IMPRESSIONS OF THE GUERRERO-MICHOACAN, MEXICO EARTHQUAKE OF 19 SEPTEMBER 1985

A PRELIMINARY RECONNAISSANCE REPORT

Committee on Natural Disasters
Commission on Engineering and Technical Systems
National Research Council

Earthquake Engineering Research Institute

October 1985
Publication No. 85-05

PREFACE

This preliminary report summarizes the impressions of the 19 September 1985 Mexico earthquake by the reconnaissance team dispatched to Mexico City jointly by the National Research Council (NRC) of the National Academy of Sciences and the Earthquake Engineering Research Institute (EERI).

The NRC and EERI have been working together in post-earthquake disaster investigations in foreign countries since 1977. The two organizations alternate in leading the investigations. The NRC is taking the lead in the current event, with full support from the staff of EERI. In addition, the Electric Power Research Institute (EPRI) has contributed to this earthquake investigation by providing findings on industrial and power facilities gathered by its six member reconnaissance team.

The main objectives of the reconnaissance team were to establish contact with Mexican researchers and engineers, document perishable information, and make general recommendations for further survey missions and research. Some of the team's findings were briefly presented on 3 October 1985 in Washington D.C., followed by a more detailed presentation in San Francisco, California, on 14 October 1985.

The members of the team, followed by their specialty area, were: Dr. Mete Sozen, Team Leader (structural engineering); Dr. James Brune (seismology); Mr. Sam Swan (industrial facilities); Mr. Edwin Johnson (structural engineering); Dr. Ellis Krinitzsky (geology and geotechnical engineering); Mr. Paul Flores (social sciences/emergency response); and Mr. Luis Escalante (lifelines).

It must be emphasized that this is a preliminary report which has not undergone the official review process of the National Academy of Sciences. It is considered a limited use document. Copies are being distributed only to members of EERI and the Committee on National Disasters of the National Research Council. This document is not to be quoted or cited. Any opinion, finding, conclusion, or recommendation expressed in this report is that of the authors and do not reflect the views of the National Research Council, the Earthquake Engineering Research Institute, the National Science Foundation, or the organizations of the authors.

ACKNOWLEDGMENTS

We are indebted to the Technical Committee on Lifeline Earthquake Engineering of the American Society of Civil Engineers and the Electric Power Research Institute for their support of the team's effort. We are also grateful to Ambassador John Gavin and his staff in Mexico City and the staff of the Office of Foreign Disaster Assistance of the Agency for International Development for their generous and efficient support of the activities of the team.

Members of the Engineering Institute of the National Autonomous University of Mexico, especially Jorge Prince, Luis Esteva, and Emilio Rosenblueth, cooperated fully with the team. Their contributions were crucial to the success of this mission. Preliminary (manual) digitization and response calculations were made by Sharon Wood, Ricky Lopez, and Marc Eberhard, staff members of the National Science Foundation's Project ECE 84-18691 at the University of Illinois, Champaign-Urbana, Illinois.

The study was financially sponsored and technically assisted by the National Science Foundation, Federal Emergency Management Agency, and National Oceanic and Atmospheric Administration.

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INTRODUCTION

The main shock of the earthquake occurred at 13:17:47.6 GMT (7:17:47.6 a.m. in Mexico City), having a Richter surface wave magnitude of 8.1 (M_s). The epicenter was located near a small town, Lazaro Cardenas, on the Pacific coast of Mexico in the state of Guerrero. The distance from the epicenter to Mexico City was estimated to be 400 km (250 miles). According to aftershock data, the rupture zone was inferred to extend about 200 km (125 miles), with Lazaro Cardenas near its middle. While progressing northwest and southeast from Lazaro Cardenas on the surface, the rupture penetrated obliquely under the landmass of Mexico. An earthquake-related tidal wave with a height of almost 2 m (6 ft) was observed on the beaches around Lazaro Cardenas.

STRONG MOTION MEASUREMENTS

The Guerrero accelerograph array, which was being installed as a joint project of the National Autonomous University of Mexico (UNAM) and the University of California at San Diego (UCSD) under the sponsorship of the National Science Foundation, had 20 of 30 planned stations in place. Seventeen of these stations produced strong motion records. Measured peak accelerations in the epicentral region were 0.15 g and the duration of shaking with accelerations not less than 0.1 g exceeded 10 sec.

The Institute of Engineering at UNAM maintains a network of a dozen stations to measure strong ground motion in Mexico City, and all of these stations have produced data. Jorge Prince of UNAM made the reduced data available to interested professionals two days after the main event. The Institute of Engineering's efforts in this respect were exemplary and reflect a high level of capability in state-of-the-art technology and data processing.

In general, the strong motion measurements in the metropolitan area indicate that the earthquake's intensity was very small in areas away from the old lake bed. However, within the central portion of Mexico City, which is founded on a dried lake bed, the motion was measured to be about 0.2 g or five times as large as in the outlying districts. Another important characteristic of the ground motion was its steady pace, depicted (manually digitized and replotted) in Figure 1 for one of the accelerograph sites (station SCT). At this site, the ground moved a total distance of about 40 cm (16 in) (peak to peak) completing each cycle in 2 sec. The steady nature of the ground motion exacerbated its influence on medium-rise buildings. At another site, 5 km (3 miles) from station SCT, the dominant ground period appeared to be 3.5 sec.

