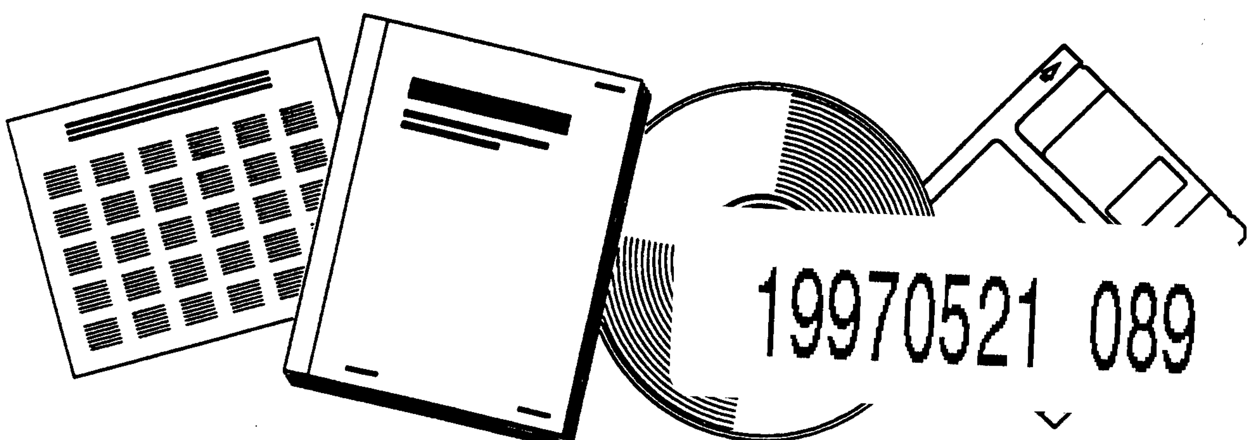
PB94-142221

RECONNAISSANCE REPORT OF DAMAGE TO HISTORIC MONUMENTS IN CAIRO, EGYPT FOLLOWING THE OCTOBER 12, 1992 DAHSHUR EARTHQUAKE

DEPARTMENT OF THE ARMY WATERWAYS EXPERIMENT STATION
VICKSBURG, MS

AUG 93



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

State University of New York at Buffalo

Reconnaissance Report of Damage to Historic Monuments in Cairo, Egypt Following the October 12, 1992 Dahshur Earthquake

by

D. Sykora, D. Look, G. Croci, E. Karaesmen and E. Karaesmen

Geotechnical Laboratory
Department of the Army
Waterways Experiment Station, Corps of Engineers
Vicksburg, Mississippi 39180

Department of the Interior
National Park Service
San Francisco, California 94107

Department of Civil Engineering
University of Rome, "La Sapienza"
Roma, Italy

and

Parlar Education and Research Foundation
Middle East Technical University
Ankara, Turkey

Technical Report NCEER-93-0016

August 19, 1993

NOTICE

This report was prepared by the U.S. Department of the Army, Waterways Experiment Station, Corps of Engineers through a grant by the National Science Foundation. Neither the Department of the Army, the National Science Foundation, the National Center for Earthquake Engineering Research, nor any person acting on their behalf:

a. makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe upon privately owned rights; or

b. assumes any liabilities of whatsoever kind with respect to the use of, or the damage resulting from the use of, any information, apparatus, method or process disclosed in this report.

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Department of the Army, National Science Foundation, the National Center for Earthquake Engineering Research, or other sponsors.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NCEER-93-0016	2.	3. PB94-142221

4. Title and Subtitle
Reconnaissance Report of Damage to Historic Monuments in Cairo, Egypt Following the October 12, 1992 Dahshur Earthquake.

5. Report Date
August 19, 1993

6.

7. Author(s)
D. Sykora, D. Look, G. Croci, E. Karaesmen and E. Karaesmen

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Geotechnical Lab
Dept. of the Army
Waterways Experiment Station, Corps of Engrs., Vicksburg, MS.

Dept of Interior
Nat'l Park Service
San Francisco, CA.

Dept of Civil Engrng.
University of Rome,
"LaSapienza", Roma,
Italy

Parlar Education & Research Foundation
Middle East Technical University
Ankara, Turkey

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) NSF Agreement Number
(G) MSS-9300955

12. Sponsoring Organization Name and Address
National Center for Earthquake Engineering Research
State University of New York at Buffalo
Red Jacket Quadrangle
Buffalo, New York 14261

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes
This report is a result of a National Science Foundation-sponsored multi-national reconnaissance trip to Egypt to investigate damage to historic munuments following the earthquake

16. Abstract (Limit: 200 words)
On October 12, 1992, a moderate earthquake occurred near Dahshur, Egypt, about 20 km south of Cairo. The intensity of ground shaking at historic districts of Cairo was VI to VII using the Modified Mercalli scale and 212 of 560 monuments in Cairo were reportedly damaged although none destroyed. Damage to historic monuments can be generally described as having resulted from the continuous degradation of foundation and structural masonry from environmental effects, especially groundwater, inadequate lateral structural resistance, and the subsequent imposition of light to moderate earthquake forces. Other large earthquakes have affected old monuments in Cairo, but the recent earthquake may have caused a disproportionate amount of damage because of wide-spread poor structural conditions. This study provides specific examples of how monuments ranging from 80 to about 1500 years in age, in various conditions, respond to near-field motions from a moderate-magnitude earthquake and helps to define problems that research studies can solve. It also provides strong evidence that a preservation strategy be adopted for historic monuments in Cairo that embraces scientific and engineering knowledge to understand these monuments and propose the least invasive repair and retrofit procedures.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms
Earthquake Engineering. Dahshur, Egypt earthquake, October 12, 1992. Damage. Cairo, Egypt earthquake, October 12, 1992. Historic monuments. Historic preservation. Local soil conditions. Maintenance. Regional tectonics. Groundwater. Environmental deterioration.

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassifed	172
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35)

PB94-142221

Reconnaissance Report of Damage to Historic Monuments in Cairo, Egypt Following the October 12, 1992 Dahshur Earthquake

by

D. Sykora[1], D. Look[2], G. Croci[3], E. Karaesmen[4] and E. Karaesmen[5]

August 19, 1993

Technical Report NCEER-93-0016

NSF Agreement Number MSS-9300955

1 Research Civil Engineer, Department of the Army, Waterways Experiment Station, Corps of Engineers
2 Chief, Preservation Assistance Branch, Division of National Register Programs, Department of the Interior, National Park Service
3 Professor, Department of Civil Engineering, University of Rome ("La Sapienza"), Rome, Italy
4 Professor, Department of Engineering Science, Parlar Education and Research Foundation, Middle East Technical University, Ankara, Turkey
5 Professor, Department of Civil Engineering, Parlar Education and Research Foundation, Middle East Technical University, Ankara, Turkey

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
State University of New York at Buffalo
Red Jacket Quadrangle, Buffalo, NY 14261

PREFACE

The National Center for Earthquake Engineering Research is publishing this report to supplement the existing literature on the Dahshur, Egypt earthquake of October 12, 1992. The report is a result of a National Science Foundation-sponsored multi-national reconnaissance trip to Egypt to investigate damage to historic monuments following the earthquake.

NCEER contributed to other reconnaissance efforts following this earthquake by cosponsoring two trips by NCEER investigators to Egypt. Dr. M. Khater of EQE International performed an assessment of damage to structures and lifelines four days after the event (see NCEER technical report 92-0033). Dr. A. Elgamal of Rensselaer Polytechnic Institute investigated liquefaction and other geotechnical aspects following the earthquake (see NCEER technical report 93-0018).

This report complements the structural and geotechnical investigations conducted on NCEER's behalf by focusing on damage to cultural property. NCEER is pleased to have the opportunity to publish and disseminate the results of this study.

ABSTRACT

On October 12, 1992, a moderate earthquake occurred near Dahshur, Egypt, located about 20 km south of Cairo. The intensity of ground shaking at historic districts of Cairo was VI to VII using the Modified Mercalli scale and 212 of 560 monuments in Cairo were reportedly damaged although none destroyed. Nineteen days after the earthquake, a reconnaissance team began making observations at 29 select Coptic and Islamic monuments, 24 of which had incurred some of the most significant damage. The team consisted of five professionals in the fields of architecture, architectural engineering, mathematical modeling, structural engineering, and geotechnical engineering from the United States, Italy, and Turkey, who also provided expertise in the areas of earthquake engineering and the preservation of historic monuments.

Damage to historic monuments can be generally described as having resulted from the continuous degradation of foundation and structural masonry from environmental effects, especially groundwater, inadequate lateral structural resistance, and the subsequent imposition of light to moderate earthquake forces. Other large earthquakes have affected old monuments in Cairo, but the recent earthquake may have caused a disproportionate amount of damage because of wide-spread poor structural conditions.

This study has provided specific examples of how monuments ranging from 80 to about 1500 years in age, in various conditions, respond to near-field motions from a moderate-magnitude earthquake and helps to define problems that research studies can solve. It also provides strong evidence that a preservation strategy be adopted for historic monuments in Cairo that embraces scientific and engineering knowledge to understand these monuments and propose the least invasive repair and retrofit procedures.

ACKNOWLEDGEMENTS

This study was organized by the U.S. Army Engineer Waterways Experiment Station (WES) during the first quarter of FY93. The National Science Foundation (NSF), Structures, Geomechanics, and Building Systems (SGBS), sponsored the visit by the reconnaissance team; Dr. Mehmet T. Tumay was the Program Director. The Principal Investigator and team leader for this study was Mr. David W. Sykora, Earthquake Engineering and Seismology Branch, Earthquake Engineering and Geosciences Division, Geotechnical Laboratory, WES. Ms. Jennifer Smith and Mr. Daniel Habeeb, WES, assisted in preparing figures. Overall direction at WES was provided by Mary Ellen Hynes, A. G. Franklin, and William F. Marcuson III, Director, GL. At the time of publication of this report, Dr. Robert W. Whalin was the Director of WES. COL Bruce K. Howard, EN, was Commander and Deputy Director. Permission was granted by the Chief of Engineers to publish this information.

The list of those who helped to make this trip possible in a very short period of time is lengthy. The coordination and in-country clearance of our visit with Egyptian civil and military authorities by Ms. Dalia M. Talaat, Cultural Affairs Specialist, Dr. Francis B. Ward III, Cultural Attache of the U.S. Embassy in Cairo, the U.S. Information Service, and the U.S. Army Corps of Engineers, Trans-Atlantic Division and Cairo Area Office, was tremendous and is greatly appreciated.

The authors would like to extend their deep and sincere appreciation to the Egyptian authorities, especially Dr. Mohammed I. Bakr, Chairman, Egyptian Antiquities Organization, and Mr. Hazem El Abd, Chairman, Central Development Authority, Ministry of Housing and New Development, for allowing our team to broadly survey the damage and learn from the disaster. The assistance from Mr. Ali Maher Mitwally, Ministry of Development, and Mr. Mahmoot Ramadan, EAO, was very helpful.

Probably the most important contributor to the mission of the team was Mr. Tamer Kafafi, Civil Engineer, USACE Egypt Area Office. Mr. Kafafi served as escort, recorder, and interpreter for the reconnaissance team. His efficient and dedicated service provided the basis for success of the mission.

The research team is also grateful for professionals within the earthquake engineering and seismology community who offered assistance to make our trip a success. Some of the more notable contributors include members of the University of Michigan and the Earthquake Engineering Research Institute (EERI) reconnaissance teams, especially the EERI team leader, Mr. Nabih Youssef, who extended his stay in Cairo to meet us and assisted in refining and focusing our mission based on their findings.

The authors tried to ascertain with the resources immediately available the damage caused by the recent earthquake. It is possible that some damage classified as recent actually existed before the earthquake. Acquisition and analysis of more definitive historical damage was beyond the scope of this study. The authors apologize for any misinterpretations that may have been made. At many monuments, tell tails had been placed in walls and arches. It was oftentimes unclear to the team whether these tell tails were installed before or after the earthquake. Also, spellings of the monuments vary considerably among publications reviewed by the authors. In general, the spellings provided by Egyptian Friends of the Antiquities Organization (1980) were followed.

The reports of some other reconnaissance teams from the U.S. were available prior to the completion of this report. The authors of this report refrained from reading the observations and conclusions about engineering aspects of the performance and damage of monuments in Cairo in order to form an independent perspective.

Finally, we appreciate the support of the National Science Foundation in funding the reconnaissance effort and the National Center for Earthquake Engineering Research for publishing this report.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

SECTION I
INTRODUCTION

A moderate earthquake occurred near Cairo, Egypt, on October 12, 1992. About 540 people were killed, 6,500 injured, and 8,300 buildings damaged or destroyed (National Earthquake Information System). Early reports by the Egyptian Antiquities Organization (EAO) stated that significant damage had occurred among post-pharonic monuments throughout Cairo, primarily Islamic mosques. At a news conference held on November 5, 1992, the Egyptian Minister of Culture reported that the earthquake affected 212* of the 560 Islamic monuments in Cairo plus ancient Coptic churches and Jewish synagogues.

The equivalent of $30 million was pledged by the government of Egypt to repair and restore damaged mosques within days after the earthquake. The EAO also sent an international request to have experts assist them in assessing the damage and rebuilding. A number of international reconnaissance teams responded and a number of governments have since pledged monetary and technical assistance to repair damage.

1.1 Reconnaissance Efforts

The day after the earthquake, the U.S. Army Engineer Waterways Experiment Station (WES) began to plan a survey of the extent of damage to historic monuments in and around Cairo. WES received financial support by the National Science Foundation (NSF) to observe damage sustained by historic monuments to enrich the understanding of how ancient, important structures perform during earthquakes. A five-person, international, inter-disciplinary reconnaissance team (whose members are co-authors of this report) organized by WES were in Cairo during the period from October 27 to November 5, 1992. The objective was to survey Coptic and Islamic monuments with significant reported damage and some adjacent, important monuments with no reported damage.

This reconnaissance team visited 29 Islamic and Coptic (post-Pharonic) monuments in Cairo of which 24 were damaged during the earthquake. This represents a small fraction of the 212 monuments reportedly damaged. The monuments visited are listed in table 1-I with respect to the historic period. Also listed in table 1-I are subjective measures of the time

* Some discrepancies still remain; SPARE (1992) reports that 174 were damaged based on reports by Egyptian government officials.

TABLE 1-I Monuments Visited and General Conditions

Monument	EAO Mon. No.	Date	Duration of Observations	Level of Earthquake Damage	Intervention Degree of Urgency[1]
Coptic Period					
Abu Sufein Church[r.1984]	-	6^{th}c	Long	Light	Desirable
el-Moalloqa Church[r.1984]	-	6^{th}c	Moderate	Severe	Immediate
Tulunid Period (827-904)					
Ahmad Ibn Tūlūn Mosque[r.1980]	220	876-879	Short	None	N/A
Fatimid Period (969-1171)					
al-Azhar Mosque	97	972[2]	Moderate	Light	Necessary
al-Hākim Bi-Amrillāh Mosque[r.1979]	15	990-1013	Long	Light	Necessary
Bāb al-Futūh	6	1087	Short	None	Desirable
Ayyubid Period (1171-1250)					
Madrasa and Minaret of as-Sālih Negm ad-Din Ayyūb	38	1243-1250	Short	Moderate	Immediate
Bahri Mamluk Period (1250-1382)					
Mausoleum of al-Mansūr Qala'ūn	43	1284-1285	Moderate	Moderate	Immediate
Mausoleum of an-Nāsir Muhammad[r.1985]	44	1295-1304	Short	Light	Necessary
Palace of the Amir Beshtāk[r.1985]	34	1334-1339	Moderate	Moderate	Necessary
Mosque of an-Nāsir Muhammad, Citadel[r]	143	1335	Short	None	N/A
Mosque of Shaykhū	147	1349	Short	Moderate	Necessary
Khanqāh Shaykhū	152	1355	Short	Moderate	Necessary
Madrasa of Sarqhatmish	218	1356	Short	Light	Urgent
Mosque, Mausoleum, & Madrasa of Sultān Hasan	133	1356-1359	Long	Moderate	Necessary
Mosque of Ibrāhim Aghā Mustahfizān	124	1456-1544	Short	Moderate	Immediate

(continued)

TABLE 1-I (Cont'd)

Monument	EAO Mon. No.	Date	Duration of Observations	Level of Earthquake Damage	Intervention Degree of Urgency[1]
Circassian Mamluk (1382-1517)					
Mosque of Sultān Barqūq	187	1384-1386	Short	Light	Desirable
Mosque and Sabil of al-Ashraf Barsbāy	175	1425	Short	Light	Desirable
Minaret of as-Saghir Mosque	529	1426-1427	Short	Severe	Immediate
Mosque of al-Ghūri	189	1504-1505	Short	Severe	Immediate
Mosque of ad-Dashtūti	12	1506	Short	Severe	Immediate
Ottoman Turks (1517-1805)					
Bayt as-Sihaymi	339	1648-1796	Long	Severe	Urgent
Muhammad 'Ali Dynasty (1805-1848)					
Hasan Pasha Tāhir Mosque	210[3]	1809[4]	Moderate	Moderate	Necessary
Saraya el-Adl, Citadel	-	1811	Long	Severe	Urgent
Mint, Citadel	606	1812	Short	Severe	Urgent
al-Gawhara Palace, Citadel[r]	1229	1814	Long	Light	Necessary
Mosque and Madrasa of Muhammad 'Ali al-Kabir[r]	503	1848	Short	None	N/A
Post-1848					
al-Rifai Mosque	-	1869-1912	Short	None	Desirable
Coptic Museum (Old Wing)[r.1984]	-	1910	Short	Moderate	Necessary

r Recently restored and date (if known)
1 International Centre for the Study of the Preservation and the Restoration of Cultural Property (ICCROM) criteria
2 Additions in 1309-1310, 1340, 1440, 1469, and 1753
3 Facade of
4 Minaret and facade show attempt to revive earlier Mamluk style of architecture

spent at each monument, the level of earthquake damage sustained, and the perceived need for intervention which will be described later. The highest priority was given to monuments with the most severe damage and priority was also given to visit monuments from each historic period.

Activities were coordinated with the U.S. Embassy in Cairo, the Cairo Area Office of the U.S. Army Corps of Engineers (USACE), the American Research Center in Egypt (ARCE), the Egyptian Antiquities Organization (EAO), and the Egyptian Ministry of Housing and New Development. Approval was obtained for the visit from Egyptian civil and military authorities since the team was under the auspices of USACE. Several local experts and academicians were also contacted during the stay. A list of personal contacts made in Egypt is provided in Appendix A.

Observations were made with the combined perspective of historic and cultural preservation and earthquake engineering. This paradigm includes the effect of earthquake shaking and related damage on historic art and architecture. From a purely engineering perspective, the monuments performed fairly well with only a few sustaining significant structural damage in the earthquake. Likewise, many modern structures were unaffected except in cases of poor construction or inadequate design.**

The assessment of damage for historic monuments differs from that for recent, conventional construction, however. The masterpieces of artists, architects, and ancient builders can not be duplicated and ancient building materials are irreplaceable. An assessment of damage to the art and architecture of historic monuments from a cultural preservation perspective was that moderate to severe damage occurred. Certainly a number of monuments would be demolished because of their precarious state if they were not historic treasures. This report serves to document the damage from this perspective.

1.2 Activities of Other Reconnaissance Teams

At least seven other U.S.-led reconnaissance teams or individuals visited Egypt to observe damage caused by the earthquake. A listing of these teams or individuals and brief descriptions of their composition and activities are presented in table 1-II. The mission, composition, and extent of activities for the U.S teams are somewhat unique. The USGS

** Engineering News Record, pg 8, Oct. 26, 1992.

TABLE 1-II Activities of Other U.S.-Sponsored Reconnaissance Teams

Team (Reference)	Specialty Fields	Date(s)	Sponsor(s)	Mission	Post-Pharonic Monuments Visited
USGS (Thenhaus et al. 1993)	Geological Seismological Structural	Oct. 21 - Oct. 27	USGS/USAID	Earthquake characteristics, bridges	None noted
EQE Engineering (Khater 1993)	Structural	Oct. 16 - Oct. 21	NCEER/ EQE Engr.	Structures, lifelines	Seven in Garden City area
Bechtel Engineering (1992)	Structural	Oct. 26 - Nov. 12	Bechtel, Egypt	Structures, monuments	Ten; all of which seen by this team
Univ. Michigan (Wight, Hryciw, and Naaman 1992)	Structural Geotechnical	Oct. 14 - Oct. 27	UM/EAO	Post-pharonic monuments	Fourteen; 8 of which same as this team
EERI (Youssef et al. 1992)	Structural Health Care	Oct. 23 - Oct. 30	EERI	Structures, lifelines, health care	Twelve Islamic, two Coptic; many of same as this team
Elgamal (Elgamal, Amer, and Adalier 1993)	Geotechnical	Dec. 2	NSF/NCEER	Liquefaction	
Idriss	Geotechnical	Dec. 2	Personal	Liquefaction	None

team concentrated on seismology, the Earthquake Engineering Research Institute (EERI), EQE Engineering, and Bechtel teams performed broader studies of effects on structures and lifelines, Profs. Elgamal and Idriss were primarily interested in geotechnical issues. Three teams (Bechtel, University of Michigan (UM), and EQE) and this team visited a number of Islamic and Coptic monuments. Eight of the monuments visited by the UM team were also visited by this team; all ten of the post-pharonic monuments visited by the Bechtel team were also visited by this team. This team met with the team leaders of the EERI and UM teams upon arrival in Cairo to discuss findings about the distribution and severity of damage to historic monuments. Preliminary findings of this team were provided separately to Profs. Idriss and Elgamal prior to their trips later in 1992.

Many other countries, including France, Italy, Japan, and Saudi Arabia, sent representatives to observe damage in Cairo. One of the authors (Sykora) attended a news conference held on November 5, 1992, at the EAO headquarters which reported on the findings of the German Institute of Archeology (GIA) who maintain a permanent office in Cairo. The GIA has been restoring Islamic monuments in Cairo since 1973. Their teams had visited 17 sites following the earthquake (four of which were visited by this team) and a summary of their findings is presented in Appendix B.

1.3 Relevance

Sustaining infrastructure and preserving cultural heritage are important issues in civil engineering. The post-Revolutionary War monuments in the U.S. are beginning to show signs of accelerated aging and some large restoration efforts have already been required (e.g., Statue of Liberty). The long-term effects (beyond two millennia) of many of the hazards that affect monuments can be witnessed and studied in the great historic religious and cultural centers of the world and the U.S. can learn lessons to protect its national monuments for the long term.

One of the most valuable learning experiences in the evolution of engineering design and safety analyses is through the study of damage and failure. Petroski (1982) succinctly states:

> I believe that the concept of failure —mechanical and structural in the context of this discussion —is central to understanding engineering, for engineering design has as its first and foremost objective the obviation of failure. Thus the colossal disasters that do occur are ultimately failures of design, but the lessons learned from those disasters can do more to advance engineering knowledge than all the successful machines and structures in the world. Indeed, failures appear to be inevitable in the wake of prolonged

success, which encourages lower margins of safety. Failures in turn lead to greater safety margins and, hence, new periods of success. To understand what engineering is and what engineers do is to understand how failures can happen and how they can contribute more than successes to advance technology.

Precedence for lessons learned from failures or near-failures in civil engineering and architecture are numerous and include the history of design of Gothic-era cathedrals in Europe (most notably the cathedral at Beauvais, France which failed during construction in 1284), the Tacoma Narrows Bridge in 1940, the liquefaction and near-failure of the Lower San Fernando Dam in Los Angeles in 1971, and the Teton Dam failure in Idaho in 1976. Lessons learned from previous earthquakes have also lead to important findings about seismic retrofit including the topic of unreinforced masonry construction. Cases of important events from which little explicit documentation of knowledge gained include the 1509 Marmara Sea Earthquake in Anatolia during which the Church of St. John Theologos failed and the Sultan Mehmet II Mosque was severely damaged while many other churches and mosques remained unscathed (Ambraseys and Finkel 1990). However, the masterbuilder Sinan (1492-1588) may have studied the varied performance of these structures, including the magnificent Hagia Sophia, before he designed numerous monumental structures in the 16th century. Many of his projects, including major mosques in Istanbul and elsewhere in Turkey, have performed well during severe earthquakes.

The NSF has undertaken a mission to support basic research that advances technical abilities to maintain and restore infrastructure[+]. NSF has chosen a course for this mission that draws upon the behavior and performance of international historic monuments that will thereby also directly benefit the preservation of cultural heritage. As part of that mission, an international workshop was sponsored by NSF in May 1992 that is described in the next section.

1.4 NSF Preservation Workshop

An international workshop was held on May 29 to 31, 1992 in Istanbul, Turkey, to explore how recent advances in the natural sciences and engineering for evaluating the vulnerability of constructed facilities to seismic hazards and the design of remedial actions may be exploited to develop an effective preservation methodology for irreplaceable historic

[+] National Science Foundation, Civil Infrastructure Systems Research, 1992.

construction. The invited participants consisted of experts of art history, architecture, chemistry, and various disciplines of civil engineering from North America, Europe, and Turkey. About 45 people participated including all five authors of this report. Some products of the workshop include research plans from each of the disciplinary groups for formulating a procedural, analytical, and decision-making strategy for preservation of important historic construction subjected to seismic hazards, to include a pilot study to serve as a model for future preservation projects (Sykora, Hynes, and Karaesmen 1993).

The participants agreed that the importance of preserving irreplaceable major historic buildings cannot be over-emphasized. The problem requires an inter-disciplinary engineering approach incorporating state-of-the-art capabilities. The problem is of an international nature, and offers an opportunity to organize a pioneering effort and perform a pilot study that will establish a basis for evaluating and repairing a wide range of historic structures.

The most striking concept that was discussed and adopted in principal during the workshop was the prototype testing of a structure. This idea involves selecting an expendable structure in Turkey that is at least a few centuries old, such as one of many old public baths, and systematically destroying it while carefully monitoring architectural and engineering performance. Although the data can be informative, this is an expensive and destructive test. Earthquake damage to historic monuments in Cairo, a dense urban environment, provided an unexpected but timely opportunity to provide insight into the problems discussed at the Istanbul workshop. Observations of performance and damage were believed to provide valuable information and could preclude the destruction of a structure.

1.5 Overview of Report

This report documents the activities and findings of the team and is organized to first present some basic information about the geotechnical and architectural setting pertaining to post-pharonic historic monuments in Cairo. The monuments visited are then described, first collectively in terms of general condition and then in terms of earthquake damage. The need for a preservation strategy is then described and supported through the use of examples noted during observations by the team. Finally, a summary of findings is presented to specifically state the lessons learned.

This effort seeks to focus on the importance of scientific and engineering observations, investigations, and model studies of preservation alternatives and reinforces recommendations and conclusions of the Istanbul workshop. Many religious, socio-economic, and urban planning aspects of preservation in Cairo have already been addressed by others prior to the earthquake and continue to be reported. However, little attention has been paid to technical evaluations of these preservation problems.

SECTION 2
GEOGRAPHIC AND GEOTECHNICAL SETTING

2.1 Locations

Cairo was founded on the eastern banks of the Nile River at the apex of the Nile Delta in northern Egypt as shown in figure 2-1. The city lies on a flood plain of the Nile River from the Mokattam Hills on the southeast to the Pyramid Plateau on the west as shown in figure 2-2. All of the sites visited are within the limits of historic Cairo, also known as the el-Gamaliya, Bāb el-Khalq, el-Darb el-Ahmar, and el-Hilmiya Districts (the collection of these contemporary districts is also referred to as "Old Fatimid City") and the Old Cairo District. The general locations of these districts are near the base of the Mokattam Hills or close to the Nile River as shown with insets in figure 2-2. Nearly all these areas are founded on flood plain deposits that range in elevation from about 25 m MSL at eastern margin of valley to 15 m MSL near the Nile River. As recent as 14th century, the Nile River existed about 2 km east of its present position.

Maps and tables identifying the locations and age of Islamic mosques by an index have been prepared in Arabic by Egyptian Friends of Antiquity (1980). Simplified and translated versions of these maps in the areas of observation are provided as figures 2-3, 2-4, and 2-5. These maps are intended to show the relative distribution of all historic monuments within the historic districts of Cairo as well as the locations of the monuments visited by this team. The spatial distribution of the observations also serves as a rough indicator of the distribution of earthquake damage since 24 of the 29 monuments visited sustained damage.

2.2 Soil Conditions

The evaluation of geotechnical and seismological information about Cairo and the recent earthquake is important to the study of damage to historic monuments. The scope of the study included only general observations at each monument site and a preliminary review of available technical literature. Little information about the groundwater conditions in Cairo was available for this study.

Shata (1988) proposed a simplistic idealization of the geology of Cairo which lies in a Quaternary valley-rift graben as idealized in figure 2-6. The geology consists of about 300 m of alluvium overlying 4,000 m of Tertiary, Cretaceous, and pre-Cretaceous sedimentary rocks

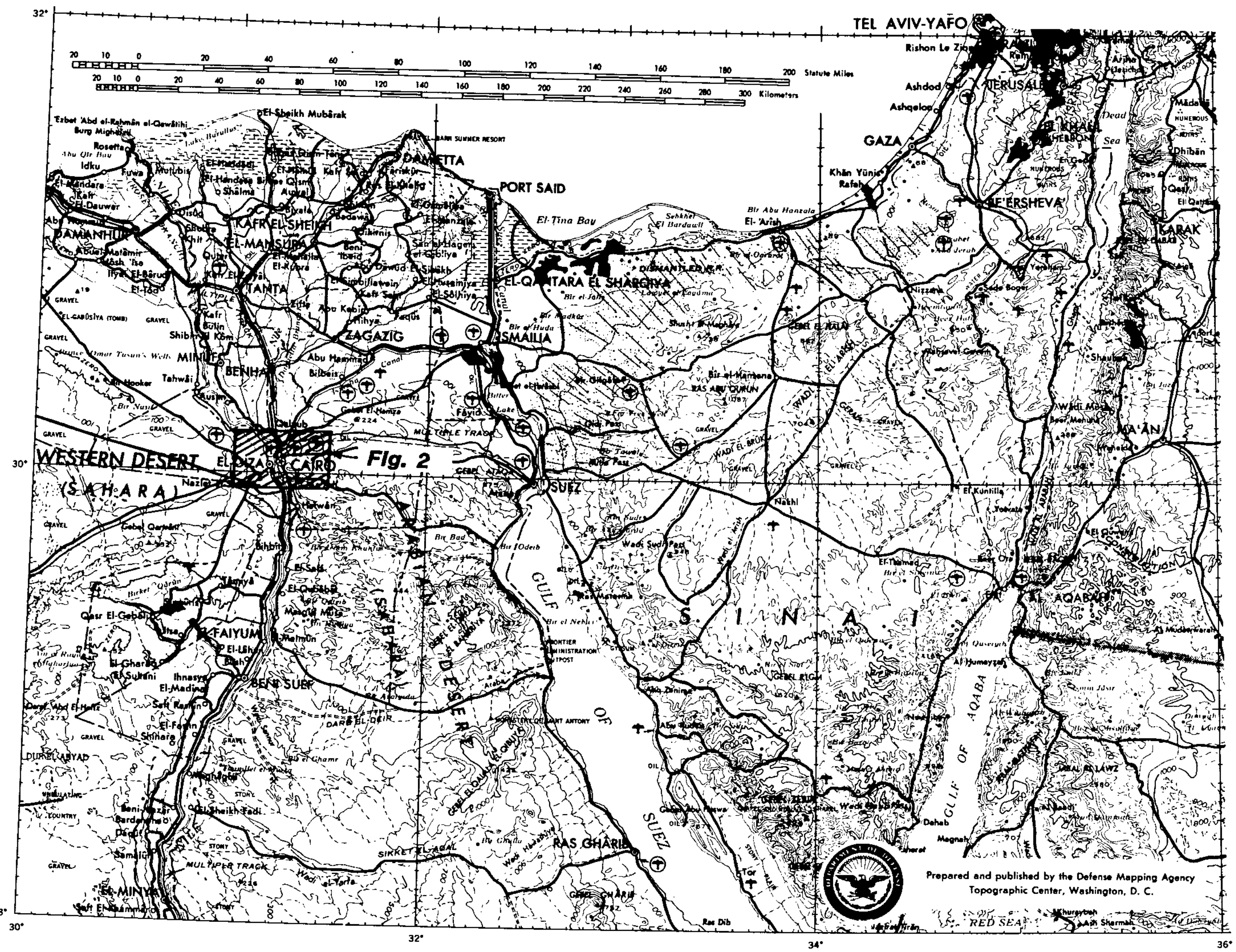


FIGURE 2-1 Map of northeastern Egypt

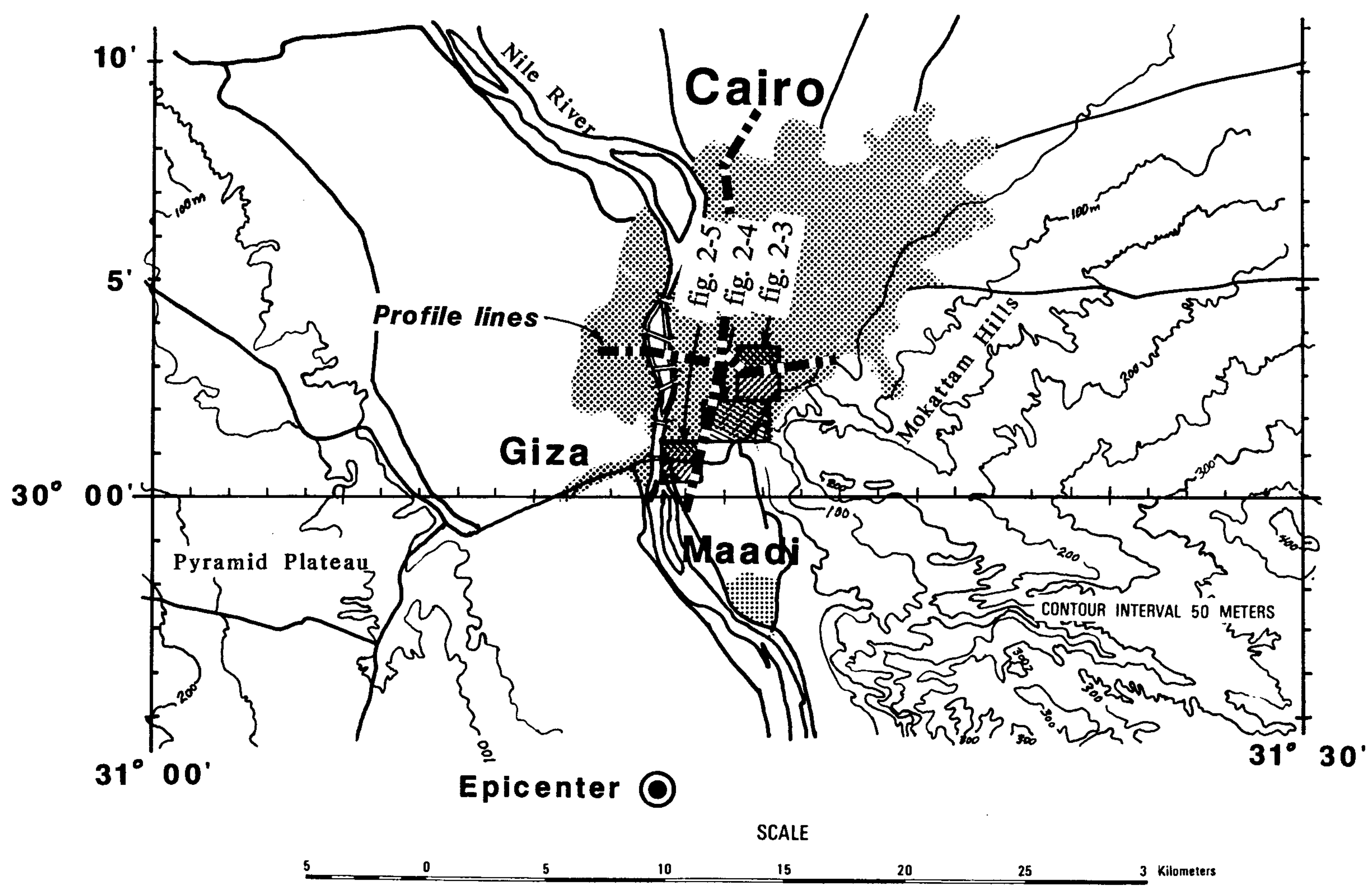


FIGURE 2-2 Map of vicinity of Cairo showing location of historic regions and epicenter of October 12, 1992 Dahshur Earthquake

