgăneşti
75 Drăgan Remeţi
76 Fruntaru
77. Floreşti I
78 Floreşti II
79. Făgăraş
80. Frumoasa
81. Fughiu
82. Galbeni
83. Gilău I
84. Gilău II
85 Gura Rîului
86. Gura Lotrului
87. Goleşti
88 Herculane
89. Ipoteşti
90. Iron Gates II
91. Lugaş
92. Munteni
93. Moldoveni
94 Motru
95 Nolaşi
96 Ostrovul Mic
97. Ostrovul Mare
98 Oriea
99 Pucioasa
100 Petreşti
101. Porumbacu
102. Răcăciuni
103. Retezat
104 Rusăneşti
105. Robeşti
106. Surduc Siriu
107. Săsciori
108. Slatina
109. Strâjeşti
110. Sibişeni
111. Sadu Bumbeşti
112. Someşul Cald
113. Sebeş Olt
114. Săcădat
115. Tr. Măgurele–Nicopol
116. Tismana
117 Taleşti
118 Turnu
119. Tismana aval
120. Turnu Roşu
121. Tileagd
122. Urvind
123. Veila
124. Viştea
125. Vadul Crişului
126. Valea Mare
127. Zăvideni

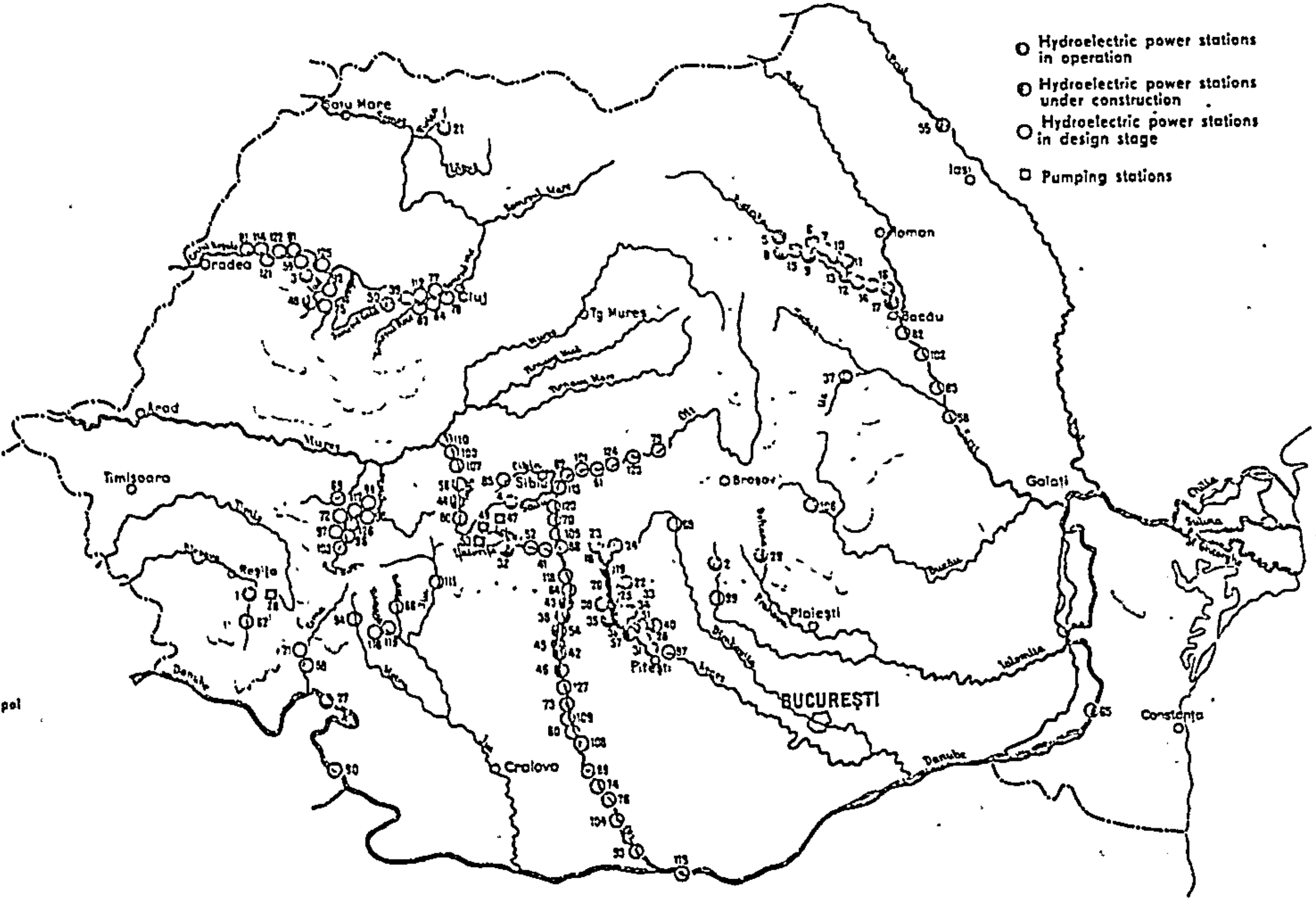
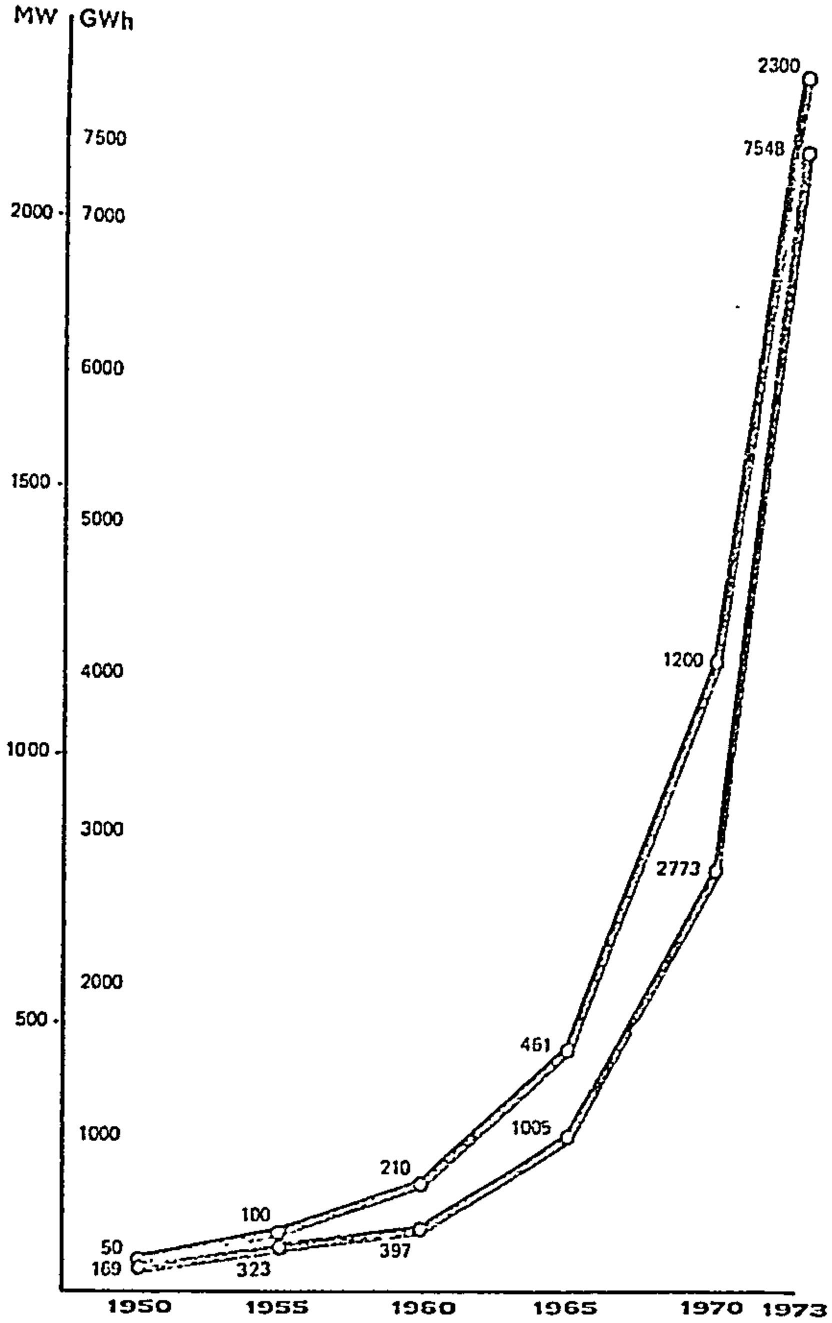


Fig. 6.2 Distribution of hydroelectric power plants (1974)



Dynamics of installed power and output growth in hydroelectric power plants in Romania in 1950—1973 period.