Figure 2 provides a preliminary measure of the intensity of the motion obtained at station SCT, Mexico City. The velocity response spectrum for that motion is compared with the response spectrum for a well-known U.S. strong motion record, El Centro 1940 N. While the spectral velocity for El Centro 1940 exceeded that of SCT 1985 for periods up to 1.5 sec, the motion at SCT had an impressively higher velocity response for higher ground motion periods.

From Figure 2 it may be concluded that low-rise buildings would not be excited by the motion measured at station SCT while medium-rise buildings with effective periods approaching
2 sec would be susceptible.

The Mexico City design spectrum for the part of the city located over the old lake region is compared with that calculated from the manually digitized record for a damping factor of 10 percent. Both plots are normalized to a maximum of one. While no quantitative conclusions can be drawn from Figure 3, it is clear that the Mexican Code writers expected the frequency content recorded on 19 September. It is not certain, however, whether the sustained nature of the almost constant periods of ground motion together with the maximum acceleration (0.2 g) was considered to be credible before the event of 19 September.

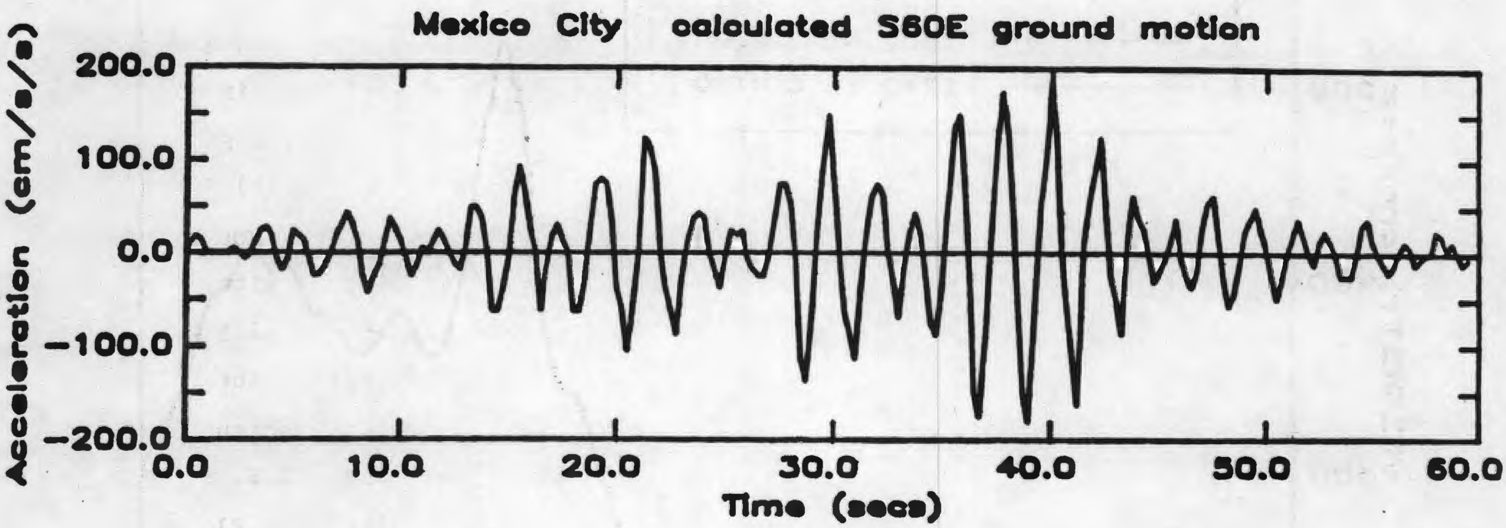

FIGURE 1 S60E component of ground accelerations determined from N and E components measured at station SCT in Mexico City (near intersection of Xola and Universidad).