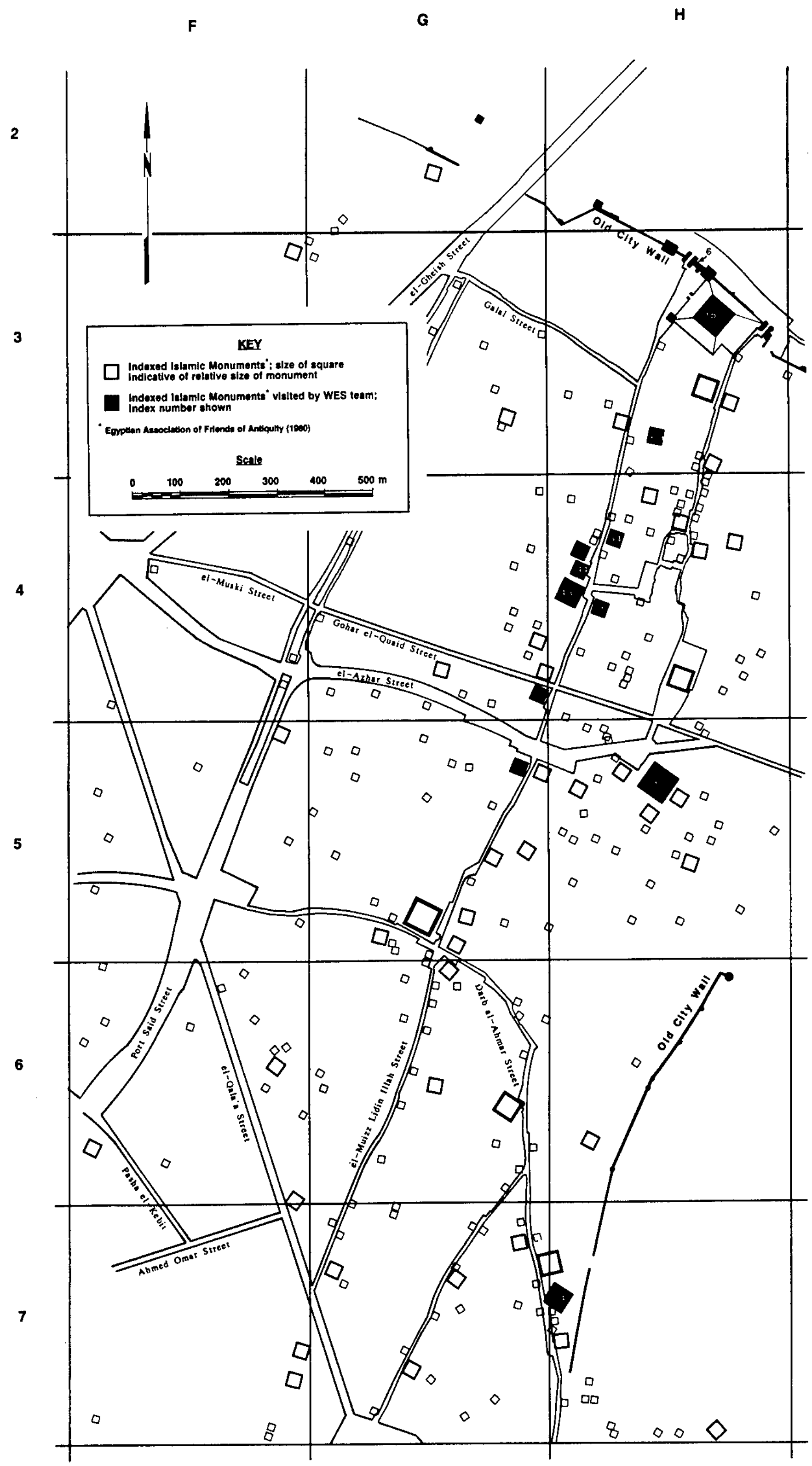


FIGURE 2-3 Map of northern portion of historic Islamic region in Cairo

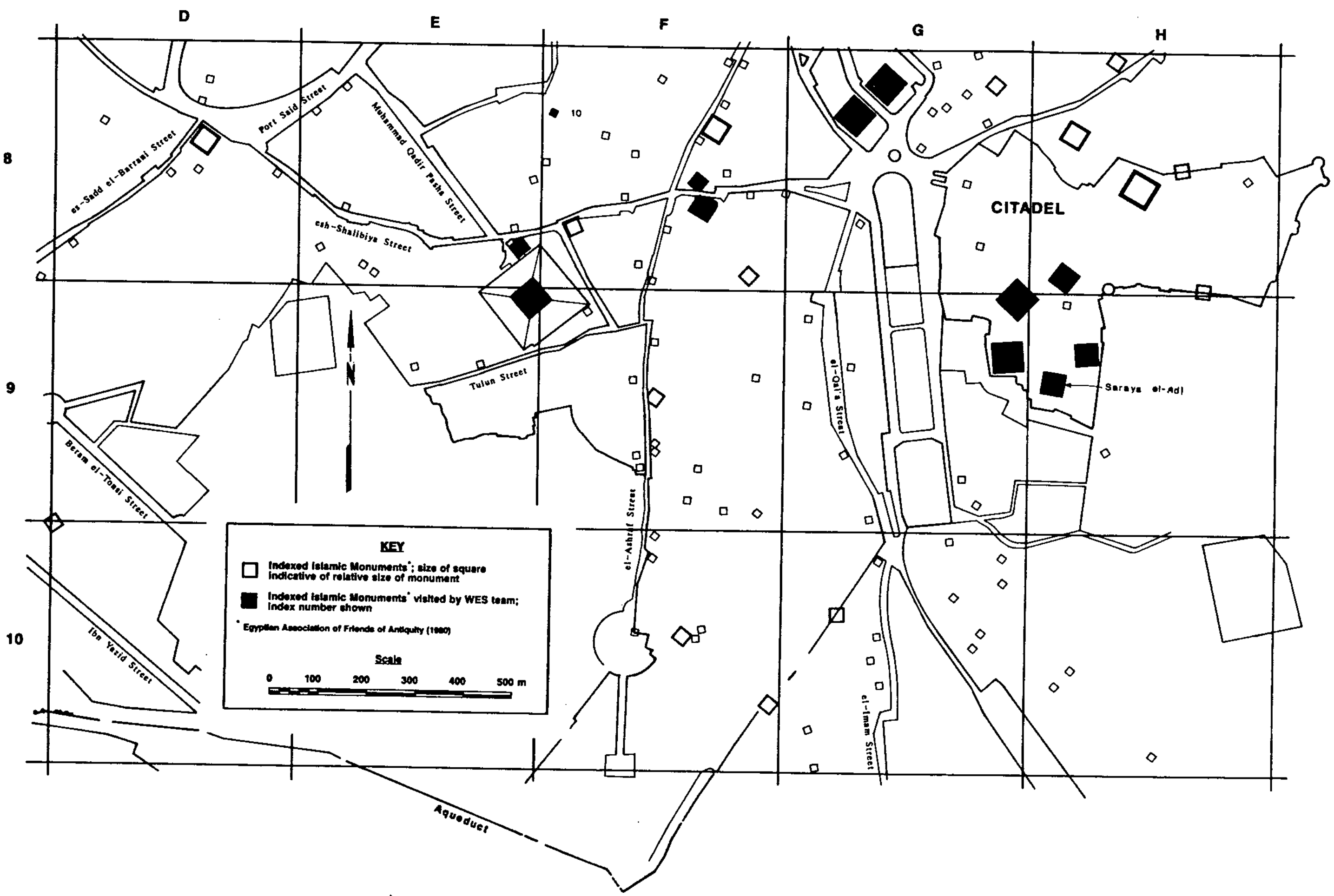


FIGURE 2-4 Map of southern portion of historic Islamic region in Cairo

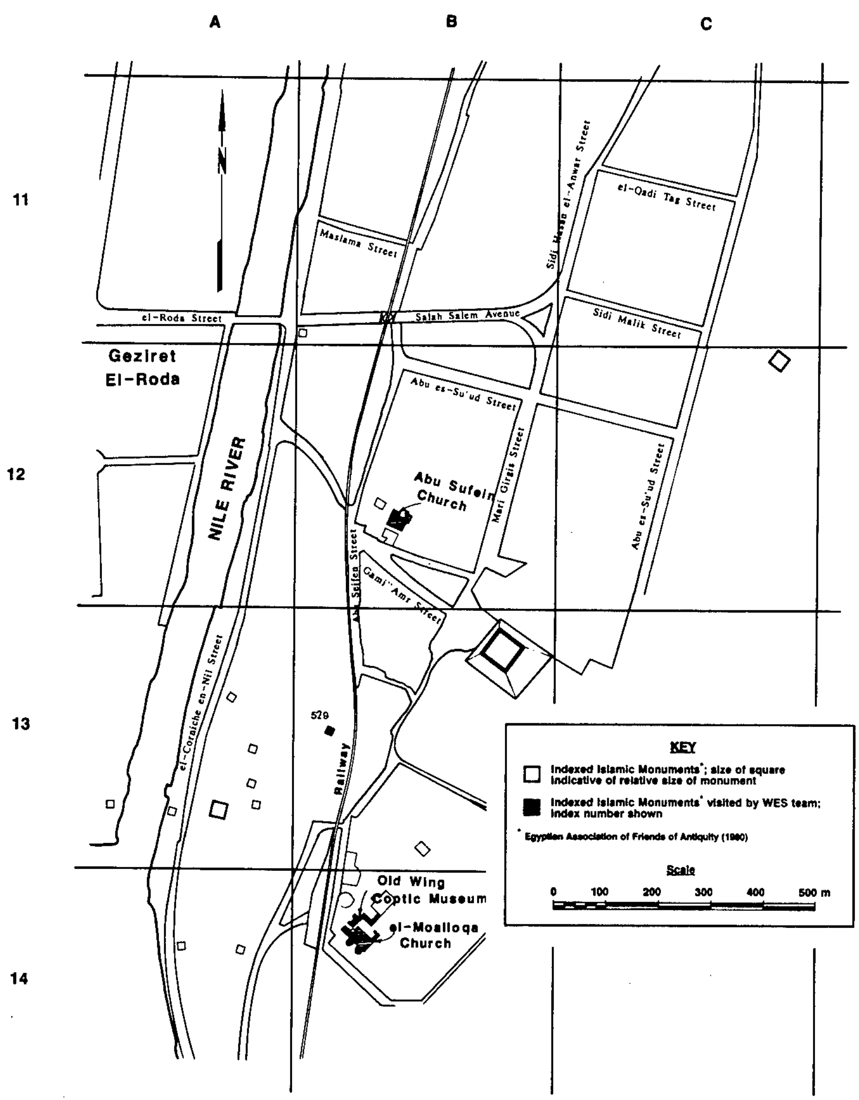
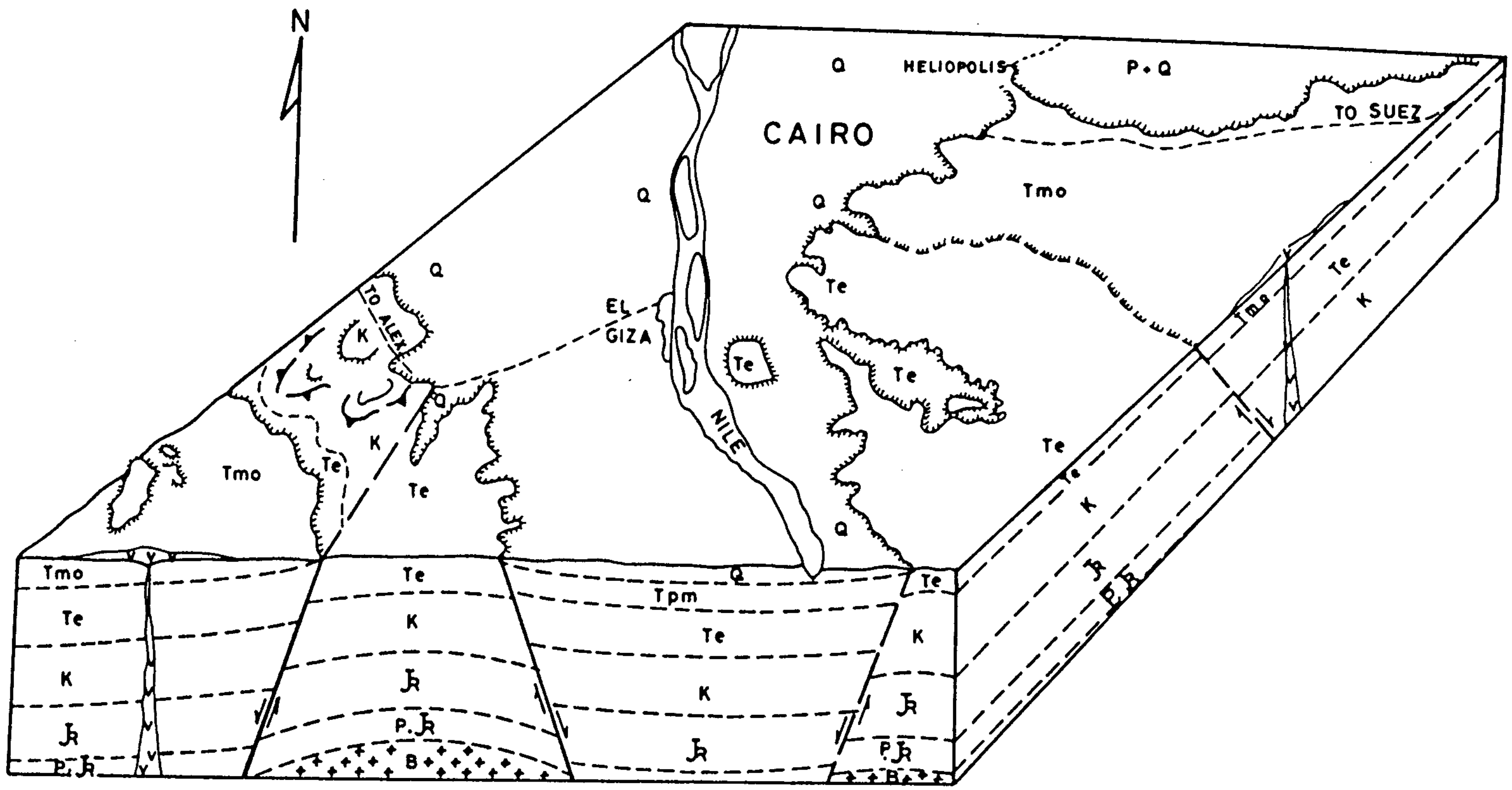


FIGURE 2-5 Map of Old Cairo and historic Coptic region



LEGEND

Q	QUATERNARY	Te	EOCENE	B	BASEMENT
P+Q	QUATERNARY + PLIOCENE	K	CRETACEOUS	V	VOLCANICS
Tpm	PLIOCENE + MIOCENE	Jr	JURASSIC	F	FAULT
Tmo	OLIGO- MIOCENE	P.Jr	PRE-JURASSIC		

FIGURE 2-6 Geologic block diagram in vicinity of Cairo (Shata 1988)

over a pre-Cambrian basement complex. Alluvial plains are the predominant geomorphic feature in the older sections of Cairo where the study was conducted.

A generalized alluvial soil profile representing general conditions beneath most of the monuments consists of fill overlying silty clay with thick sand and gravel layers beneath. A Pleistocene-age plastic clay unit is believed to underly the entire alluvial valley (Said 1975). This unit outcrops on the eastern margin of the valley. General cross sections of alluvial soils are shown in figures 2-7 and 2-8 corresponding to plan locations shown in figure 2-2. General descriptions of soil comprising the alluvium are described below.

2.2.1 Fill

Substantial amounts of fill and rubbish are known to exist throughout the Cairo area. Hefny (1982) has published a map of the variation in thickness of fill and rubbish in Cairo and proposes that this material may extend as deep as 20 m. Work by Said (1975) shows that large rubbish heaps were founded on the southeastern edge of the city on either side of the Citadel. Canals, remnant river channels, and ponds that are found on maps from the 14th century have also been filled. Apparently there is no record of placement of these materials.

2.2.2 Holocene Silt and Clay

The upper portion of the natural alluvium are flood plain deposits consisting primarily of silt and clay with an average thickness of about 10 m. The rate of sedimentation was estimated by Said (1975) to be about 10 cm/century before the Aswan High Dam was completed.

2.2.3 Pleistocene Sand and Gravel

Two separate alluvial units have been identified beneath the fine-grained surficial soils, both of which are of Pleistocene age. The upper 6 to 16 m are termed the Abassia Gravels which are well rounded and well sorted. Beneath this unit is the coarse massive sand and gravel unit which varies in thickness up to 70 m in the Cairo area (Said 1975). Hefny (1982) reports that the depth to uppermost sand layer ranges from about 4 to 20 m in Cairo.

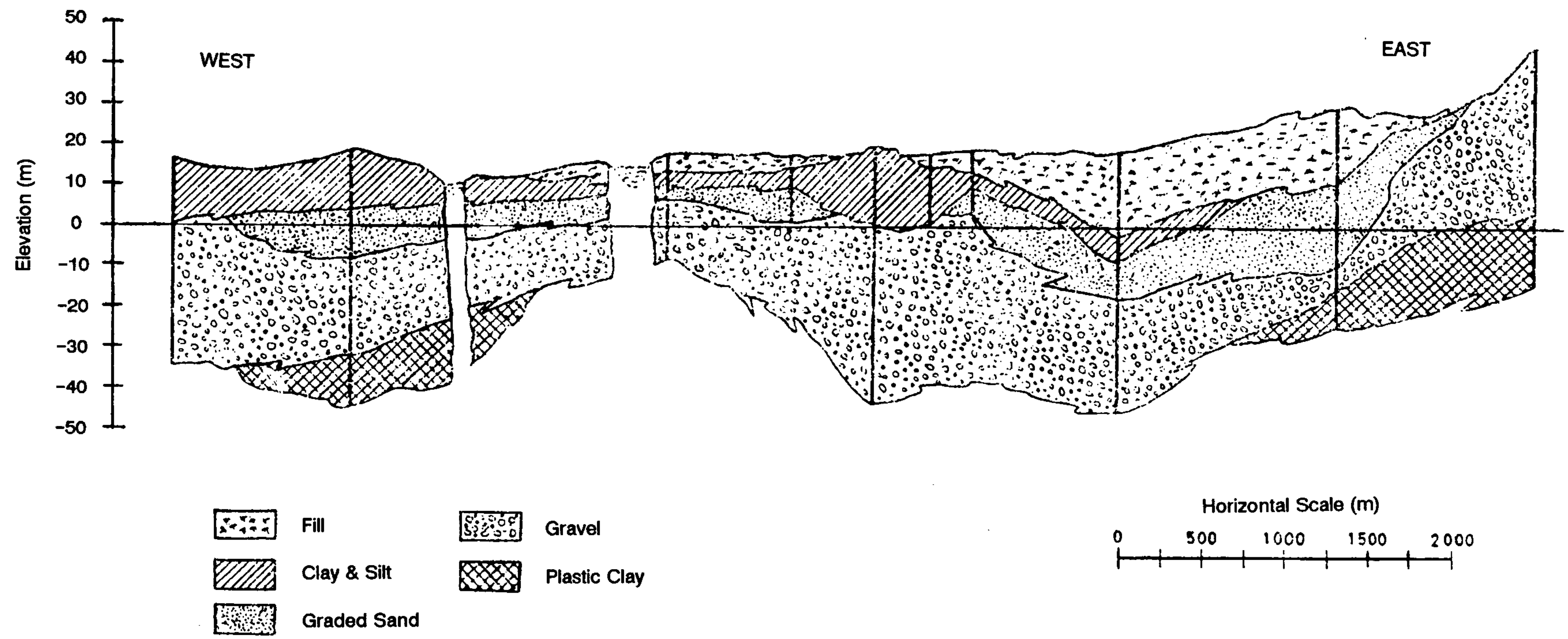


FIGURE 2-7 General cross section of sub-surface materials in east-west direction through Cairo (Said 1975)

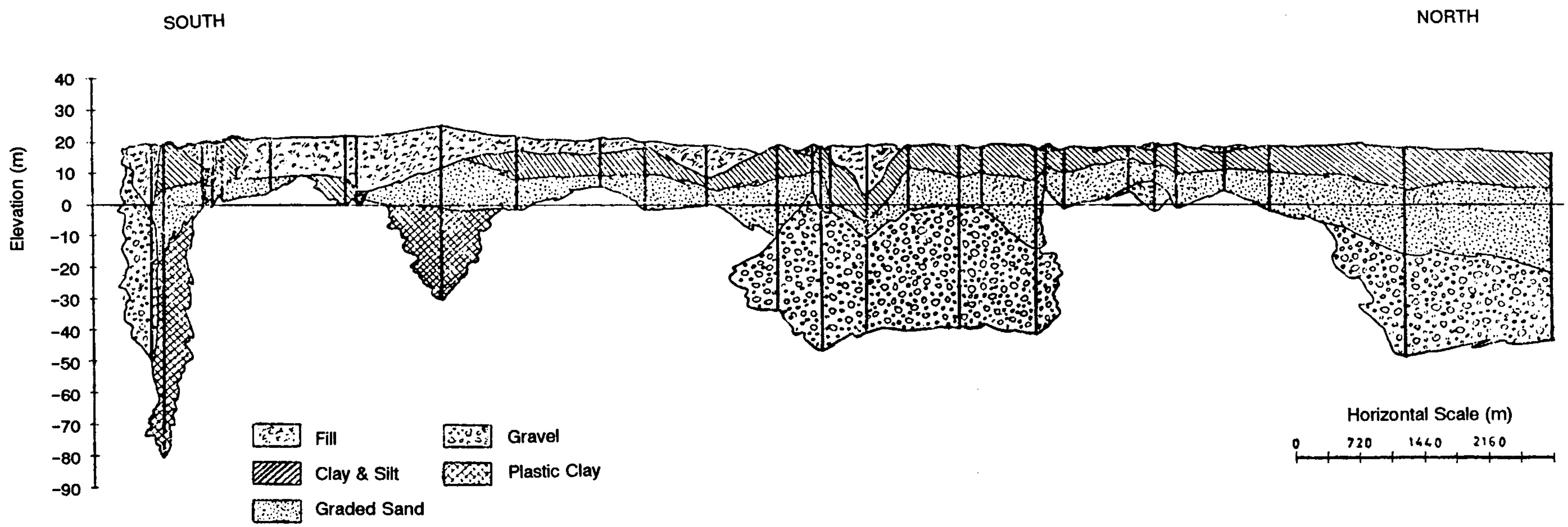


FIGURE 2-8 General cross section of sub-surface materials in north-south direction through Cairo (Said 1975)

2.2.4 Lower Plastic Clay

A Pliocene-age unit of plastic clay exists at depths up to 120 m but also outcrops on the eastern edge of the valley. In most areas of interest for this study, this unit is 20 to 40 m thick.

2.2.5 Range of Site Conditions

Nearly all of the sites visited lie on alluvial flood plains within the limits of Cairo. The exceptions are five monuments at the Citadel located at the base of the Mokattam Hills. The conditions at the base of the Mokattam Hills, practically speaking at elevations of about 50 m or greater, are likely to be scattered pockets of fill overlying hard rock.

The conditions at sites on the flood plain are likely to range from moderate to deep soil sites. The overall thickness of soil overlying rock is the thinnest at sites close to the Mokattam Hills and deepens rapidly as the distance from the hills increases. The thickness of fill and rubble ranges from 0 to 10 m. The range in thickness of Holocene-age fine-grained deposits is 0 to 12 m, and the range in depths to granular alluvium is about 6 to 10 m. Plastic clay is close to the surface on the eastern margin of the valley.

The general soil conditions, prevalence of fill and piles of rubble, and shallow depths to groundwater in Cairo suggest that a significant amount of foundation problems are likely to exist. There is no evidence that fill and rubbish were pre-loaded or compacted prior to construction of medieval structures. Plastic clays may exist at shallow depths and could shrink and swell in volume if the groundwater begins to fluctuate significantly. Groundwater is discussed next.

2.3 Groundwater and Pipeline Leakage

Surveys for the Greater Cairo Wastewater Project indicate that a dramatic rise in groundwater levels has occurred, even since 1965. This rise is believed to be caused by an increasing population and failing, outdated water supply and sewerage systems built near the turn of this century. Free-standing water was observed in open ditches at depths of less than a meter at a few sites. The water supply network is estimated to leak 30 liters per capita per day (SPARE 1984b). Breaks in water mains are evident on any given day in Cairo and several were observed by the team.

Some site-specific studies have been conducted at large project sites in and around Cairo, but not in the historic districts. Shata (1988) presented some groundwater elevation contours using well data throughout Cairo but accurate ground elevations at the monuments were not available to determine depth to groundwater. Antoniou (1980) reported that a long-term research project addressing the behavior of groundwater had been initiated and sponsored by the Ministry of Irrigation and the Academy of Scientific Research. The outcome or status of this effort is unknown.

2.4 Seismic History

Northern Egypt is seismically active with two seismic belts—the Nile Delta N-S trend and the Pelusium NE-SW trend—intersecting just north of Cairo (Said 1981). Inhabitants of northern Egypt have documented earthquakes for over 4,000 years; the first recorded earthquake occurred around 2200 B.C. (Kebeasy and Maamoun 1981). A general listing of events producing a Modified Mercalli site intensity greater than or equal to VI in the Cairo area are presented in table 2-I. The history of felt earthquake motions at Cairo suggests that moderate levels of motion occur rather infrequently.

2.5 Earthquake of October 12, 1992

On October 12, 1992, a magnitude M_b=5.9 earthquake occurred near Dahshur, Egypt, at 3:10 pm local time as reported by the U.S. Geological Survey, National Earthquake Information Center. The earthquake was felt throughout much of Egypt, as far south as Aswan, Egypt, (670 km) and as far northeast as Tel Aviv, Israel (410 km). The location of the epicenter is shown in figure 2-1 and basic characteristics of the earthquake are presented in table 2-II. The distance from the epicenter to the historic Coptic and Islamic districts ranges from 13 to 30 km. An iso-seismal map of the damage compiled by Thenhaus et al. (1993) is shown in figure 2-9. The historic districts experienced ground shaking with a Modified Mercalli Intensity of VI or VII. There are no known strong motion recordings of the event.

2.6 Liquefaction

Surface manifestations of liquefaction—sand boils, depressions, and lateral spreading near a canal—were not found in close proximity to any of the monuments. However, several manifestations of liquefaction were evident south of Cairo along the Nile River within the

TABLE 2-I Earthquakes Causing Intensity VI or Greater in Cairo (modified from Kebeasy and Maamoun 1981)

Date	Location	Intensity: Epicentral	Intensity: Cairo	EQ Mag.[1]	Remarks
5/26/1111	East Cairo	VII	VII		
8/8/1303	Fayum	VIII	VI		Many places in Cairo destroyed
9/1754	Tanta	VIII	VII		Two-thirds of Cairo bldgs. damaged; 40,000 fatalities
8/7/1847	Fayum	VIII	VI		3000 houses and 42 mosques destroyed; 85 fatalities
6/24/1870	East of Medit.	VIII	VI		
10/1/1920	N29.4° E31.0°	VII	V-VI	5.8	
7/24/1954	N31.5° E30.0°	VII	V-VI	5.7	
9/12/1955	N32.2° E29.6°	IX	VI	6.8	

[1] Helwan Observatory, Egypt, magnitude scale

TABLE 2-II Summary of October 12, 1992 Dahshur Earthquake

Characteristic	Value
Location	29.89° N 31.22° E
Depth	25 km
Magnitude	$M_S=5.2$ $m_b=5.9$ $M_o=8 \times 10^{17}$ N-m

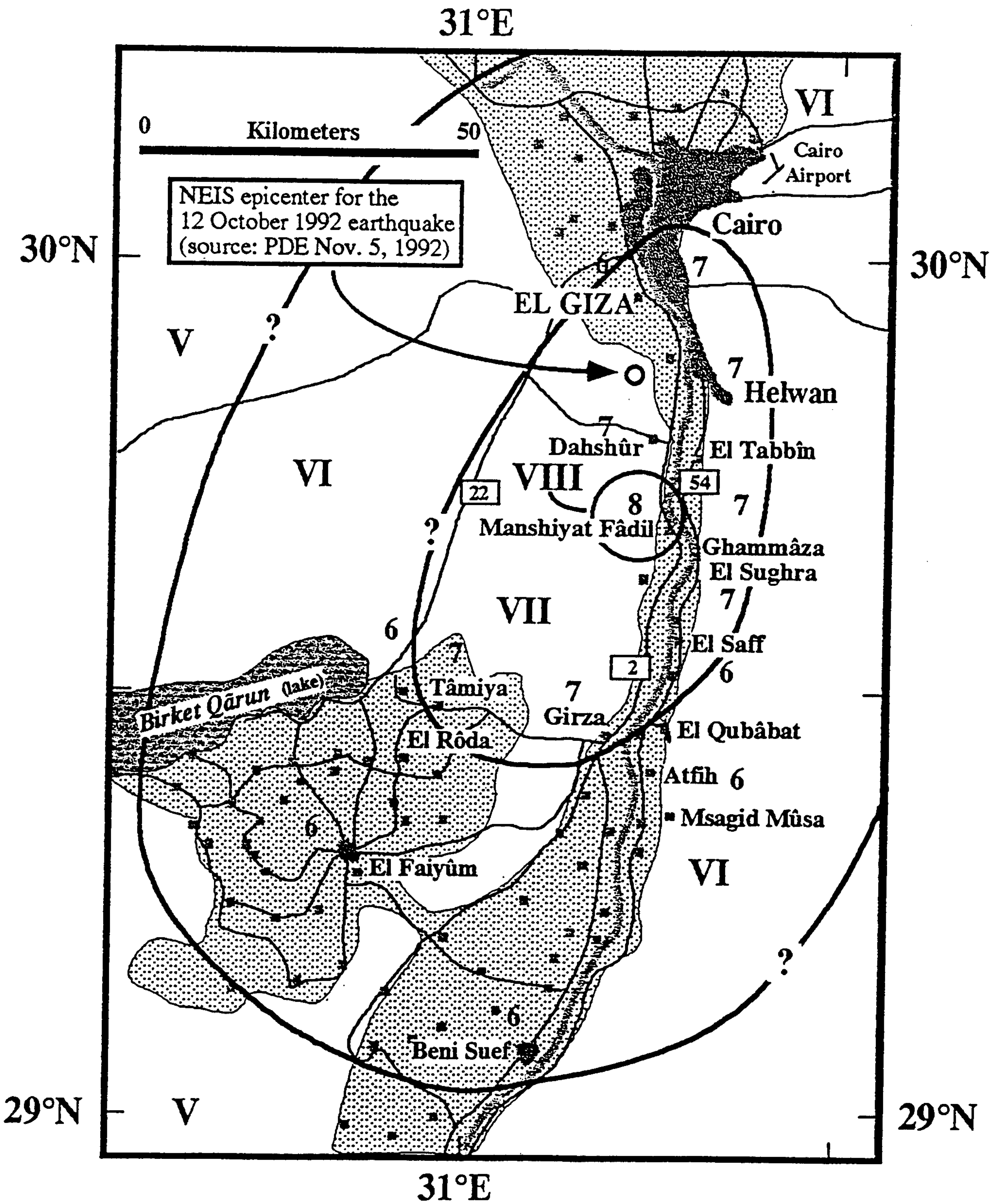


FIGURE 2-9 Iso-seismal map for October 12, 1992 Dahshur Earthquake (Thenhaus et al. 1993)

area defined by a seismic intensity of VIII (refer to figure 2-9). These manifestations included sand boils, earthquake-induced settlements of saturated soils, and lateral spreading and were documented shortly after the earthquake by Prof. Mohamed Amer at Cairo University (Elgamal, Amer, and Adalier 1993). An example of a remnant depression from a sand boil is shown in figure 2-10.