Fig. 6.3 Growth of hydroelectric power generation

Fig. 6.4 Distribution of hydroelectric facilities

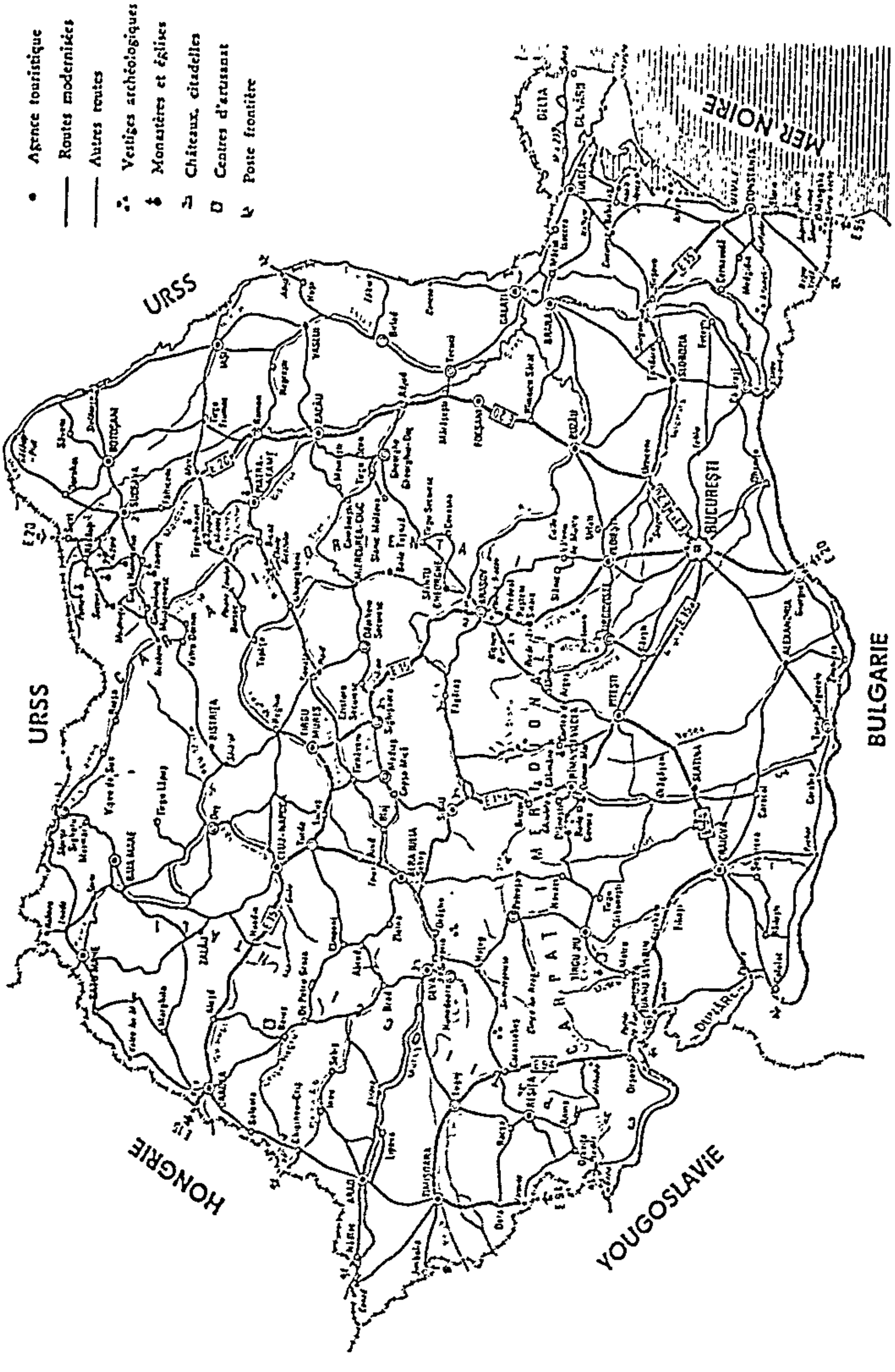


Fig. 6.5 Major roads

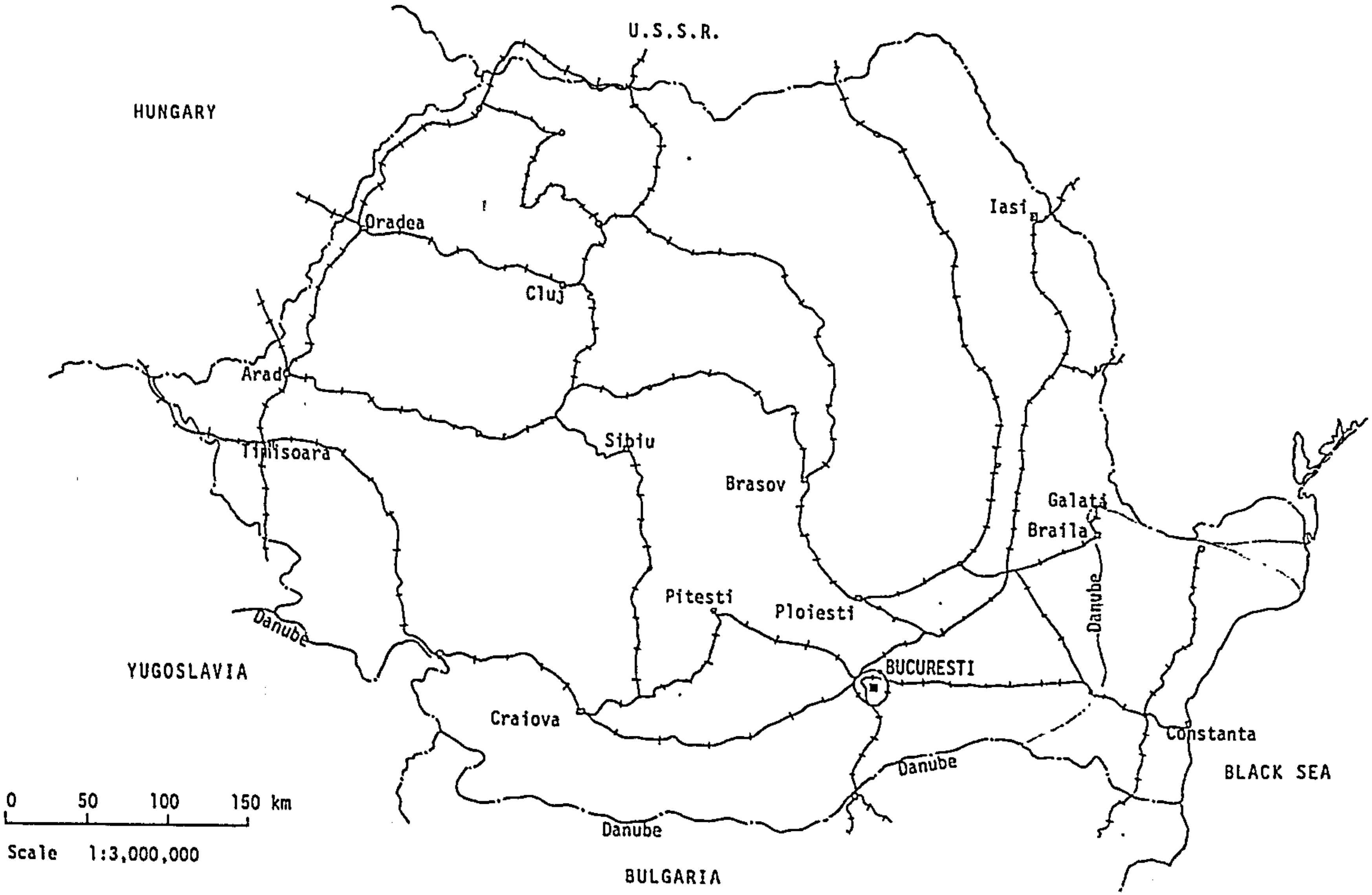


Fig. 6.6 Chart of Romanian railway network

Chapter 7 DAMAGE TO CIVIL ENGINEERING FACILITIES AND CHARACTERISTICS

7.1 Damage to Civil Engineering Facilities

The earthquake did not seriously damage roads, railways, dams, kikes, water gates, bridges, ports, petroleum pipelines, thermal supply pipelines, gas facilities and transmission lines.

Some dislodgment, occurred between shoes and ends of a suspension span(about 80 m) in the central part of spans(160 m) of a cantilever truss type railway bridge over the Danube river near its estuary, at Cernavoda. This was not so severe as to hamper functions and operations. However, work was in progress to restore the suspension span to its proper place.

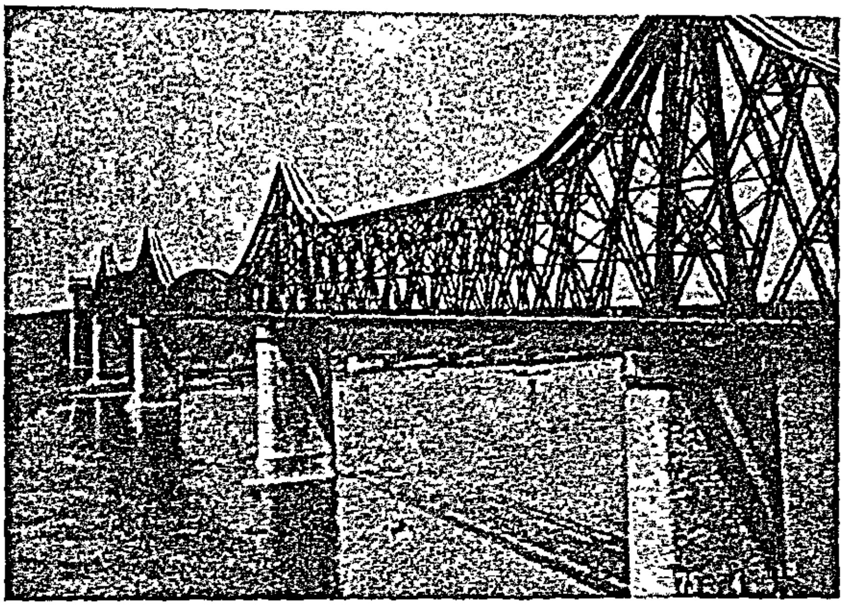


Photo 7.1 Cernavoda Railway Bridge

In Giurgini, about 30 km north of the bridge, no damage ocurred to highway bridge (the central section made of continuous five span steel box girders with a span of 140 km and approaches made of PC girders).

However, some damage appears to have occured to retaining walls.

In regard to water supply facilities, joints were broken at 120 places of the total 1,600 km of pipelines in Bucharest. In Craiova, water supply pipes were broken at 18 places. Also some damage was reported in wewer pipes.

Some of elevated water tanks are said to have been bent up or broken.

Electric power plants sustained significant damage. At the thermal power plants in Bucharest and Ploiesti, portions of the roof truss fell and caused damage to turbines and other machines. Also transformers were displaced at a total of 60 substations, causing malinsulation and short circuits.

In Faurei (Δ = 100 km) and in Bucharest (Δ = 170 km) and Bragadiru (Δ = 270 km), liquefication of soil occurred, but this did not cause any damage. (See Figs. 8.1, 8.2, 8.3 and Photos 8.4, 8.5)

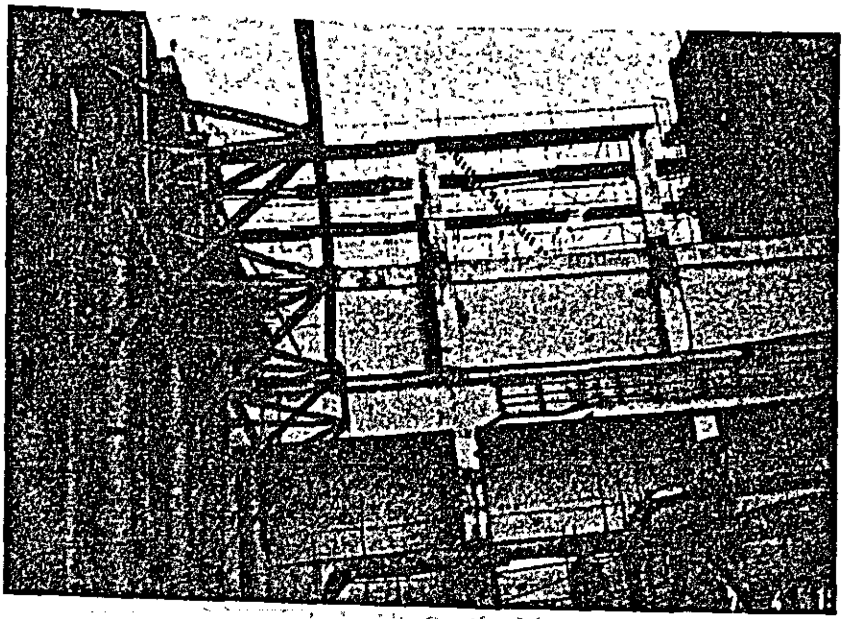


Photo 7.2 Brazi Thermal Power Plant after collapse of roof truss in Ploiesti.

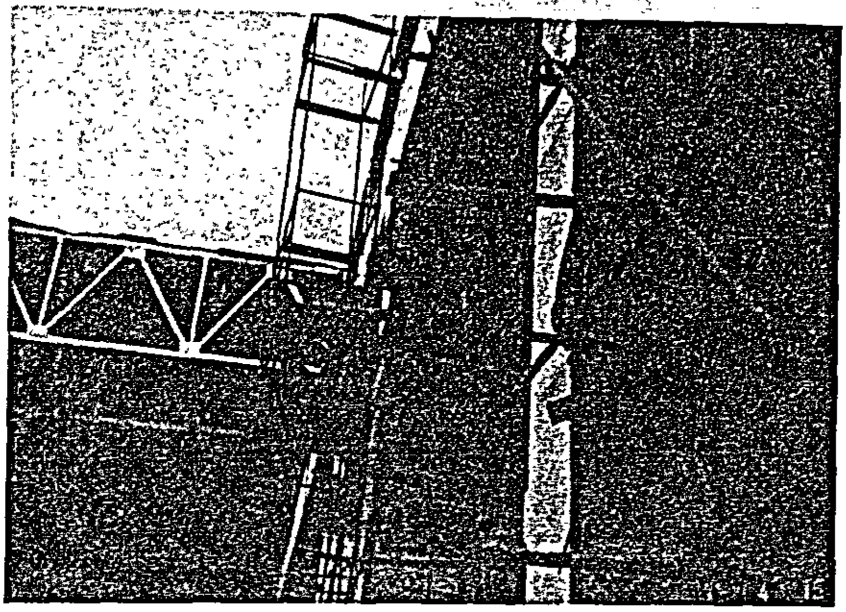


Photo 7.3 The same plant viewed from a different angle.

7.2 Characteristics of Damage

The earthquake caused serious damage not only to old, worn buildings but also new ones. But as far as civil engineering facilities are concerned, damage was concentrated worn-out buried pipes especially at butt joints. There was no damage to dams.

The causes for the fall of rool trusses at power plants should be clarified by architectural engin-ers in the future because they are new structures.