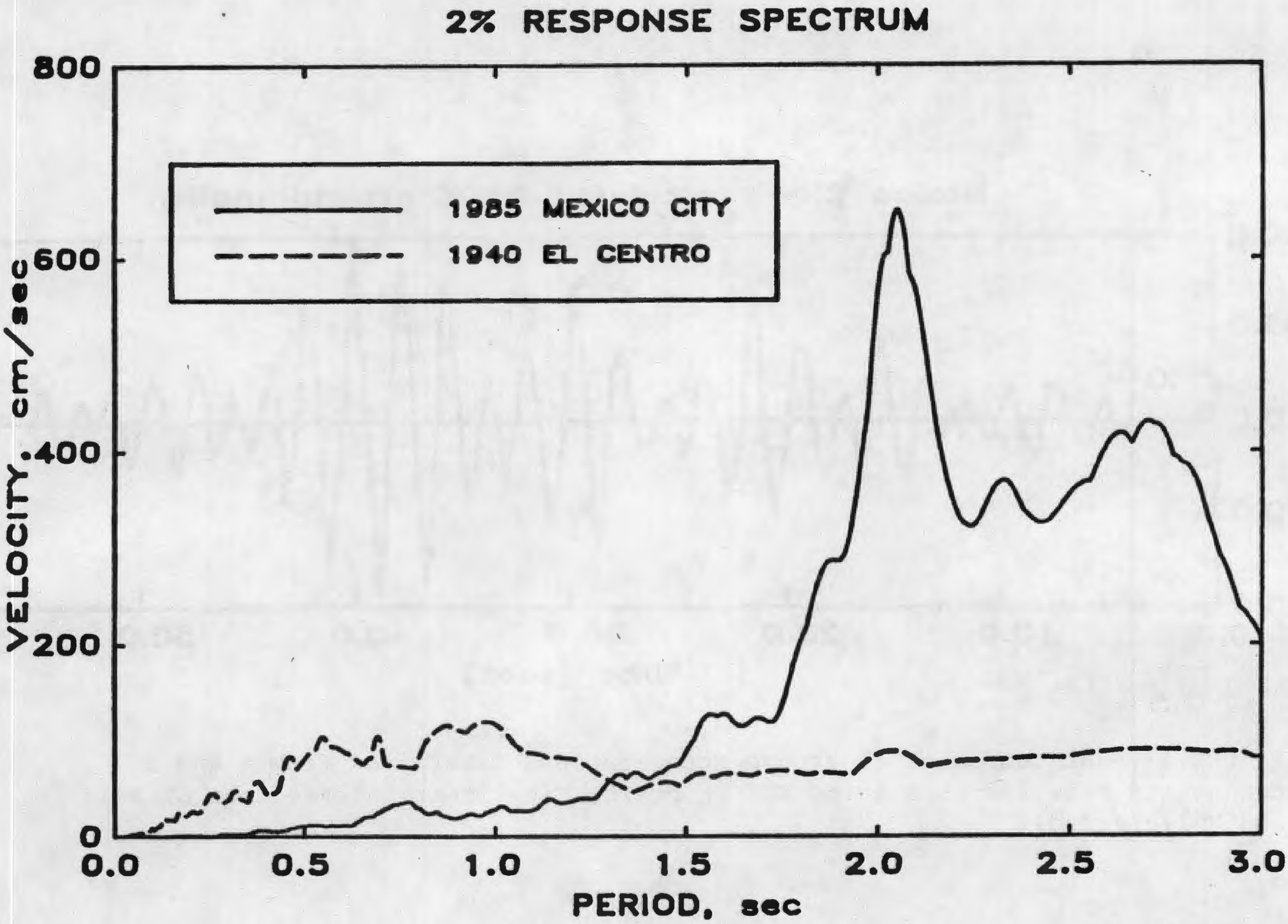

FIGURE 2 Comparison of El Centro 1940 N velocity response with the record obtained at station SCT, Mexico City, S60E component.