FIGURE 2-10 Remnant craters from sand boils 20 km south of Cairo (courtesy of Ahmed Elgamal, Rensselaer Polytechnic Institute)

SECTION 3
COPTIC AND ISLAMIC ARCHITECTURE IN CAIRO

Cairo is one of the principal world centers of historic monuments and buildings. The range of cultural heritage varies from such antique monuments like the pyramids to the early 19th century masterwork—the Muhammad 'Ali Mosque. The World Heritage Convention listed Cairo on the World Heritage List in 1979. UNESCO listed Cairo as one of the "Cities of Human Heritage." Residents of Cairo and Egypt derive a great deal of pride from this heritage and recognition. A great deal of responsibility is also inherent with this rich tradition. The multi-ethnic heritage of Cairo is reflected in the diversity of terms used to describe architectural features. Arabic, Turkish, and Persian terms used are shown in italics and a glossary of these and other architectural terms is provided in Appendix C.

The architecture of historic churches, mosques, and buildings in Cairo was studied to understand the evolution in design, materials usage, and construction. The architectural styles of monuments may have a significant effect on earthquake resistance. Styles from different periods are likely to reflect the knowledge and experience of masterbuilders from other regions of the world. For instance, structures built during Ottoman Turkish rule may have structural features that are earthquake resistant reflecting common designs developed by master builders such as Sinan for earthquake-prone Istanbul. Much of the information on Coptic churches was obtained from Kamil (1990) and on Islamic mosques and monuments from Behrens-Abouseif (1989) and Hoag (1975).

3.1 Coptic Period

The word "Coptic" refers to Orthodox Egyptian Christianity that likely originated in the first century A.D. This religion was aligned with the Holy See in Rome, and later, with Constantinople (Istanbul), until the 4th century. Not surprisingly, the Coptic architecture of Cairo evolved from early Christian basilican architecture and was influenced by Byzantine architecture. Early Coptic Churches were plain and simple on the exterior and richly decorated on the interior. The structures generally consist of an oblong brick building with side aisles divided by Greek or Roman columns and covered with domed roofs (this "Byzantine" style actually originated in the east but was adopted by the Byzantines) or Roman style wagon-vaulting (this is the only Christian architecture with this type of roofing except in Ireland).

The early churches had an east-west primary orientation, with triple-door entrance at the west and an altar in the east. Coptic churches tend to be monapsal (i.e., the apse is internal and the outer wall straight) rather than triapsal. Niches and chapels vary from church to church and have often been a later addition. A second story was added to the aisles in order to accommodate women worshippers. The walls of the nave were supported on columns with continuous wooden architraves and small relieving arches which developed into arches and piers. There was a cross row of columns at the west which subsequently became walled up creating the "narthex," an area of the church in which baptisms, confirmations, and admonitions took place.

The sanctuary is separated from the church by a raised platform with a railing and wooden screen, usually ebony with inlaid ivory. The sanctuary consists of three chapels in domed apses, or *haikals*. The center chapel is the high altar dedicated to the saint after whom the church is named. The side chapels are usually dedicated to other saints. The high altar usually has a domed wooden canopy over the altar and a bishop's throne and seats for other clergy on circular steps in the apse.

After Islamic domination, the Coptic churches developed their architectural form internally, rather than externally, to avoid confrontation. This development also corresponds to the general growth of the city as the churches were no longer free-standing but were both fortified and build onto. The orientation was not necessarily east-west anymore, but rather, depended on the street orientation (this is also the case with mosques as will be discussed in the next section).

3.2 Islamic Period

The Islamic Period is very rich and varied with many influences reflecting the many layers of civilization. The history of Islamic architecture in Cairo began with the Arab conquest in 639 A.D. and the establishment of the City of Fustat in 641. Five primary periods are generally used to describe the ruling society and religious customs beginning in 827 and continuing until 1848:

1. Abbasid or Tulunid (827 to 904)
2. Fatimid (969 to 1171)
3. Ayyubid (1171 to 1250)
4. Mamluk (1250 to 1517)
5. Ottoman Turk (1517 to 1848)

The Mamluk Period is further separated into the Bahri Mamluk (1250 to 1382) and the Circassian Mamluk (1382 to 1517) periods and the Ottoman Turk period is further split by the Muhammad 'Ali Period beginning in 1805. Of the 29 monuments visited, nine were of the Bahri Mamluk Period; two-thirds of the mosques visited were constructed during three of the periods (Bahri Mamluk, Circassian Mamluk, and Muhammad 'Ali). Only one monument from each of the Tulunid, Ayyubid, and Ottoman Turk Periods are represented.

3.2.1 Tulunid Period

The Islamic architecture of this period was influenced by the architecture of the imperial capitals of Damascus, Baghdad, and Samarra. The Mosque of Ahmad Ibn Tūlūn has a Samarran style, the only surviving example in Cairo. This monument is a very large congregational (or Friday) mosque with a large *sahn*. It is a flat-roofed hypostyle mosque constructed of well-fired red brick covered with stucco and fine decorative plaster (Hoag 1975). The interior central court is surrounded by a *riwaq* on piers. The arches are pointed with slight horse-shoe shape. The decorative plaster is mainly on the face and soffit of the voussoirs. Each pier has an engaged column at each corner. It has three *ziyadahs* making the overall complex almost a perfect square. The outer walls of the *ziyadah* have a *pishtaq* (Hoag 1975).

3.2.2 Fatimid Period

During the Fatimid Period, Cairo became the seat of the Fatimid Caliphate which raised its status from a provincial city to an imperial capital. The Fatimids were Egypt's only Shiite dynasty. The indigenous Cairene architectural style was forged during this period as Fatimids typically built a large number of mosques and shrines as well as walls and gates. The use of stone rather than brick is also landmark for this period. Coptic, Byzantine, and Samarran elements were integrated in the architecture and art of the Fatimid period (Behrens-Abouseif 1989). It was during this period that mosques were aligned with the street while the *qibla* wall with its *mihrab* remained oriented toward Mecca (azimuth of about 135 degrees at Cairo). This positioning required the architect-engineer to use great ingenuity resulting in some very interesting floor plans.

The mosques of the Fatimid period retained the hypostyle plan, with column-supported arcades surrounding a courtyard (Behrens-Abouseif 1989). It was during this period that the keel arch was introduced supported by columns with Corinthian capitals frequently borrowed from earlier monuments. An Islamic bell-shaped design was also used as a capital and inverted as a base. These were used for the raised platform in front of the minbar and mihrab at the Mosque of Ibn Tulun. In Fatimid mosques the prayer niche is enhanced by a dome above it or a transept as seen at al-Azhar and al-Hakim mosques, or by a widening of the aisle adjacent to the *qibla* wall, as at al-Aqmar mosque, or the aisle perpendicular to it as at al-Salih Talai mosque (Behrens-Abouseif 1989).

The street facades were embellished for the first time with architectural details, windows, and shop fronts in the lower level below the mosque. Stone, wood, and stucco (plaster) were carved in geometric, floral, and arabesque patterns influenced by Samarran and Byzantine designs and frequently incorporated ornate *kufic* inscriptions. Glass and stucco window grills in floral and geometric designs and niches with keel arches and radiating fluted hoods were introduced. Horizontal inscription bands continued during later periods, but arched inscription bands are unique to the Fatimid Period. The design of the minarets also evolved during the Fatimid period. Most minarets had a square base and shaft surmounted by a domed octagonal tower with arched openings and balcony sometimes referred to as *mabkhara*, or incense burner (Behrens-Abouseif 1989).

3.2.3 Ayyubid Period

The Ayyubids were the dynasty of Salah al-Din, the chivalrous opponent of the Crusaders, who reconquered Jerusalem, saved Cairo, and became sultan in 1186 (SPARE 1979b). The Sunni sect of the Islamic faith was re-established during this period. Since the Sunnis did not allow more than one large Friday or congregation mosque, no new large mosques were constructed. Instead they built *madrasas* to teach theology and law and *khanqāhs*, usually for the *Sufi* order of *dervishes*. The Ayyubids extended the city walls in 1169 to enclose the whole city (refer to figure 2-3) and the Citadel was built on the Mokattam Hill in 1183 to connect and reinforce the city walls against the crusaders. The walls have both circular and rectangular towers and a circumference of about 1,700 m.

The Shiite sect had previously established a university, al-Azhar, during the Fatimid Period. The Sunnis used the many madrasas to re-establish their faith. The ruling class founded the madrasas in palaces, houses, and mosques combining religious and domestic architecture (Behrens-Abouseif 1989). Often the irregular "left-over" spaces around a mosque were filled with class rooms, reception halls, libraries, dormitories, kitchens, baths, and even stables.

The *liwan* was a domestic element adopted to the construction of mosques, *madrasas*, and *khanqāhs*. Some had two liwans facing each other across an open courtyard with living quarters on the other sides (Behrens-Abouseif 1989). The *mabkhara*-type minaret was developed further with the addition of stalactites and increases in height making them appear more slender than earlier minarets.

3.2.4 Bahri Mamluk Period

The Mamluks were military slaves, many of whom were Turkish. In 1250, the Bahri (river) Mamluks overthrew the Ayyubid dynasty. Continuing the tradition of previous sultans, the sultans of this period resided in the palace complex at the Citadel. The area west of the Citadel grew into an upper class residential area with mosques, mansions, palaces, and markets for the ruling class and military.

The most dynamic evolution of architectural design occurred during this period, especially in the late 13th and early 14th centuries. The style of Bahrite Mamluk architecture is derived mainly from that of the Fatimid and Ayyubid but showed more variation as it evolved. The Mamlukes increased the number of Friday or congregational mosques. Starting with the rule of Sultān Hasan, madrasas and *khanqāhs* were also used as Friday mosques. The cruciform plan of four unequal *liwans* was developed during this period. Living quarters usually occupied the corners between the *liwans*. The central courtyard was not roofed or domed. Although hypostyle mosques continued to be constructed during the Bahri Mamluk period, they were generally smaller, not free standing, with main entrances usually not on axis because of the smaller, irregular lots (Behrens-Abouseif 1989). The size and constraints imposed by existing buildings meant that it was no longer possible to build free-standing mosques and the liwan style of mosque became common. Mecca orientation clashed with the street plan and the available building space and in some cases had to be abandoned.

Funerary architecture became more important during this period and the domes that were often used to cover mausoleums went through several changes. Mausoleums were frequently added to mosques, preferably on the Mecca side and accessible from the street. They were usually highly ornate reflecting the great wealth of the deceased and had large windows with iron grills so that people could hear the Quran being read. The panel-and-recess pattern became standardized on the Bahri Mamluk facades. Entrances were given a variety of treatments but the rectangular portal with stalactites became the more preferred treatment.

The design of minarets continued to evolve, generally becoming more slender during this period. Earthquake-resistant design may also have been incorporated by the Turks. The octagonal section increased in proportion to the square base. The *mabkhara* top was discontinued by the last half of the 14th century in favor a pavilion of eight columns, carrying above a "crown of stalactites and a pear-shaped bulb" (Behrens-Abouseif 1989). Eventually, the octagonal shape of the minaret was continued to the first story.

Domes had two predominate shapes: low domes and those raised on a cylindrical drum, frequently with a ribbed surface. The interior of domes were treated in one of two ways based upon the transitional area between the square base and the round dome. The earlier domes usually had tiers of squinches alternating with tiers of windows and niches with the squinches, windows, and niches all having a consistent shape. Later, pendentives were used, first in wood and later in stone. There are also some examples of stone squinches (Behrens-Abouseif 1989). By increasing the height of the transitional area high domes were constructed. Domes constructed of stone first appear during the Bahri Mamluk Period although initially they were plastered over to hide the joints as was done with brick domes.

3.2.5 Circassian Mamluk Period

In 1382, a Circassian group in the Mamluk army overthrew the last Bahri sultan and founded a second Mamluk dynasty (SPARE 1990a). The Circassian Mamluks, similar to the earlier Bahri Mamluks, built mosques and *madrasas* which fulfilled most of the educational and charitable functions of society. By the 15th century, Cairo was so densely developed that Circassian Mamluk monuments were usually constructed on the small, and often irregular, remaining pieces of vacant land (SPARE 1990a).

3.2.6 Ottoman Turk Period

Cairo fell to the Ottoman Turks in 1517 and its status was lowered to that of a provincial capital. Around 100 religious establishments called *sabil-kuttabs* were built using three basic styles: Ottoman, a hybrid style, and Mamluk style with Ottoman mosques. These are free-standing buildings with loggie and curved facades. There is Turkish influence in the decoration of these buildings although local craftsmen sometimes lacked the skills required to interpret this style.

A new form of *khanaqah*, a *takiyyah*, developed in which a courtyard was surrounded by cells separate from the mosque. Because *pashas* were not necessarily based in the city permanently, they did not erect mausolea and the funerary dome died out during their rule. This shift corresponds with the reappearance of mosque domes. These mosque domes are somewhat more round and flatter as they do not have the transitional zone used to increase the height.

Under Muhammad Ali, Turkish mosque architecture was introduced. The flat, round domes and slender minarets of the mosque of Muhammad Ali are reminiscent of the work of the great 16th-century Turkish architect Sinan and is totally alien in style to Egypt. The mausolea reappear with onion-shaped domes.

3.2.7 Structural Resistance

Unreinforced masonry is predominant in Islamic monuments. Brick and plaster was commonly used during the early periods (pre-Fatimid Period) for interior and exterior walls. During the Fatimid Period, limestone block masonry became common for exterior and interior walls of large and important monuments although brick and mortar was commonly used for interior walls of *bayts, madrasas, and māristans.* Unreinforced masonry, including stone masonry, is the prime culprit for structural damage to buildings during earthquakes (e.g., Wyllie and Lew 1989).

Beyond this obvious problem, Islamic architecture typically has inefficient connections. These problems may be amplified as the size of the building increases. Also, the presence of large domes and arches creates thrust that is not always resisted by the masonry connections or the wooden tie beams. The unusual shape in floor plans for later monuments generally makes the analysis of dynamic response more difficult.

Structural elements of particular interest are domes and minarets. A dome is an unusual structural component: it reflects an enigmatic spatial effect and is recognized to bring a solemn character to the building to which it is associated. Historic domed structures are constructed from mortared brick and/or stone, materials long used and understood by mankind. Construction of major domes with these common building materials was attempted much later, however, because of the difficulty in controlling three-dimensional thrust action under gravity and seismic loads. Minarets in Cairo vary considerably in design, height, and slenderness. When combined with poor masonry or inadequate foundations and the imposition of earthquake forces, local cracks and global out-of-plumb can lead to serious flexural and compressive stresses.

SECTION 4
OBSERVATIONS

The objective of the team was to quickly determine the extent and types of damage sustained by each monument through observations by each team member and translated personal accounts of the full-time monument attendants. This determination strongly depended on the evaluation of pre-earthquake conditions which was also assessed based on accounts by the attendant. Additional resources are available, such as documentation of recent restoration efforts, but analysis of that data was beyond the scope of this study. Because the assessments were rapid and pre-earthquake conditions were not directly observed by this team, it is possible that some damage classified as recent actually existed before the earthquake.

Once an initial assessment of the monument was complete, the team decided if a more thorough examination would be fruitful. Records of damage were made through personal notes, voice recordings, and photographs. A brief log of daily activities is provided in Appendix D.

4.1 Conditions Prior to 1992 Earthquake

The post-pharonic monuments visited, as a whole, are in poor condition and are not adequately protected against societal or natural hazards. Of the 600 monuments indexed by the Egyptian Friends of Antiquities (1980) near the turn of the 20th century, only 400 remained in 1979 (SPARE 1979b). In 1981, the EAO estimated that 90 percent of the remaining monuments were either on the verge of collapse, in bad condition, or in need of total restoration (SPARE 1981). Antoniou et al. (1980) report that the monuments were well maintained until the early 1950s and that "the rising water table and lack of maintenance have led to rapid deterioration of masonry and wooden ceilings." The poor condition of the monuments is reflected by the periodic collapse of monuments (without perceptible earthquake shaking). A recent example includes the minaret at the Mosque of Qāni-Bāy ar-Rammāh which fell and killed two people in 1990 (SPARE 1990b).

Observations made by this team included the recognition of the general condition of the monument and the estimation of pre-earthquake condition. The poor overall condition of the monuments made a lasting impression upon the team because it directly affects the ability of these structures to withstand earthquake loads. Some general examples of stone and brick deterioration are shown in figures 4-1 through 4-3. Five general topic areas are addressed below, three of which—general maintenance, impact of society, and effect of groundwater—have been mentioned regularly by others. The remaining two—effect of previous earthquakes and other causes—appear to be mentioned less often.

4.1.1 General Maintenance

The level of maintenance and cleanliness varies considerably among the monuments visited. Monuments such as the two Coptic churches and the al-Azhar, al-Hākim Bi-Amrillāh, Sultān Hasan, and Muhammad 'Ali al-Kabir Mosques appear to be well maintained. On the other hand, maintenance of the al-Ashraf Barsbāy Mosque and the Mosque of Ibrāhim Āghā Mustahfizān leaves much to be desired.

Unfortunately the trend in maintenance operations is that once the cleanliness decreases, the monument receives fewer supporting tourists and consequently it receives even less maintenance. This downward spiral of attention may eventually result in the closing of the monument to the public and no maintenance. The abandoned site is then subject to vandals and an acceleration of deterioration. As deterioration progresses, the capacity to resist structural loads diminishes at an accelerated rate.

Adequate routine maintenance is important for all monuments. Studies by the National Park Service for sites in the U.S. have shown that the cost of deferred maintenance (once excessive damage has occurred) is about three times that of routine maintenance for only a five to ten-year time lapse. When maintenance is deferred for decades, the cost is greatly increased and may be hundreds of times more expensive. Moreover, no cost can be placed on the loss of original design and craftsmanship.

4.1.2 Impact of Society

Many of the monuments visited exist in heavily-populated areas of Cairo. Most monuments represent not only religious centers but also social centers of life as they have for hundreds of years. These monuments lie among shops and vendors that line the streets. In some cases such as al-Ghuri, the shops (caravanserai) used to exist beneath the mosque. Although the mosques are the pivotal buildings in these historic districts, the vast majority of the land is occupied by residential buildings as they were originally. Without these buildings, the street scape of the districts would be greatly so a balance of societal use and

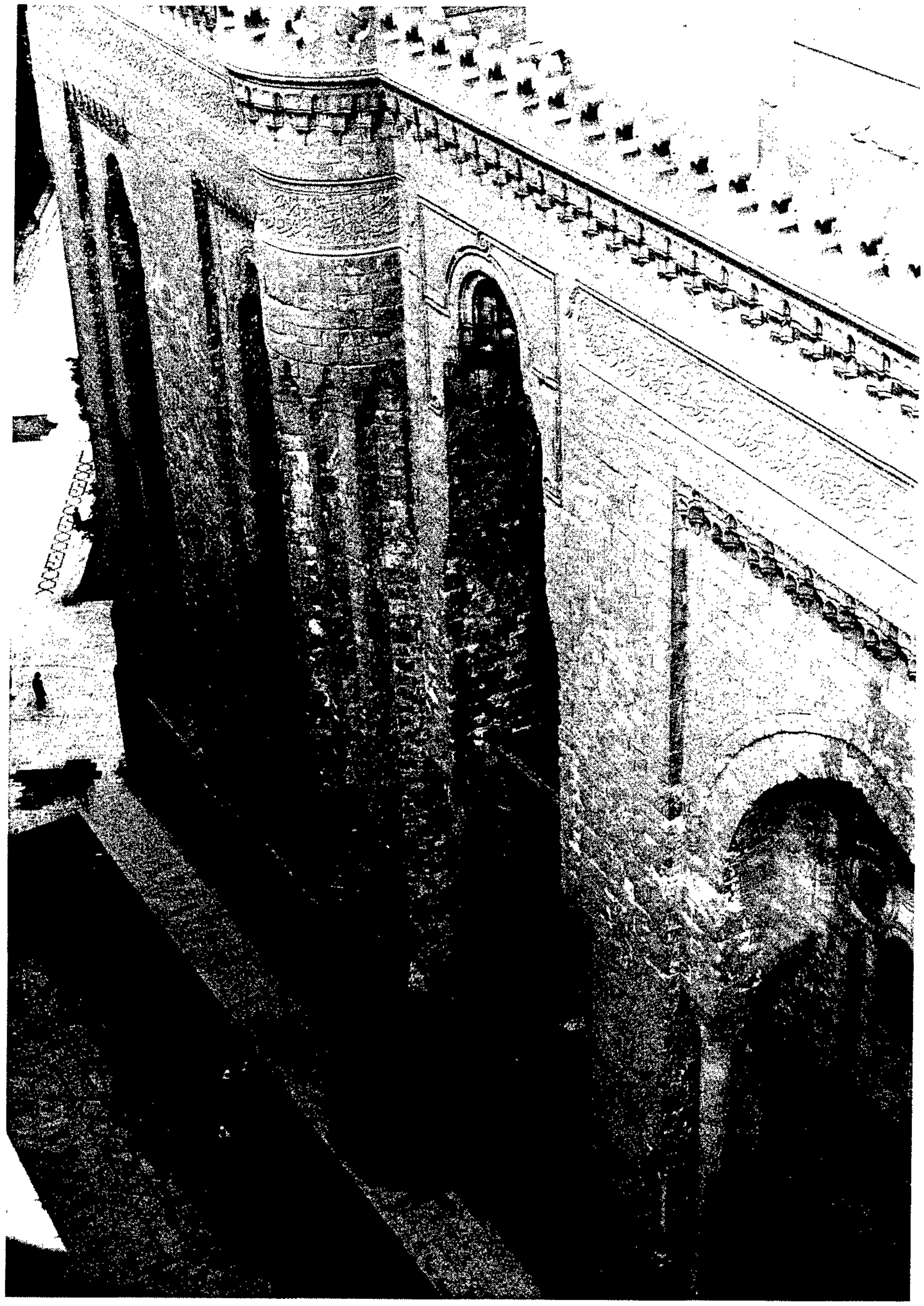


FIGURE 4-1 Main portal of century-old al-Rifai Mosque looking down from the eastern minaret of the Sultān Hasan Mosque showing deterioration of masonry near arches

FIGURE 4-2 Balcony wall masonry of Hasan Pasha Tāhir Mosque showing deterioration of stone and spalling resulting from earthquake

FIGURE 4-3 Brick arch in crypt of Abu Sufein Church showing the loss of a considerable amount of material

diminished and the character and fabric of the districts would be irretrievably altered. And intervention is necessary for effective historic preservation. Evidence of excessive wear from societal use and misuse is resulting from waste and water disposal from vendors stationed by monuments, work animals, political posters glued to historic masonry, cooking fires, and improvised shelters.

4.1.3 Effect of Groundwater

Possibly the single most important issue in the preservation of historic monuments in Cairo is the effect of moisture on masonry stone and palm wood. The Ministry of Public Works (1902) apparently was the first to recognize this hazard. Although the medieval builders reportedly used impermeable footings (Rodenbeck 1992), the significant rise in the groundwater likely has overtopped preventative measures.

Groundwater is very close to the ground surface at many monuments and likely to be at or above footing level. The masonry (limestone) block acts like a wick from capillary action (sometimes referred to as rising damp). Moisture continues to creep vertically in the stone until the capillary pressures equilibrate, generally well above the ground surface. Excessive moisture is evident up to a couple of meters above the ground level in the walls of several historic monuments. An example is shown in figure 4-4. The impact of groundwater is detrimental not only to masonry block but to wood, too. The increased humidity caused by evaporation of water in the foundation of the el-Moalloqa Church (shown in figure 4-5) has caused the rapid deterioration of palm wood floor joists.

Increased moisture of the masonry block for long periods of time causes a chemical breakdown of the limestone which can be accelerated by soluble salts. The soluble salts migrate to the surface of the stone and then evaporate. As the soluble salts evaporate, the salts recrystallize. Great quantities of salts can accumulate on the surface of the stone, called efflorescence. The crystals change from crystalline compounds to a powdery state when exposed to air. Since limestone, the predominant building stone, is very porous, the crystals can also form within the pores of the stone. Frequently, the salt crystals are larger than the pore causing the surface of the stone to spall off. Crystals that form behind the surface of the stone is called subflorescence. The exterior of the block can then be scratched with a fingernail and typically spalls from gravitational forces.

FIGURE 4-4 Southwest exterior wall of Mosque of Sultān Barqūq looking north showing dampness in masonry and progressive deterioration with height

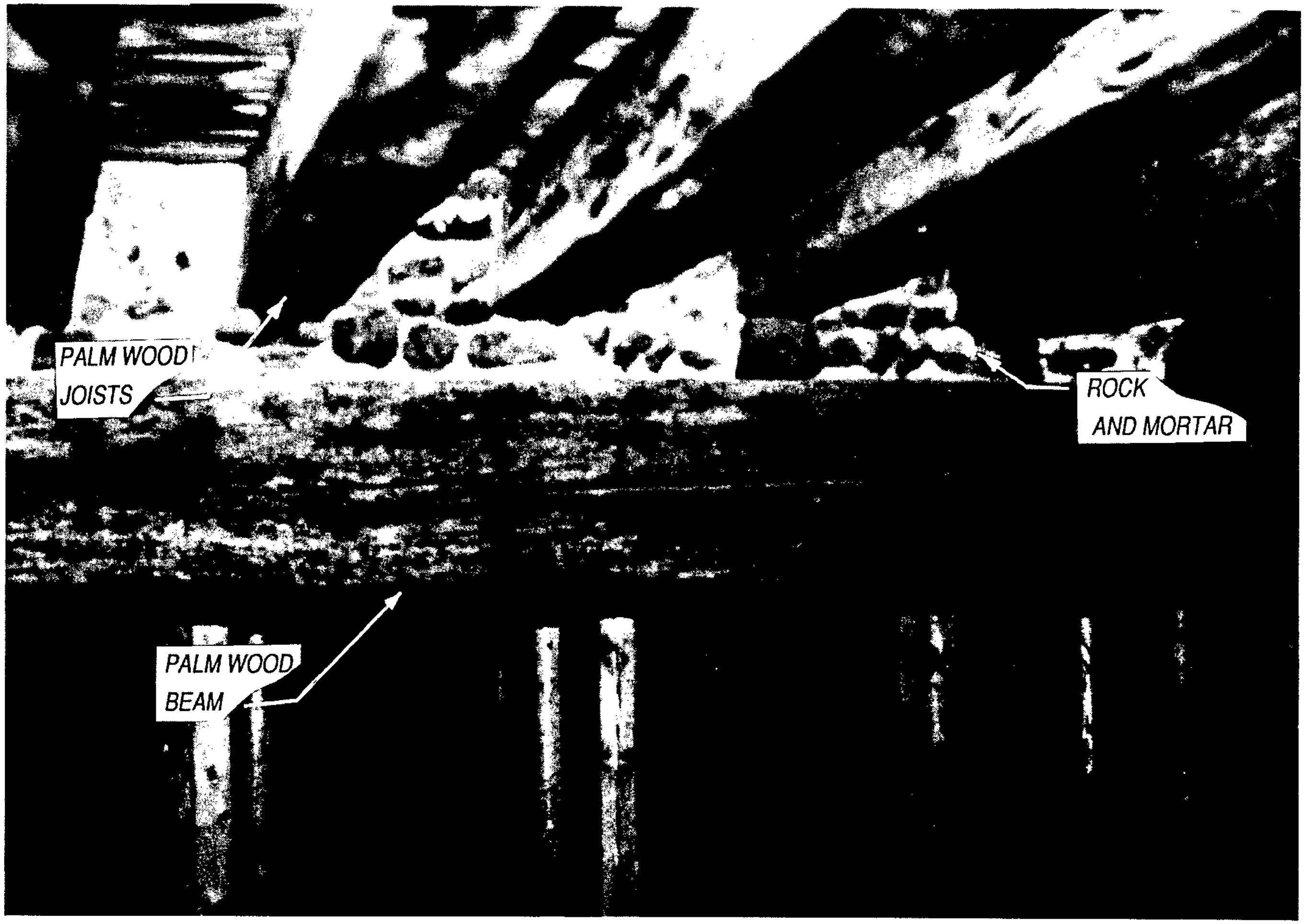


FIGURE 4-5 Structural floor system at el-Moalloqa Church

Pollutants are also deposited on the surface of the stone from the air. Where the surface of the stone is totally dry the stone is only discolored as the deposits increase. Where the surface of the stone is moist, the pollutants are converted to mild acids that eat away the surface of the stone by dissolving the binder in the stone causing particles to separate and erode away easily. Although there are other minor contributing causes of stone deterioration, such as bird droppings, these appear to be negligible in the Medieval area of Cairo. Many of these issues are being addressed by the North Atlantic Treaty Organization (NATO) Committee of Challenge for a Modern Society (CCMS). A recent proceedings summarizes these efforts (Fitz 1993).

In cases where the water table is not expected to drop over the long term, it may be necessary to adopt radical intervention such as passive techniques—cutting the wall at its base with special saws or drills and introducing sheets of lead or pouring a special resin cover. However, if moisture barriers are installed incorrectly or in the wrong place, this measure is wasted and may cause more damage. Active, localized, dewatering techniques, particularly horizontal well technology, provides a more reliable and non-intrusive technique.

4.1.4 Effect of Previous Earthquakes

Most of the historic monuments in Cairo have been shaken a number of times by moderate earthquake motions. The six oldest monuments visited were subjected to all the earthquakes listed in Table 3 (the oldest being the 1111 earthquake). Two more monuments survived all but the 1111 earthquake. About half of the monuments visited were completed during the period between the 1303 and 1754 earthquakes. The eighty-year-old Coptic Museum had been subjected to only three moderate earthquakes prior to the 1992 event.

It is not known if thorough records of damage to historic monuments and reports of lessons learned exist anywhere in Egypt. Historic records generally state that mosques have been damaged and destroyed during previous earthquakes (refer to Table 3). Behrens-Abouseif (1985 and 1989) and SPARE (1981a) report that minarets at al-Hākim Bi-Amrillāh and al-Mansūr Qala'ūn mosques were damaged during the 1303 earthquake. The minarets of al-Hākim Bi-Amrillāh were rebuilt using the remaining base. The minaret of al-Mansūr Qala'ūn was repaired. Many of the monuments visited have cracks or other remnants from previous earthquakes. A tilted column remains at al-Azhar as shown in figure 4-6 (even though this monument was restored in 1980).

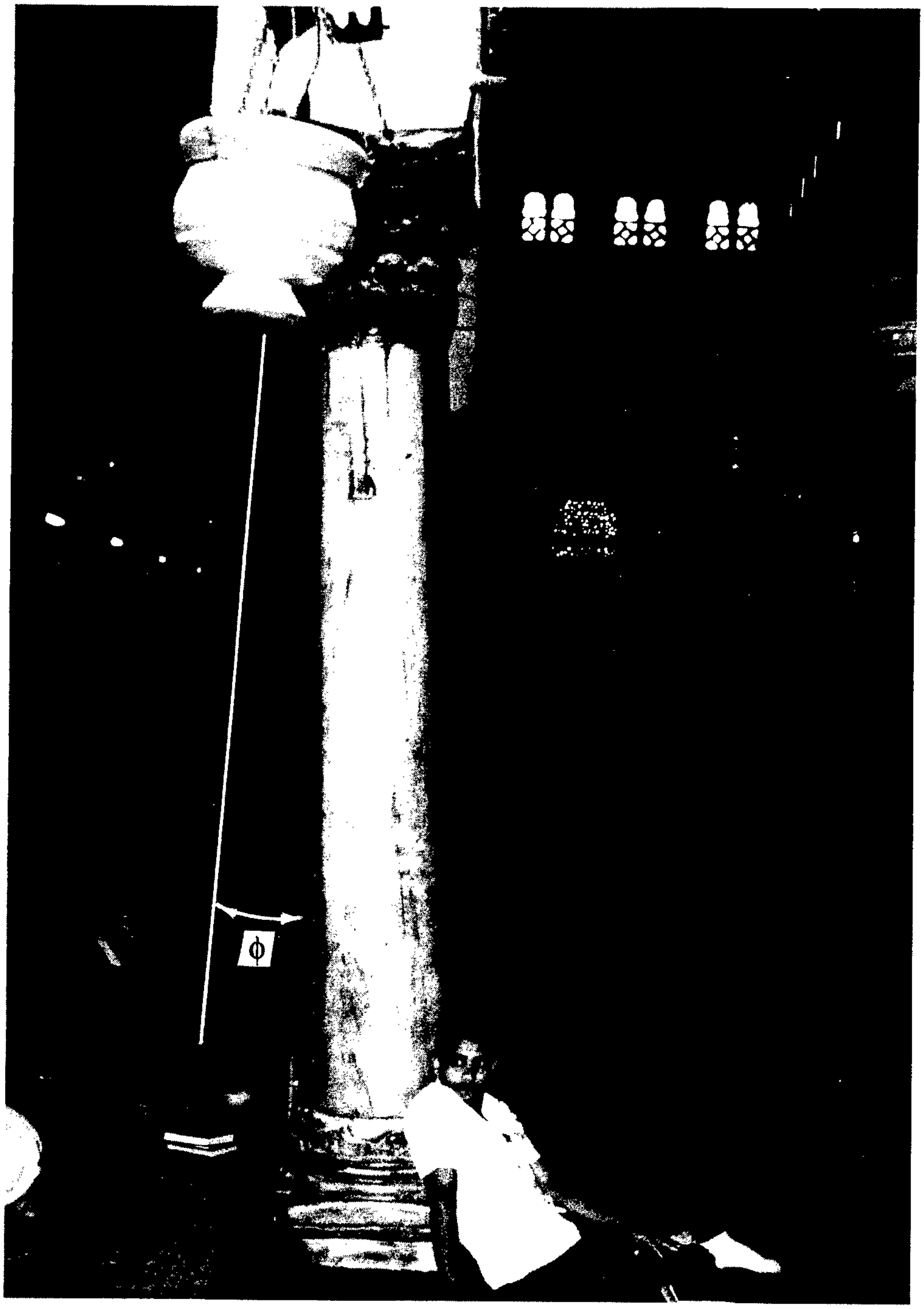


FIGURE 4-6 Column of arcade at al-Azhar Mosque showing tilting effect from previous earthquake

4.1.5 Other Causes

Other detrimental effects stem from two other causes—vehicular traffic and watering. An example of the impact of vehicular traffic is seen at the Bāb al-Futūh. Periodic contact from automobiles, trucks, and hand carts chip and wear the masonry and exhaust from engines causes a concentrated discoloration of the stone. The effects are shown in figure 4-7. Although the remainder of the structure is in good condition, continued exposure to these hazards will cause irreversible damage and potentially structural problems with the portal.