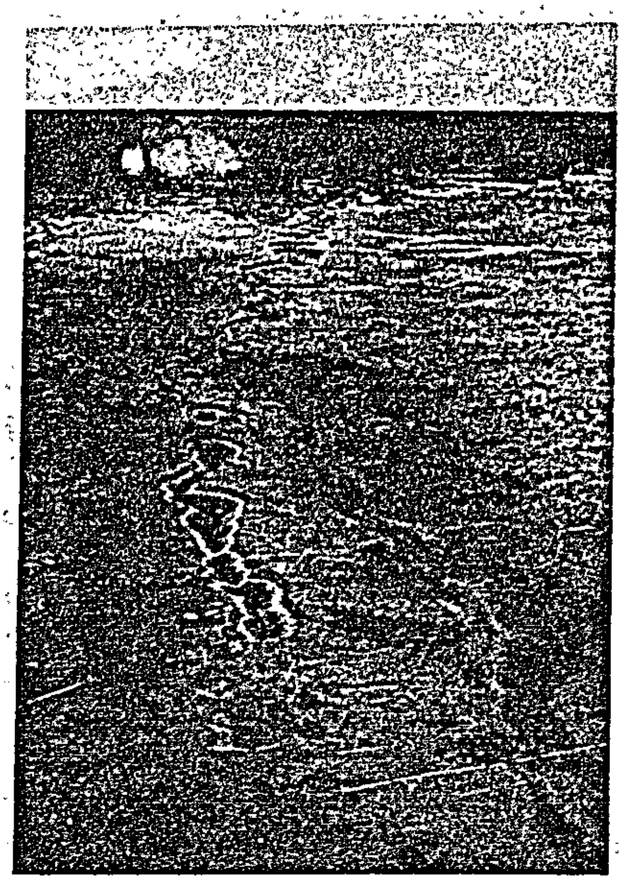


Photo 7.4 Sandy soil liquefaction at Faurei

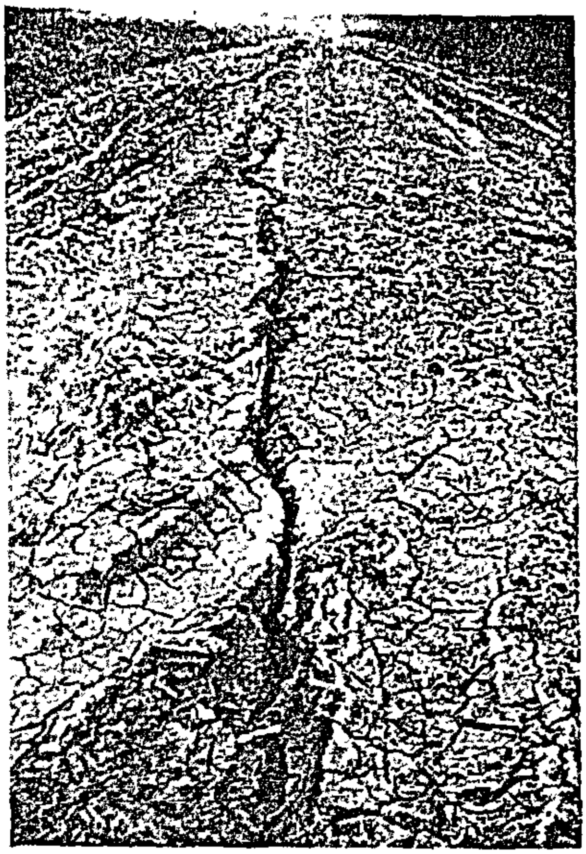


Photo 7.5 Liquefaction at Faurei

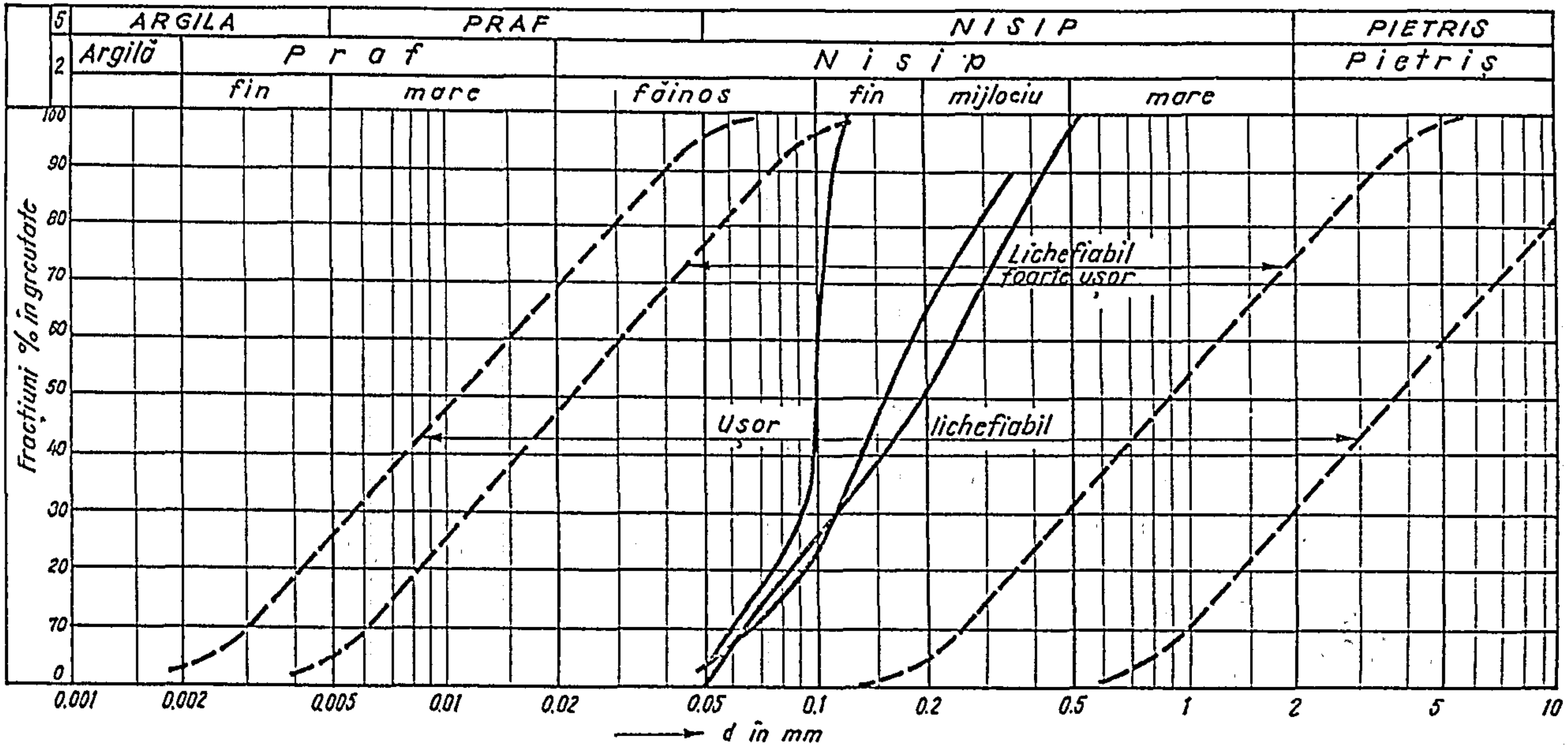


Fig. 7.1 Gradation Curve of Sands in Faurei (Δ = 100 km)

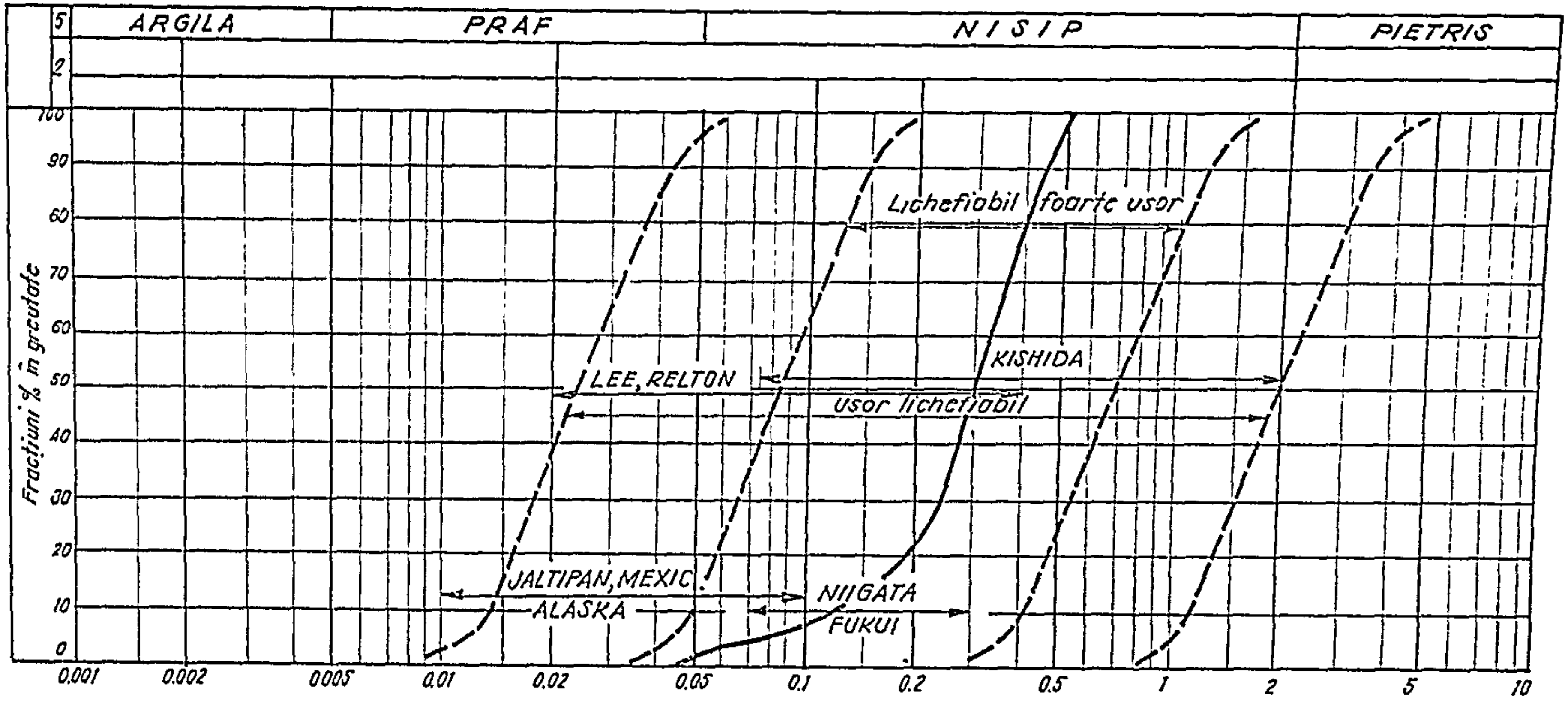


Fig. 7.2 Grading Curve of Sands in Bragadira (Δ = 270 km)

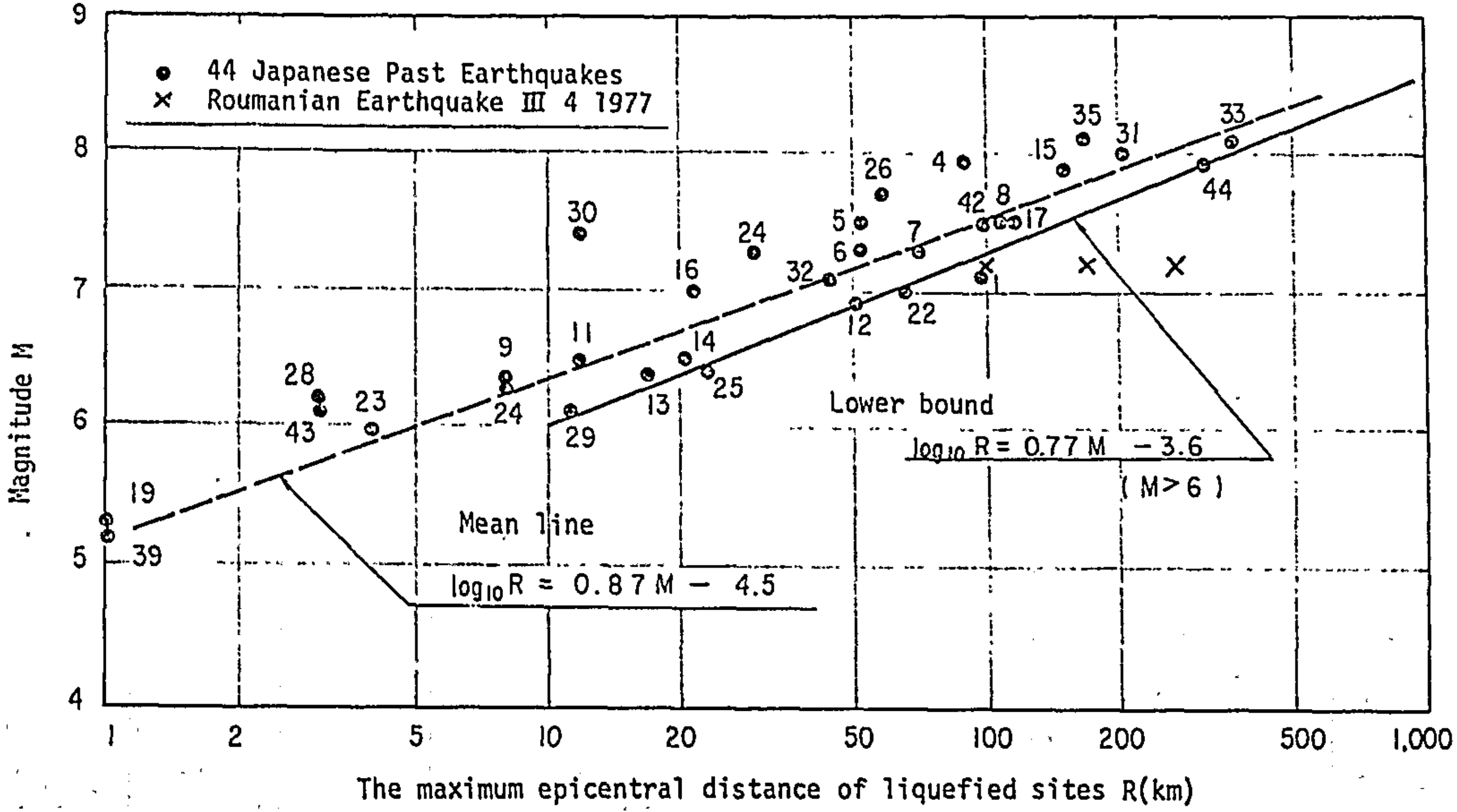


Fig. 7.3 Peculiarity in the Occurence of Liquefaction Phenomena in the 1977 Romanian Earthquake

CHAPTER 8: PRESENT CONDITION OF CITY SUPPLY FACILITIES AND EXTENT OF DAMAGE

8.1 Present Condition of and Extent of Damage to Water Supply Facilities

8.1.1 Present Condition of and Extent of Damage to Water Supply Facilities

The Waterworks Agency, which belongs to the Romanian Public Administrative Group (Waterworks, Sewage, Water Heating, City Cleaning, Gardening and Service Activites), is the department in charge of waterworks in Bucharest.