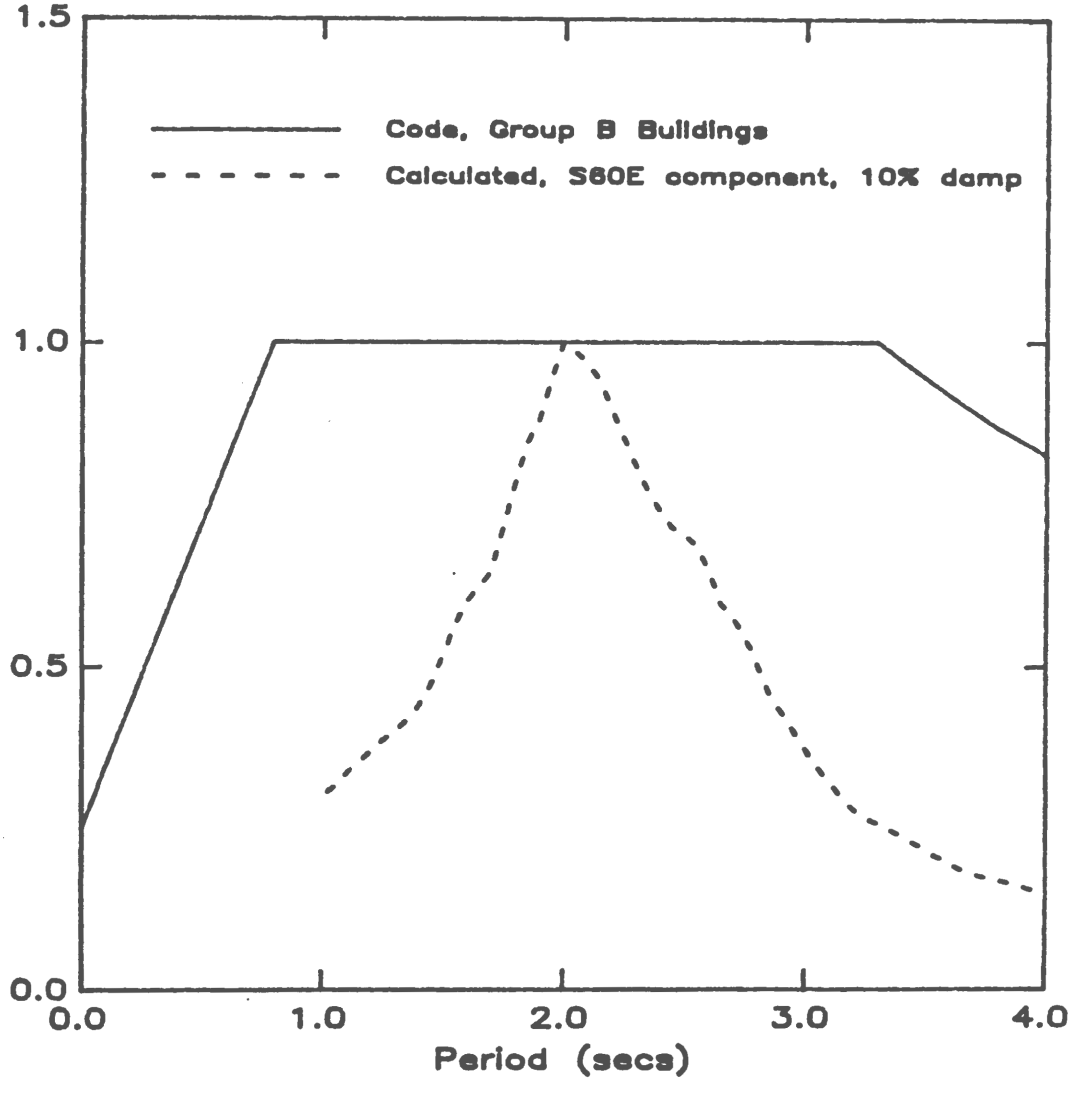

FIGURE 3 Nonquantitative comparison of Mexico City design spectrum with acceleration spectrum (damping factor 10 percent) for the S60E record, station SCT.

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EARTHQUAKE EFFECTS

STRUCTURAL DAMAGE

As widely reported, structural damage to buildings within the lake bed region was severe. As many as 500 structures may have been severely damaged or totally destroyed. In general, this group included buildings ranging in height from 5 to 21 stories. Casualties could approach 10,000.

Much of the structural damage occurred in medium-rise reinforced concrete structures because reinforced concrete was the most common construction material for such buildings. Before discussing failure, it must be stated that even within the lake area, the number of collapsed or heavily damaged buildings will not likely amount to more than a fraction of 1 percent of all building units.

Some of the failures can be attributable to the age of the buildings. Strong evidence indicates that the ground motion in Mexico City during the 19 September earthquake was appreciably stronger than that for the 1957 event. Several buildings that had survived that event suffered serious damage or collapsed on 19 September. It is conceivable that those buildings, unless strengthened after construction, might have had obvious defects. However, Mexico City buildings are typically built to resist earthquake effects. Systematic inspection and tests may reveal examples of substandard construction or design, but it is unlikely that more than a very small fraction of medium-rise buildings constructed in the last two decades are substandard.

Definitive identification of characteristics that led to damage or destruction must await further documentation and study. A few preliminary impressions about structural characteristics that were observed in damaged buildings follow.

STRUCTURAL CHARACTERISTICS OF DAMAGED BUILDINGS

A preliminary inspection revealed that buildings with structural or architectural damage tended to have relatively flexible construction caused by girders of low depth (filled-in segments of "reticular" or waffle slabs), long span lengths, and slender columns. Many cases of collapse also involved first stories of buildings that were more flexible than upper stories because of the need to accommodate garages or stores.

Many structures had columns that were progressively reduced in size from the base upwards, giving the impression that the designers did their best to economize and presumably stay within building code requirements. In some cases, the amount of transverse reinforcement used in columns appeared to be less than the amount required by U.S. building standards for earthquake regions.

A recurrent cause of damage in the upper stories of adjacent buildings of different heights involved a seismic joint or space between the two buildings that appeared inadequate for the nature of this earthquake.

One 21-story structural steel building and its adjacent 14-story building of similar construction were both totally destroyed. It was quite possible that when the 21-story building failed, it took the 14-story building with it.

As previously stated, the low-rise and colonial-type construction in the city fared very well. This success was not necessarily attributed to strength but rather the fact that the ground motion did not excite low-rise structures.

Critical damage from possible foundation movement needs to be evaluated. It is not too much of an exaggeration to claim that virtually no building in the lake region of Mexico City is standing exactly as it did before the earthquake. There were several instances of buildings leaning out of plumb from 10 to 15 degrees.

Outside Mexico City, Ixtapa (a town near Lazaro Cardenas) was reported to have several severely damaged modern buildings. Structural damage was also reported in the states of Jalisco and Michoacan.

DAMAGE TO PUBLIC AND SUPPORT SYSTEMS

Schools and Hospitals

The survey team observed structural problems with three school buildings; one was totally collapsed and the other two were partially collapsed. For the two with relatively heavy reinforced concrete construction, it appeared again that architectural requirements had made them flexible, making them vulnerable to the long earthquake ground motion. One of the school buildings, near the Tepito district of Mexico City, had very slender walls that had clearly overturned.

Mexico City has three main hospital systems: the Juarez Hospital, the General Hospital, and the IMSS or Social Security Hospital. During the first week after the earthquake, none was fully operational. There was a very serious failure of a 13-story building in the Juarez Hospital complex. The General Hospital complex had suffered two serious failures--collapse of the seven-story obstetrics building (apparently a post-tensioned construction) and the intern dormitory. The Social Security complex had serious partial collapses in its Medical Center and the Children's Hospital. According to reports, surviving patients found adequate space elsewhere in the city.