Watering is also taking its toll on masonry retaining walls at the Citadel. The custodians maintain lush grass, bushes, and trees within the complex as shown in figure 4-8 from extensive watering. These gardens and lawns apparently were created in 1984 (SPARE 1984b). The consequence of watering is the steady seepage of water through the walls of the Citadel. This is clearly evident on the east and west sides. A view of the western portion of the wall is shown in figure 4-9. The preservation of the masonry stone will require a change in the current practice of maintaining the flora at the Citadel or a return to a more historic appearance with drought-resistant plants and trees.

4.2 Findings of Earthquake Damage

Post-pharonic monuments were significantly damaged during the earthquake. Portions of at least five minarets broke and fell, about seven others tilted and/or were cracked, one small dome collapsed, arches pulled apart and keystones dropped, walls buckled, and countless cracks were formed or existing cracks extended and widened. Unlike more modern buildings in Cairo, however, there were no instances of major collapse. General descriptions of the damage are summarized in table 4-II and mentioned in the following sections.

Earthquake damage to historic monuments can be generally described as having resulted from the continuous degradation of foundation and structural masonry from environmental effects, especially groundwater, inadequate lateral resistance (unreinforced block masonry and inadequate lateral ties), and the subsequent imposition of light to moderate earthquake forces. More specific effects include poor foundation conditions, design and support of minarets, and inadequate anchorage of domes.

There were no regions observed within the historic districts where extensive damage was sustained that might be indicative of wide-spread strong ground shaking. Few of the

FIGURE 4-7 Inside wall of Bāb al-Futūh showing deterioration from moisture and scraping

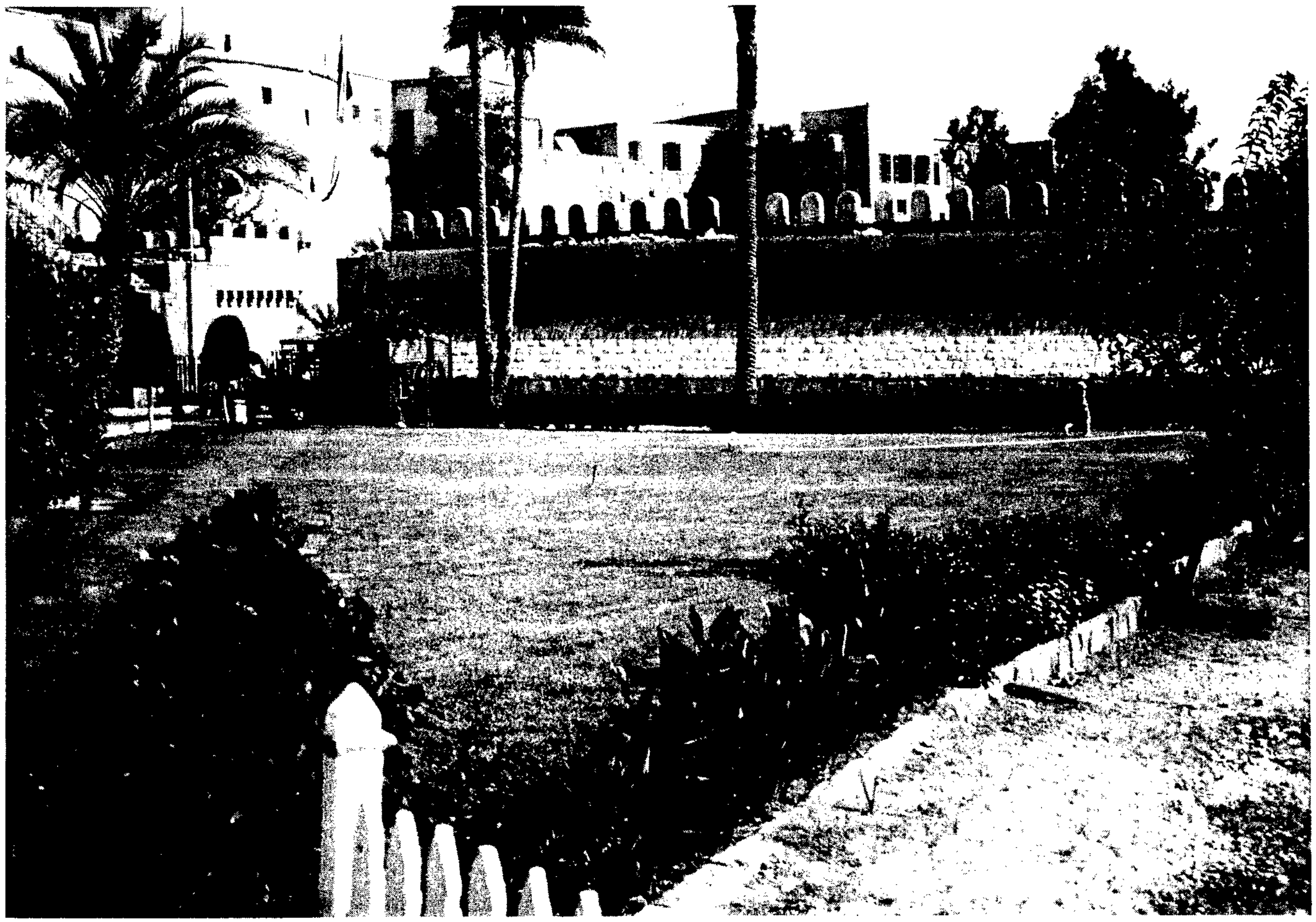


FIGURE 4-8 Manicured lawn of Citadel in Southern Enclosure looking norhteast toward Bāb al-Gabal

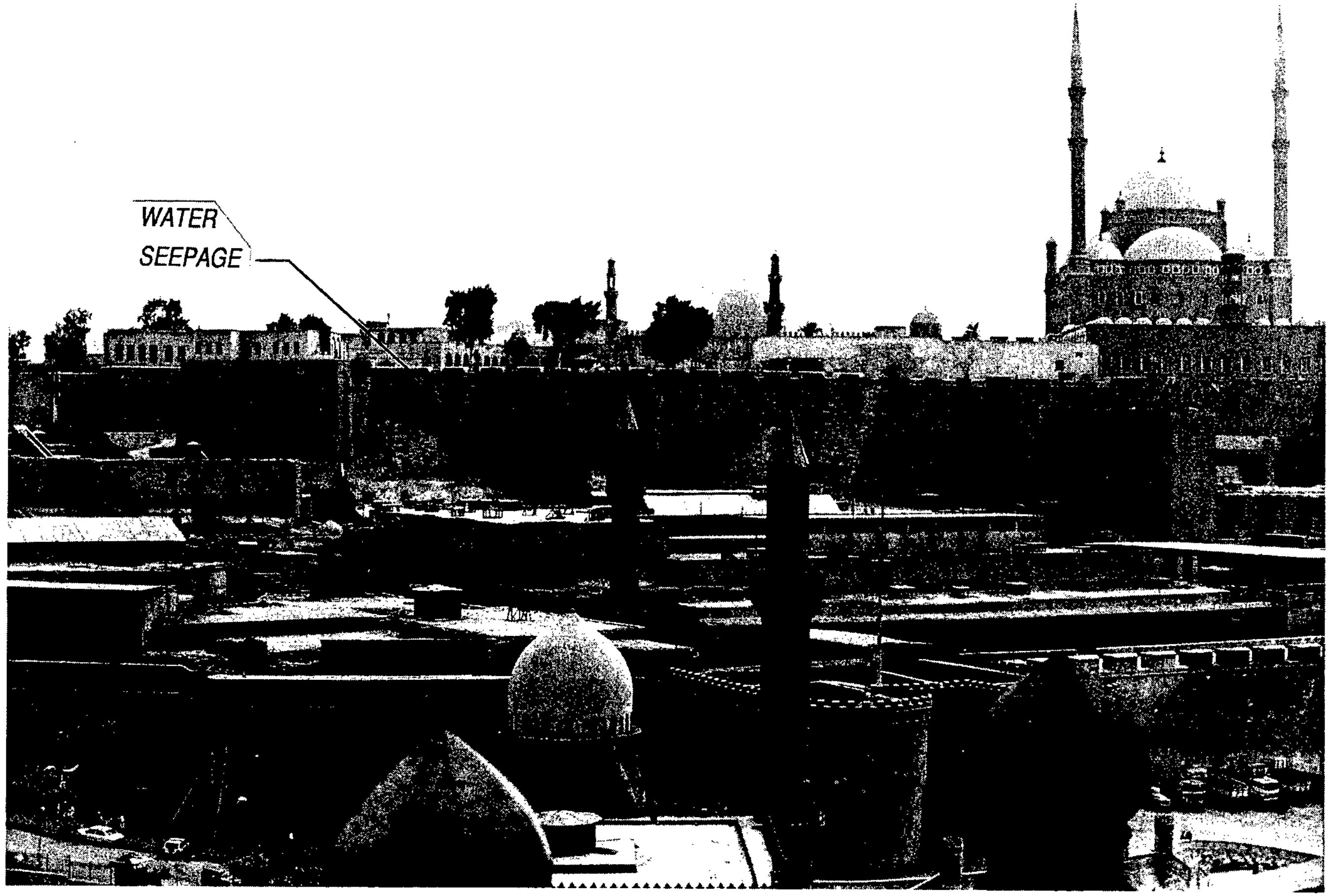


FIGURE 4-9 Citadel looking east from Mosque of Sultān Hasan showing significant moisture seepage through upper wall

TABLE 4-I Observations of Earthquake Damage to Monuments

Monument	Minaret(s)	Walls	Arches	Other
Coptic Period				
el-Moalloqa Church	N/A	Many cracks int. & ext.	Many sign. cracks	Sagging floor; cracked parapet wall; cracks in vaults
Abu Sufein Church	N/A	Minor cracks on 2nd flr.	Minor cracks in one arch	Minor crack in small dome
Fatimid Period (969-1171)				
al-Azhar Mosque	Minor cracking[1]	No damage	Minor cracks	Leaning cols.; 10 broken parapets; crescent fell
al-Hākim Bi-Amrillāh Mosque	No damage (North) N.O. (West)	Minor cracks	Minor cracks	Crack in dome & supporting wall; broken parapets
Ayyubid Period (1171-1250)				
Madrasa and Minaret of as-Sālih Negm ad-Din Ayyūb	Leaning	N/A	N/A	None

(Cont'd)

TABLE 4-I (Cont'd)

Monument	Minaret(s)	Walls	Arches	Other
Bahri Mamluk Period (1250-1382)				
Mausoleum of al-Mansūr Qala'ūn	N.O.	Buckling of int. hallway wall	Sign. cracking in most arches	Cols. spalling; piers buckling
Mausoleum of an-Nāsir Muhammad	N.O.		Cracking & separ. with vault	
Palace of the Amir Beshtāk	N/A	Contin. cracks to restored walls; severe damage to 2nd flr. hall	No damage	
Mosque of an-Nāsir Muhammad, Citadel	N.O.	No damage	No damage	
Mosque of Shaykhū	West side of bulb broke and fell through roof	Cracks in façade to left of ent. port.	No damage	Hole in roof
Khanqāh Shaykhū	Minor damage	Some minor cracks	Keystone & 2 adj. voussoirs dropped; crack above	Debris fell into qa'a
Madrasa of Sarqhatmish	N/A	N. corner dropped		Floor sagging
Mosque and Madrasa of Sultān Hasan	Large cracks & separ. in walls & central col.	Mostly older; new crack in header at entrance portal	Minor cracks & separation	Signif. inter. cracks in supports for dome; enlarged from earthquake
Mosque of Ibrāhim Āghā Mustahfizān	Leaning	Complete separ. of wall from vault; one wall leaning and buckling	Cracks in vault	Some cracks in dome; signif. enlarged

(Cont'd)

TABLE 4-I (Cont'd)

Monument	Minaret(s)	Walls	Arches	Other
Circassian Mamluk (1382-1517)				
Mosque of Sultān Barqūq	leaning	Crack in back widened & extended;	Separ. between arch & roof	
Mosque and Sabil of al-Ashraf Barsbāy	N.O.	Many cracks widened & extended	Cracks widened & extended thru arches supporting major dome	Cracks in dome (exterior only)
Minaret of as-Saghir Mosque	Upper 4-5 m broke and fell	N.O.	N.O.	Debris from minaret broke through roof and hit entry stairs
Mosque of al-Ghūri	Leaning	Sign. cracks widened & extend.	Severely damaged, esp. NE & SW sides	Floors sagging
Mosque of ad-Dashtūti	N/A	Some cracking	Cracking & separ. at tops of arched windows	Collapsed dome; rubble fell and broke roof at two spots
Ottoman Turks (1517-1805)				
Bayt as-Sihaymi	N/A	Sign. new cracks; some extended; buckling and major distortions	N/A	

(Cont.)

TABLE 4-I (Cont'd)

Monument	Minaret(s)	Walls	Arches	Other
Muhammad 'Ali Dynasty (1805-1848)				
Hasan Pasha Tāhir Mosque	Add. separ., cracking, leaning	Block separ., bulging	No damage	Walkway banging; pumping of soil; parapet fell
Saraya el-Adl, Citadel	N/A	Severe cracks	Large cracks & separ.	Separ. between wall and ceiling
Mint, Citadel	N/A	Corner dropped; severe cracking		Minor domes with severe cracks
al-Gawhara Palace, Citadel	N/A	Signif. cracks in decor. walls		
Mosque and Madrasa of Muhammad 'Alī al-Kabir	N.O.	No damage	No damage	
Post-1848				
Coptic Museum (Old Wing)	N/A	Most damage to east wall (adj. Hanging Church); ext. & int.	Sign. cracks	

N.O. = No observation
N/A = Not applicable
[1] Tour guide was thrown to floor of lower balcony in SW minaret during earthquake

more-recent, general-use structures in the vicinity of the monuments visited appeared to have sustained any more than light damage. There does appear to be sufficient evidence to suggest that the alluvial deposits amplified ground motions at natural periods.

A representative comparison of damage relative to period of construction for monuments visited by this team is shown in table 4-II. The age of the monument alone is not a good indicator of expected damage. For instance, the four monuments visited from the Tulunid and Fatimid Periods performed very well, incurring no damage or light damage. Conversely, some monuments less than 200 years old sustained moderate and severe damage. Rather, condition of the monument seems to be much more important.

TABLE 4-II Survey of Historic Monuments on the Basis of Age

		Level of Earthquake Damage Observed[2]		
Period	Total No. Monuments[1]	Light	Moderate	Severe
Coptic	-	1	0	1
Tulunid (827-904)	4	0	0	0
Fatimid (969-1171)	28	2	0	0
Ayyubid (1171-1250)	15	0	1	0
Bahri Mamluk (1250-1382)	98	2	6	0
Circassian Mamluk (1382-1517)	133	2	0	4
Ottoman Turk (1517-1805)	203	0	0	1
Muhammad 'Ali (1805-1848)	18	1	1	2
Post-1848		0	1	0
TOTAL		8	8	8

[1] From The Egyptian Association of Friends of Antiquity (1980)
[2] Five monuments visited had no observable damage (one each from Tulunid, Fatimid, Bahri Mamluk, Muhammad 'Ali Periods, and post-1848)

Several examples exist to show how the condition of a monument relates to earthquake resistance. This team purposely visited some monuments where no damage occurred, especially when adjacent to damaged mosques. For example, the al-Ghūri and al-Azhar

Mosques are within a few hundred meters of each other of each other. The al-Ghūri Mosque, in poor condition before the earthquake, sustained severe damage whereas the older al-Azhar was only lightly damaged. At the Citadel, the most prominent (and largest) structure (the Mosque of Muhammad 'Ali al-Kabir) was undamaged whereas the Saraya el-Adl and the Mint were severely damaged, again within a few hundred meters of the other structures. (The natural period of these smaller structures may have closely corresponded to the predominant period of shaking at the Citadel, however.) Another pair of monuments are the Mausoleum of Sultān Hasan (moderately damaged) and the al-Rifai Mosque (undamaged) which are adjacent to each other. The mausoleum had cracks in the dome before the earthquake that cracked further and widened.

The period during which the monument was constructed may also be a general indicator of relative resistance to earthquakes and may reflect design and construction practices from elsewhere. For example, the percentages of monuments constructed between 969 and 1517 and damaged during the earthquake are fairly uniform for the four periods represented—5 to 7 percent (or 7 to 13 percent if other teams findings are included). However, the percentages of damaged monuments during the Ottoman Turk and Muhammad 'Ali Periods are significantly different. A very small percentage from the Ottoman Turk Period were damaged (0.5 percent for this team's survey, 3 percent if one includes data from other teams) and a large percentage from the Muhammad 'Ali Period were damaged (22 percent for this survey, 28 percent if one includes data from other teams). Even more striking about these statistics is that over 200 years had passed since the destructive 1303 earthquake when most of the Ottoman Turk monuments were built whereas only 50-plus years had passed since the 1754 earthquake when the Muhammad 'Ali monuments were constructed. (Note that this assessment does not include an evaluation of the prevalent types of structures built during these periods, e.g., several new congregational mosques were built during the Bahri Mamluk Period, and that only 11 percent of the structures reportedly damaged were surveyed.)

Some of the specific observations are presented below using three levels of damage—light, moderate, and severe—as listed in table 1-I. These levels reflect not only a scientific and engineering perspective, but also a preservationist perspective. Light damage refers to the creation or widening of isolated minor cracks in walls, arches, domes, and minarets. Moderate damage refers to leaning minarets, large separation between adjoining structural elements, and significant cracks in large domes and minarets. Severe damage refers to broken minarets, buckling walls, large depressions in floors, and collapse of domes. A general description and examples of lightly-damaged monuments are provided below whereas more specific observations are presented for moderately- and severely-damaged monuments. It is important to note that in nearly all cases, further environmental damage and earthquake shaking are expected to cause increased levels of damage at these same monuments. In fact, the existence of previous damage will likely cause a disproportionate rate of destructive damage during future earthquakes.

4.2.1 Lightly-Damaged Monuments

Eight monuments were categorized as having light damage. These monuments are: Abu Sufein Church, al-Azhar Mosque, al-Hākim Bi-Amrillāh Mosque, Mausoleum of an-Nāsir Muhammad, Madrasa of Sarqhatmish, Mosque of Sultān Barqūq, Mosque and Sabil of al-Ashraf Barsbāy, and the al-Gawhara Palace. Some examples of this category of damage are shown in figures 4-10 through 4-13. This level of damage is generally not important by engineering standards. However, the impact on irreplaceable art and architectural monuments is much different. Earthquake damage must be repaired to prevent escalating damage from environmental effects and future earthquakes.

An example of how a structural discontinuity without proper anchorage can cause cracking was noticed at al-Hākim Bi-Amrillāh Mosque. The cracks through the window and in the small dome above shown in figure 4-14 correspond exactly to where the main arched section on the southwest wall and the corner wall fortress meet. The base of the fortress may be seen through the window. These two structural components responded differently causing the crack and permanent displacment.

Decorative masonry parapets (*pishtaq*) fell during the earthquake at several of the monuments as shown in figures 4-15 and 4-16. Although the failure of parapets usually represents minor structural and architectural damage, falling stone represents a serious life safety issue. Some of the parapets had mounds of cement plastered on the back side, possibly intended to prevent failure. This is not an effective practice. Bracing the parapet usually consists of tying the top of the parapet back to the roof by a diagonal steel angle if the roof is in sound condition.

The City of San Francisco, CA, has had a parapet ordinance for over ten years. This has been found to be an extremely cost effective method of preventing damage and loss of life. Almost all of the parapets that fell during the Loma Prieta Earthquake of 1989 were from

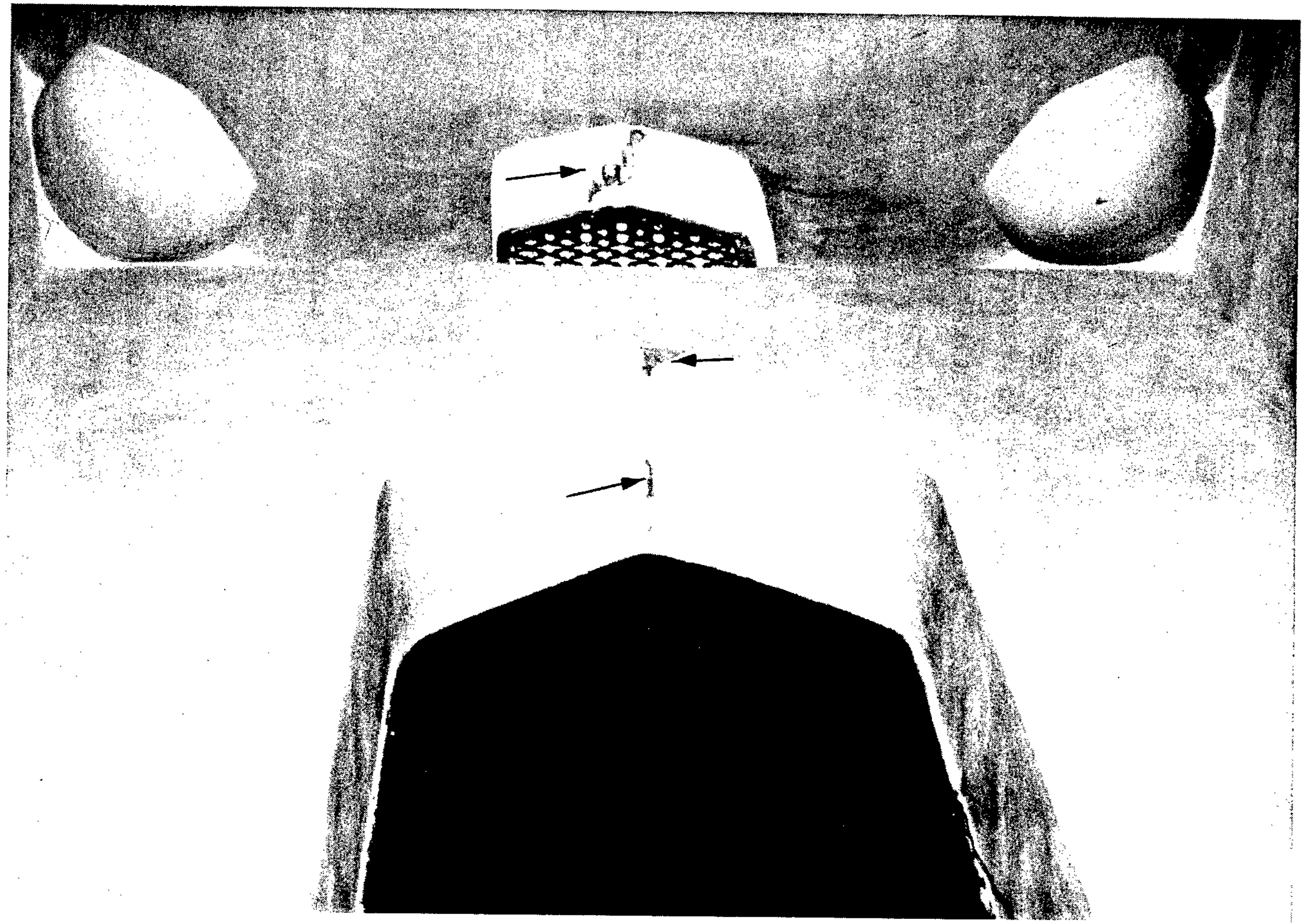


FIGURE 4-10 Wall and small dome at Abu Sufein Church showing cracks and spalling at top of arches

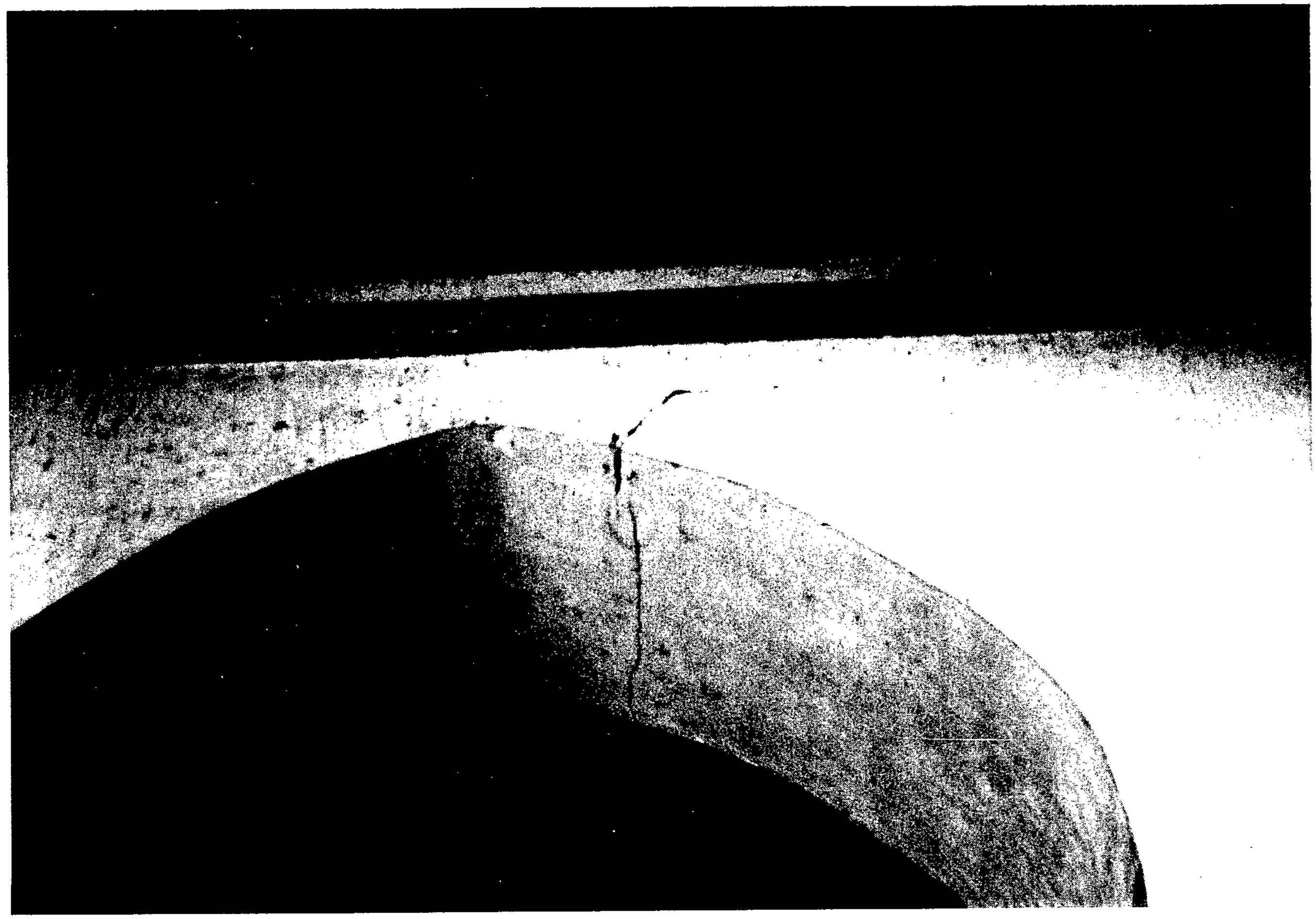


FIGURE 4-11 Arch in arcade of al-Hākim Bi-Amrillāh Mosque showing minor crack

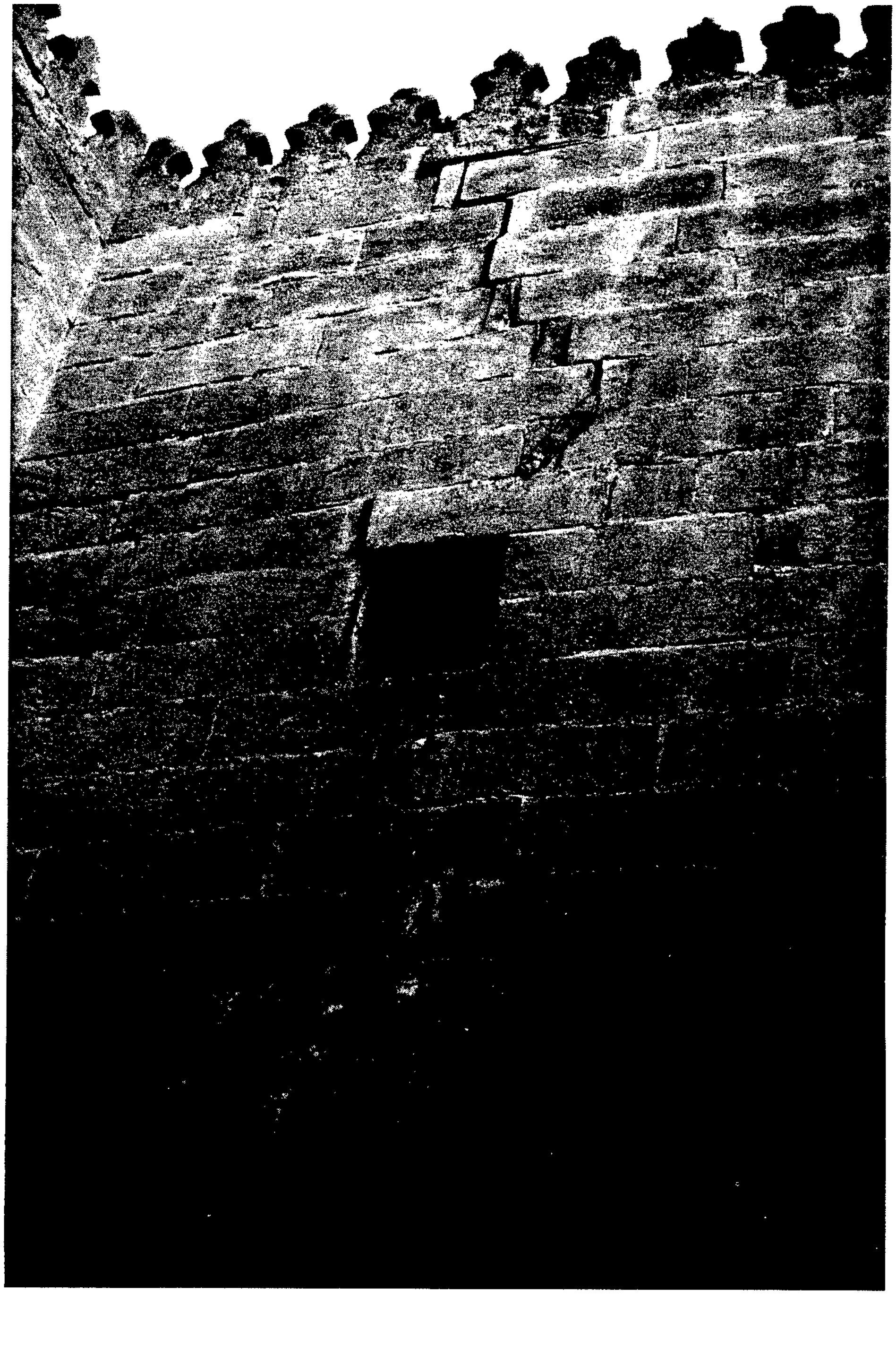


FIGURE 4-12 Wall near back of Mosque of Sultān Barqūq showing extensive crack in southwestern wall

FIGURE 4-13 Wall at southern corner of inner court of Mosque of Sultān Barqūq showing crack in southwestern wall extending down to arch