The present population of Bucharest is approximately 1.6 million persons and between 1 and 1.1 million m^3 of water is supplied to the city each day. Drinking water accounts for 40% of total water consumption while the remaining 60% is for commercial use. Twenty-two percent of the drinking water is ground water and 78% river water. Lake water is used for industrial purposes.

The three water purification plants in Bucharest have processing capacities of 600,000 m^3/day, 300,000 m^3/day and 300,000 m^3/day respectively. A 300,000 m^3/day water plant is currently under construction. City water is supplied from five pumping stations through 1600 km of service pipes.

The water supply reaches 100% of Bucharest and 85% of the households receive direct a supply while the remaining 15% households share community taps.

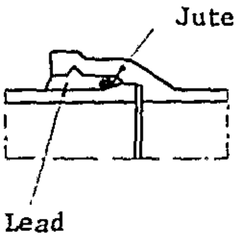
The pipe arrangement in Bucharest is based on a network pattern enabling a continuous supply of water in a pipe from other mains even if trouble develops at one location.

Pipes for distribution mains and large housing complexes are normally larger than 300 mm in diameter; the total length of such pipes exceeds 400 km. Pipes serving general households are between 200 and 250 mm in diameter and total 1200 km in length.

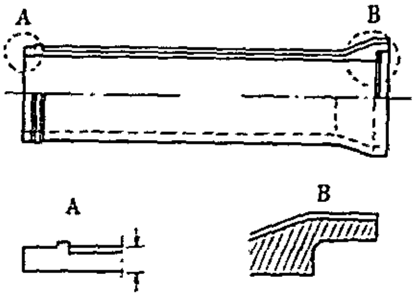
There are four types of pipe in general use: cast iron, concrete, asbestos-cement and steel. Table 8.1 shows the share of pipe employing each material.

All pipes passed a pressure test of 20 atmospheres at manufacturing plants and must pass an on-the-spot pressure test of over 10 atmospheres as well. The pipes must withstand 6 atmospheres of water. However, as pipe joints are susceptible to water leakage, standards for joints used in Romania are as shown in Fig. 8.1.

(1) Cast-iron Pipe Joint



(2) Concrete Pipe Joint



(3) Asbestos-cement Pipe Joint

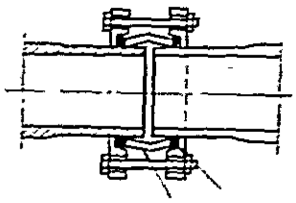


Fig. 8.1 Detail of Pipe Joint

Table 8.1 PIPES FOR WATER SUPPLY

Types of Water Pipe	Caliber	Percentage of Use
Cast-iron	100 ∿ 900 mm	70%
Concrete	600 ∿ 1000 mm	15%
Asbestos-cement	100 ∿ 300 mm	10%
Steel	800 ∿ 1000 mm	5%

Note: Total length of waterpipes in Bucharest

1,600 kilometers

Distribution Mains and Pipes for Housing Complexes

Over 300 mm 400 km

Service Pipes for General Households

100 ∿ 200 mm 1,200 km

8.1.2 Extent of Damage to Waterworks

The subject earthquake caused extensive damage to pump facilities and water service pipes.

At pumping stations, the earthquake caused power transformers to move out of position, insulators of transformers to break down, etc. But in most cases, damage was easily repaired.

However, the earthquake caused heavy damage to the water service pipes through outright breakage. However, only a few pipes were detected to have cracks. The power failure slowed down pumping functions and allowed backwash causing abnormal pressure to develop in the pipes and damaging the vulnerable joints at many places.

Table 8.2 shows an example of joint damage caused by the earthquake in Bucharest.

Table 8.2 shows that of the 120 broken joints of 600 ∿ 900 mm pipes, concrete pipes accounted for 90% of those damaged while the remaining 10% were cast-iron pipes. Moreover, 45 joints were damaged in 100 ∿ 600 mm cast-iron pipes.

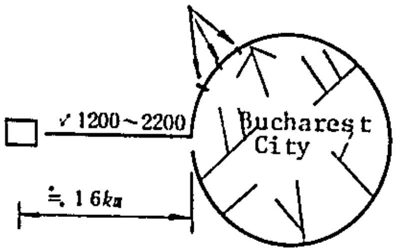
The rubber units used in concrete pipe joints and the lead parts in cast-iron pipe joints sustained damage. No joint damage was found in asbestos-cement and steel pipes.

Table 8.2 DAMAGE TO WATERPIPES IN BUCHAREST

Facility	Damaged Part
Water Treatment Facilities (Sedimentation Basin, Distribution Basin, Pump Site.)	Transformers at pumping station moved out of place and insulators in transformers broken, etc. Repair work was readily performed.
Distribution Main	Three joints were damaged in the 200 km of pipes of 1200 ∿ 2200 mm in diameter.
Service Pipe	Backwash caused by power failure damaged 120 joints (600 ∿ 900 mm)
Cast iron Pipe	10% of the 120 damaged joints.
Concrete Pipe	90% of the 120 damaged joints
Steel Pipe	Undamaged

Note: In the smaller caliber cast-iron pipes, 45 joints were damaged.

In Bucharest, as shown in Fig. 8.2 the main supply line extending over 1600 km includes 200 km of distribution mains (1200 ∿ 2200 mm concrete pipe). However, the this earthquake caused damage to three joints as previously noted. Since the damage was caused in the distribution main, repair was conducted as shown in Fig. 8.3 by regulating the flow. A similar case was also observed in Craiova City.



TOTAL : 200KM

Fig. 8.2 Layout of Distribution Mains

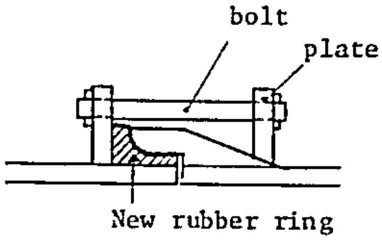


Fig. 8.3 Method of Repairing Joints with
Broken Rubber and Lead Units

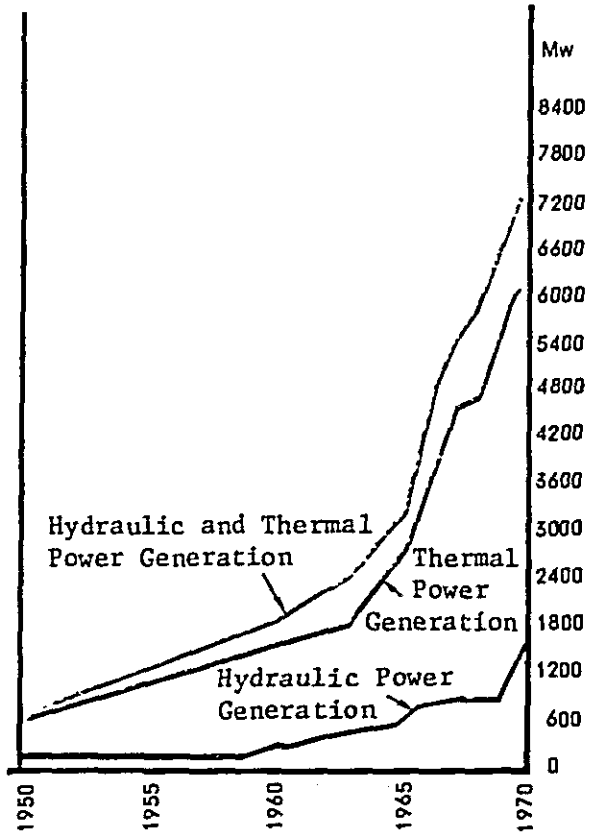


Fig. 8.5 Hydraulic and Thermal Power Generation

8.2 Power Generating Facilities

8.2.1 Present Condition of Power Supply

We visited the Ministry of Power and received an explanation of the present condition of power supply in Bucharest and Romania.

Today, a total 12,000 MW of power is supplied throughout Romania by numerous hydroelectric and thermal power plants. Transmission and distribution stations of 400 kV, 220 kV and 110 kV are situated in each region. The proportional shares of hydroelectric and thermal power stations are as shown in Fig. 8.5 from this figure, it is obvious that thermal power stations outrate the hydroelectric stations. The thermal power plants in larger cities not only supply power but also have the important role of delivering hot water for room heating to households.

The power supply network of transmission lines in Romania covers 200,000 km over the total breadth and width of the country. The three thermal power plants in Bucharest are Bucharest South (650 MW), Bucharest West (250 MW) and Grozavesti (188 MW), all serving as part of the larger power network of the country. Power produced by the three plants in Bucharest is more than adequate for the city's needs. The majority of the power transmission and distribution lines is found underground and there are practically no cable poles in Bucharest.

8.2.2 Extent of Damage to Power Facilities

This earthquake caused great damage to the power supply facilities, causing no light of over four hours.

(1) Power Plants

Immediately after the earthquake, thermal power plants discontinued functioning. Two plants sustained heavy damage to the buildings which caused secondary damage to the turbines, although the power generating facilities remained intact.

The roofs of the motor turbine rooms of two power plants (Bucharest West and Brazi Plant in Ploiesti) caved in on top of the turbines and caused a fire hazard. To prevent an outbreak of fire, oil (Lubricating oil, etc.) and hydrogen (for generator cooling) were released from turbine by desperate efforts.

At Brazi, although there was a minor fire reported, it was immediately brought under control.

There was no reported damage caused by the earthquake to dams and hydroelectric power plants.

(2) Stations

This earthquake caused damage to four 400 kV and 220 kV stations and 56 110 kV and 35 kV class stations.

In most cases, batteries were damaged as sulfuric acid leaked out or they were inclined and moved out of place or internal parts were broken. The batteries, however, were for automatic operation and were replaced by temporary and portable units to restore functioning.

Eight transformers were damaged by the earthquake. In most cases, insulators inside the transformers cracked open, porcelein was broken or short circuits occurred. There were also cases, as shown in Fig. 8.6, of a transformer being moved out of position; these were comparatively easy to repair. In Romania, partitions erected between transformers helped a great deal in preventing fires.

(3) Transmission & Distribution Lines

The transmission lines remained intact in the earthquake but in some areas the poles of distribution lines sustained slight damage. However, most of the damage was minor, such as moving of transformers and breaking of insulators.

There was no report of any objects falling down. There was one case of a pole toppling.

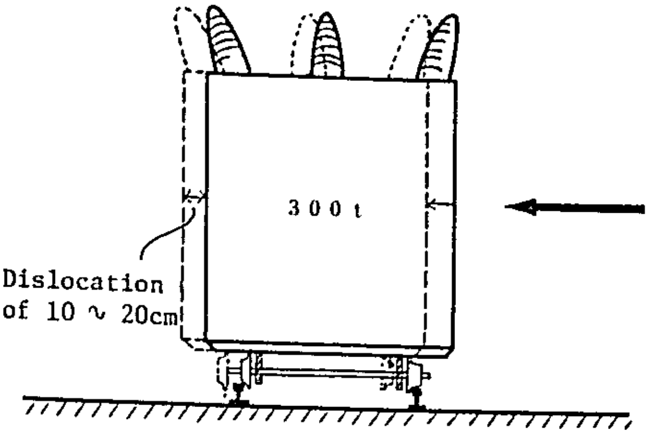


Fig. 8.6 An example of a power transformer moving out of position

8.3 Gas Supply Facilities

8.3.1 Conditions of Gas Supply Facilities

We visited the Gas Supply Service Department of the Ministry of Petroleum. Mines and Geology (in charge of Bucharest and southern regions of Rumania) in Bucharest and received an explanation of the gas supply conditions after this earthquake.