Power Systems

The National Power Generation and Transmission System did not suffer significant damage. Distribution lines were damaged in various areas by collapsed buildings, but power loss occurred only in the immediate vicinity of severely damaged buildings. Estimated effects to the distribution system within Mexico City are as follows:

- Damaged transformers: 113 out of 26,000
- Poles affected: 50 out of 350,000 primary feeder lines
- Lines damaged: 6 km (3.7 miles) out of 10,500 km (6,520 miles)
- Secondary distribution lines damaged: 10 km (6.2 miles) out of 15,750 km (9,790 miles)
- Consumer connections out of service: about 15,000 out of 3.2 million.

Water Systems

Damage to water systems occurred mostly in the distribution pipelines in the eastern and southeastern regions of Mexico City. It has been reported that an aqueduct conveying water from the south had been damaged.

Insufficient water flow and loss of water pressure affected 3 to 5 million citizens out of about 18 million citizens in Mexico City. The normal use of water per capita in Mexico City is 30 to 80 gallons per day. Immediately after the earthquake only 3 to 4 gallons per capita per day were available. By 25 September 1985, most private water cisterns were empty, and many communities were relying on tank truck deliveries or purchases by container from itinerant vendors.

Propane Gas

Propane gas systems did not suffer significant damage. Collapsed buildings caused some gas leakage. The only reported major fire from gas leakage was at the St. Regis Hotel where gas from ruptured pipelines ignited and caused a major explosion.

Communications

Telefonos de Mexico, the National Telephone Company, suffered major damage to its long distance telephone transmission equipment and heavy loss of life among personnel when the top three stories of its five-story office building collapsed. All service outside of Mexico City was lost, and no estimate was possible about when service would be restored. Telephone communications within Mexico City appeared to be completely operational.

Sanitation Lines

Very little damage was reported to pipes carrying sewage for Mexico City. Water distribution lines were more likely to be damaged. Because sewage lines were inactive from lack of water, thorough damage assessment could not be made by officials.

Transportation

No significant damage to streets and bridges within Mexico City was found. Minor buckling of pavements was observed in the lake area primarily because of previous excavation in these areas. The Metro was working smoothly. Airports were not damaged and were operational the day after the earthquake.

EFFECTS ON INDUSTRIAL AND POWER FACILITIES

There are two major hydroelectric power plants (La Villita and El Infiernillo) and a large modern steel mill (SICARTSA) near the epicenters of the main earthquake and the major aftershock. Near Mexico City are two large fossil-fueled power plants. Smaller substations and power plants exist throughout the affected area. The power plants and substations are designed to modern seismic code requirements and include many seismic resistant features. The steel mill consists mainly of large structural steel industrial buildings that are earthquake resistant.

In the epicentral region, recorded peak ground accelerations (on rock) were about 0.15 g. Many buildings suffered significant architectural and structural damage in the towns of Lazaro Cardenas and Ixtapa, requiring evacuation and extensive repairs.

There was no significant damage to the power generating facilities in the epicentral region. Equipment installations were adequately anchored, and had no damage. All systems at the plants operated normally through the severe ground shaking. Some units tripped off line by protective systems. This was caused by problems associated with the power distribution system. Following the earthquake, the units were reconnected with the power grid following a brief inspection.

Except for its concrete structures, the steel plant had minimal damage from the earthquake. Equipment damage was limited to high voltage switchyard equipment that caused partial loss of offsite power. The plant's emergency onsite power generating system was put into operation immediately. One emergency turbine generator of the two unit system would not start. The cause is not yet confirmed and may be earthquake related. All of the many steel frame industrial structures performed well. The only building damage was to a large concrete administration building. An underground water pipe cracked. Long runs of pipes and cable trays on overhead steel frame structures had no apparent damage.

The power plants near Mexico City are situated on the firmer soils outside of the city and are seismically designed. They were subjected to only very weak ground shaking and had no damage, as evidenced by the team's survey of the Valle de Mexico power plant.

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EMERGENCY MANAGEMENT AND SOCIETAL RESPONSE

A report issued in 1981 by the National Security Council and the Federal Emergency Management Agency indicated that California was unprepared to handle the consequences of a catastrophic earthquake affecting one of its metropolitan regions. A similar assessment could have been made of Mexico City. The problem of disaster preparedness in Mexico City has been further compounded by poor socio-economic conditions during the past few years. The discussion that follows addresses three general areas relating to emergency management: hazards reduction and preparedness, emergency response, and post-earthquake construction.

HAZARDS REDUCTION AND PREPAREDNESS

Programs to reduce hazards and educate the public on preparedness in Mexico City were in need of greater support before the earthquake struck. The federal department established in 1977 to develop such programs was eliminated by the current administration, most likely for austerity reasons. The importance and cost-effectiveness of such programs constitute a lesson learned from this tragic event. Hazards reduction programs are difficult to design and costly to carry out, but such programs prove to be cost-effective in the aftermath of a catastrophic earthquake. Mexico now faces billions of dollars in physical losses and staggering social losses, such as human casualties and suffering, as well as the disruption of daily living.

In any large metropolitan area exposed to seismic risk, the appropriate caretaker for emergency preparedness is the local level of government. Although Mexico City may be considered to be administered by the national government, in the final analysis it is not much differently managed than most U.S. metropolitan areas.

EMERGENCY RESPONSE

Mexico City's emergency response was both exhilarating and extremely problematic. Search and rescue efforts took some time to organize. Whether or not a faster response would have saved more lives is a question that merits further study. There is no doubt, however, that many rescues immediately after the earthquake were attributed to tremendous citizen response.