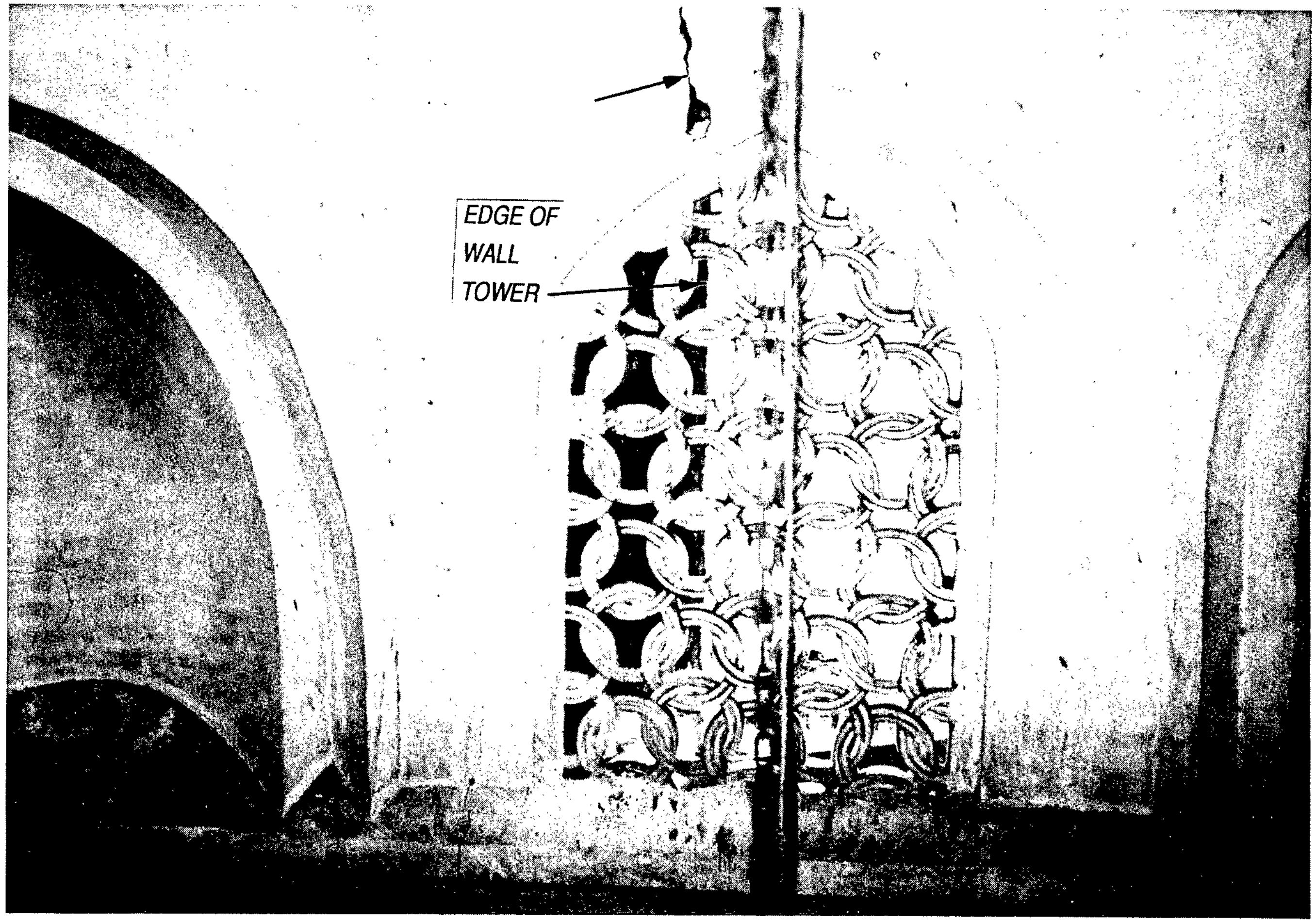


FIGURE 4-14 Base of dome at eastern corner of al-Hākim Bi-Amrillāh Mosque showing crack extending up from window corresponding to wall tower

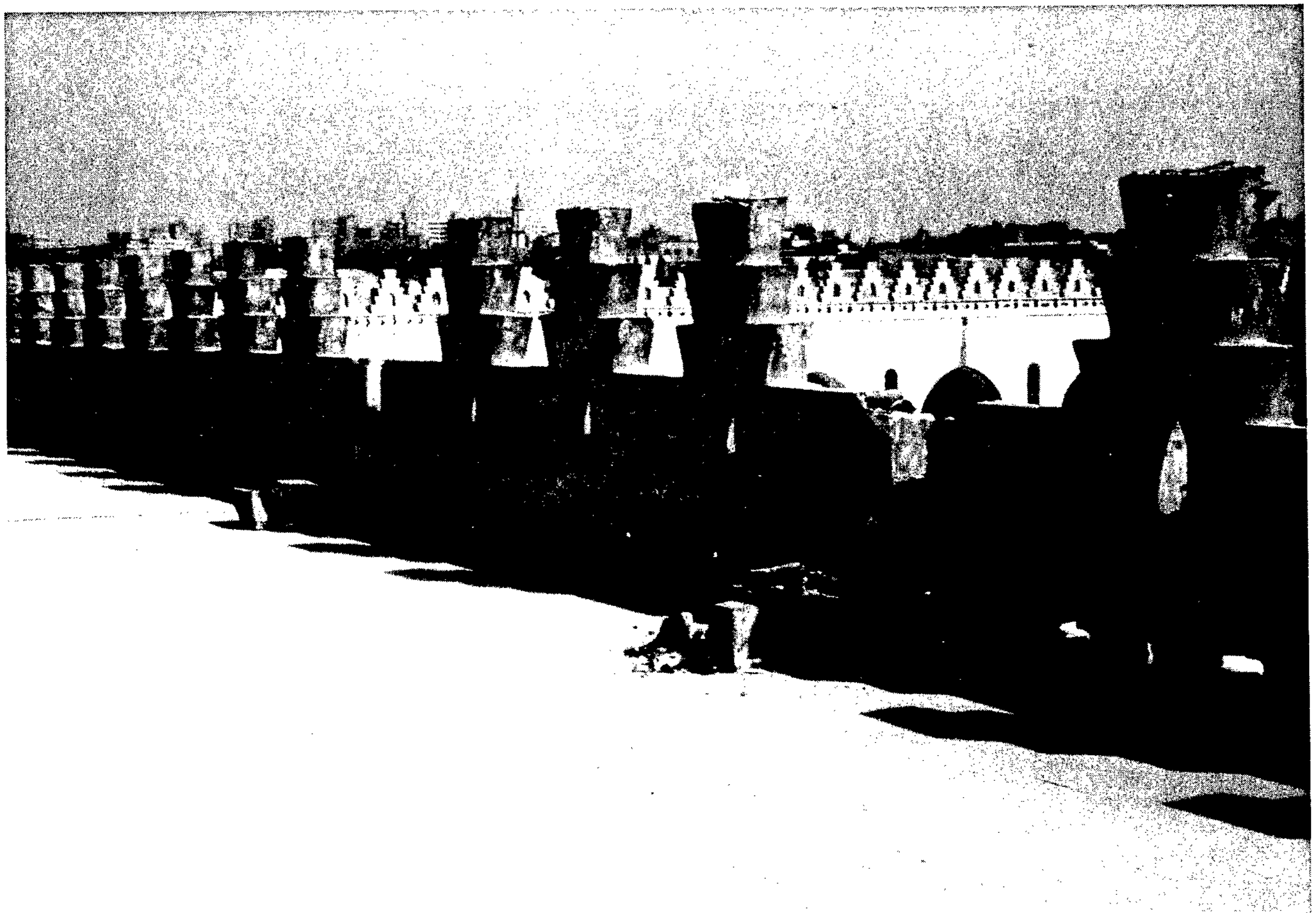


FIGURE 4-15 Walkway above arcade at al-Hākim Bi-Amrillāh Mosque showing fallen parapets

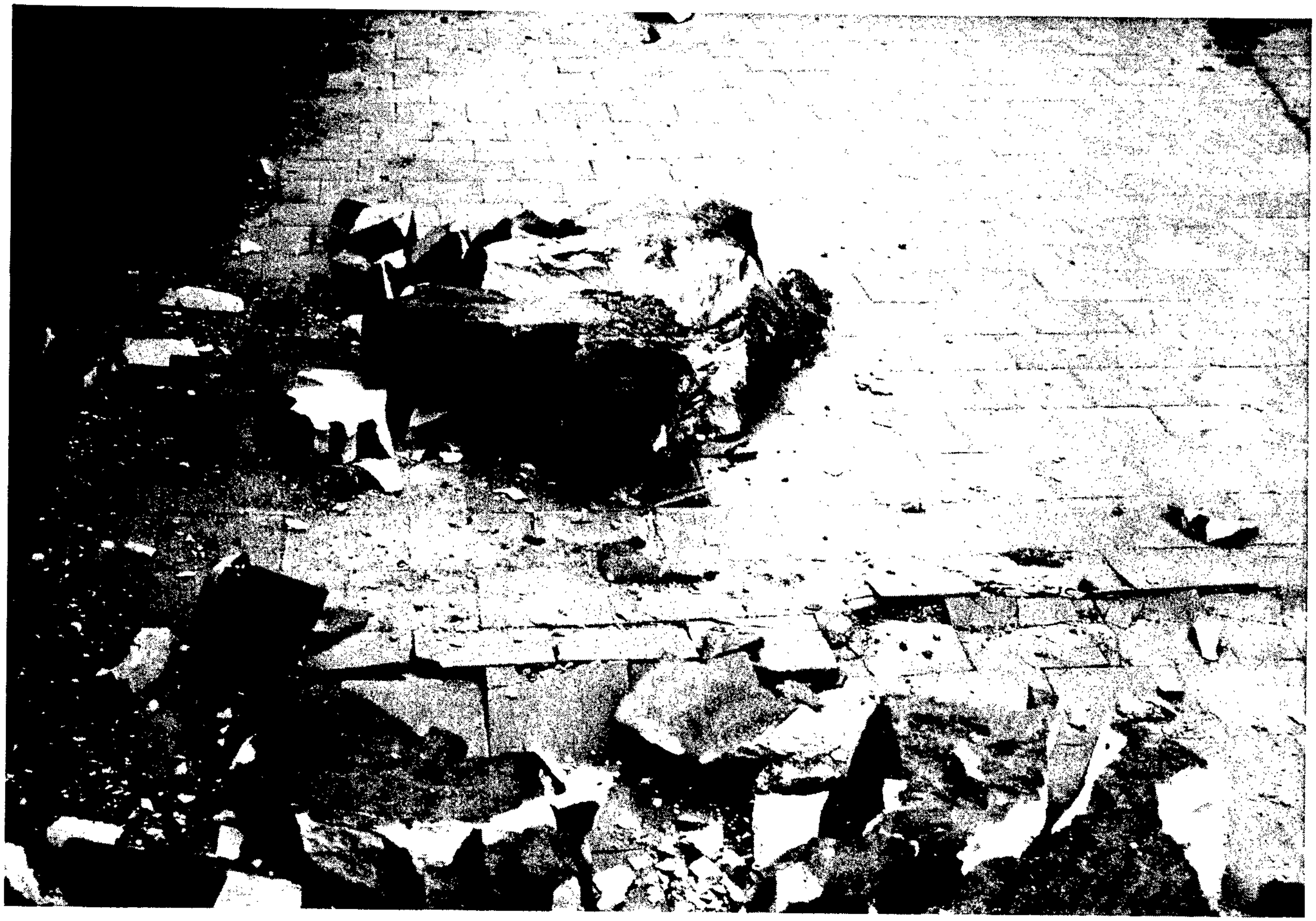


FIGURE 4-16 Walkway above arcade at al-Azhar Mosque showing fallen parapets

buildings outside the area where parapet bracing was required. Similar codes should be adopted in Cairo with retroactive application to historic monuments.

4.2.2 Moderately-Damaged Monuments

Seven monuments have been classified as having incurred moderate damage from the recent earthquake. The spatial distribution of these monuments designated in table 1-I can be seen in figures 2-3 through 2-5. The Coptic Museum, although not very old, was included because it is adjacent to the Hanging Church and was constructed on the same bastions of a Roman fortress as this church. Specific observations for each site are presented below.

4.2.2.1 Minaret of as-Sālih Negm ad-Din Ayyūb

This *mabkhara*-style minaret is about all that remains of the madrasa bearing the same name and is the only minaret of the Ayyubid Period to survive intact (Behrens-Abouseif 1989). Moreover, this minaret is one of only fifteen monuments remaining from the Ayyubid Period. A view of the base of the minaret looking from the remains of the interior of the madrasa is shown in figure 4-17. There is little lateral support at the base of the minaret since the madrasa is no longer present. The remnant unreinforced masonry walls are evident.

The recent earthquake caused existing cracks to be significantly widened and extended. Some of the cracks may have formed as the madrasa progressively deteriorated and collapsed. An inhabited residential building behind the remnant madrasa also shows similar disrepair and signs of distress as seen in figure 4-18 and should be evacuated. The minaret is also reported to be leaning. The upper portion of the minaret, which has a smaller cross section, is leaning observably more than the lower portion, which has a larger cross section. Access to the interior or base of the minaret was not made available.

4.2.2.2 Mausoleum of al-Mansūr Qala'ūn

This mausoleum was in poor structural condition and incurred moderate damage to numerous architectural and structural elements on the exterior and interior. A floor plan of the total complex is shown in figure 4-19 and views of the monument are shown in figures 4-20 through 4-22. It was particularly difficult to ascertain the extent of recent

FIGURE 4-17 Base of Minaret of as-Sālih Negm ad-Din Ayyūb looking north from remains of madrasa

FIGURE 4-18 Residential housing unit behind remains of Madrasa of as-Sālih Negm ad-Din Ayyūb showing significant cracks

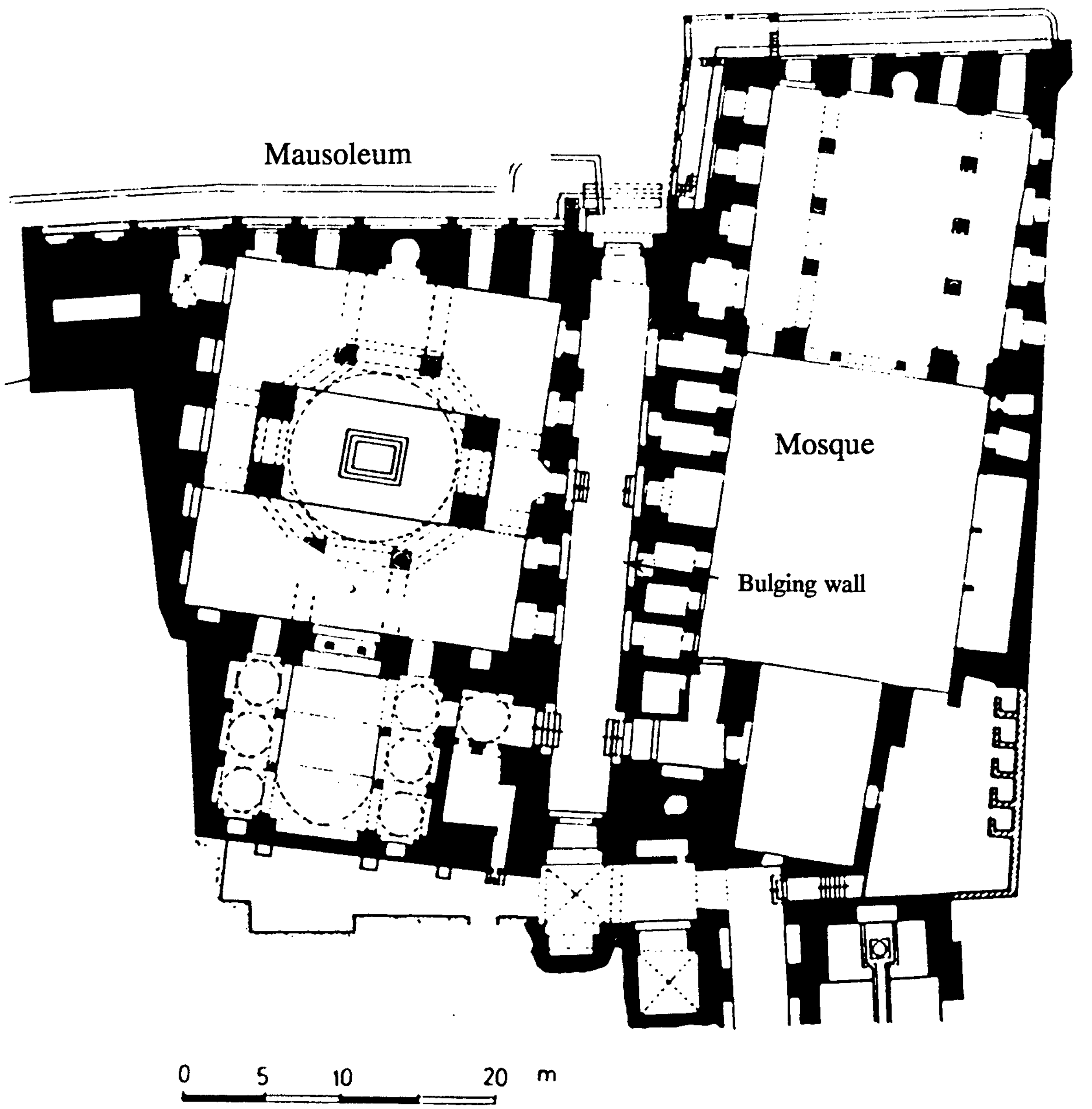


FIGURE 4-19 Floor plan of Mosque and Mausoleum of al-Mansūr Qala'ūn (Creswell 1959)

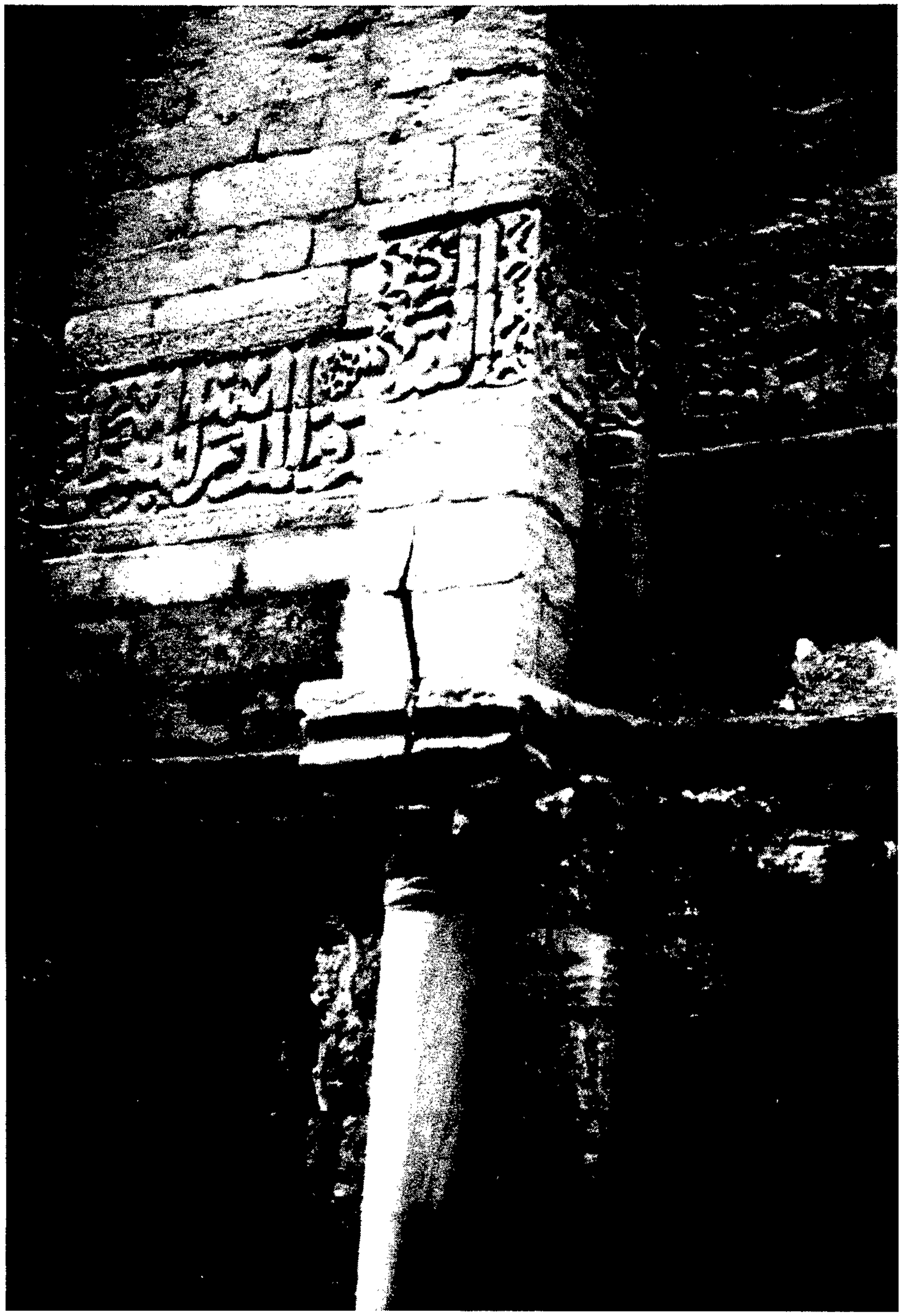


FIGURE 4-20 Marble column at base of recessed panel at Mausoleum of al-Mansūr Qala'ūn showing large crack

FIGURE 4-21 Top of arch and minor dome in Mausoleum of al-Mansūr Qala'ūn showing significant cracks

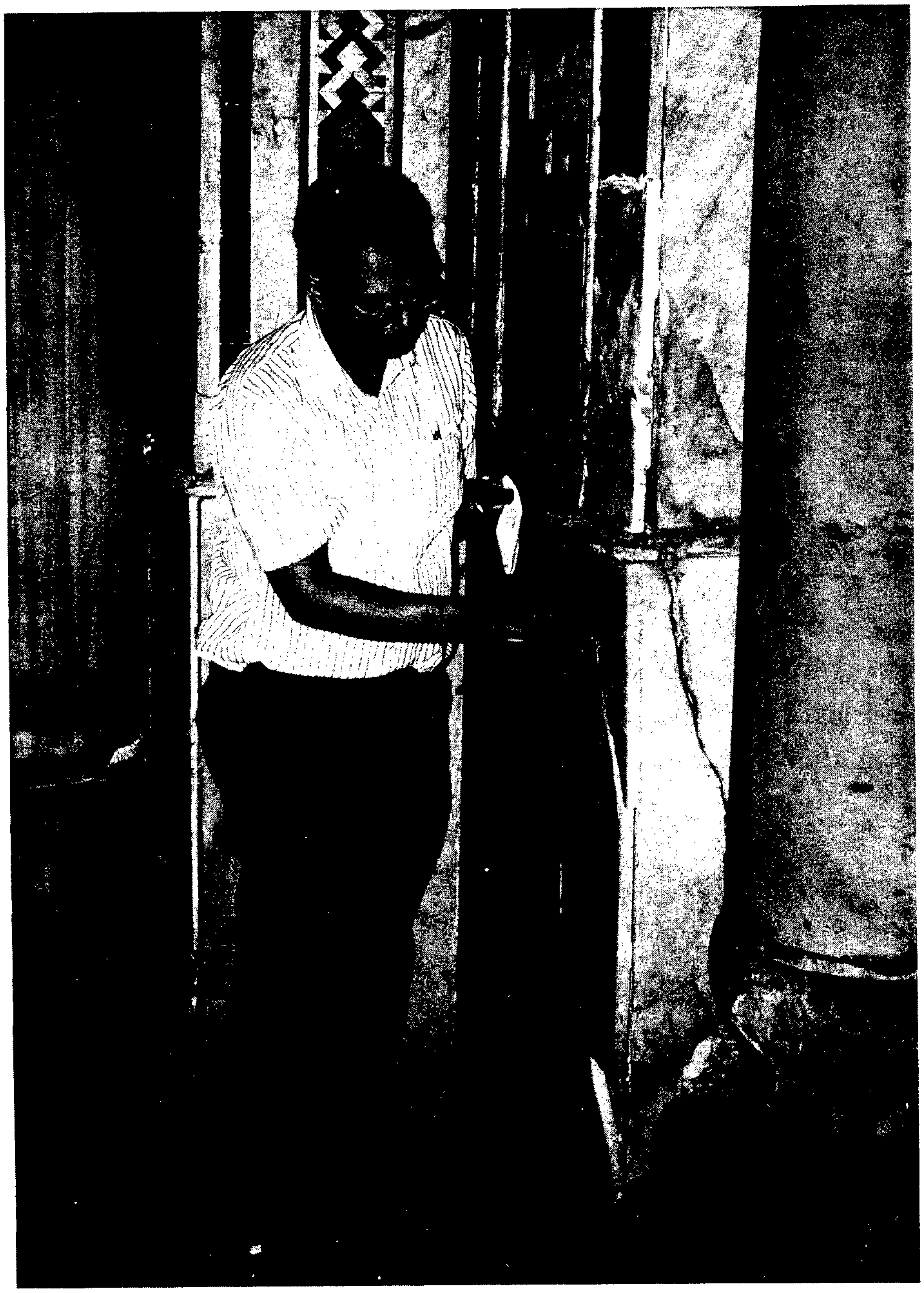


FIGURE 4-22 Base of pier in Mausoleum of al-Mansūr Qala'ūn showing large cracks

earthquake damage here, partially because of the poor ambient lighting. The damage level would have been classified as severe if all the observed damage were attributed to the recent earthquake. There is strong evidence to suggest that a majority of damage already existed.

On the exterior, the masonry walls show significant cracks between the stone and distress in recessed panels at the base and near the top as shown in figure 4-20. Some of these cracks existed prior to the earthquake and were widened and extended. The minaret sustained damage during the 1303 earthquake (inscription on minaret) only eighteen years after construction and was consequently repaired although the extent of damage or repair is not known (Behrens-Abouseif 1985). The team was not allowed access to the minaret for observation.

On the interior, structural, architectural, and artistic elements show significant signs of distress: massive granite columns are spalling near the base (apparently from compression forces exceeding material strength), the interior hallway wall is bulging, piers are buckling causing inlaid marble panels to separate and shatter, and large cracks exist in walls and small domes. Atil (1981) notes that these panels are "the first extensive use of marble paneling"...in Islamic art. Two photographs of the damage are shown in figures 4-21 and 4-22. The condition of structural elements suggests that a dangerous situation exists at this monument.

4.2.2.3 Palace of the Amir Beshtāk

The earthquake caused distortions in the northwest exterior wall and large cracks in three areas—the upper portion of the northeast and southwest walls in the *qa'a*, the ceiling and walls of the hallway overlooking the street, and the second floor hallway and room in the western corner. All the cracks and other damage were caused by the recent earthquake as the restoration of this monument was recently completed by the GIA in 1985.

This monument was restored from a partial shell of the original palace. The walls on the northwest and southwest sides are original for the full three stories. However, the walls on the other two sides of the structure range from one to three stories in height. The original roof only extends over less than half of the floor plan. The restoration involved maintaining the existing shell and making interior walls now exposed to the exterior to be weather resistant. The effect of having only partial walls and a discontinuous roof is that the lateral resistance is very low.

One area of damage at the *qa'a* is shown in figure 4-23. The crack shown extends through the window and then curves to form a transverse crack connecting with a similar crack at the other corner as shown in figure 4-24. This pattern exists on both walls and on the southwest exterior wall seen through the arched breezeway in figure 4-23. The relative displacement on the exterior wall was about 0.5 cm with the center portion having moved down.

Some of the damage to the second-floor hallway is shown in figure 4-25. The walls and ceiling incurred large cracks and displacements. The distortions on the exterior wall correspond to this same general location. The combination of these two occurrences confirms that there is inadequate lateral resistance in the out-of-plane direction for the northwest wall. As the northwest wall moved away from the main structure, cracking occurred in the walls while the main arches (see figures 4-23 and 4-24) remained stable and effectively carried the loads.

4.2.2.4 Mosque of Shaykhū

The western part of the large stone bulb atop the minaret fell during the earthquake and hit the roof and parapet below as shown in figure 4-26. The earthquake also caused cracks in the facade to the left of the entrance portal. The facade has been covered with scaffolding and plaster tell tales have been installed across the cracks for monitoring. The facade had lost its *pishtaq* prior to the earthquake.

4.2.2.5 Khanqāh Shaykhū

The room in the northeast corner of the building that contains the tomb of Amir Shaykhū has a large arch damaged by the earthquake. The keystone and two flanking voussoirs have dropped and a crack has opened above as shown in figure 4-27.

4.2.2.6 Mosque, Mausoleum, and Madrasa of Sultān Hasan

The damage to this mosque, mausoleum, and madrasa was on the border between light and moderate classifications. Since this structure is a major monument and tourist attraction,

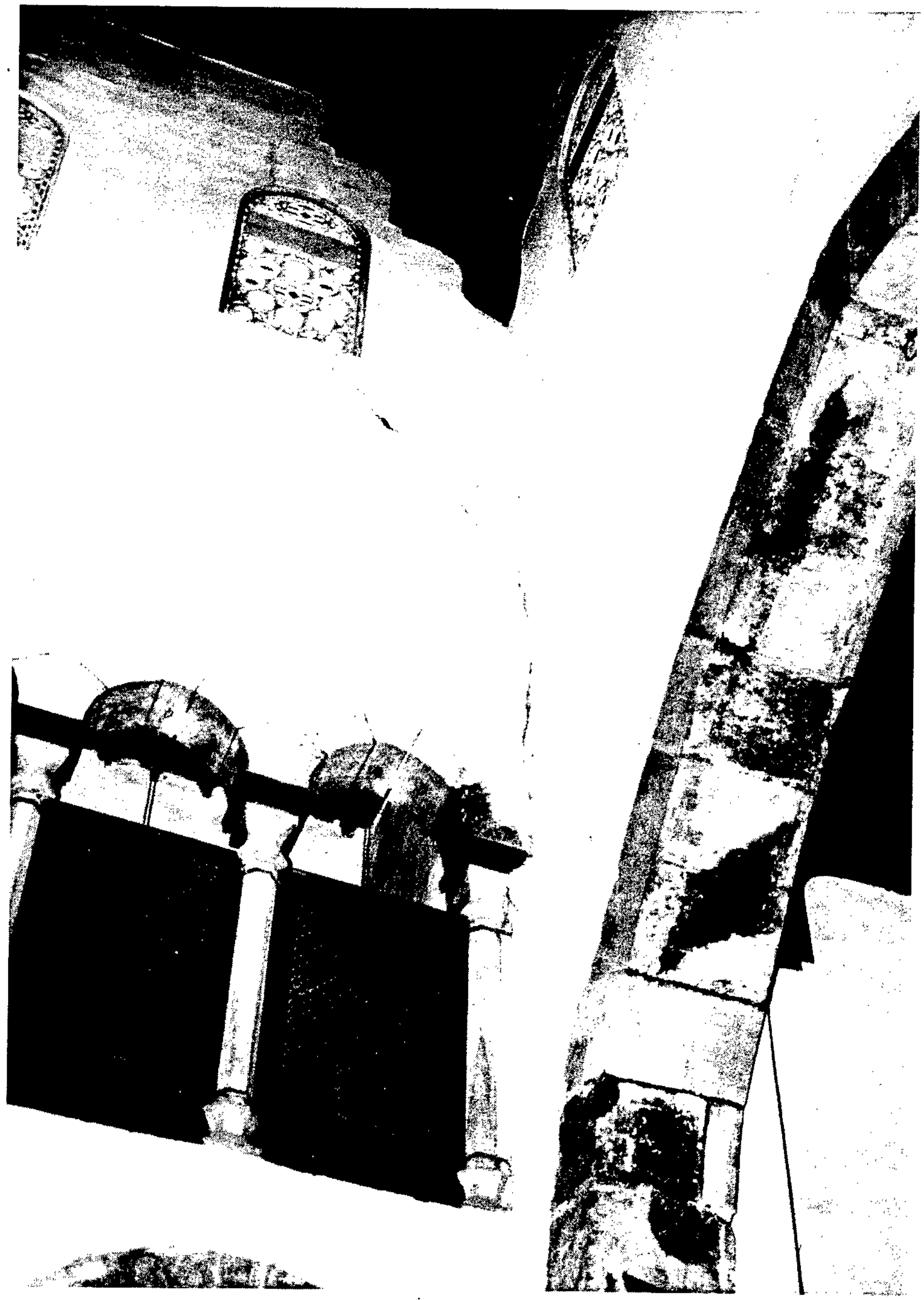


FIGURE 4-23 Western corner of qa'a at Palace of the Amir Beshtāk showing large and continuous crack on southwest wall emanating from corner