Methane gas is produced in the Transylvania Region of Rumania. Through the four divisions (Prospecting, Transporting and Two Supply Divisions) of the Methane Gas Technological Center, gas is supplied to each household.

City gas was used until 1942 in Bucharest, but it switched to natural gas (mainly methane plus ethane, and propane).

In Bucharest, the three regulating points receive processed gas after going through dust and odor treatment in the Supply Division.

The gas supplied in the morning is between 40 and 45 atmospheres. It is lowered to 10 - 15 atmospheres during the day to continue into the evening.

The three regulating points belong to the transportation corporation for regulating the gas pressure to 6 atmospheric pressures. This value is the average pressure in the gas supply network for main consumers (thermal power plant and major manufacturing units).

The Gas Supply Service Department also has three regulating points, where the pressure of gas is reduced from 6 to 2 atmospheric pressures, (1.5 atmospheric pressure in summer) for supply to small-scale manufacturing units and individual households.

Many small-scale plants employ their own pressure reducing units.

Central Bucharest, worst hit by the earthquake, is a low pressure gas network district. The gas pipeline built between 1942 and 1943 is still in use. The city plans to switch to 2 atmospheres in the future.

The five adjustment stations in the city further reduce the gas pressure from 2 to 0.5 atmospheres to supply gas in the city.

In the gas network of Romania, including Bucharest, there are no gas storage facilities to speak of. Therefore, during the peak gas consumption peak season (winter), gas is supplied from wells where production was stopped during the summer season.

It was reputed that old steel pipes were used to supply gas. But we confirmed that welded steel pipes are in use throughout the country. The joints are also welded.

The joint welding method is generally gas welding for pipes less than 100 mm in diameter. When the pipes exceed 100 mm, electric welding is employed.

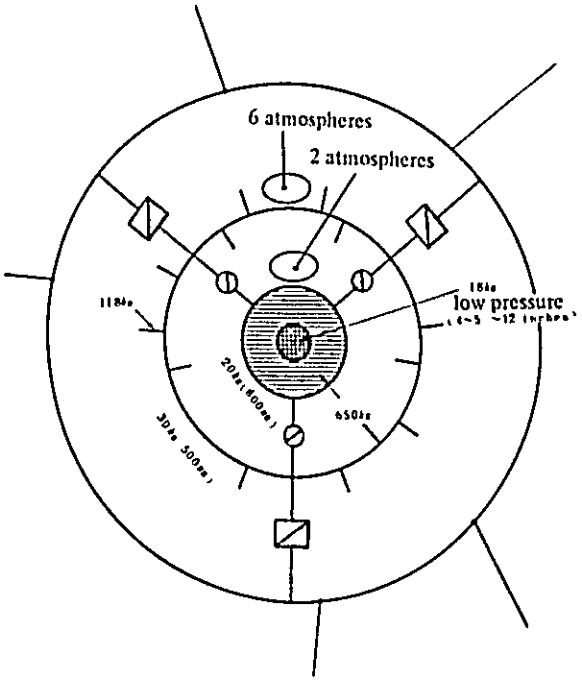


Fig. 8.7 Gas Supply Network in Bucharest

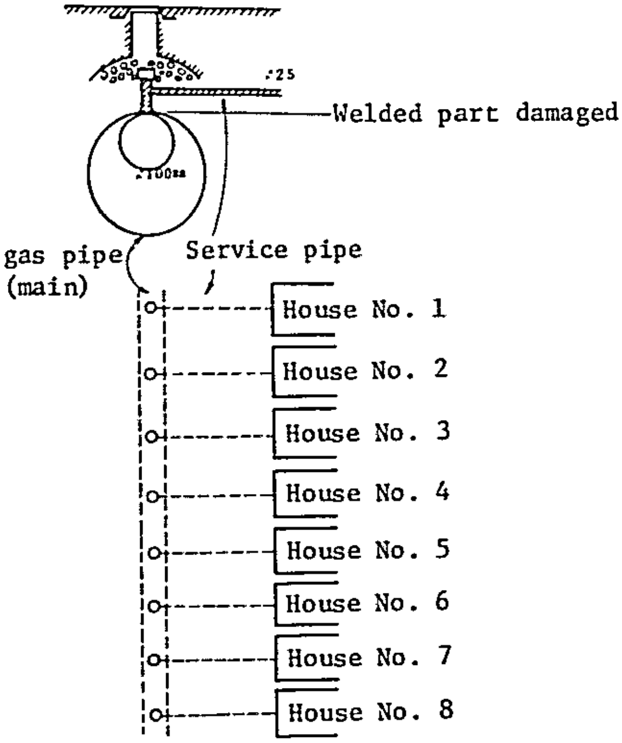


Fig. 8.8 Conditions of Damage to Gas Pipes in Pitesti

8.3.2 The Extent of Damage of Gas Supply Service Facilities

It was reported that gas supply service facilities in Bucharest were not damaged except for those accompanying the destruction of buildings and structures. The steel pipes used for gas supply, like the water supply pipes, were not damaged. Also, there were no reports pertaining to damage to other facilities.

In Pitesti, only a small portion of gas pipe was damaged but it was apparently not serious. This damage occurred at a welded part of a pipe linking with the distributing main. As shown in Fig. 8.8, the damage occurred in the direction of the earthquake tremor, inconveniencing 8 households. Although the welding method was not confirmed, we believe it was gas welding. As the joint proved to be weak, studies of improving the joints are considered necessary to cope with the situation in the future.

8.4 Other City Supply Service Facilities

Communications can be cited as one of the major city service facilities. In regard to damage caused to the communication facilities, we had no opportunity to make a firsthand investigation.

In regard to the sewage facilities, we were told that no damage was caused to facilities, pipes (totalling over 1400 km) and other equipment.

Chapter 9 PROBLEMS AND LESSONS OF THE ROMANIAN EARTHQUAKE

9.1 Necessary Steps for Earthquake Prediction in Romania

In 1975 a Romanian seismologist published results of his study on the time history of moderately deep earthquakes in the Vrancea Region. In his paper, he warned that the "next" violent quake could occur fairly soon and that the probability of its occurrence should be considered as high.

There is no available data to judge what influence this warning had on the Romanian Government or society. However, this sort of prediction though based only on the probability theory, will be helpful if it is taken into account in governmental policies in an appropriate manner, especially because quakes in the Vrancea Region tend to recur at short intervals, i.e., with a high frequency.

What is really needed for Romania now is not prediction based on probability but one based on precursory phenomena. It is common knowledge in seismology that violent quakes are preceded by premonitors of a quake of this sort were caught. Consequently, Romania will have to start the study of earthquake prediction from the very beginning.

One known point of interest worth future study is the fact that the Vrancea Region had been frequently hit by small quakes about 150 to 200 times every month until February, 1977, when the frequency suddenly dropped to about 30 per month.

The time history of the occurrence of these small quakes must be studied closely by statistical methods. No doubt this change will by very meaningful from the statistical point of view.

There is another remarkable phenomenon. Figure 9.1 shows the crustal movement in Romania by contour lines drawn to the scale of mm/year. There is a section in the Carpathian Mountain range that shows an annual upheaval of 5 mm. Also the contour lines are shaped in a very meaningful manner in that area, which lies in the curved part of the mountains. The lines show that some areas annually move up by 1.5 mm while other areas move down by 2 mm.

It is not known whether this movement took place continuously or intermittently, since surveying was conducted only intermittently. It is probable that the Carpathian Mountains are rising in the north and the west and the Walachia Region subsiding continuously.

But judging from the conditions of crustal movement in Japan and other parts of the world, it can be assumed that the ground upheaval in the Vrancea Region is not continuous. This can be taken to mean that there is special behavior preceding and following an earthquake.

In any case, repeated surveying and continuous observation of the crustal movement, recognized as an effective means of study in Japan and other countries will help predict Romania's moderately deep earthquakes.

Earthquake prediction is a very important problem for Romania. More concrete ideas on this problem will be described in Section 9.2.

9.2 Problems of Seismological Studies in Romania

The level of seismology in Romania is high. This may be shown by the fact that practically all materials for the seismological aspects of this report were prepared by Romanian researchers.

However, improvements must be made, particularly in the country's observation network and in activities to determine the epicenters of quakes. Geophysical observation should preferable be conducted in more varied ways and an increase in personnel is necessary.

The ways earthquakes occur in Romania have very special characteristics which provide valuable data for seismology. In this view, Romania has a good chance of becoming a leading country in the field of earthquake studies.

Also it is not overstatement to say that the necessity for earthquake prediction is as acute in Romania as in Japan. In order to advance this field of studies, appropriate measures must be taken.

The following are recommendations for the improvement of Romanian seismological studies.

General Aspects:

(1) It appears that the use of computers for seismology is very limited in Romania. Computerized determination of quake hypocenter determination is the fundamental work of seismology and the present state of this process, being undertaken outside the country, is not desirable.

Not performing this vitally needed work shows a lack of concern for crustal structures that can be understood by using data of natural earthquakes. It must also be noted that the use of computers is a prerequisite for many items of research in current seismological data analysis. The majority of seismological studies nowadays, except for purely theoretical studies or experiments, depend on computers.

(2) The observation network must be improved. The observation network here means only the assemblage of seismic observatories whose function, in this case, is limited to earthquake observation.

The most important point of recommendation is wider use of the time mark with the use of crystal clocks. In Romania at present, only three observatories are time-marked by crystal clocks and two of them are dependent on the clocks of astonomical observatories.

If clocks of 10^{-9} class precision are used, adjustment will be needed only once a year. Even with the use of cheaper models of 10^{-6} class, adequate accuracy will be ensured by adjustment every one or two days.

For the study of moderately deep earthquakes in the Vrancea Region, the present distribution of observatories is not balanced. Several more observatories should be established in the Transylvania Region. The Romanian observation network can match that of Japan, if more than one hundred observation points are established across the country. The observation points might be connected to subcenters by telemeters.

Also recommended for Romania is standardization of the types of seismographs as far as possible. A good first step forward would be 20 observatories placed in proper distribution across Romania, all equipped with crystal clocks.

The establishment of the telemetering system should follow this first stage of progress.

The above-mentioned two points are the most basic requirements for seismological studies. There is another vital necessity for the progress of seismology and earthquake prediction.

By a very strict definition of terms, the number of seismologists in Romania is only ten or so. This is obviously not enough. And, moreover, their ages are imbalanced. At least another ten seismologists, thirty or younger in age, will be necessary. It would not be very difficult to recruit the required number of younger students, since there are 500 geophysical inspectors in Romania. The personnel increase will not adversely affect any sector if the recruiting is carried out at the pace of two or three persons a year.

When the above-mentioned conditions are met, Romania's studies on earthquake prediction can be considered to have come to the starting point. But for full-scale studies, more observation facilities will be necessary.

(1) In order to detect premonitors of earthquakes, the most effective method is repeated geodetic surveying. This has been the experience of Japan. In this survey, leveling or measurement by laser distance meters must be repetitive. The survey work load will be much lighter in Romania than in Japan, since, in Romania,

the area requiring this survey is limited to the Vrancea Region. With regard to the frequency of the survey, it is desirable that it be repeated at intervals of two or three years.

(2) Romania should have a network for continuous observation of crustal movement. The Vrancea Region should be the first area for such observation. The recommended measuring devices are extension meters, tiltmeters (water-tube or borehole-type) and borehole-type strain meters, etc. The observatories should not be built in large numbers at one time. The first step needed is establishment of one observatory where scientists can get totally familiarized with the operation of the various instruments. Eventually, however, it is desirable that more than ten observatories will built in Vrancea and Transylvania districts.

(3) Seismologists, however, cannot predict earthquakes without the help of specialists in several other fields of science. Especially, geomagnetic and geochemical observation is vitally necessary.

So seismologiest are required to cooperate with experts in these scientific sectors and also with geologists.

Furthermore, seismologists must work together with experts in electronics, since various up-to-date instruments are being developed with their aid.

Accordingly, full discussions should be continued between those scientists and experts concerned in order to achieve the goal of correct earthquake prediction.

To conclude this portion of the report, it must be recalled with many thanks that almost all of the data used for this report were prepared and provided by Romanian experts.

9.3 Problems of Romania's Construction Technology

9.3.1 On Seismic Design Building Method

The level of the current building design system in Romania is generally high as mentioned in Chapter 4. But there are many problems that require a review when the system is studied in light of the magnitude of the earthquake load present, the zoning coefficients of earthquake load based on micro-zoning, the demand for economy, the actual damage resulting from the latest quake, the records of the first severe quake experienced by the country and conceivable quake dangers.