A critical period was reached in the city's search and rescue effort when organization and technical expertise were of the utmost necessity. It became evident that a multidisciplinary team was required for expeditious rescues. Engineers and medical and fire personnel should have been working together as a team as the time to find victims alive became more critical.

Mexico is not alone in its need for more effective methods of urban search and rescue. In the United States, dedicated special training programs are also needed to upgrade emergency response capability. The experience in Mexico City provides a necessary base by which to structure urban search and rescue training programs.

Damage assessment and communications in Mexico City also proved to be problematic. The importance of communications in managing a large disaster is not only related to hardware but also the collection and processing of assessment information. Many decisions are required during a major disaster, and they should be based on the best information available at that moment. In Mexico City, even a few days after the earthquake, it was not clear that a comprehensive assessment had been formulated.

Initial government estimates were underestimated; a situation that could have been avoided if better methods for collecting emergency information and estimating damage and losses had been in place before the earthquake occurred. These methods can be of particular importance when communications hardware fail.

POST-EARTHQUAKE RECONSTRUCTION

The reconstruction in central Mexico City, the area most affected by the earthquake, will be a slow process. The city is just beginning to collect information systematically on the earthquake's consequences for its people, environment, and economy. This evaluation process will take time, but hopefully it can be completed before major reconstruction decisions are made.

This principle will be as important and applicable to the United States when faced with a similar disaster. Earthquake disasters of this magnitude also provide opportunities to act in the public's best interest, but only when tangible data have been gathered and all the alternatives have been weighed. For Mexico City, the necessity of moving slowly may be an opportunity in itself.

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IMPLICATIONS FOR RESEARCH RELATED TO PUBLIC SAFETY

The tragic experience in Mexico City provides invaluable data for improving earthquake engineering construction and emergency response for the international community. To derive the optimum benefit for avoiding future catastrophes, certain projects research should be implemented as soon as possible.

ENGINEERING-RELATED RESEARCH PROJECTS

Ground Motion

The information network in the epicentral area, maintained by the University of California at San Diego and the National Autonomous University of Mexico (UNAM), has yielded the richest collection of strong motion data ever obtained from the movement of a subduction-type fault. Also, data from the strong motion accelerograph network maintained by UNAM has provided a reasonably good idea of the types of strong motion observed in the city. An analysis of the information regarding the nature of the rupture phenomenon and the attenuation and amplification phenomena will significantly improve the ability to estimate strong motion.

Foundations

The confusion created by rescue efforts has prevented an orderly investigation of the contribution of foundation distress to building failure. It is urgent to establish the possible causes and instances of foundation failure and to relate the overall building behavior to amplification studies.

Reinforced Concrete Construction

Much of the damage in the city occurred in reasonably modern or recently built reinforced concrete construction. The specific causes of failure must be understood to avoid similar catastrophes in the United States and other parts of the world.

Damage to Steel Construction

Two modern, high-rise, structural steel buildings of 14- and 21 story in height failed in this earthquake. Because cities in seismic regions of the world have a significant amount of similar structural steel construction, it is essential to establish the failure mechanism of these two buildings.

Building Code Enforcement

It is well known that Mexico has a building code that is one of the most advanced in the world. The relationship between the building code and the actual performance of the buildings needs to be investigated.

Essential Facilities

Most hospital systems in the United States, notably the Veterns Administration (VA) system, have been very carefully evaluated for earthquake resistance.

Nevertheless, it would be important to compare the methods used to evaluate the VA and other hospitals with the actual failures that occurred in Mexico City.

Emergency

It would seem that hundreds of lives might have been saved in Mexico City if the correct equipment and experienced people had been available. Considering the extremes possible, it is necessary to study the capability of major U.S. cities, especially St. Louis, Missouri, and Charleston, South Carolina, to lift heavy slabs in a matter of hours in rescuing survivors from collapsed buildings.

Evaluation of Existing Buildings

Analysis of the failures of buildings constructed before 1957 (pre-code) and of the newer hospital buildings would enhance the current state of knowledge on building safety evaluation and performance. In view of the large inventory of buildings constructed in seismic areas of the world before modern codes were implemented, it would seem proper to reinforce the research and development effort in the area of strength evaluation--a task considerably more difficult than design and construction of new earthquake-resistant buildings.

RESEARCH PROJECTS RELATED TO EMERGENCY MANAGEMENT AND SOCIETAL RESPONSE

Public education programs in the United States are raising the overall awareness of the population. The next step concerns mobilizing preparedness and self-help at the community level. This effort will be more complicated and will require greater commitment on the part of government and community leaders. Local governments must be provided with more support to carry out long-term hazards reduction and preparedness programs and should be more involved in directly planning such programs.

In the United States, hazards reduction programs are in the developmental stages, with only a few local jurisdictions having such programs in place. These programs can be a costly burden to local government and must be supported by the states and federal government directly with financial assistance or indirectly through incentives. Given the complexity of large metropolitan areas with many autonomous jurisdictions, a regional approach may be more appropriate.

The emergency information management systems in the United States are at a proposal stage. Feasibility studies have been conducted and recommendations have been made, but such systems are not yet in place. Cost is a major obstacle, but the cost of mismanaging emergency information could be staggering. Each metropolitan region in the United States should have an operable information management system that can integrate hazard analysis information, inventories of buildings at risk, and emergency management resources to develop hazards reduction programs, to manage the disaster, and to plan reconstruction.