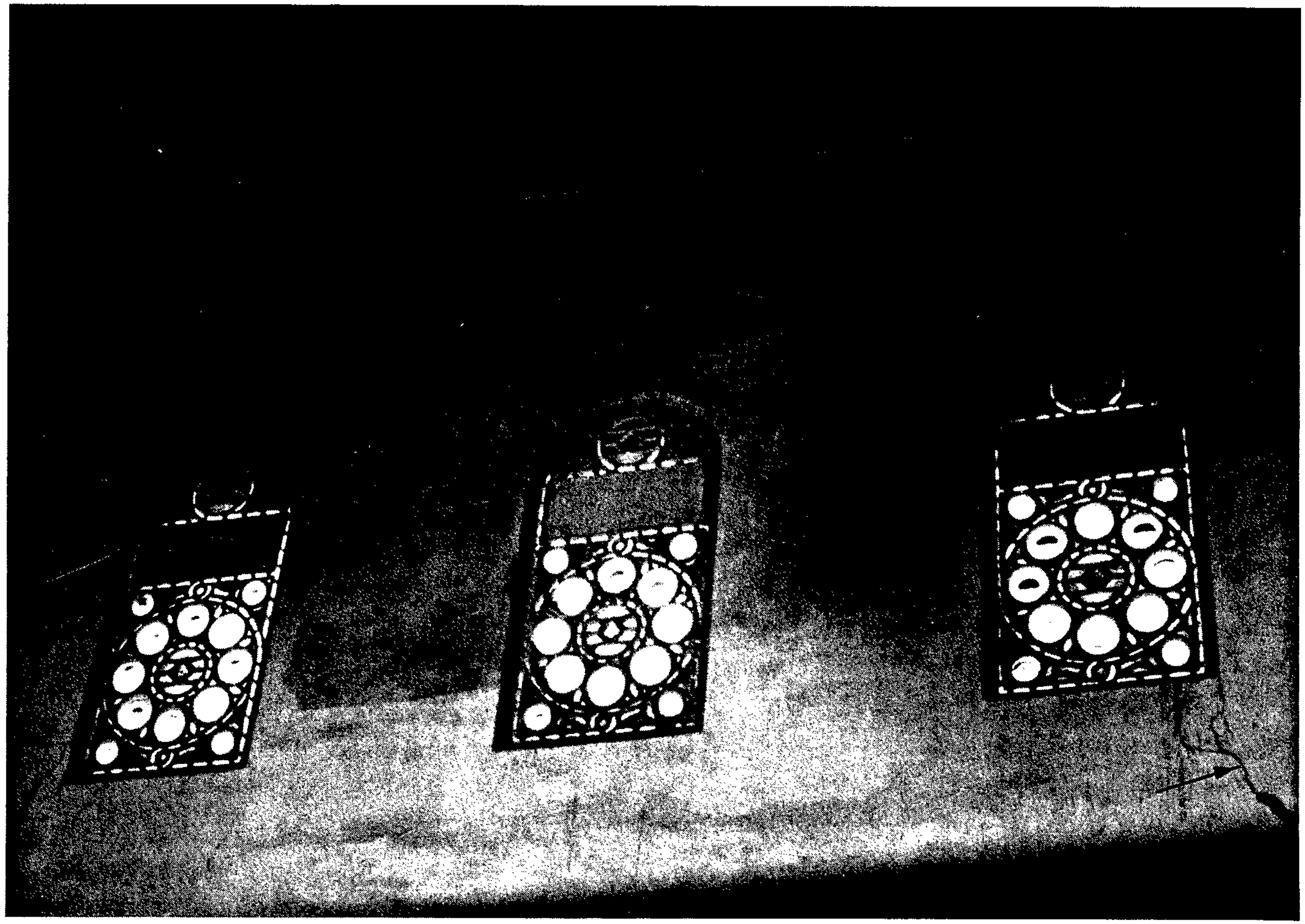


FIGURE 4-24 Southwest wall of qa'a at Palace of the Amir Beshtāk showing extent of large and continuous crack

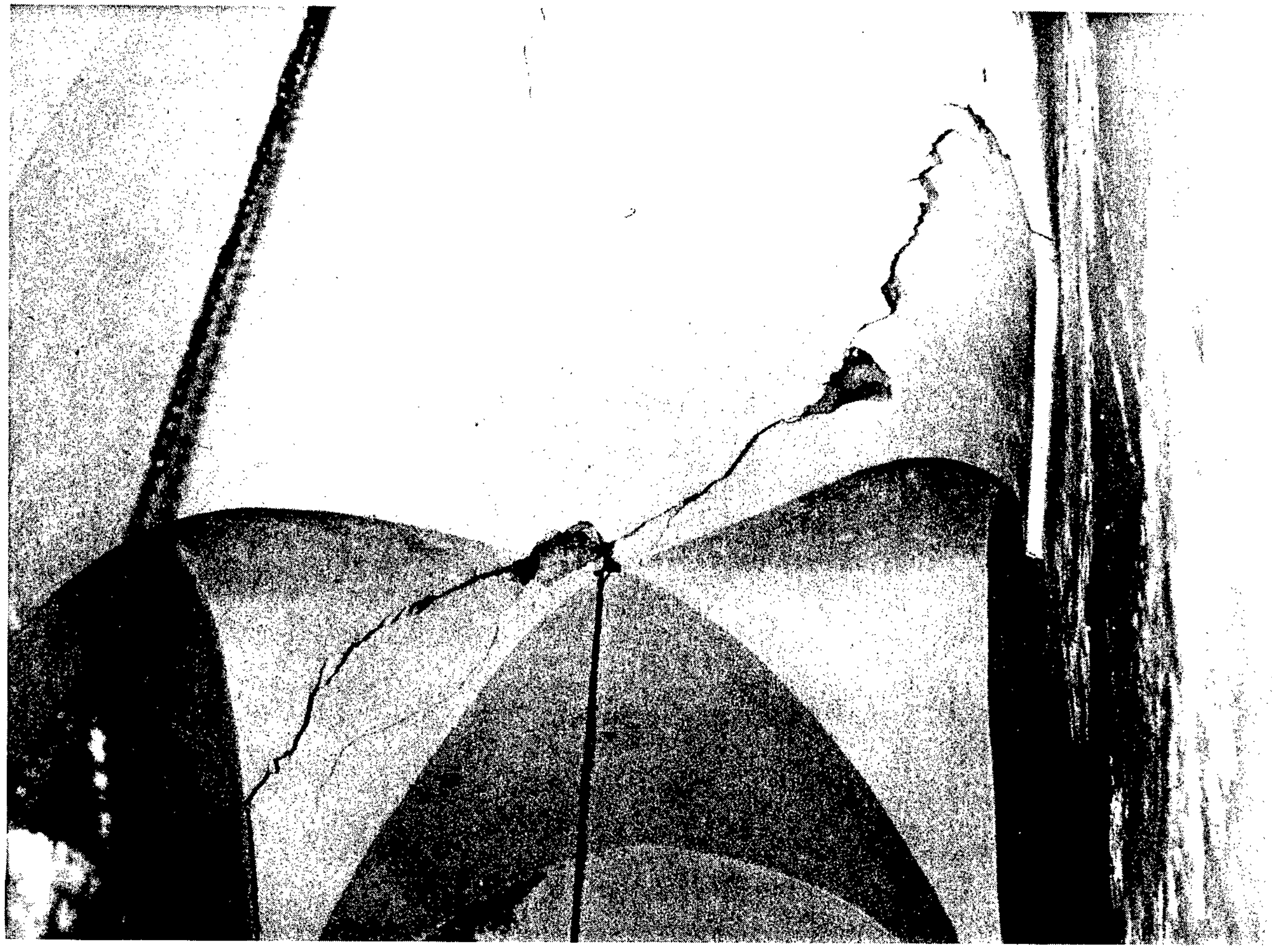


FIGURE 4-25 Ceiling of hallway on northwest side of Palace of the Amir Beshtāk showing large and extensive cracks

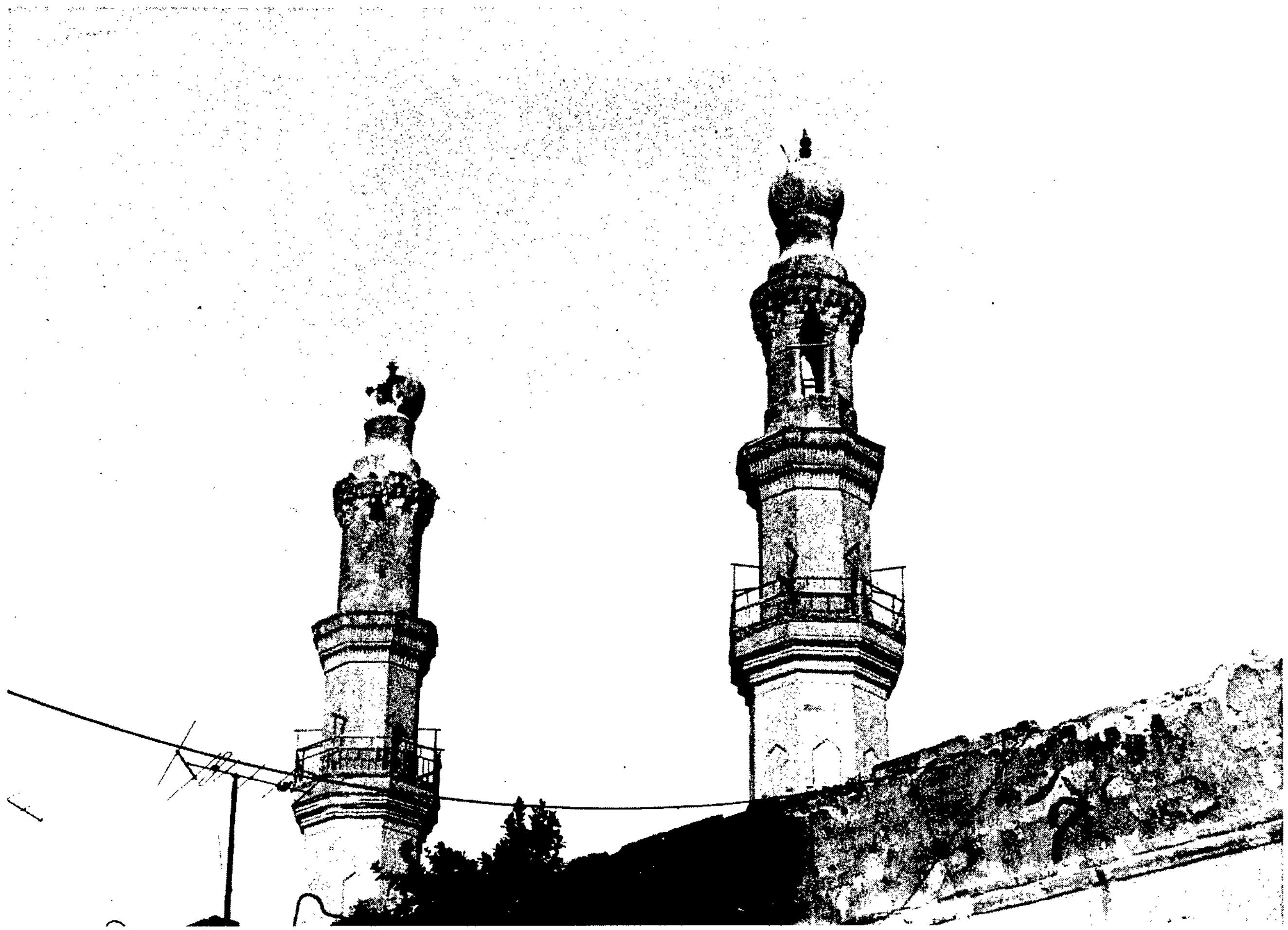


FIGURE 4-26 Minarets of the Mosque of Amir Shaykhū (left) and the Khanqāh of Amir Shaykhū (right) showing damage to the bulb at the mosque

FIGURE 4-27 Arch on the west side of the northwest corner at the Khanqāh of Amir Shaykhū showing downdrop of keystone and two flanking voussoirs

the moderate classification was chosen. Curiously, the EAO and other teams had previously reported no damage here. A floor plan of the complex is shown in figure 4-28 along with perspectives for accompanying photographs.

The earthquake affected the walls and arches around the *sahn*, the eastern (taller) minaret, and the main dome. Small to moderately-sized vertical cracks exist in walls and above arches at a few locations including the wall of a small court of the madrasa. A significant amount of patching with cement was evident on walls and parapets accessible from the roof. The minaret has large vertical cracks between the masonry stone near the base of the minaret as shown in figure 4-29. The minarets present the most critical situation having important cracks and large separations at the bases. Particularly evident are the new and old (subsequently filled) cracks present in the connection between the large minaret and the mosque. Cracks are visible in the interior of the minaret both in the cylindrical wall and in the steps. Having spoken with the people who frequent the mosque, this team discovered that the cracks existed before the earthquake but that the situation worsened considerably as a result of it.

The cracks in the dome are likely to be more critical as they only recently formed and were extended during the earthquake. One mosque attendant reported that cracks were apparent in the main dome about one year before the earthquake. Following the earthquake, small fragments of the dome were removed from the floor indicating additional cracking and displacement. The pattern of cracking at the time of this observation is represented in figure 4-30. There has been some movement between the four arches and walls supporting the dome which is also noteworthy for the interesting wooden hoop detail at its base as shown in figure 4-31. The cracks in the dome begin at the intersection of the walls and the stalactite pendentives and travel upwards at an angle of approximately 45 degrees.

4.2.2.7 Mosque of Ibrāhim Āghā Mustahfizān

Originally known as the Mosque of Aqsunqur (SPARE 1990a) built in 1347, this mosque is also called the Blue Mosque because in the 17th century, during the Ottoman Period, the mosque was heavily restored in 1652 by the Turkish governor Ibrāhim Aghā. The walls were covered with blue tile from Iznik, Anatolia. Adjoining this mosque are structures enclosing the Tomb of Ibrāhim Āghā Mustahfizān and the brother of Sultān Hasan. Antoniou et al. (1980) used this mosque as an example of "neglect and inadequate maintenance." Although the mosque has been seriously damaged, it is likely that a great

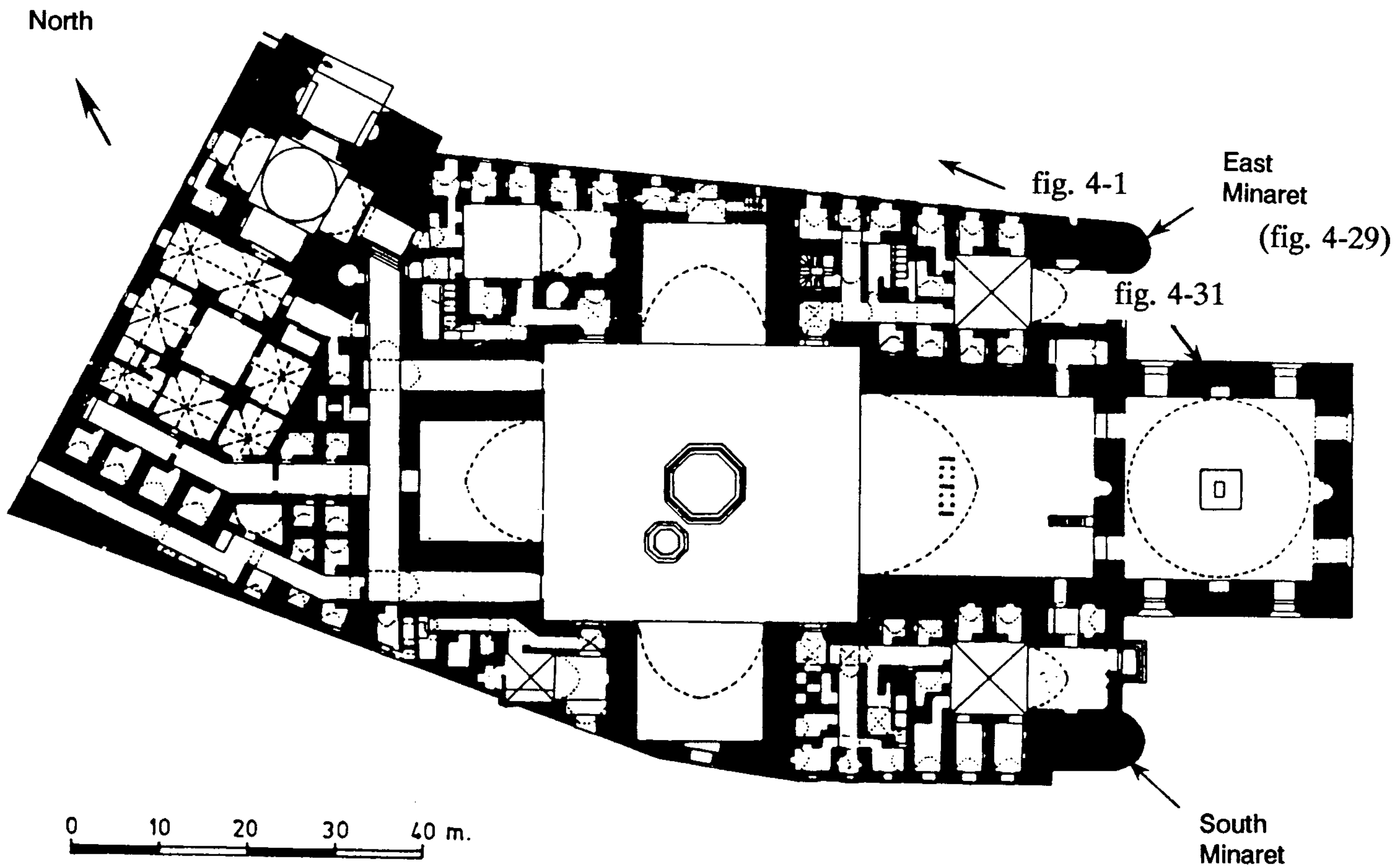


FIGURE 4-28 Floor plan of Mosque, Mausoleum, and Madrasa of Sultān Hasan

FIGURE 4-29 Interior of southern minaret wall at Mosque, Mausoleum, and Madrasa of Sultān Hasan showing large vertical crack

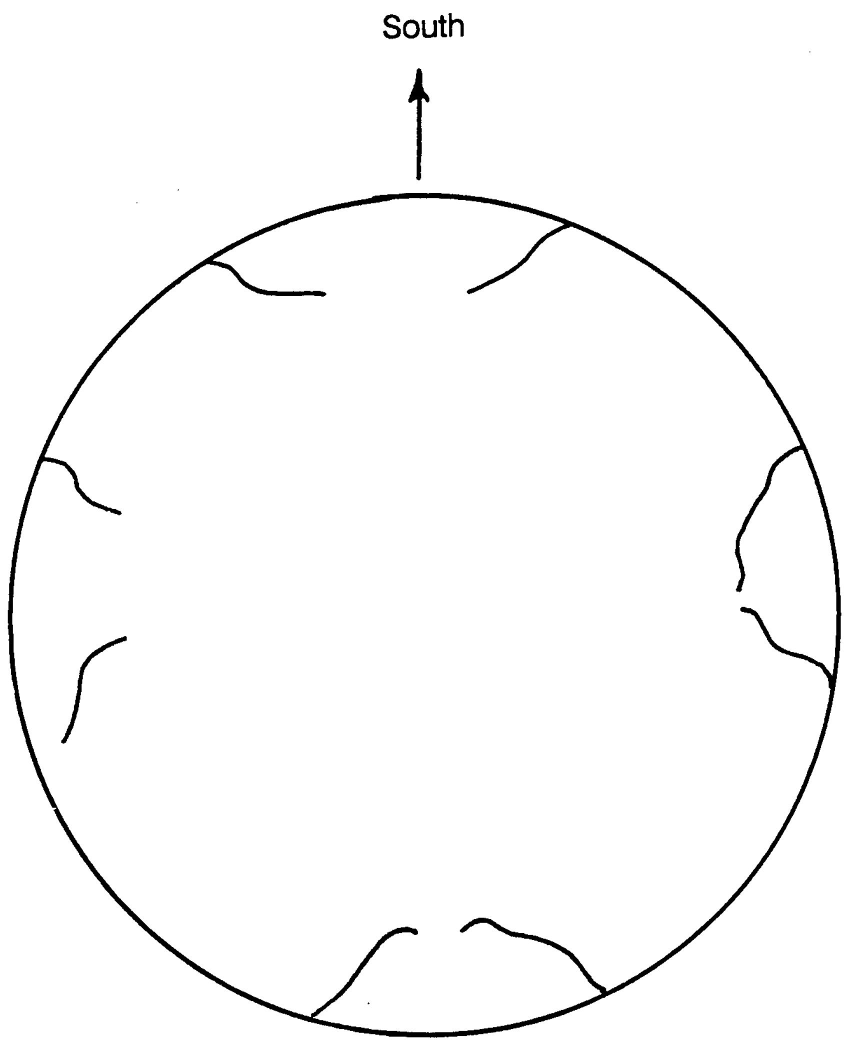


FIGURE 4-30 Sketch of interior crack pattern in dome of Mausoleum of Sultān Hasan looking up

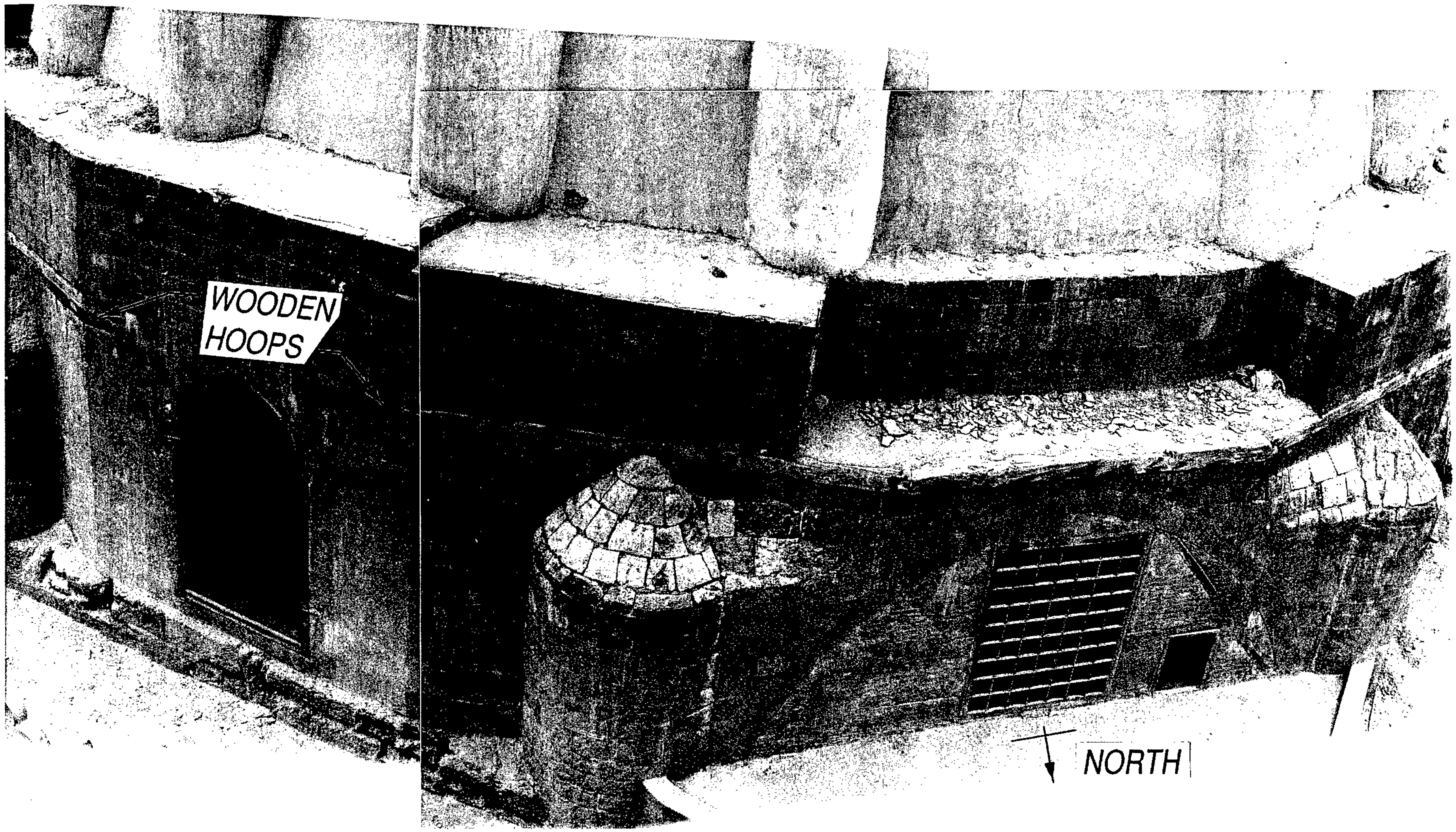


FIGURE 4-31 Exterior of major dome at Mausoleum of Sultān Hasan looking south showing wooden hoop structural support system

deal of this damage existed prior to the earthquake. The mosque attendant reported that many cracks existed prior to the earthquake, but were widened and extended as a consequence of the earthquake. Therefore, the level of earthquake damage is estimated to be moderate.

Damage was observed on the interior and exterior walls, moderate damage to arches and *liwans*, and *minbar*. Some photographs of the damage are shown in figures 4-32 through 4-34. An exterior wall adjacent to the street adjacent to the tomb buckled requiring temporary bracing. The minaret was reported to be leaning slightly because of the earthquake. The wall incorporating the *mihrab* (southeast edge) was found to have several large vertical cracks and be leaning outward. Small domes were severely cracked.

4.2.2.8 Hasan Pasha Tāhir Mosque

The damaged portions of the Hasan Pasha Tāhir Mosque are the minaret and facade. The facade reportedly had some stone separation and a slight bulge prior to the earthquake. Additional cracking and separation occurred during the earthquake, most seriously near the minaret. The mosque was classified as having moderate damage because of the extent of damage to the minaret. Prior to the 1992 earthquake, the minaret was reported to be leaning away from the mosque with the center of gravity about 3 cm from a vertical projection through the base. After the earthquake, the center of gravity is about 6 cm from vertical. A substantial separation crack is present at the upper-most contact between the minaret and mosque as shown in figure 4-35. Close inspection of the central column near the base of the minaret revealed substantial horizonal cracks in the mortar between stones. recent mortar apparently placed as a patch to previous cracking had spalled at these locations.

The deformations and detachment, together with the generally poor condition of the materials, caused alarm at the EAO. Wooden scaffolding had been placed around the minaret following the earthquake and the minaret was in the process of being disassembled with the intention of rebuilding the minaret in a vertical position. The upper bulb had already been removed. It is not certain if any strengthening of the foundation soils or additional structural ties with the mosque were included in this plan. The durability of the ornate platform railing (shown previously in figure 2-1) to this process is questionable. However, the strategy of disassembly was being reconsidered by the EAO following the visit of this team.

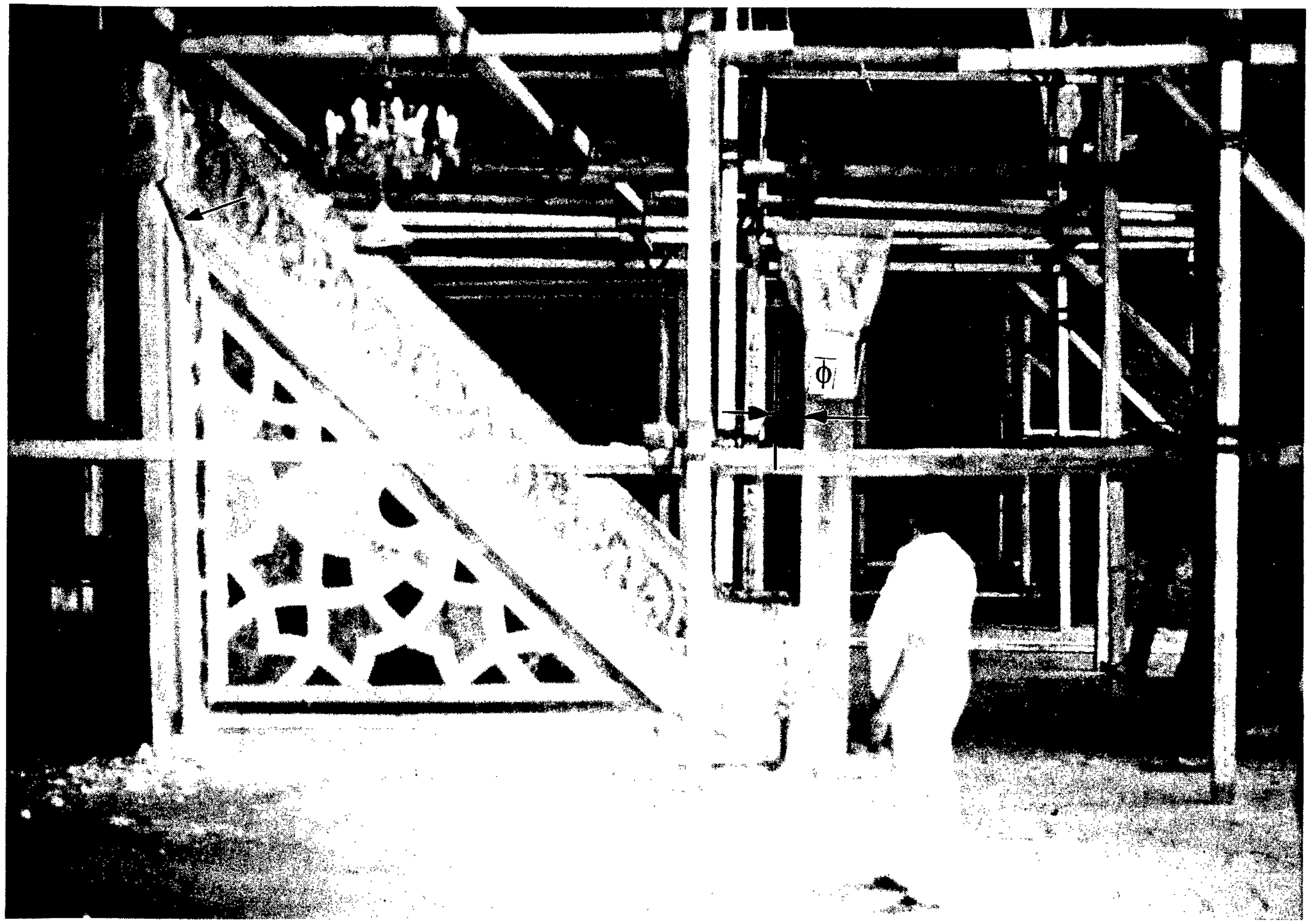


FIGURE 4-32 Minbar of Mosque of Ibrāhim Āghā Mustahfizān showing signs of relative displacement

FIGURE 4-33 Arch at Mosque of Ibrāhim Āghā Mustahfizān showing cracks and bracing

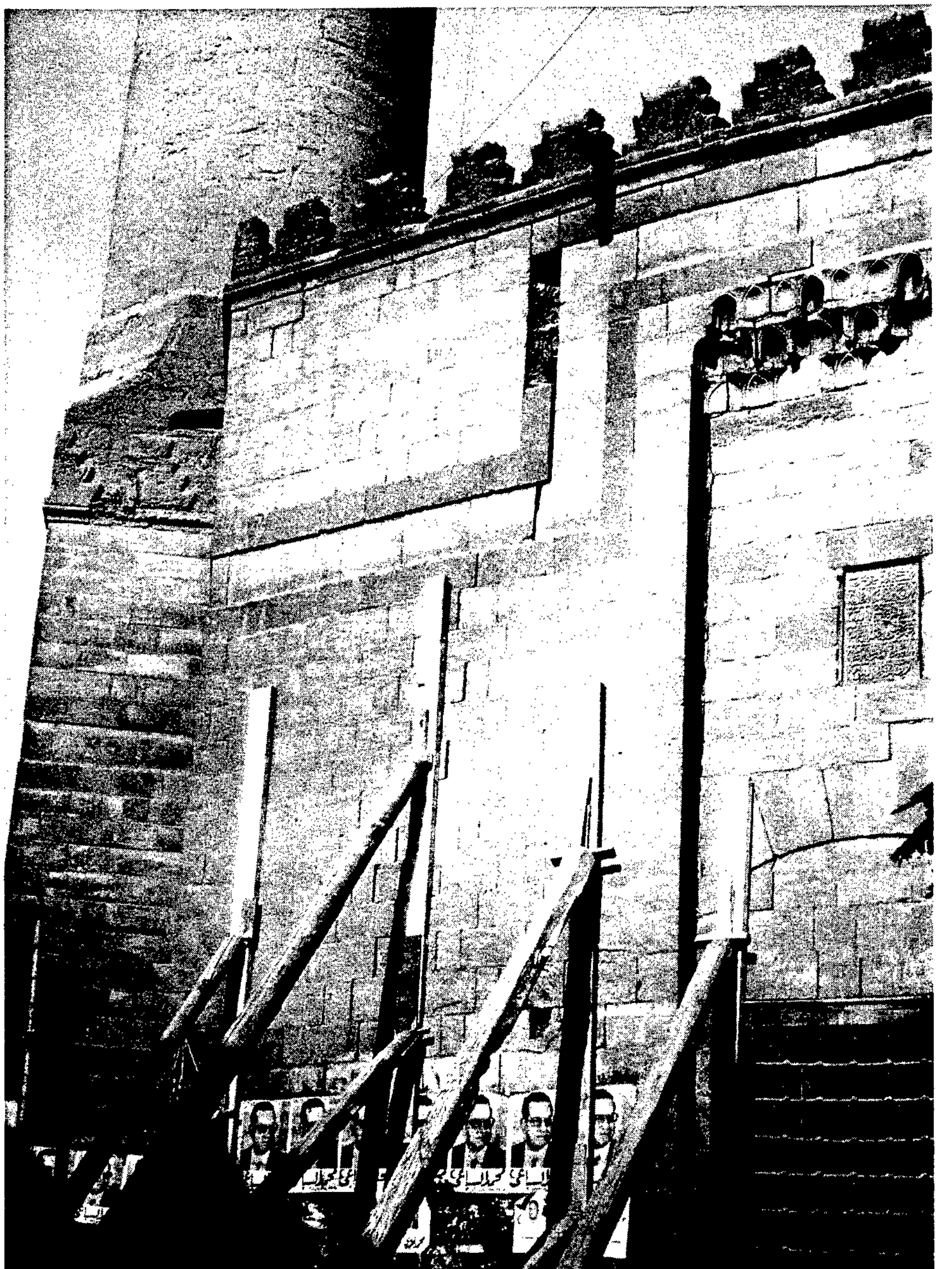


FIGURE 4-34. Exterior wall and base of minaret at Mosque of Ibrāhim Aghā Mustahfizān looking northeast showing cracks, distortions, and bracing

FIGURE 4-35 Base of minaret at Hasan Pasha Tãhir Mosque showing separation between mosque and minaret

4.2.2.9 Coptic Museum (Old Wing)

The old wing of the Coptic Museum is a two-story stucco building that was completed in 1911 adjacent to the el-Moalloqa (Hanging) Church. It was also repaired and modernized in 1984 after being closed for 15 years (SPARE 1984b). The foundations on the south side of the museum rest on the remains of the west gate of The Fortress of Babylon. The date of this fortress is uncertain but part of it may date to 98 B.C. (Aziz-Khalil 1985). The fortress was made of limestone block and a red stone with wall thicknesses of about 3 m. The Nile River flowed through this fortress at the time and recent excavations indicate that a harbor once existed here.