While in Romania, the survey mission exchanged views with Romanian experts at several study meetings. An outline of the specific contents of the discussions may be obtained from the questions and answers at the end of this section.

The following is an outline of opinions on present and future seismic design systems in Romania.

(1) The usual values of load for seismic design may be set more rationally through more adequate studies of the conceivable magnitude of earthquakes in Romania.

(2) The micro-zoning map should not be too sophisticated since earthquake prediction techniques are quite limited.
The micro-zoning map reflecting ground conditions is important in a practical sense.

(3) The ground motion spectrum should be provided for each ground condition. For this purpose, however, a large volume of data of severe quakes is required. Without this, conservative spectrum should be set.

(4) Limits in the compressive stress of reinforced concrete columns should be provided. It is desirable to set the upper limit of the compressive stress of dead loads and live loads at 0.2 Fc for corner and side columns and about 0.3 Fc for center columns (Fc: concrete design strength).

(5) Limits to horizontal deformation should be set. Most damage prevalent in buildings of modern design lies in non-structural materials. These limits therefore, will be effective in reducing damage from earthquakes. The value of the limits must correspond to the deformation characteristics of non-structural materials.

(6) Accumulation of data on the deformation performance of non-structural materials is desirable. Structural materials used for prefabricated buildings have shown remarkable strength in recent earthquakes due to outstanding quality controls. The quality of field-cast concrete is an important factor in building quake- proof structures.

9.3.1-ADD Questions from Romanian Government and Answers on Design of Seismic Structures ( ) Supplements by Translator

Problems related to the design of antiseismic structures

(1) It is known that during earthquakes stiff structures suffer great massic loadings, while flexible structures are loaded to a lesser degree but being more flexible they are more sensitive to second degree supplementary effects. Taking into account the dynamic characteristics of the March 4 earthquake, what measure of flexibility - verifiable by means of the value of the natural vibration period - do you recommend for various types of constructions (single-story halls, storied halls, water towers, multi-storied civil buildings, a.s.o.)?.

(2) What static diagram do you consider more adequate for single-story halls, taking into account the deformability requirements imposed by the quake, in the case of:

- articulated knots;
- total continuity in the knots.

(3) Do you consider that, in the case of single-story halls with important vertical geometrical dissymmetries, it is preferable to have a seismic joint, realized by doubling the columns, or no joint but a single column.

(4) What is your view of the mode of action under seismic stress of welded joints in the knots of prefabricated structures when these knots must work as;

- (imperfect) hinges;
- knots resistant to bending.

(5) Do you consider that, in the case of single-story halls with a stiff floor made of prestressed concrete roof components placed on transverse beams, longitudinal stiffening girders are still necessary?

(6) What are the values of massic loads for which welded metal joints between prefabricated concrete members ought to be designed to withstand great load concentrations (for instance, the joining between girder and column in a single-story hall)?

(7) In view of the fact that real seismic stresses are much greater than the conventional design ones, what possibilities do you consider applicable for the correct determination of the width of seismic joints so as to avoid sections of buildings from knocking against each other, especially when adjacent sections have greatly different dynamic characteristics?

(8) Which is, in your view, the proper design principle applicable to the columns of a building located in a seismic area so as to ensure their remaining in the range of working conditions, their capacity of seismic energy dissipation, their damping rate, their behaviour under dynamically applied shearing forces, the state of unitary stress in concrete and the latter's part within the structural whole.

(9) Which of the following types of storied industrial structures for great working loads of 1,000 - 2,500 kg/sq.m. do you consider as offering a better antiseismic conformation?

- frame structure,
- shear-wall structure,
- central-core structure,
- central- and peripheral-core structure.

(10) Since we have at our disposal calculation programs which make possible the testing of structural behaviour of buildings under given seismic stress - bigraphic calculations that allow for the analysis of structural behaviour in the non-elastic range - and bearing in mind the nature of the March 4 earthquake, which of the following accelerogram do you consider we should use:

- EL CENTRO
- U.S. Standard Accelerogram
- TAFT
- BUCHAREST, 4 March, 1977.

(11) What is your view of the possibility of turning from a seismic calculation based on conventional equivalent static forces to a calculation based on an analysis of the strains caused to the structure by the quake.

(12) In considering the overall behaviour of a construction under seismic stress, which are in your views the requirements for ensuring an elastic behaviour under the real seismic stress?

(13) Taking into consideration the ductibility requirements and knowing the necessary ductibility to be ensured in various characteristic sections on the basis of the analysis of the structural behaviour in the non-elastic range, what practical design measures can you suggest with a view to achieving the required ductility level.

(14) What ductility factor do you recommend as obligatory so that various types of structures may satisfy the conditions of strain imposed by the earthquake in the case of:

- frame structures;
- shear-wall structures;
- central-core structures;
- tube-in-tube structures.

(15) Do you consider that removal of masonry infill walls in frame structures would results in the overloading of the supporting members which will have to dissipate alone the whole quantity of seismic energy absorbed by the structure? In such situations, ought greater ductility factors to be stipulated and how much greater?

(16) How do you appreciate the ability of a concrete shear-wall to dissipate seismic energy, especially in the case of structures with cracks caused by shearing forces of an earlier seismic loading.

(17) What is the value of the relation ductility factor of the bending sections of a frame's collar beam which you deem necessary to achieve an overall non-elastic strain of the order 4 to 6 of a structure upon parallel displacement?

(18) Are there principles for the reinforcing of vertical members subjected to dynamically applied shearing forces?

(19) What is your opinion of a possible diminution of the seismic forces absorbed by a structure through the swinging and rolling effect, in the case of a stiff understructure?

(20) Do you consider useful for elastic structures to be linked at foundation level so that they move together under seismic movements and, as far as possible, synchronically with the mass of the surrounding ground, especially in the case of multi-storied buildings?

(21) Can a reduction of seismic loadings be taken into consideration, in case the foundation level rises, and by how much?

(22) As regards cuboid buildings, can the differences between the acceleration spectra along the two directions results in detrimental loadings, and in the affirmative how can these be included in the design procedure?

(23) What can be said about the ability of shear walls to dissipate seismic energy, especially in the case of earthquakes with vibratory movements characterized by high frequency and low amplitude, in the circumstances of long-duration seismic?' What are the principles of reinforcement - quality of cement and reinforcement percentage - which you consider necessary to be applied in design?

(24) What is in your opinion the seismic force to be used when calculating water towers, bearing in mind that the supporting tower being cantilevered has but a reduced capacity of dissipating seismic energy.

(25) Do you consider the building of a silo with its compartments (cells) supported by columns included in its understructure as a proper antiseismic solution, or do you appreciate as more adequate a direct support of the cells on the foundation?

(26) What types of solutions do you consider possible for ensuring a sufficient load-bearing capacity against future seismic stresses for the 9 and 11-story apartment buildings built between 1930 and 1940 and which have sustained column damages during the March 4 earthquake?

(27) What is your view as to the possibility of using prestressed concrete for earthquake-resistant structures, taking into account the necessary ductility to be ensured to the structural whole?

(28) We would like to know if the Japanese prescriptions allow the use of the steel marks having a short deformation at rupture for the reinforcement of the ductile concrete frames.

Please, mention these marks of steel - mainly the physical and the mechanical characteristics - and also the allowable stresses for both elastic and inelastic calculation of the structure.

Answer to the questionnaire of IPCT

1. Keeping natural period of vibration of buildings apart from predominant period of ground is always preferable.

   However, it is not always feasible to design buildings as mentioned above.

   It is recommendable that well balanced estimation of deflection of buildings and proper design details to prevent damage to non-structural members are provided.

   The following stops should be taken for the above purpose:

   (1) Compiling the ground motion spectrums,

   (2) Providing equivalent static force which is used for the calculation of elastic drift,

   (3) Providing the value of limitation of the elastic drift.

2. Provided that proper design was done, both scheme will behave well under seismic load. It is necessary to assure clear and stable behaviour of knots.

3. It will be preferable to make these halls consolidate considering their geometrical dissymmetries.

   When they are designed to be separated with each other for shrinkage, adequate expansion shall be considered taking account of the seismic drift.

4. When joints are well designed and welding is well done, they will behave so as to have been designed. Especially at altimate the above mentioned behavior can be expected.

5. The stiffening girders are not necessary as longitudinal resisting system is composed of prestressed floor panels. However the plastic behavior of T- and - sectioned beams shall be checked by experimental or theoretical analysis.

6. When columns and beams are connected directly with each other, their connection can be safely designed using stress modified by concentration coefficient, say 1.5-2.0 However, connections between floor slabs shall be so designed as to be able to carry 50% of permanent load, supported by the slabs, from central panels to external panels.

7. The width of seismic joint would be limited to about 5-6 times elastic drift due to conventional design load.

8. As concerned with seismic design for reinforced concrete columns, it will be necessary to satisfy the following fundamental items for good ductilities.

   (I) To keep axial unit stress ( ) in small values, say 0.3 F_c.

   (II) Not to make the ratio of celar height (h_o) of columns to width of columns (D) very small, say h_o.   2D

   (III) To keep the spacing of web reinforcement in columns less than 10 cm and 8 times diameter of compressive axial bars.

   And to arrange web bars more than adequate lower limit, say 0.2% 0.1%.

   (IV) Not to use so many axial bars and columns, say p_t 1.0% Here, p_t is tensile reinforcement ratio.

9. Anything will do. But shear wall structures will be the most economical solution.

10. It will be necessary to choose several strong motion accelerogram records which were recorded at the sites where the soil conditions are similar to those of a construction site.

    You may refer the records obtained in Japan as well as in U.S.A.

11. Although the calculation based on an analysis of the strains is an effective measure to evaluate structural behavior in the plastic range, a static calculation based on conventional equivalent forces is sometimes more reliable.

12. It will be necessary to ensure elastic behavior under moderate earthquakes which may occur several times during the life-span of structures. In Japan, we assume that the ground motion acceleration related to moderate earthquakes is around 70 - 80 gals.

13. It will be necessary to avoid shear failure for the purpose of obtaining sufficient ductility.

    Special care should be paid for girders and shear walls which have shallow web or wall thickness where shear distress is anticipated.

14. It will not be difficult to obtain the values of ductility more than 3 for frame structures, central-core structures, and tube-in-tube structures provided that shear-span ratio*) of vertical members is not less than 2.

    In the case of shear-wall structures the ductibility factor should be assumed conservative by say 2 at most.

15. When removing masonry infill wall, load bearing capacity of frame structures will not be compensated by increasing ductility factor of the structure. Then, it is preferable to reconstruct sound masonry in-filled wall, or to install reinforced concrete wing walls in both sides of a column.

16. Provided that the width of crack is less than around 0.5 mm, injection of epoxy resin may be effective to recover the load bearing capacity of the shear walls. In the case that the width of crack is more than the above value, it is preferable to take off existing concrete totally and pour concrete again.

*) Here, shear span ratio means the ratio of the distance from the end of a member to the inflection point to the over all depth of the member.

17. Local ductility factor for girder up to 4 - 5 will easily be achieved by a careful design. The overall ductility factor of structures may well be assumed to one half of that of girders.

18. Please refer to No. 8.

19. It will be possible to expect diminution of seismic forces due to swinging and rolling between stiff underground and subsoil. However, quantitative estimation is still difficult.

20. It is always preferable to provide underground girders which integrate the structures.

21. It may be reasonable to decrease seismic load when the level of foundation is lowered. But quantitative evaluation is now at the stage of research.

22. Design solution should be provided for two directions separately. But special care should be paid for designing corner columns.

23. Repeating loads which cause shear stress up to 0.5 u (= shear strength of concrete) would not deteriorate load carrying capacity of shear walls, provided a sufficient shear reinforcement is provided, say, more than 0.2%.

24. Amplification factor for those structures, should be decided considering dynamic behavior of bending type model.

25. Either will do.

26. The best solution would be to remove ineffective masonry walls and install effective reinforced concrete shear walls as well as reinforcing the damaged columns.

27. To obtain ductility of prestressed concrete members, the research works performed by BRI may be a guide line for designing these members.

28. The conventional values related to Japanese standard, are roughly shown in the table below.

Mark	Yield stress (min)	elongation (min.)	Allowable stresses		(Earthquake)
			Permanent	Temporary	
SR 24	2400	about 25%	1600	2400	
SR 30 SD 30	3000	about 25%	2000	3000	
SD 35	3500	about 15%	2200	3500	
SD 40	4000	about 15%	2200	4000	
Welded mesh ϕ 6	more than 5000	about 5%	2000	3000	
Prestressing tendons	about 6000	about 3∿5%	(0.6 ∿ 0.7)	0.8	

The values of minimum elongation listed above seems adequate for structural use in seismic zone. Any defect caused by lack of elongation of the steels has not been observed during our experiments and experience.