The earthquake disaster in Mexico City emphasizes the need to develop better training programs based on experience. Urban search and rescue is only one area that merits further study.

The need to understand the seismic risk in U.S. metropolitan regions is also important, but more important is the application of that knowledge in reducing hazards and in improving emergency management capability.

The United States must learn all it can from reconstruction efforts in Mexico City. Assistance could be offered to Mexico, not with pledges of millions of dollars for the physical reconstruction, but with lower cost research to determine the full social and economic implications of the disaster. Collaborative efforts could involve support of private and public research institutions in Mexico to obtain a base for proposing sound alternatives to the problem of socioeconomic and physical reconstruction.

APPENDIX:

PHOTOGRAPHS

photo: C. Arnold

Collapsed Regis Hotel

photo: C. Arnold

7-story commercial building --
lower floor collapse

photo: C. Arnold

Building near Regis Hotel -- glass and stucco
spandrel cracking

photo: C. Arnold

Intact older building 1 block from
Regis Hotel

photo: C. Arnold

Older concrete building --
upper floor collapse

photo: C. Arnold

Older concrete building --
upper floor collapse


photo: C. Arnold

Nuevo Leon Housing Project -- remaining building end wall showing open first floor. The back of this building collapsed completely and caused many deaths.


photo: C. Arnold

Nuevo Leon Housing Project showing the braced wall adjoining the building completely collapsed.

photo: C. Arnold

Intact old masonry building. Damaged government office building in background -- top floor collapse.

photo: C. Arnold

Undamaged old masonry building. Next door is newer office building with upper floor collapse

photo: C. Arnold

Hotel DeCarlo -- mid-floor collapse

photo: C. Arnold

Hotel DeCarlo detail

photo: C. Arnold

State Lottery building -- undamaged. This steel frame structure is located 1 block from Regis Hotel.

photo: C. Arnold

44-story Latino-American Tower (built 1948) -- undamaged

photo: C. Arnold

Distorted glass framing

photo: C. Arnold

Central telecommunications complex

photo: EQE, Inc.

photo: EQE, Inc.

Jose Maria Morelos Dam. The dam and La Villita power station are located near the mouth of the Rio Balsas. The earth-filled dam is approximately 150 feet high by 1,000 feet long. The large array of high voltage equipment in the station switchyard (adjacent to the dam crest) was unaffected by the earthquake, even though this type of equipment is often susceptable to seismic damage. The power station is housed in a large steel frame building and consists of four 76 megawatt units, completed in 1973. Mechnical and electrical equipment in the station were undamaged by the earthquake. Protective relays disconnected the station from the power grid during the earthquake.

photo: EQE, Inc.

photo: EQE, Inc.

El Infiernillo Dam and Power Station. Located on the Rio Balsas about 20 miles from the Pacific coast, El Infiernillo is an earth-filled dam about 500 feet high by 1,000 feet long. The power station is located at the discharge of the penstock about 1/2 mile downstream of the dam. Built into the rock face of a hillside, the power station includes four 160 megawatt units and two 180 megawatt units. It was constructed in the mid 1960's. The station disconnected from the power grid during the earthquake due to protective relay action.

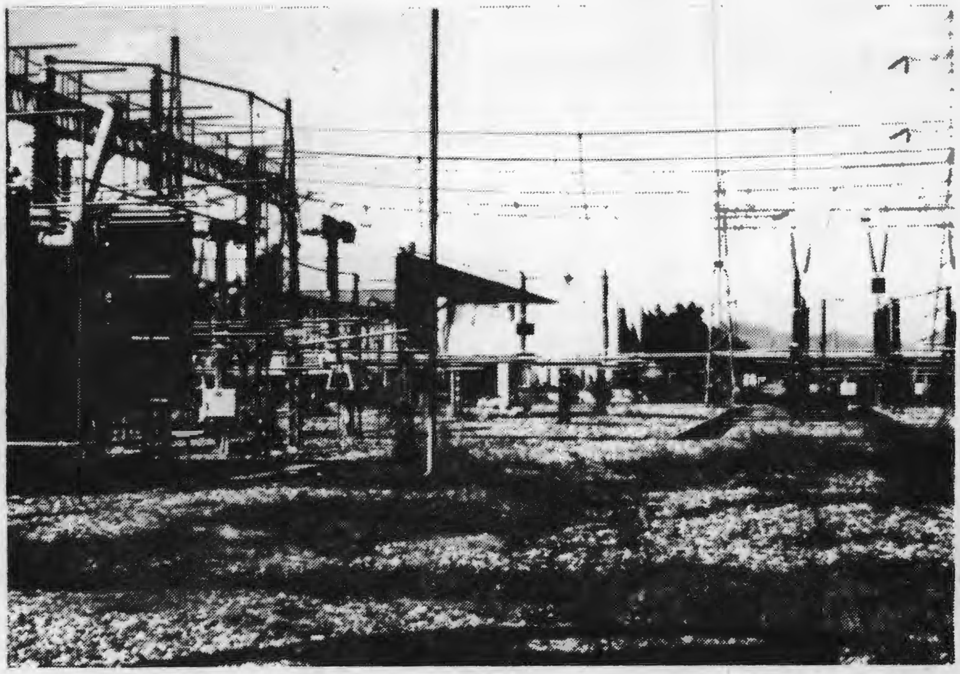

photo: EQE, Inc.