Large cracks were created on the exterior and interior faces of the walls and ceiling at the Coptic Museum, especially on the second floor. Some of the damage is shown in figure 4-36 and 4-37. Most artifacts have been removed and the building is again abandoned. Fortunately, little if any damage was sustained by the pieces of art.

4.3 Severely-Damaged Monuments

Seven of the 29 monuments visited were classified as having been severely damaged by the earthquake. The spatial distribution of these monuments designated in Table 1 can be seen in figures 2-3 through 2-5. Surprisingly, most of these monuments have been recently restored or repaired. Most restoration efforts apparently focused on cosmetic treatments; engineering studies of these monuments, especially analysis of earthquake response, apparently were not undertaken.

4.3.1 el-Moalloqa Church

El-Moalloqa Church (also called the Hanging or Suspended Church) is the oldest monument visited by the reconnaissance team. One attendant reported that the church has suffered damage from at least four to five earthquakes in the past and was repaired each time. The most recent restoration was completed by the EAO in 1984 at a cost of about 2,000,000 Egyptian pounds (about $500,000 U.S.). A floor plan of this church is shown in figure 4-38. Despite the known history of earthquake damage to this church and age of the foundation system apparently no seismic retrofit nor foundation strengthening were incorporated and this church incurred severe damage from the earthquake. Some of the documented damage and related causes are described below.

FIGURE 4-36 Exterior wall of Coptic Museum looking north showing large cracks

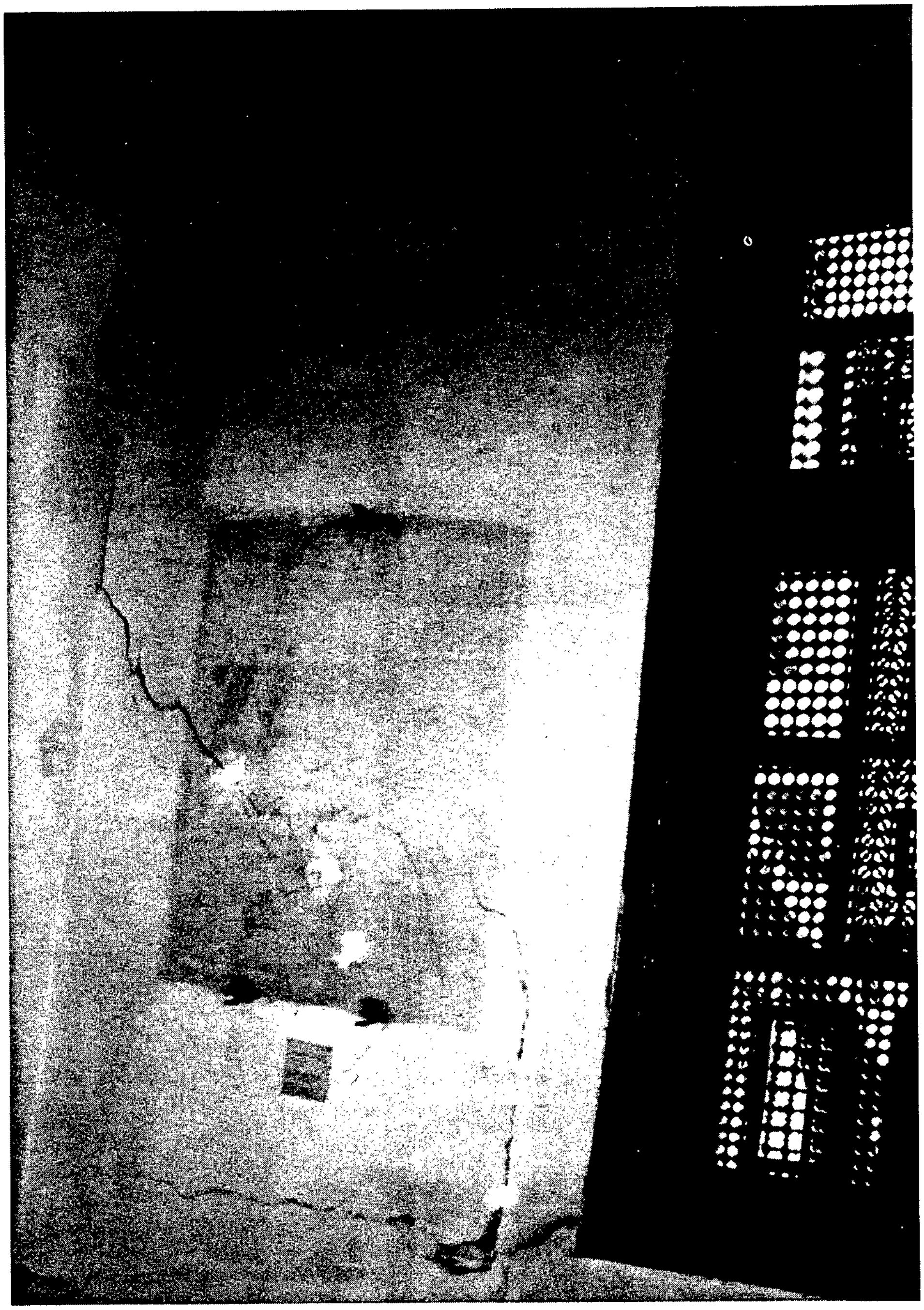


FIGURE 4-37 Interior wall of Coptic Museum showing large cracks

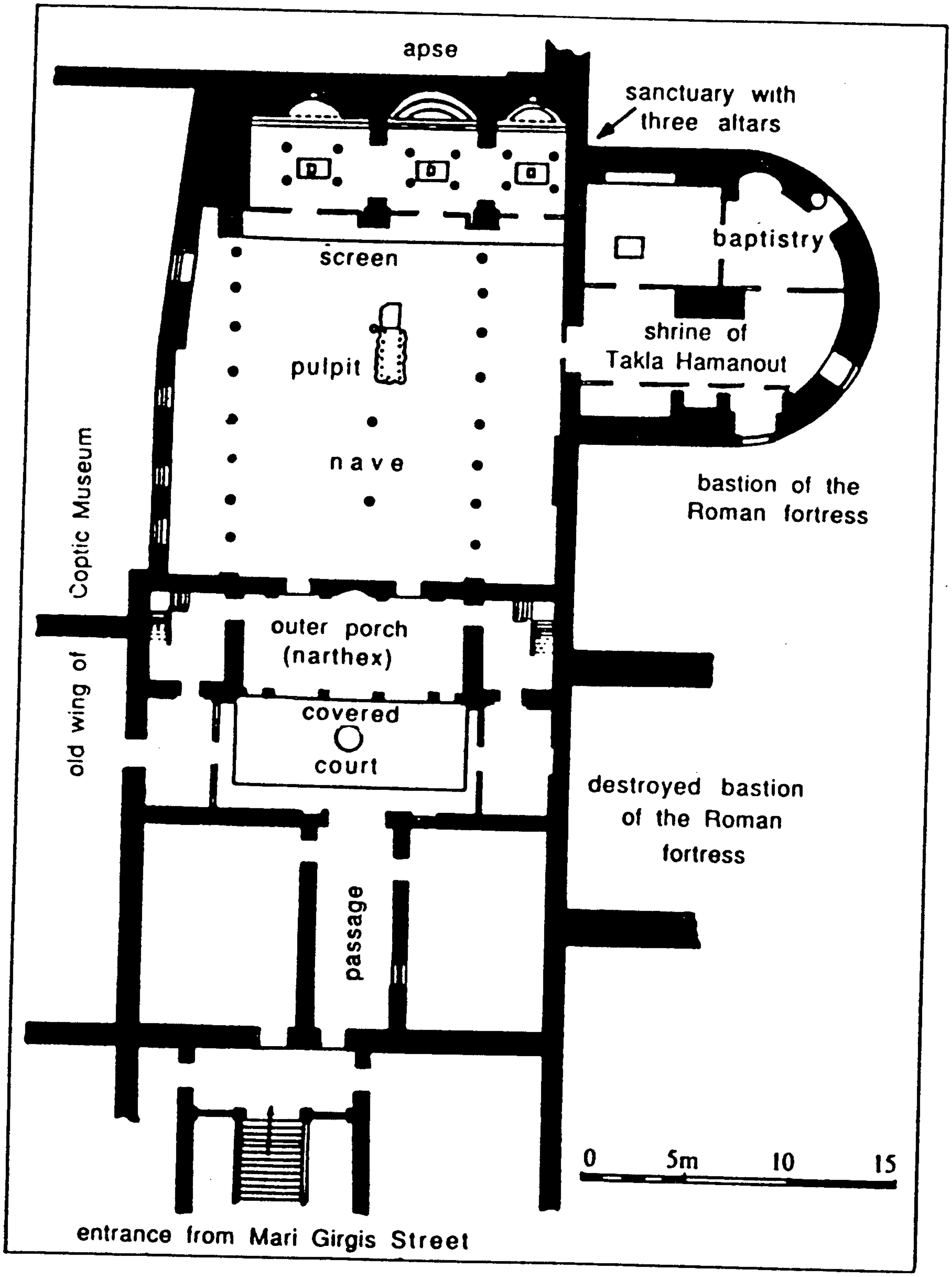


FIGURE 4-38 Floor plan of el-Moallaqa Church (Kamil 1990)

The structural foundations of el-Moalloqa Church rest on the open-air remains of the west gate of The Fortress of Babylon, in particular two bastions (see previous discussion about Coptic Museum). Palm wood joists span the bastions and other massive foundation walls. The church maintenance people reported that for the past eight years about 1.5 m of standing water has been present at the base of the foundation walls. Increased moisture in this trapped airspace has been absorbed into the ancient palm wood. Consequently, the palm wood, already over 2000 years old[++], is deteriorating more rapidly and can now be dug into easily with a fingernail. A contractor was in the basement shoring arches in the foundation walls at the time of the team's visit.

The church incurred damaged throughout. Large cracks formed in walls and through arches in the nave. The floor in the nave underwent distortions and has a slope of up to 8 percent. The parapet wall on the roof and the secondary roof cracked. Figures 4-39 through 4-41 show some of the damage.

4.3.2 Minaret of as-Saghir Mosque

The upper four to five meters of this minaret separated and fell onto the roof and portal steps during the earthquake. The remains of the minaret are shown in figure 4-42. This minaret is rather short and had a varying cross-section from square at the base, to octagonal, to cylindrical with a bulb and finial at the top.

4.3.3 Mosque of al-Ghūri

This mosque was built in 1503. There is severe cracking throughout the mosque and the underlying problem appears to be the occurrence of large soil settlement, that may have been exacerbated by the earthquake. Restoration efforts were in progress at the time of the earthquake and much of the damage existed prior to the earthquake.

The most serious problem is reported to be the detachment and leaning of the minaret from the mosque resulting in a large crack. A temporary structure has been erected to halt the leaning of the minaret and the current project is probably to dismantle and rebuild the

---

[++] Radio-carbon 14 dating of the wood suggest that the wood originated from 150 to 140 B.C. It was not uncommon to re-use wood in the construction of Coptic structures. (Kamil 1990)

FIGURE 4-39 Interior wall of el-Moalloqa Church showing cracks and deformations

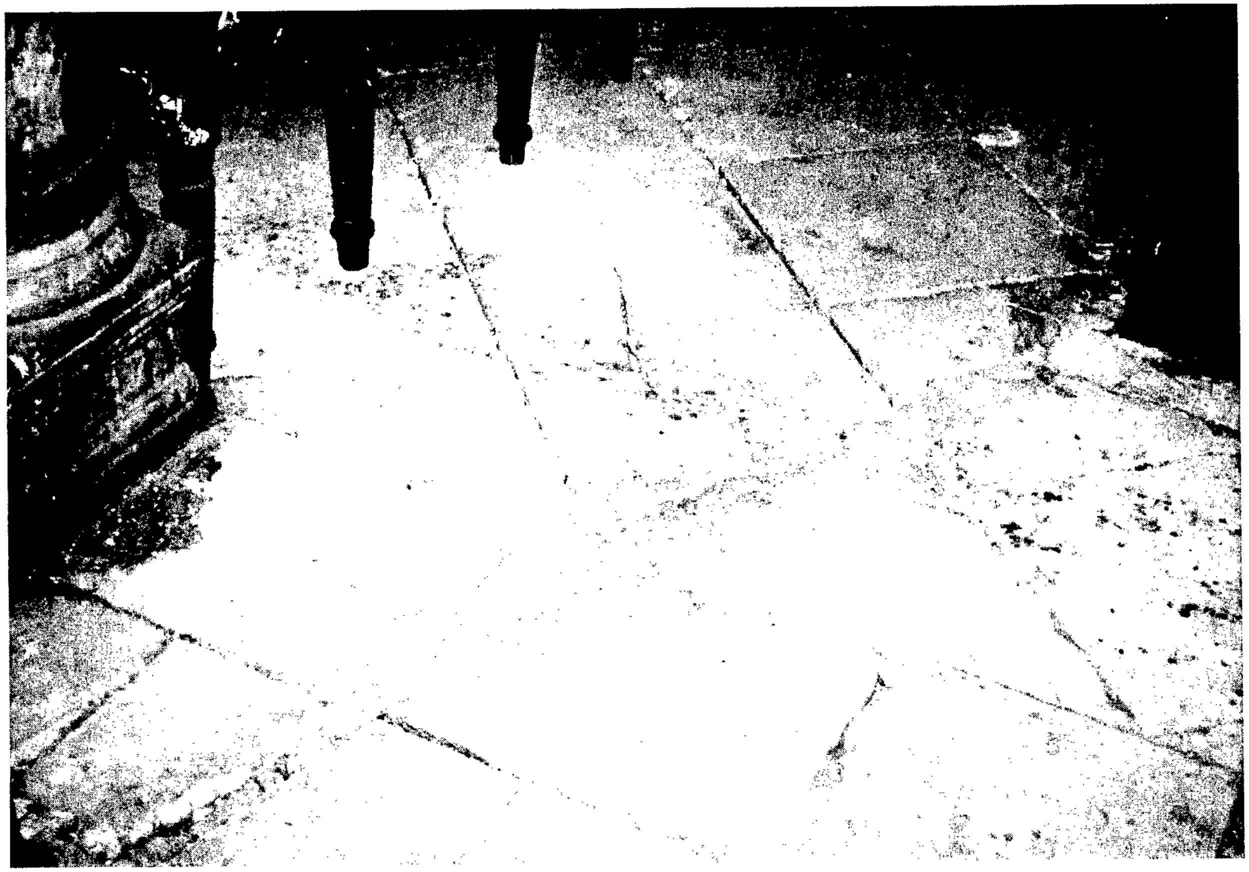


FIGURE 4-40 Floor of el-Moalloqa Church in nave showing cracks in area of large depression

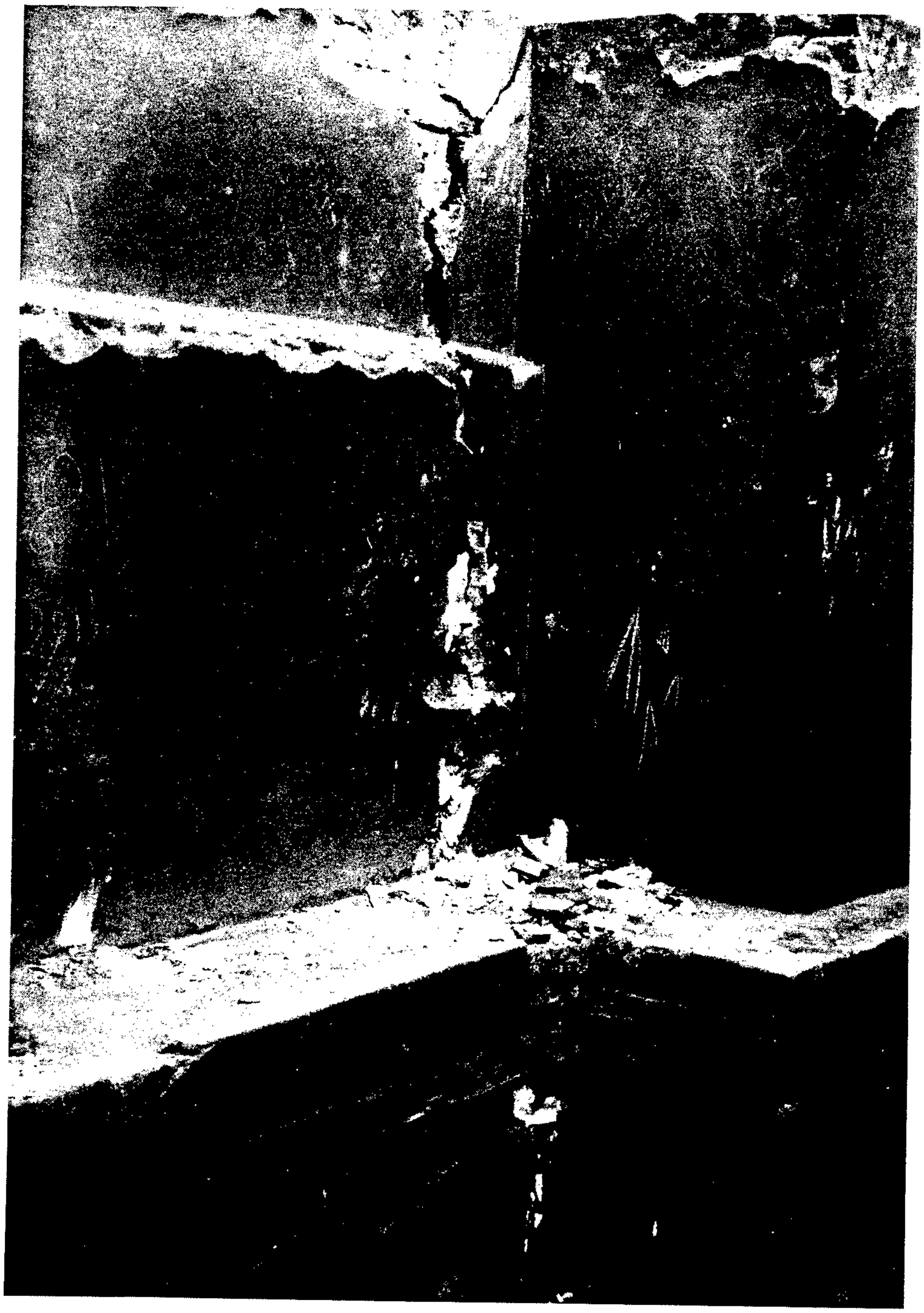


FIGURE 4-41 Northern parapet wall of el-Moalloqa Church looking east showing cracks and deformations

FIGURE 4-42 Broken minaret of as-Saghir Mosque looking east

minaret replacing the blocks which have deteriorated. In the main hall of the mosque, the floor is sagging on the order of 0.3 m as shown in figure 4-43.

A contractor was in the process of rebuilding large interior arches with the same stones. Close observation of these arches indicated that it is the movement of the walls that created problems for the arches. The arches normal to the northeast-southwest direction were affected more. One of these arches is shown in figure 4-44. Cracks existing on tops of the arches were opening creating a significant increase in the compression of the reduced section. However, the main problem is not the resistance of individual structural elements, but the global behavior of the monument.

4.3.4 Mosque of ad-Dashtũti

Most of the damage to this mosque was caused by the collapse of a small-diameter (about 4 m) dome. Pieces of the dome fell through the roof in two places as shown in figure 4-45. After the dome broke, pieces fell on either side of the clerestory monitor and also through the drum of the dome. Additional damage was noted to the masonry over the arch to the entrance portal.

4.8.5 Bayt as-Sihaymi

This house has three stories and was built in two sections. The first section was roughly rectangular and was completed in 1648. A U-shaped addition with an extension to the north was placed on the west side of the existing building to make a courtyard in 1796. This house incurred extensive damage to interior and exterior walls, ceilings, floors, and supporting arches. Some of the damage is shown in figures 4-46 and 4-47.

This building has undergone significant deformations both in the foundation and the structure. Manifestations of the deformations include: two large vertical cracks and deflection of a wooden arch in the men's reception room on ground floor in west portion, vertical cracks at entrance wall and above a door in women's reception area, and a transverse crack in the massage room of the west (newer) portion and buckling of a courtyard wall, cracks in walls of a corridor and staircase, large cracks at southeast corner of men's guest room and in area with high bay ceiling, and deflection of ceiling in the east (older) portion.

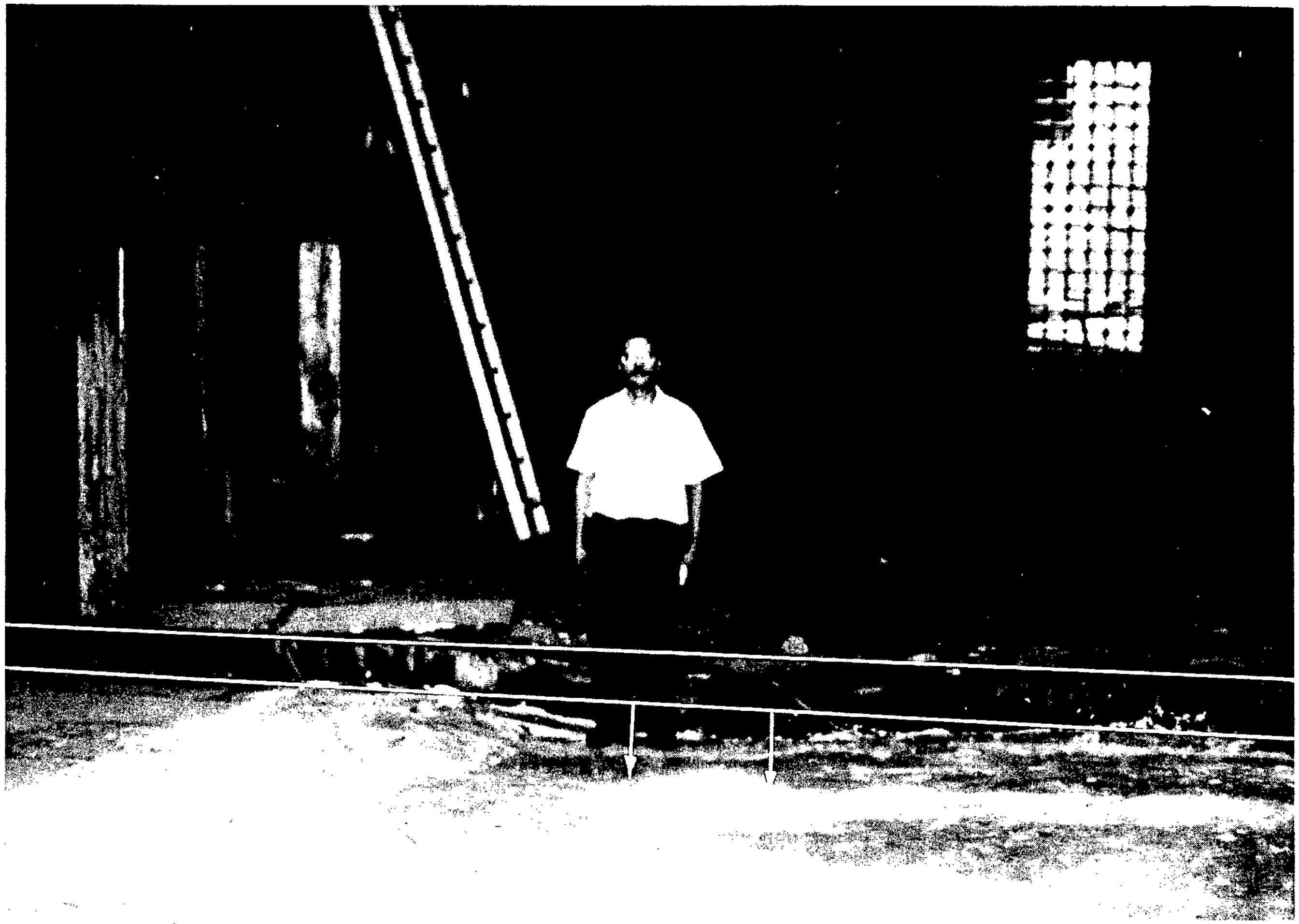


FIGURE 4-43 Floor of Mosque of al-Ghūri looking southwest showing depression

FIGURE 4-44 Main arch of Mosque of al-Ghūri looking northwest showing cracks and distortions

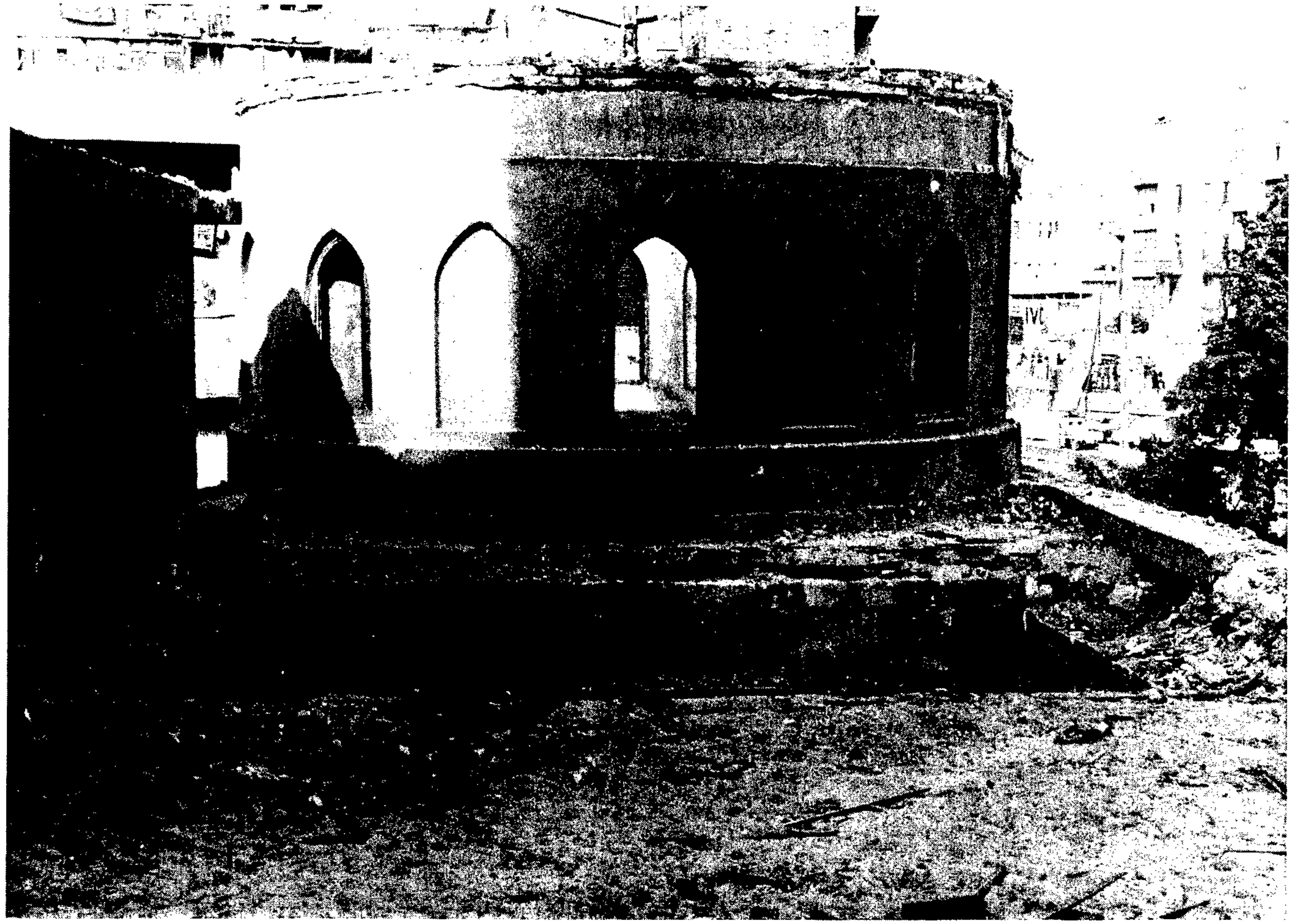


FIGURE 4-45 Collapsed dome of ad-Dashtūti Mosque looking southwest showing damage to roof

FIGURE 4-46 Exterior walls of court at Bayt as-Sihaymi showing cracks and missing stucco

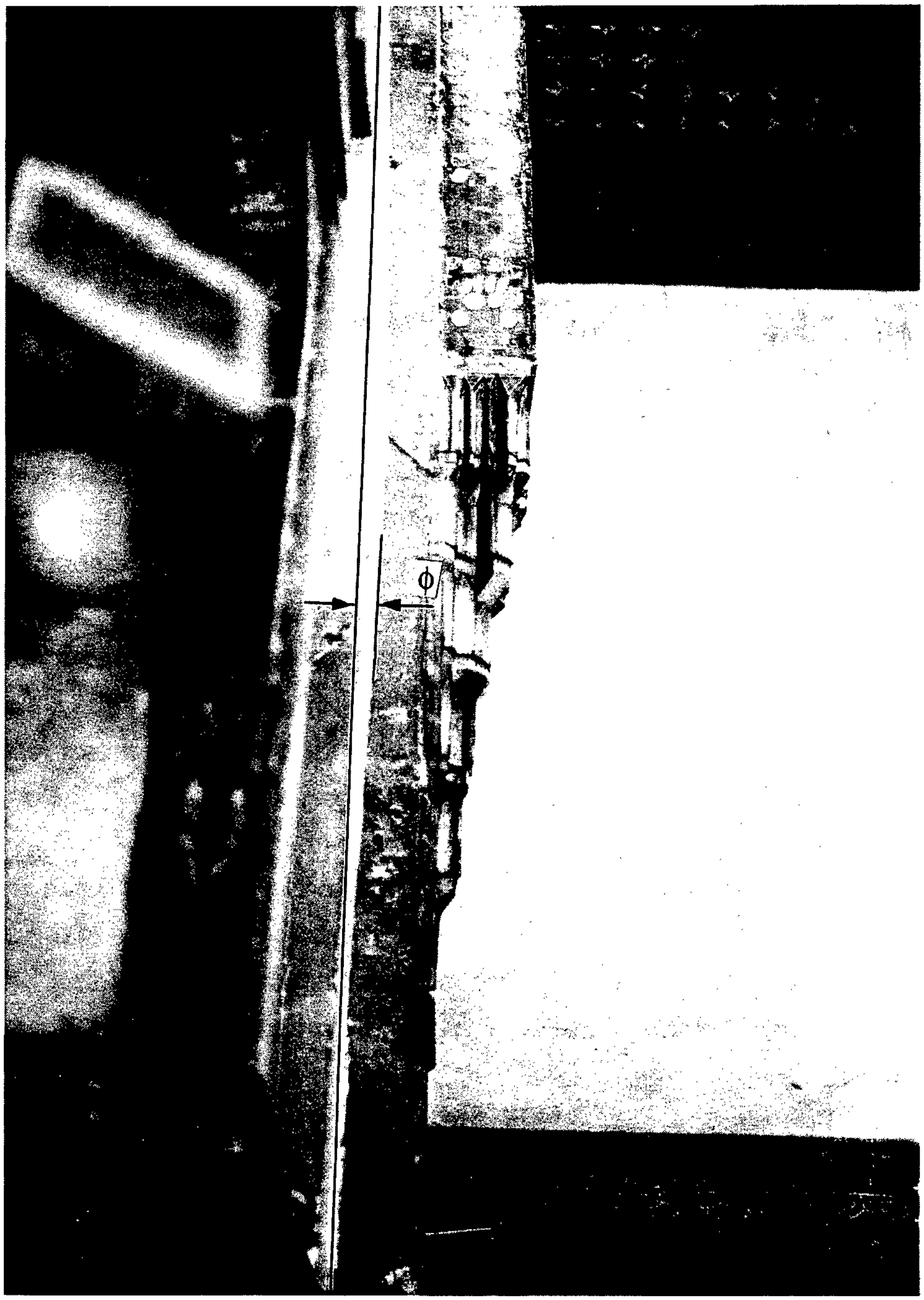


FIGURE 4-47 Interior wall and column at Bayt as-Sihaymi showing out-of-plumb column

4.3.6 Saraya el-Adl

The two most recent monuments with severe damage are located at the Citadel. These are the Saraya el-Adl and the Mint. A more detailed map of the Citadel is provided in figure 4-48. The Saraya el-Adl was the location of the court proceedings. This skeleton of a building is adjacent to, and the east of, the el-Gawhara Palace at the Citadel. It is a two-story structure (although only a facade exists on the front of the second floor) built with the European style favored at the time. Timber and mortar construction of the walls is visible in the remains of wall burnt in a fire. The primary components of the earthquake motions appear to have been in the out-of-plane direction.

There are serious cracks that are clearly visible on the interior and exterior of longitudinal building walls. Some examples are shown in figures 4-49 and 4-50. There is evidently a loss of anchorage of one of the ties at the top of the courtyard stair. The floor structure within the palace varies from a traditional timber construction (with suspended ceiling) to a newer reinforced concrete slab, probably installed to replace the section of the floor consumed by fire or deterioration. Large vertical cracks exist in piers and large horizontal cracks exist at the contact between a concrete ceiling of the first floor and the walls as shown in figure 4-51. It is interesting to note that the timber floor and its adjacent masonry walls of the three structural bays at the northeast end of the building (just northeast of the portico) fared better than the concrete slab due to its lightness and the fact that the concrete has not been well anchored into the walls. The uneven stiffness of the concrete and wooden sections of the floor and the greater mass of the concrete floor pounding the facade in the out-of-plane direction caused the greater damage at the northeast end of the building. The serious nature of the damage is attributed to this replacement mismatch.