9.3.2 Repairs on damaged structures

Repairs now under way on the buildings that were damaged in the March 4 earthquake have some basic problems, as mentioned in Chapter 5 section 4. That is, clear-cut policies have not necessarily been established as to the standards of repair-how much seismic safety of buildings should be improved by repairs, details of each repair methods and cautions in performing works to ensure maximum effectiveness of the repairs. The following matters, therefore, need to be studied.

(1) In planning repairs, it is recommended to set the objective seismic performance in quantitative form.
The value should have a rational relation with the new seismic load to be set for designs in the future. The value should be established on the basis of a survey of damaged and undamaged structures.

(2) The effectiveness of repair designs should be evaluated on the bases the calculation of the seismic strength of repaired buildings. In this case, the possible deterioration of seismic strength must be properly calculated.

(3) Details of joints between the existing part and repaired part and repaired part will have a significant effect on the result of repair. Therefore, extreme care must given to both planning and execution of work.

(4) It is desirable to urgently establish interim requlations concerning repair planning.

(5) If it is difficult to perform effective repairs quickly on the basis of the above-mentioned recommendations, temporary repairs should be made after oftaining detailed data concerning the state of damage. Full-scale repairs under a long-range plan may become necessary after studying the survey of damaged buildings.

9.3.3 Damage to buildings and its lessons

The degree of damage to buildings is described in Chapter 5. An outline of its causes is as follows:

(1) No seismic design had been made on the majority of lod brick buildings and reinforced brick buildings. Many of the reinforced brick apartment buildings in Bucharest had diminished quake-resistant characteristics due to the earthquake of 1940.

(2) Even in the case of those buildings with seismic design, the magnitude of the actual earthquake far exceeded the quake strength the buildings were designed to stand. Consequently, the reinforced concrete frame-type buildings with low seismic capacity suffered heavy damage on both the inside and outside. Defective construction caused many buildings to be heavily damaged. Japan can learn the following from these condition of damage.

1) Review of earthquake loads containing long period components.

2) Necessity of preventing the destruction of both interior and exterior finish that pose a danger to humans as well as the super-structure.

3) Measures to prevent defective construction.

4) Diagnosis of the quake-resistant properties of existing buildings.

5) Promotion of post-quake planning

9.4 Romania's Tasks in making Civil Engineering Facilities Quake-Resistant in Romania

Measures to make major civil engineering facilities earthquake-resistant are described as follows.

(1) Dams

There are many points concerning the earthquake resistance of concrete dams which require discussion. In some of the fill dams, the slope of the legal level 1 : 1.5 - steeper than 1 : 2.5 slope which is legal in Japan. In order to raise the earthquake resistance, it is necessary to lower the slope by or take operational measures to impose restrictions on the level of the reservoir water.

(2) Bridges

There are no specific points to be discussed concerning bridges. However, it is desirable to add support structures to all bridges in order to prevent them from falling.
(See Photograph 9.4.1)

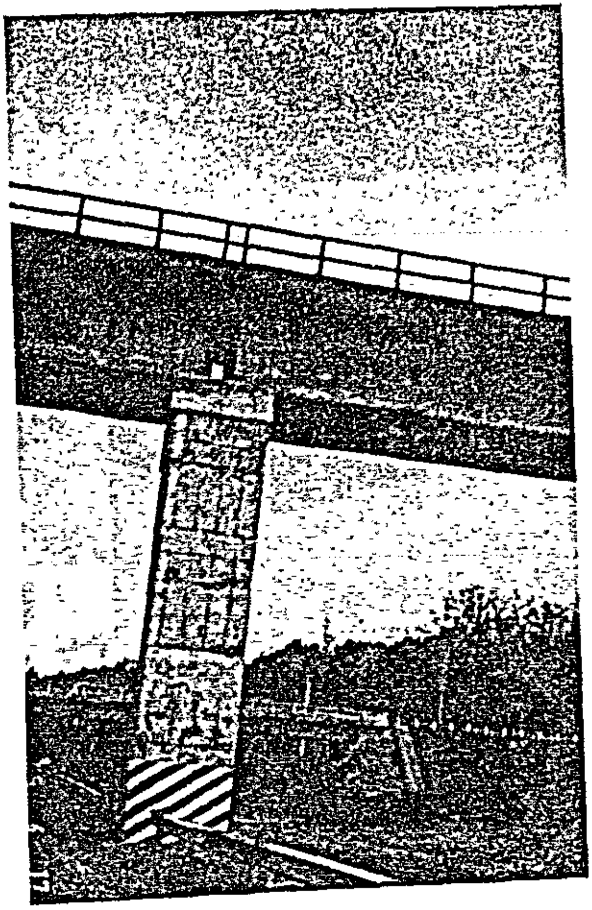


Photo 9.1

An example of the bridge recommended to be provided with support structures to prevent it from falling

(3) Pipelines

Insofar as overland pipes were observed, bent sections are bendable, and there are no specific problems.

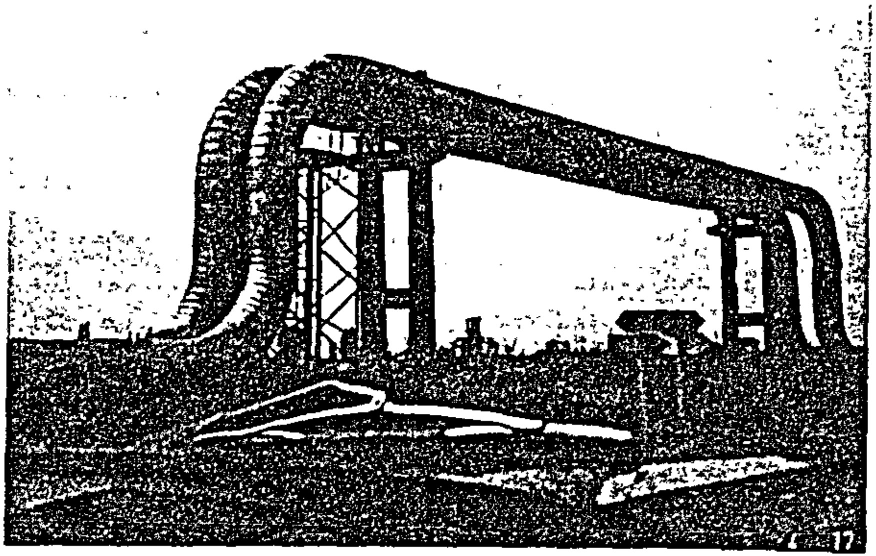


Photo 9.2 Pipeline support structures

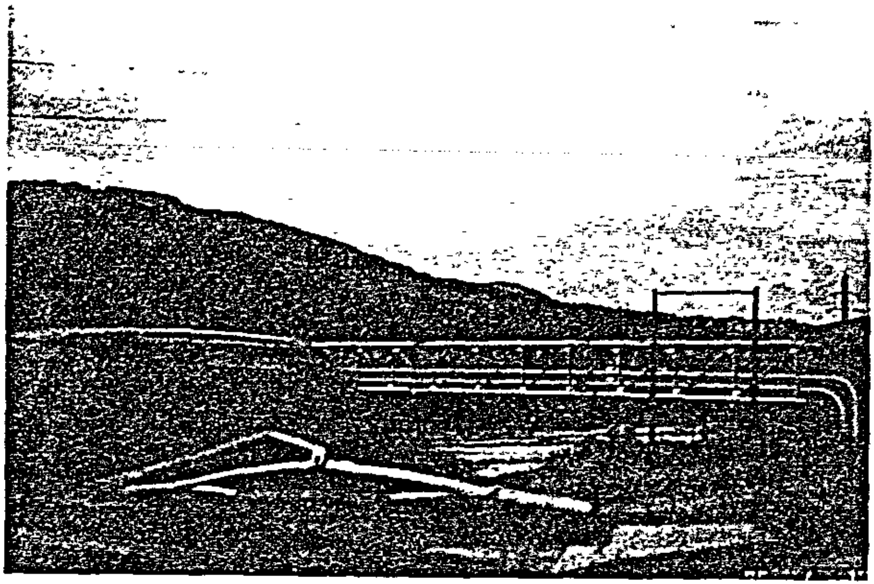


Photo 9.3 Exclusive facilities for pipeline

Supplement: Problems related to the design of Antiseismic Structures

1. It is known that during earthquakes stiff structures suffer great massic loadings, while flexible strutures are loaded to alesser degree but being more flexible they are more sensitive to secondary effects. Taking into account the dynamic chracteristics of the March 4 earth-quake, what measure of flexibility - as a function value of the natural vibration period - do you recommend for various types of structures?

2. What static scheme do you consider more adequate for single-story halls, taking into account the deformability requirements imposed by the quake, in the case of

   - articulated knots,
   - total continuity in the knots?

3. Do you consider that, in the case of single-story halls with major vertical geometrical dissymmetries, it is preferable to have a seismic joint, realized by doubling the columns, or a single column. With no joint ?

4. What is your view of the mode of action of welded joints under seismic stress in the knots of prefabricated structures when these knots must work as

   - (imperfect) hinges; or
   - knots resistant to bending?

5. Do you consider that, in the case of a single-story hall with a stiff floor made of prestressed concrete rool components placed on transverse beams, longitudinal stiffening girders are still necessary ?

6. What are the values of messic loads for which welded metal joints between prefabricated concrete members ought to be designed to withstand great load concentrations (for instance, the joining between girder and column in a single-story hall) ?

7. In view of the fact that real seismic stresses are much greater than those anticipated by convention design values, what do you consider to be the correct width of expansion joints to avoid sections of buildings from knocking against each other, especially when adjacent sections have greatly different dynamic characteristics ?

8. What is the proper design principle for columns of a building located in a seismic area to ensure their remaining in the range of working conditions, their capacity for seismic energy dissipation, their damping rate, their behaviour under dynamically applied shearing forces, the state of unitary stress in concrete and the part of concrete within the structural whole ?

9. Which of the following types of multi-story industrial structures for large working loads of 1,000 - 2,500 kg/sq.m. do you consider offers the best antiseismic configuration ?

   - frame structure
   - shear-wall structure
   - central-core structure
   - central-and peripheral-core structure

10. Since we have calculation programs which enable testing of structural behaviour of buildings under given seismic stress - bigraphic calculations that allow for the analysis of structural behaviour in the non-elastic range-and considering the nature of the March 4 earthquake, which of the following accelerograms do you recommend we use ?

    - EL CENTRO
    - U.S. Standard Accelerogram
    - TAFT
    - BUCHAREST, 4 March, 1977.

11. What is your view of the desirability of turning from a seismic calculation based on conventional equivalent static forces to a calculation based on an analysis of the strains caused to the structure by the quake (time history calculation) ?

12. In considering the overall behaviour of a structure under seismic stress, what are, in your view, the requirements for ensuring elastic behaviour under the actual seismic stress ?

13. Taking into consideration the ductubility requirements and knowing the necessary ductility required in various characteristic sections on the basis of the analysis of structural behaviour in the non-elastic range, what practical design measures can you suggest to achieve the required ductility ?

14 What ductility factor do you recommend for various types of structures to withstand the conditions of strain imposed by earthquakes in the case of

- frame structures;
- shear-wall structures;
- central-core structures;
- tube-in-tube structures.?

15. Do you consider that removal of masonry infill walls in frams structures would result in overloading of the supporting members which alone have to dissipate the seismic energy absorbed by the structure ? In such situation, should greater ductility factors to be stipulated and , if so, how much greater ?

16. How do you rate the ability of a concrete shear-wall to dissipate seismic energy, especially in the case of structures with cracks caused by shearing forces of an earlier seismic loading ?

17. What value of the relation ductility factor of the bending sections of a frame's collar beam is necessary to achieve an overall non-elastic strain of 4 to 6 in a structure during parallel displacement ?

18. What principles are applicable for reinforcing vertical members subject to dynamically applied shearing forces ?

19. What is your opinion of the diminution of seismic forces absorbed by a structure through the swinging and rolling effect in the case of a stiff understructure ?

20. Do you recommend that elastic structures be linked at foundation level so that they move together during seismic movements and, as far as possible, synchronically with the mass of the surrounding ground, especially in the case of multi-story buildings ?

21. Can seismic loadings be reduced if the foundation level rises, and by how much ?

22. In regard to cuboid buildings, can the difference between the acceleration spectra in the two directions result in detrimental loadings, and affirmative by how can this be conpensated for in the design ?

23. What is the ability of shear walls to dissipate seismic energy, especially in the case of earthquakes with vibratory movements characterized by high frequency and low amplitude, during long seisms? What are amount of reinforcement - quality of cement and reinforcement percentage - that you consider necessary in the design ?