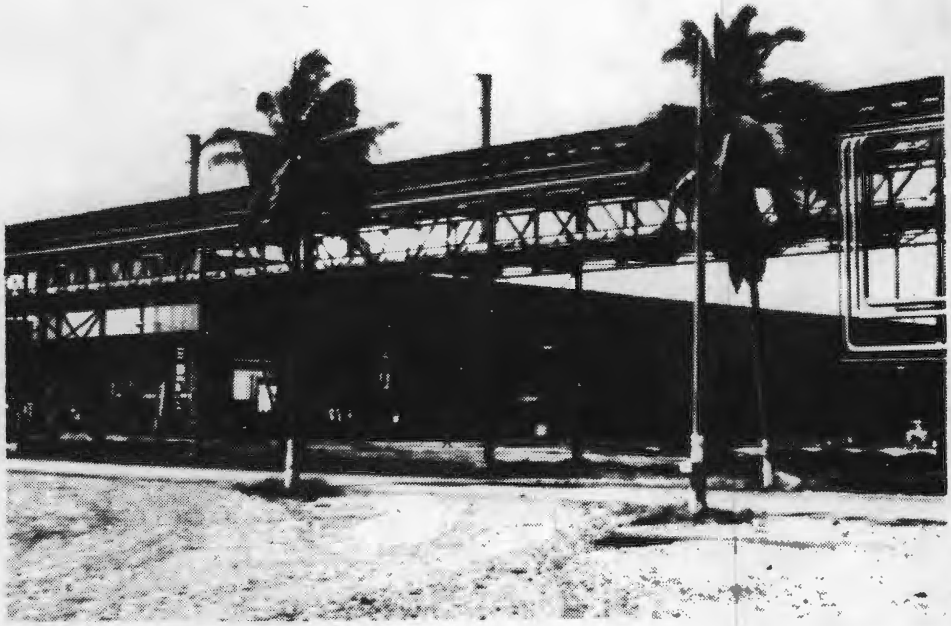

photo: EQE, Inc.

SICARTSA Steel Mill. The top photograph shows the switchyard where a disconnector switch similar to the one seen near the center of the photograph fell due to a cracked ceramic insulator. A transformer similar to the one at the left also suffered a cracked oil seal. The lower photograph shows a pipe support structure with a large structural steel building in the background. Both are representative of the types of components located at this plant, all of which performed well during the earthquake. A concrete frame administration building had severe damage to masonry panels and was evacuated.

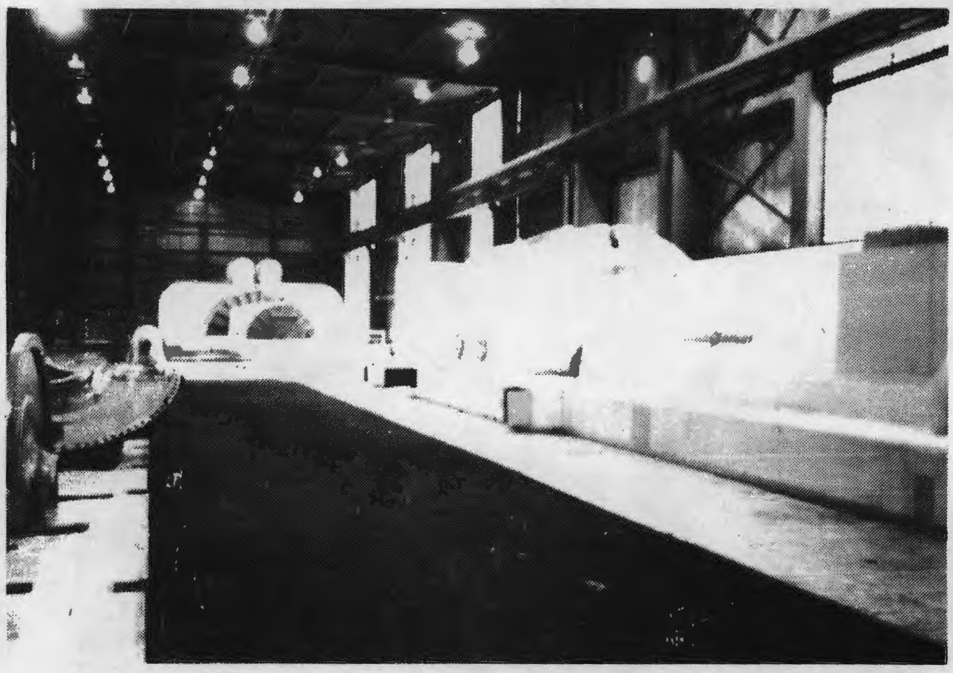

photo: EQE, Inc.

Valle de Mexico Power Plant. The operating floor of this fossil power plant is shown. It is located about 20 miles west of Mexico City and is built on a rock site. The plant includes three 150 megawatt units and one 300 megawatt unit. Plant personnel reported minor shaking from the earthquake. Three units were operating at the time of the earthquake; two remained on-line and one disconnected from the power grid due to relay actuation caused by loss of load in Mexico City. There was no damage to the plant.