24. What seismic force should be used when calculating water towers, considering that the supporting tower being cantilevered has a reduced capacity for dissipating seismic energy.

25. Do you regard the building of a silo with compartments (cells) supported by columns in the understructure to be a proper antiseismic solution, or do you consider direct support of the cells on the foundation to be more adequate ?

26. What solutions will ensure sufficient load-bearing capacity against future seismic stresses for the 9 and 11 - story apartment buildings built between 1930 and 1940 and which have sustained column damage during the March 4 earthquake ?

27. What is the possibility of using prestressed concrete for earthquake-resistant structures, considering the ductility necessary for the structural whole ?

28. We would like to know if Japanese formulas allow use of steel marks having a short deformation at rupture for reinforcement of ductile concrete frames. Please describe these steel marks, particularly the physical and the mechanical characteristics and the allowable stresses for both elastic and inelastic calculations of the structure.

Supplement: Answer to the Questionnaire of IPCT

1. Keeping the natural period of the vibration of buildings separate from the predominant period of the ground is always preferable.

   However, it is not always feasible to design buildings as described above.

   A balanced estimate of the deflection of buildings and proper design details to prevent damege to non-structural members should be provided.

   The following steps should be taken to achieve the above objectives.

   (1) compiling the ground motion spectums.

   (2) providing equivalent static force for the calculation of elastic drift.

   (3) providing the limits of elastic drift.

2. Provided that the design was properly executed, both shemes behave well under seismic load. It is necessary to assure cear and stable behaviour of knots.

3. These halls should be consolidated due to their geometrical dessymmetries.

   When the are designed to be separated from each other for shrinkage, adequate expansion should be provided taking account of the sesmic drift.

4. When joints are well designed and welding is properly executed, they will behave as designed. The above dehavior can be anticipated particularly at ultimate.

5. Stiffening sirders are not necessary as the longitudinal resisting system is composed of prestressed floor panels. However, the plastic behavior of T - and - sectioned beams should be checked by experimental of theoretical analysis.

6. When columns and beams are connected directly, their connections can be safely designed using stress modified by the concentration coefficient, for example 1.5 ∿ 2.0. However, connections between floor slebls shall be desinged to be able to carry 50% of the permanent load, supported by the slabs, from central panels to external panels.

7. The width of the seismic joint should be limited to about 5∿6 times the elastic drift due to conventional design load.

8. In regard to the seismic design for reinforced concrete columns, it is necessary to satisfy the following fundamental items for good ductilities.

   I) To keep axial unit stress values (   ) small, say 0.3 F_c.

   II) The ratio of clear height (h_o) of columns to width of columns (D) must hot be small, say h_o 2D.

   III) The spacing of web reinforcement in columns must be less than 10 cm and 8 times the diameter of the compressive axial bars.

   Veb bars must exceed the appropriate lower limit, for example 0.2% to 0.1%.

   IV) Excessive axial bars must not be used in columns, for example P_t 1.0%.
   Here, P_t is tensile reinforcement ratio.

9. Any design will suffice but shear wall structures are the most economical solution.

10. It is necessary to select several strong motion accelerogram records recorded at sites where soil conditions are similar to those of the construction site.

    You may refer to records obtained in Japan as well as the U.S.A..

11. Although the time history calculation is an effective means of evaluating atructural behavior in the plastic range, a static calculation based on conventional equivalent forces is sometimes more reliable.

12. It is necessary to ensure elastic behavior during moderate earthquakes which may occur several times during the life-span of structures. In Japan, we assume that the ground motion acceleration of moderate earthquakes is around 70 ~ 80 gals.

13. It is necessary to avoid shear failure to obtain suffecient ductility.

    Special care should be given to girders and shear walls which have shallow web or wall thickness where shear stress is anticipated.

14. It is not difficult to obtain ductility values of more than 3 for frame structures, central-core structures, and tube-in-tube structures provided that the shear-span ratio of vertical members is not less than 2.

    In the case of shear-wall structures the ductibility factor should be estimated conservatively, for example, 2 at most.

15. When removing masonry fill wall, the load bearing capacity of frame structures is not vompensated by increasing the ductility factor of the structure. Then, it is preferable to reconstruct a sound masonry-filled wall, or to install reinforced concrete wing walls on both sides of a column.

16. Provided that the width of a crack is less than approximately 0.5 mm, injection of epoxy resin effectively restores the load vearing capacity of shear walls. If the width of the crack is more than the above value, it is preferable to totally remove existing concrete and pour concrete again.

17. A local ductility factor for girder of up to 4 ~ 5 will easily be achieved by a careful design. The overall ductility factor of s structures may be assumed to be one half that of girders.

18. Please refer to No. 8.

19. Diminished seismic forces are libely due to swinging and rolling between stiff underground and subsoil.

However, a quantitative estimate is still difficult.

X) Shear span ratio refers here to the ratio of the distance from the end of a member to the inflection point to the overall depth of the member.

20. It is always preferable to provide underground dirders which integrate structure.

21. Decreased seismic load is likely when the level of foundation is lowered. Quantitative evaluation is still a subject of research.

22. Designs should be provided separately for two the directions. Special care should be given to designing corner columns.

23. Repeating loads which cause shear stress of up to $0.5\,\tau_u$ (τ_u - shear strength of concrete) would not deteriorate load carrying capacity of shear walls provided sufficient shear reinforcement is provided, for example more than 0.2%.

24. The amplification factor for those structures should be determined by considering the dynamic behavior of a bending type model.

25. Either design.

26. The best solution suffice is removal of ineffective masonry walls and installation of effective reinforced concrete shear walls as well as reinforcing the damaged columns.

27. To obtain ductility of prestressed concrete members, the research performed by BRI may be used a as a guideline for designing these members.

28. The conventional values used in Japanese standards, are roughly as shown in the table below.

Mark	Yield Stress (min)	Min. Elongation	Allowable Stresses	
			Permanent	Temporary (Earthquake)
SR 24	2400	about 25%	1600	2400
SR 30 SD 30	3000	about 25%	2000	3000
SD 35	3500	about 20%	2200	3500
SD 40	4000	about 15%	2200	4000
Welded mesh 6φ	more than 5000	about 5%	2000	3000
Prestressing tendons	about 6000	about 3∼5%	(0.6 0.7)	0.8

The values of minimum elongation listed above seem adequate for structural use in seismic zones. No defect caused by lack of elongation of steel has been observed during our experiments and experience.

CHAPTER 10 THE SURVEY REPORT PRESENTED TO THE ROMANIAN GOVERNMENT

We have thus explained the outline of the results of the survey work conducted by our group of experts.

Based on these findings, the group conducted repeated meetings, complied the 'Report on the March 4, 1977 Romania Earthquake', and sumbitted the Report to Romanian Government on April 25.

The Report is consisted of Four parts: Earthquake, Architecture, Civil Engineering Facilities and City Disaster Prevention.

In each part, we tabled suggestions and other opinions concerning the opinions concerning the

The complete text of the Report is as follows:

TENTATIVE REPORT ON ROMANIAN EARTHQUAKE
OF MARCH 4th 1977

April 25, 1977

Japanese Delegation for Romanian Earthquake
of the Japan International Cooperation Agency

CONTENTS

1. Seismology

1) Determination of foci.

In this country seismologists do not use the most advanced methods for determining the locations of hypocenters. However, the determination of foci is the most funcamental in seismology. Numerical determination of foci with a computer should be done by Romanian seismologists.

2) Seismological network

In order to make accurate detexmination of foci of earthquakes in Vrancea area, the number of seismographic stations equipped with quartz clocks should be increased. Time signals broadcasted by a central radio station should be recorded on seismic records, as well as time signals by quartz clocks.

It is also necessary to increase the sensitivity of seismometers, because detection of microearthquakes in Vrancea is fundamental for the study of earthquake prediction.

Study of seismicity of shallow-earthquakes all over Romanis is aosl very important.

3) Geodetic works

Study of vertical movements in Romania is important. However, messurement of horizontal lend deformation with optical distance meters (Telurometer, Geodimeter) is also important from the viewpoint of earthquake prediction.

4) Continuous observation of cruetal movements.

Poutine observation of crustal movements with strainmeters water-tube tiltmeters, borehole tilmeters and borehole dilatationmeters should be carried out in the near future. Networks of crustal deformation observatories is fundamental in order to study the occurrence of earthquakes in Vrancea area.

5) Telemetering

Telemetering of seismic signals from some of seismological stations may be quite helpful in determining a focus quickly.

6) Earthquake prediction

Predication of the earthquakes in Vrancea area will be possible in the future. It should be noticed that the time aeries of the occurrence of the Vrancea earthquakes had already been studied by Romanian scientists and that probebility of occurrence of a big earthquake had already been warned by a Romanian seismologist.

For the above prediction, it will be necessary to provide adequate numbers of instruments, and to increase the number of seismologits as well as to consolldate the cooperation among seismologists, geophyaicists, geochemists and geologists.

7) Acknowledgement

We express hearty thanks to Romanian seismologists who have provided us with appropriate data.

2. Buildings

1. Design Method

(1) Conventional Design Load for Earthquake may well be set up after careful investigation on seismic danger anticipated in Romania.

(2) Macrozoning map should not be so sophisticated, as we have only limited knowledge on seismic danger.

Microzoning map, taking into account soil condition will have important practical meaning.

(3) Ground motion spectrum should be provided corresponding to each soil condition. A considerable number of strong motion seismographs will be required for the above purpose. A conservative spectrum might be used before compiling these data.

(4) Limitation of compressive stress for colums should be provided. It is preferable that arround 0.2 Fc corner and side columns and around 0.3 Fc for the other columns under live load and dead load are provided at maximum values (Fc = design strength of concrete).

(5) Limitation of horizontal drift should be provided. Most of damage to new type buildings is that of nonstructural elements. Then, the limitation will be effective to lessen earthquake damages. Value of the limitation should well be conform with deformability of nonstructural elements.

Accumulation of data concerning deformability of nonstructural elements will be required.

2. Method of construction

Well controlled structural materials in prefabricated members behoaved quite well against the recent earthquake. Quality control of insite concrete elements shall be effective to realise aseismic structures.

3) Consolidation projects

(1) Objective seismic performance for consolidation solutions should be guided quantitatively. The value shall be reasonably related with the prospective seismic design load and it may be set up by analysing the investigated results on damaged and non-damaged buildings.

(2) Efficiency of consolidation shall be evaluated based on the computed horizontal capacity of buildings after the consolidation. In this case, deterioration of load bearing capacity shall properly be estimated.

(3) Consolidation effect may considerably be influenced by details of connections between existing members and elements used for consolidation. Careful design and execution works are required.

(4) Tentative provisions for consoliation solutions would preferably be developed urgently.

3. Bridges, Dams, Pipe-Lines and Power Plants

1) Generally speaking, earthquake resistant designe of these special structures are carried out very fairly in view of earthquake engineering. Engineers concerned with those pay strict attention on strengths of existing structures, because they believe that they do not have sufficient experiences on earthquake damage.

Through the experience of the earthquake of March 4th 1977, we would like to recommend that seismic design methods and related practices of the structures to earthquakes will be modified supplementarilly.

Their knowledge concerning structural analyses of dams and bridges is recognized as fairly high level in civil engineering field. However we would like to propose that verification of analytical results should be promoted through carrying out followings,

(1) strong earthquake motion observation for actual structures and the adjacent subgrounds,

(2) survey on subgrounds, and

(3) experimental studies on actual structures, structural elements and their models.

2) In view of practices we would like to recommend as follows,

(1) existing dams will be required to reinforce to future earthquakes,

(2) before construction of bridges, careful survey and consideration will be required to subground conditions and layout of structural systems respectively,

(3) practices for pipe-lines to increase resistance to earthquakes will be required by employing analyses of the damage caused by the earthquake, and

(4) codes and practices for power plants to increase resistance to earthquakes will be required by employing the experiences through the earthquake.

4. Urban disaster prevention

The earthquake which occurred on March, 4 destroyed many buildings and public facilities of electric power, water service and gas service.

In the terrible circumstances which were created by the earthquake, it is highly appraised that the secondary disaster has been prevented by the adequate steps taken by the National and Local governments.

Conclusion

Thanks to the great cooperation extended to our Japanese Government's "Romania Earthquake Survey Group of Specialists" by the Second East Europe Division of the European and Oceanic Affairs Bureau and the First Technical Cooperation Division of the Economic Cooperation Bureau of the Ministry of Foreign Affairs and the Second Dispatch Division of Dispatch Headquarters of the Japan International Cooperation Agency, the compilation of this report was possible.

We earnestly hope that this report would be of use in all fields of activities in coping with earthquakes.