4.3.7 Mint at Citadel

The Mint at the Citadel is a small, one-story, stucco-covered brick structure located near the Bāb al-Gabal. Damage to walls and small domes of the structure was extensive but very isolated to the southwest corner as shown in figures 4-52 and 4-53. External bracing had been placed but the cracks seemed to widen over the week of the team's visit. The combination of the severity and isolated nature of this damage suggests that fill and/or rubble exists beneath the foundation at this corner. Underpinning of the foundation may provide a means to correct this problem and prevent severe damage in the future.

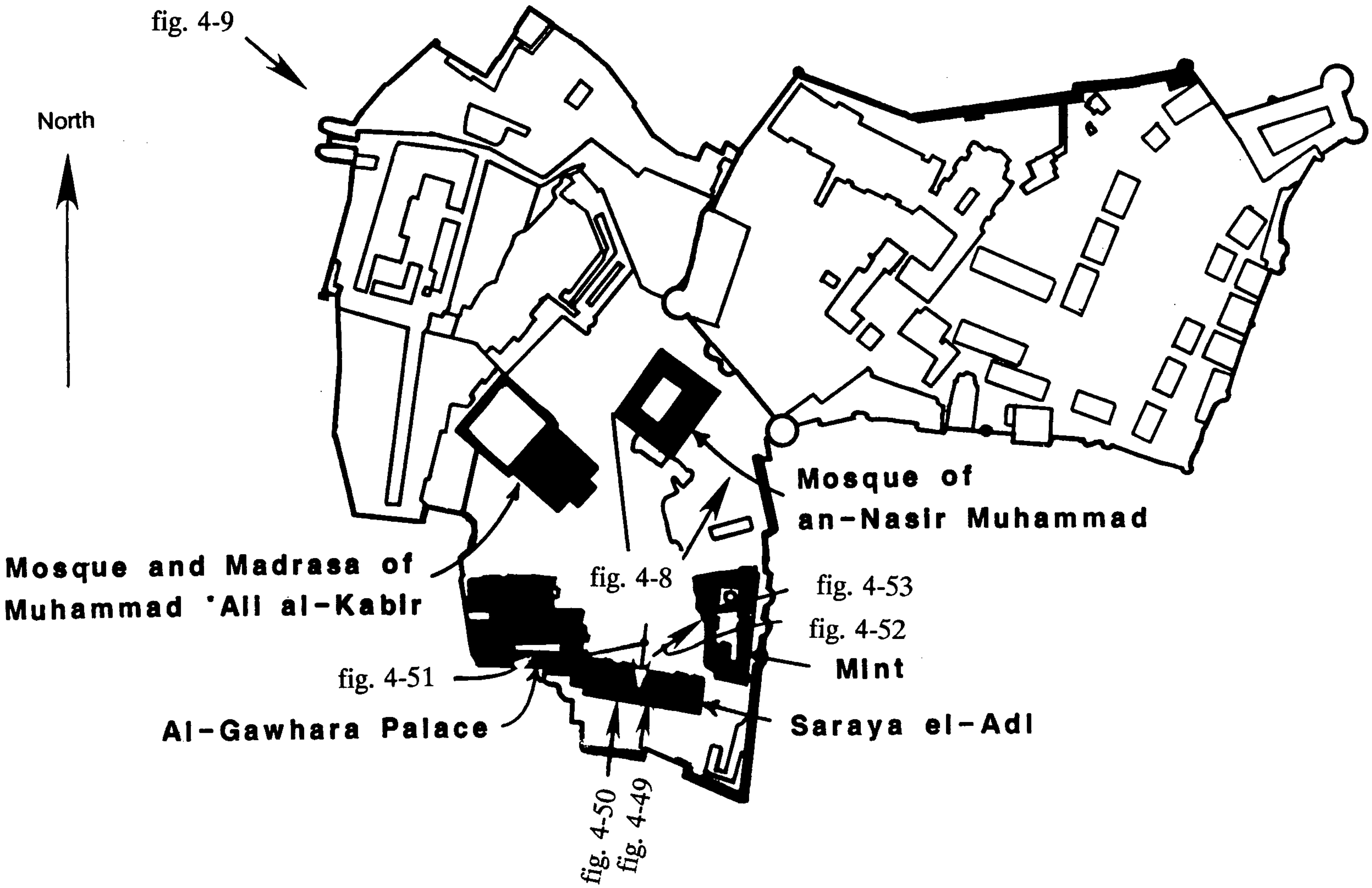


FIGURE 4-48 Map of Citadel (adapted from Egyptian Association of Friends of Antiquities 1980)

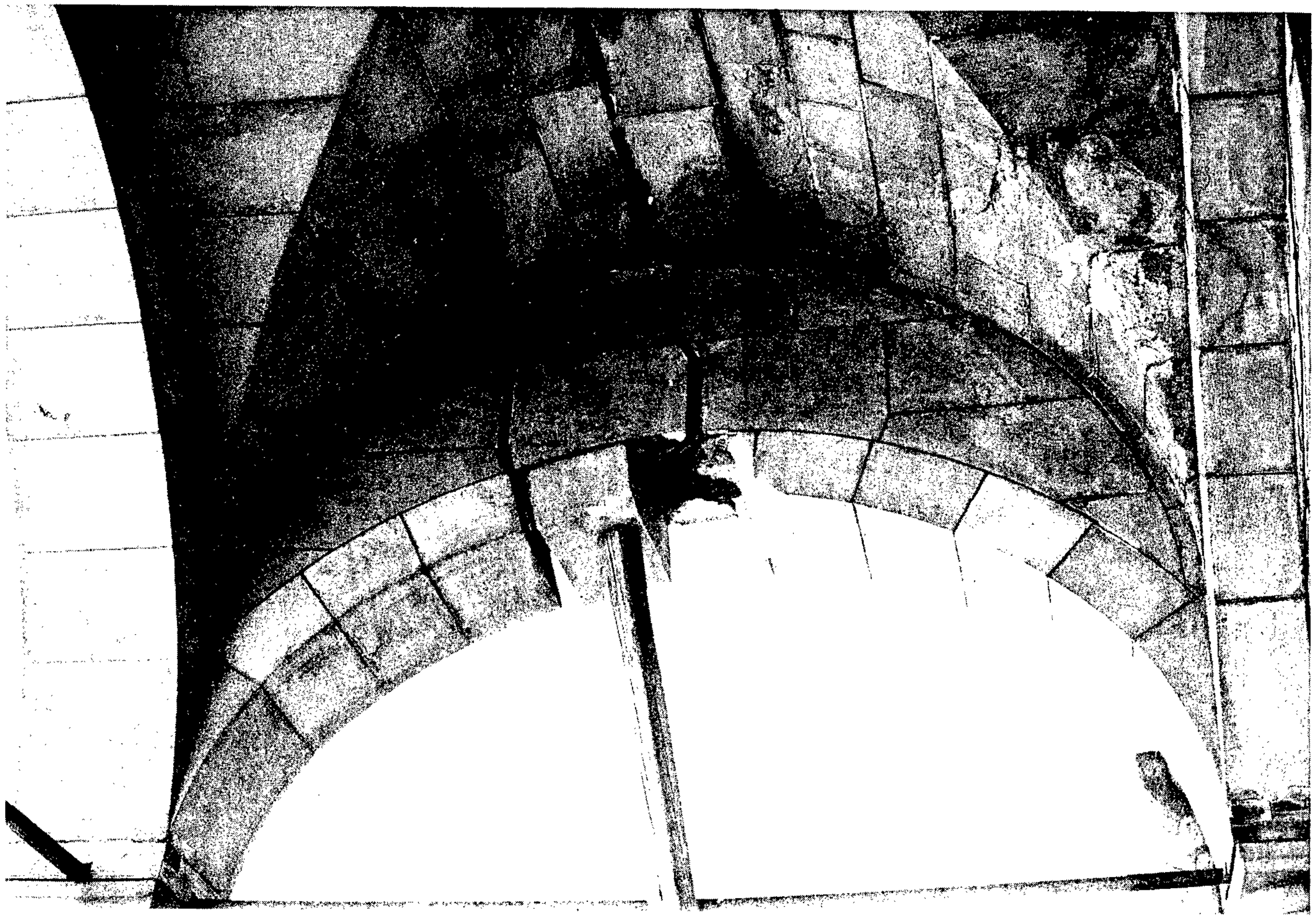


FIGURE 4-49 Arch of portico to Saraya el-Adl at Citadel showing missing stone, large cracks, separation, and distortion

FIGURE 4-50 Back wall of Saraya el-Adl at Citadel showing missing stones, large cracks and separation

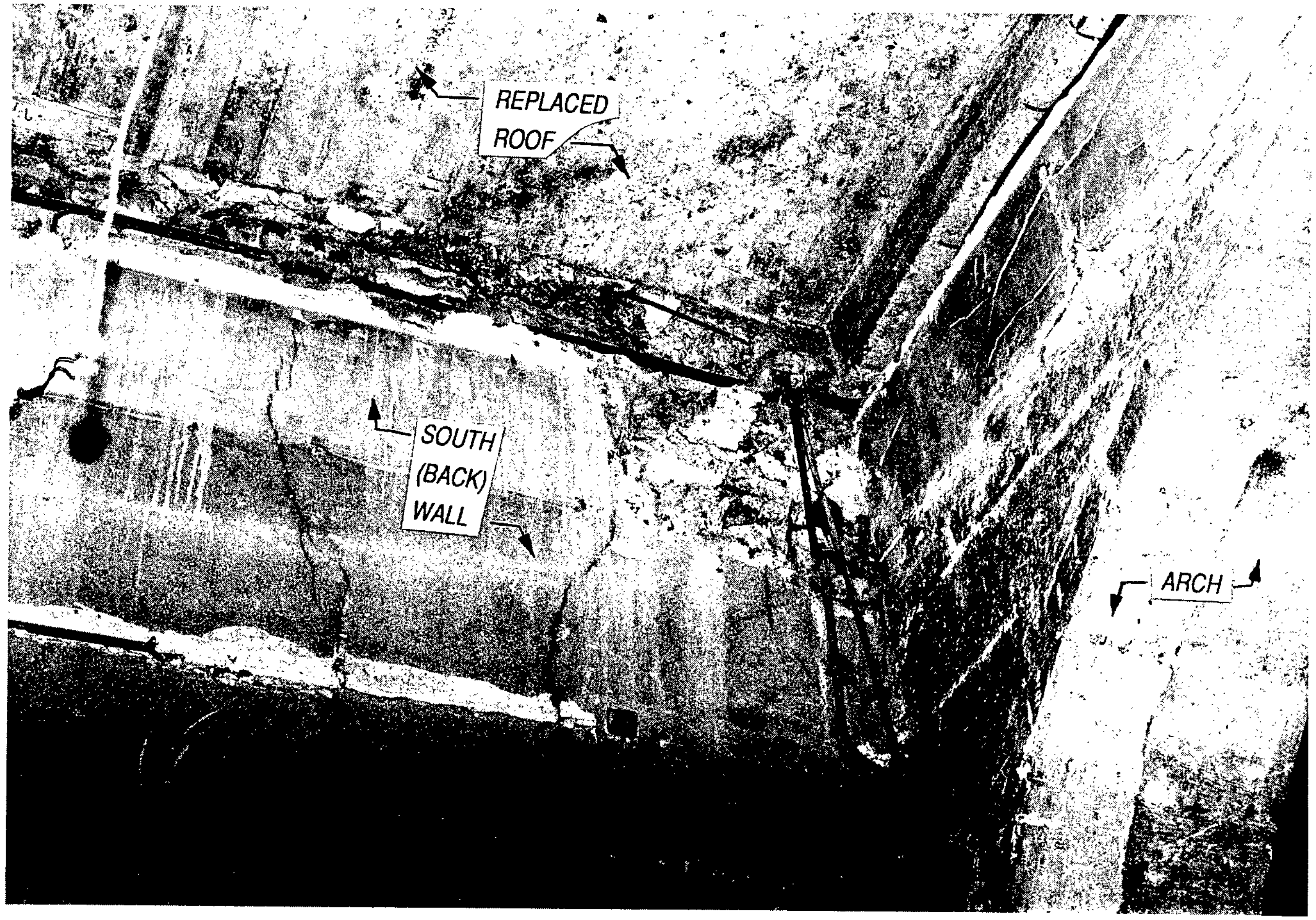


FIGURE 4-51 Interior south wall of Saraya el-Adl looking up at contact between wall, arch, and concrete ceiling showing cracks, separation, and distortions

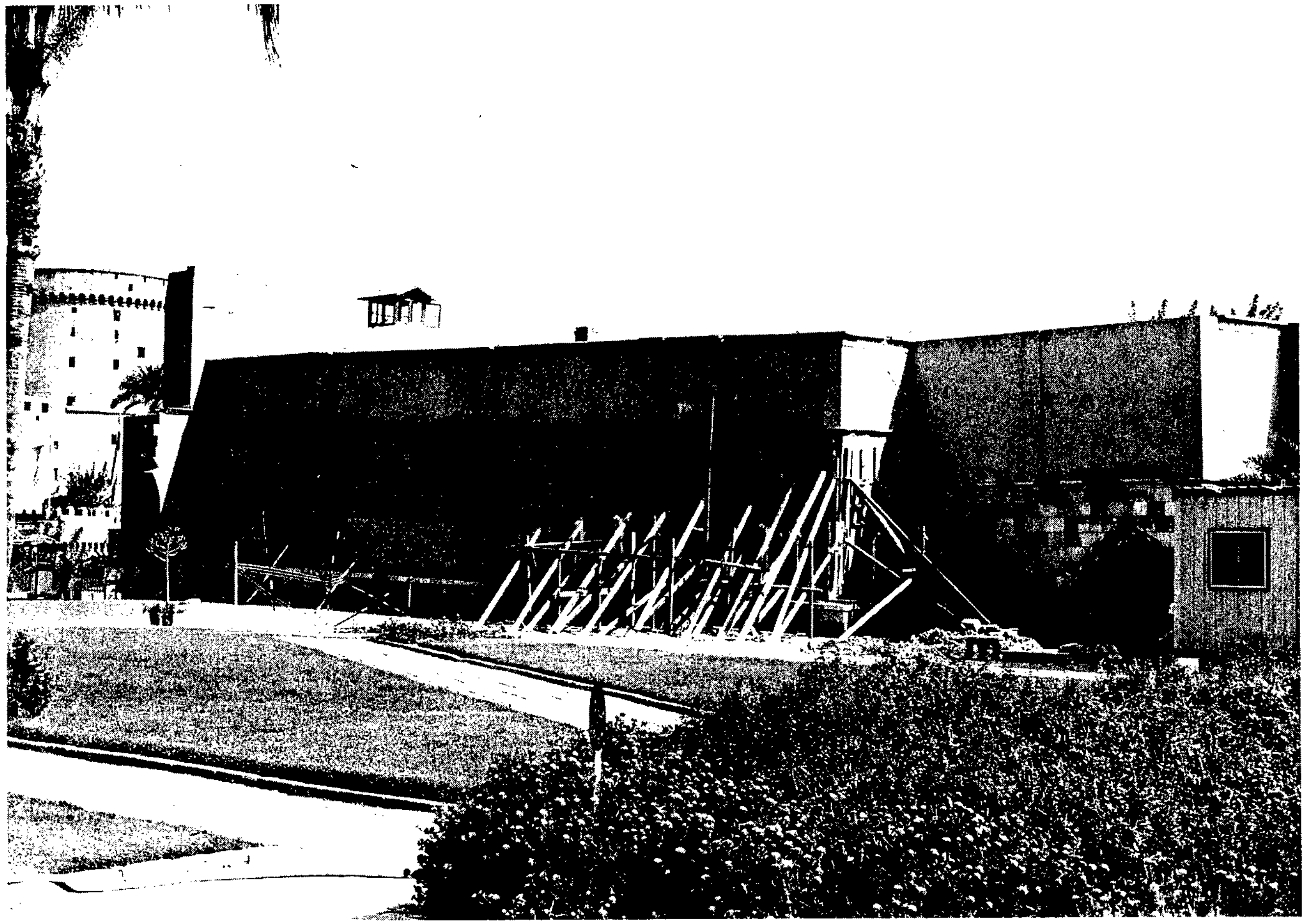


FIGURE 4-52 Collapsed southwest corner of Mint at Citadel showing large crack and separation and external bracing

FIGURE 4-53 Interior minor dome near southwest corner of Mint at Citadel showing large cracks and separation

SECTION 5
RECOMMENDATIONS FOR PRESERVATION STRATEGY

The reconnaissance team developed some recommendations regarding the preservation and restoration of historic monuments in Cairo during the course of their observations. These thoughts and ideas focus on the importance of properly defining and solving technical issues. First, the need for developing an overall preservation strategy is presented.

5.1 Statement of Need

The NSF workshop in Istanbul, Turkey, focused on the importance of preservation strategies and defining research necessary to develop a comprehensive plan for monuments (Sykora, Hynes, and Karaesmen 1993). Most of these findings are applicable to monuments elsewhere, including Egypt. The process of developing a strategy and performing related research is necessarily inter-disciplinary and should include the expertise of professionals worldwide.

Stating the need for a preservation strategy regarding Coptic and Islamic monuments in Cairo is not new. This effort first began in 1881 by the Khedivial government's Committee for the Conservation of Monuments of Arab Art (Rodenbeck 1992). It was this committee who began to index the Islamic monuments at the turn of the century (Egyptian Antiquities Organization 1980). In 1952, the EAO was formed and has continued the mission to protect Coptic and medieval Islamic buildings. Several individuals (e.g., Bergne 1978) and independent organizations such as SPARE have also attempted to raise an awareness of the need to preserve historic monuments.

Egyptian officials have been made aware of the threat to the monuments and attempts have been made to establish a preservation strategy (misc. SPARE newsletters). However, a comprehensive program has yet to be adopted. The notoriety brought by damage to the monuments caused by the combination of poor structural condition and the moderate earthquake may provide the impetus to make a commitment. For that reason, some recommendations about establishing a program are provided.

A comprehensive preservation strategy should also include an emergency response plan for monuments. Clear and concise instructions should be provided to field personnel on when and how to best enact emergency restraint (protection and stabilization treatment) measures until a more thorough examination can be made by respective professionals and experts.

5.2 Monument Records

The record of performance and maintenance of important structures is very important. For example, the ability to gage the response of monuments to environmental and natural hazards such as earthquakes is directly related to the pre-earthquake record of condition as shown in this report. A system of documenting and indexing all available information per monument should be established to provide necessary information to those people involved in preservation, restoration, and damage assessment. This duty should be centralized to maintain consistency and provide a central point of distribution and retention. An analogy in the U.S. might be the Nuclear Regulatory Commission (NRC) repository where all public information about each nuclear power plant is stored and can be retrieved upon request.

Some documentation exists already. For instance, many local consultants appear to have conducted studies to determine geotechnical properties. Also, the EAO has published monographs summarizing the restoration of individual monuments which is commendable. Existing books, reports, surveys, and newsletters are a good beginning to establishing historic surveys, but they typically concentrate on political, religious, artistic, and architectural aspects. Structural design, detail, and seismic retrofit are very important components of historical record. SPARE and EAO separately conduct periodic observations of monuments which are also part of the process.

Systems of monitoring and inspection are common for irreplaceable construction in the U.S. For instance, publicly-owned reservoir dams typically have a full-time attendant who maintains the dam and appurtenant structures, monitors instrumentation, and reports any irregularities. A separate team of professionals inspect the dam every five years and report on their observations. Following natural hazards, the dam is again inspected and the performance and safety are evaluated. Data from instrumentation is evaluated periodically and possibly used in numerical models to further evaluate performance and response.

5.3 Geographic Information System

One tool that could greatly assist the planners and administrators of historic monuments is a Geographic Information System (GIS). A GIS is a computer-based method of storing massive amounts of spatial data such as the locations of: monuments, borings, streets, utilities, property lines, topographic contours, different soil layer contours, and groundwater contours and juxtaposing the various pieces of information of interest. This visual and computational tool has been shown to be valuable to city planners, geographers, engineers, and scientists and is gaining wide-spread popularity.

Some examples of the application of GIS and benefits to preservation studies are:

1. Evaluate priority of inspections following natural disasters based on such factors as past performance, location relative to source, type of construction, elevation, etc.
2. Conduct impact studies relative to natural hazards, road and utility improvements, etc.
3. Conduct land use studies for areas around monuments to optimize space available and propose alternatives when relocating people or resources
4. Monitor schedule of inspections, conditions, and status of work at each monument
5. Reconstruct the history of land use and development based on the accounts and records of various sources

Once established, the data collected and stored in a GIS can be used for a wide variety of applications.

5.4 Acceptable Limits of Damage

Part of the development of an overall preservation strategy includes criteria to determine when and where a monument should be isolated, reinforced, and retrofitted to prevent or control cracking. Cracks are difficult to control, especially during an earthquake. However, some pieces of art and architecture might be considered to be too precious to have a perceptible crack mandating strong preventative actions. The same cracks in the domes which rest tens of meters above the floor of major mosques would be imperceptible and would not be a threat to the structure. These criteria can only be established through constructive dialogue among an international team of inter-disciplinary of artists, historians, scientists, architects, and engineers. Criteria have been adopted in the past (e.g., Venice Charter in 1964) but would require modification and refinement to address some of the issues raised.

5.5 Role of Scientific and Engineering Studies

Previous efforts have focused on many aspects of preservation but have underemphasized the value of suitable scientific and engineering observations, investigations, and model testing. For instance, of all the references listed in this report, there are but a couple of remarks about earthquakes having damaged the monuments despite the number of earthquakes that have occurred, even in recent history, and obvious earthquake damage. The minarets at al-Hākim Bi-Amrillāh and al-Mansūr Qala'ūn mosques have been mentioned as having been damaged during the 1303 earthquake. Detailed descriptions about the type of damage and/or repairs made apparently do not exist.

Scientific and engineering studies are paramount to preservation and restoration effort, especially in Cairo where the influence of deterioration of materials throughout the centuries, groundwater, soil settlement, and earthquakes are important. Scientific studies are necessary to allow the engineers to quantify the available strength and the resistance of walls subjected to lateral forces, of domes affected by cracks, and of leaning columns and minarets, taking into account the deterioration of the materials and the effects of water. Recognition of this aspect is not new; SPARE (1984b) reported on some recent restoration efforts as follows:

> Though structural repairs have not been neglected, major attention seems to have been given to cosmetic effects directed at recreating the 'original' appearance of monuments, especially in the interiors, where a great deal of paint has been used...

The solution to technical problems of preservation can be thought of in terms of six basic steps:

1. Historic surveys;
2. Direct observations (art, architectural and engineering);
3. Investigation and model studies of the existing system;
4. Evaluation of viable alternatives;
5. Documentation of steps 1. through 4.; and then,
6. Restoration, repair, and retrofit.

These steps are necessarily inter-disciplinary. The role of surveys and observations were described above. Some specifics about numerical modeling and how it can be applied to the study of minarets are described below.

5.5.1 Numerical modeling

Numerical modeling of historic monuments in several different countries has been undertaken by researchers from around the world. Examples include the Basilica of St. Francis in Assissi (Croci, Carluccio, and Viskovic 1993), the Colosseum (Croci, D'Ayala, and Conforto 1992), Ottoman temples (Karaesmen 1993), and the Hagia Sophia in Istanbul (Cakmak et al. 1993). These studies have revealed important details about how various systems respond to different loads, including earthquakes.

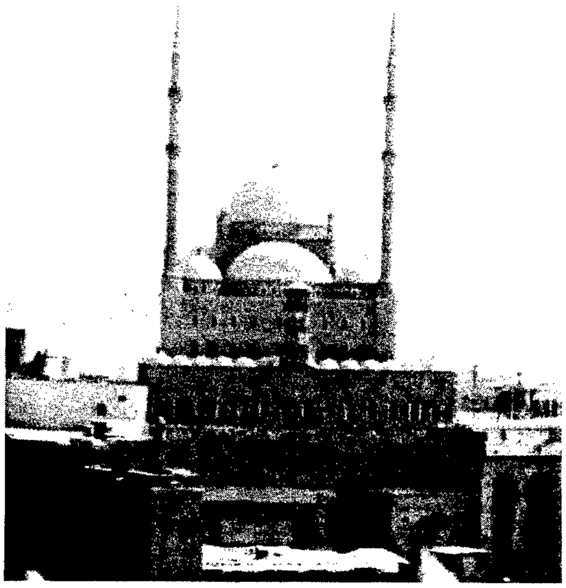
Although numerical modeling uses simplified schemes of reality, it can explain general phenomena, and give, in conjunction with subjective interpretation based on personal experience, a reliable safe evaluation and useful guidance for restoration and strengthening criteria. Another of the greatest values of numerical modelling is the possibility of carrying out parametric analysis of the benefit of remedial measures to find a cost effective, yet adequate, retrofit to assure material durability and damage prevention related to the artistic value of the monument.

5.5.2 Minarets

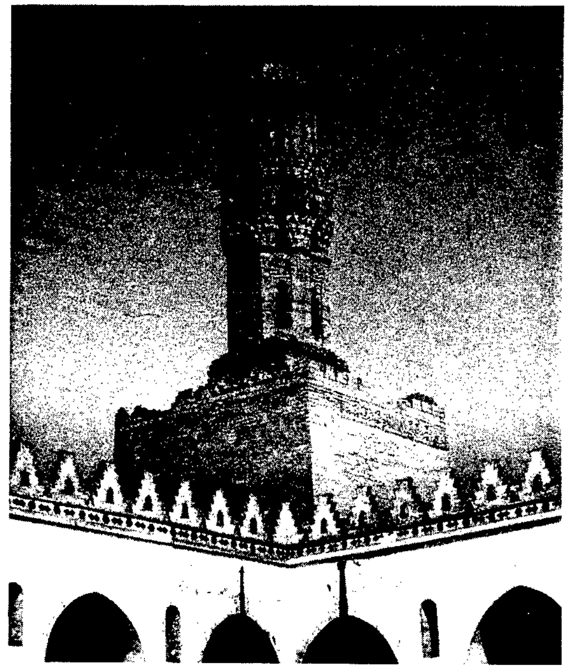
A relevant example of how engineering studies can preserve cultural heritage, save lives, and conserve natural and monetary resources is the study of minarets. Behrens-Abouseif (1985) has published an enlightening treatise on the history of minarets in Cairo. The shape and design of these minarets envelop the history and needs of the residents of Cairo and the activities of the *mu'adhdhin*. Paraphrasing Ms. Behrens-Abouseif: 'minarets in Cairo have come and gone.' More abruptly put, minarets have been used and abused, built and rebuilt. There are few cases of historic minarets in Cairo that have not undergone some degree of failure, rebuilding, and/or addition.

Portions of minarets have periodically fallen in Cairo due to earthquakes, deterioration, or poor design. For example, a minaret at the Mosque of Sultān Hasan fell shortly after construction and killed 200 children (Behrens-Abouseif 1985). Many of these minarets are likely to be in a state of marginal safety because of inadequate ties to the adjacent structure and poor foundation conditions. The general poor performance of minarets during this past earthquake attest to this conclusion.

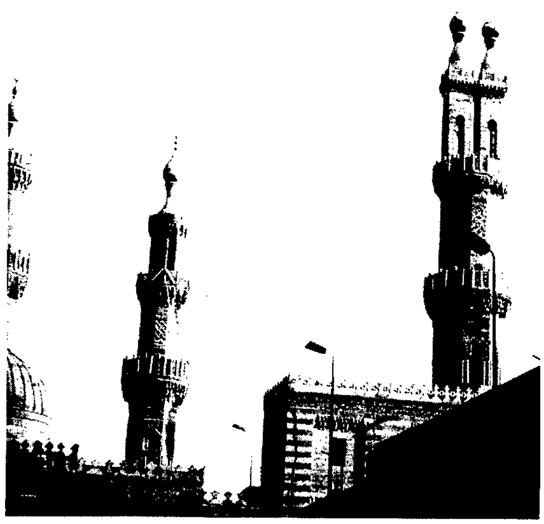
The minarets in Cairo are not simple structures that can be adequately modeled with simple one-degree-of-freedom models. Unlike tall, slender minarets like those at the Mosque of Muhammad 'Ali al-Kabir shown in figures 4-9 and 5-1a (designed after minarets of Istanbul), most minarets in Cairo have varying cross-sections (and therefore moments of inertia) with some very weak portions (stalactites for mabkhara type used in earlier designs and at the base of bulb for later designs). Examples of variations are shown in figures 5-1b, c, and d and previously in figures 4-26 and 4-42. Therefore, computer modeling of minarets should be used to understand the behavior of different designs to suggest and model alternative retrofits and assist in the design of new minarets.



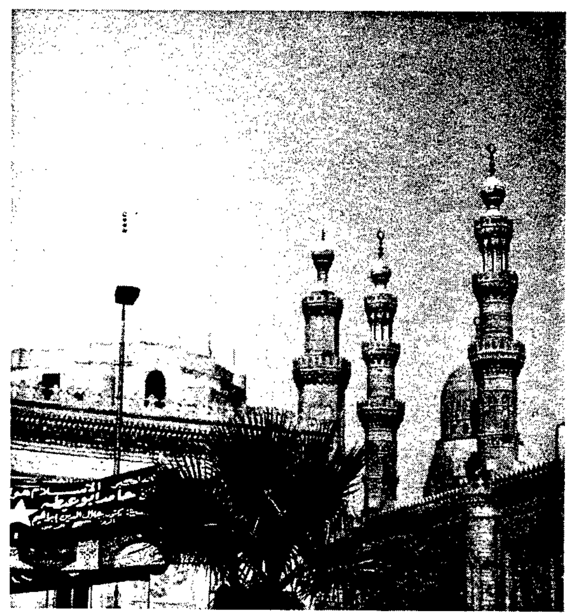
a. Mosque of Muhammad 'Ali al-Kabir



b. al-Hākim Bi-Amrillāh Mosque



c. al-Azhar Mosque



d. Sultān Hasan Mosque (left)
and al-Rifai Mosque (right)

FIGURE 5-1 Different styles of minarets in Cairo

SECTION 6
SUMMARY AND CONCLUSIONS

The observations and preliminary findings made by an international, inter-disciplinary team that inspected 29 monuments in Cairo, Egypt, about three weeks after the October 12, 1992, Dahshur Earthquake have been documented. Earthquake damage to historic monuments can be generally described as resulting from the continuous degradation of structural masonry, inadequate lateral resistance, and the subsequent imposition of light to moderate earthquake forces. The observations of earthquake damage have opened discussion on and brought world-wide recognition to the dilapidation and spiraling degradation of building materials of these monuments. The results of several studies over the past 90 years document this crisis.

Post-pharonic monuments were significantly damaged during the earthquake although none were destroyed. Portions of at least five minarets broke and fell, as many as seven tilted and/or were cracked, one small dome collapsed, arches pulled apart and keystones dropped, walls buckled, and countless cracks were formed or existing cracks extended and widened. Using a subjective categorization, 5 monuments had no damage, 8 had light damage, 9 had moderate damage, and 7 had severe damage due to the recent earthquake. These same monuments were also evaluated on the need for intervention from an engineering perspective that includes past and recent damage. Using categories proposed by ICCROM, 7 monuments are in immediate need, 4 have an urgent need, and 10 have a necessary need. Nearly all of the damaged monuments visited require scientific and engineering evaluation of material strengths, dynamic response of systems (especially the minarets), and viable alternatives for seismic retrofit and dewatering schemes.

6.1 Lessons Learned

Several lessons were learned from the reconnaissance of earthquake damage to historic monuments. Many of the lessons are not new but take on a different perspective when applied to historic monuments. The most unique aspect of the damage to historic monuments in Cairo is the combination of moderate ground shaking coupled with a wide range of monument structural conditions. The earthquake did not cause damage to many monuments in good condition with no or few existing cracks. The level of damage sustained appeared to be closely related to the pre-earthquake condition (which corresponds well with the site intensities of VI and VII chosen for the historic areas).

The pattern of damage to historic monuments in Cairo suggests that specific architectural and structural elements should be retrofitted for seismic resistance. These include contacts between minarets and mosques, the stalactite-portion of minarets, minaret walls and steps, domes and their supporting systems, parapets walls, other projecting ornaments (e.g., *pishtaqs*), especially above entrances, and *liwans*. In general, unreinforced masonry walls should be retrofitted with guidance from current practice to develop the most effective yet least noticeable system and a parapet ordinance should be adopted and enforced.

Some evidence exists to support the premise that structures built during the Ottoman Turk Period (1517-1805) are more resistant to earthquake shaking and structures built during the Mohammad 'Ali Period (1805 to 1848) are less resistant than the remaining monuments on the average. The builders during the Ottoman Turk Period may have included features common among structures in more earthquake-prone regions such as Istanbul. This premise should be examined more closely. If proven factual, the structural and architectural details from these two periods should be studied, compared, and contrasted to assist in designing standard seismic retrofit procedures for Islamic monuments.

At least one example of previous repair work causing damage to a monument was found at the Saraya el-Adl. A concrete roof had been placed in lieu of the original timber and mortar construction. The dynamic displacements of the concrete section were obviously larger and out of phase with the adjoining timber-roof section. The result was considerable (serious) damage to the both the repaired and unrepaired portions of the structure. A combination of adequate structural analysis and good judgement could have easily shown the danger of this restoration.

6.2 Preservation Strategy

This team strongly recommends that an all-encompassing preservation strategy that incorporates suitable levels of scientific and engineering evaluations be crafted and implemented. In a UNESCO report proposing a preservation strategy for Cairo, Antoniou et al. (1980) state that "to continue with conservation work without controlling the effect of groundwater on the fabric will quickly prove a false economy." Similarly, the authors of this report suggest that to perform restoration work without proper scientific and engineering observations, investigations, and model testing, especially related to earthquake hazards, is reckless. Earthquake damage to historic monuments will continue to be severe, even to restored monuments, unless proper study and active seismic retrofit actions are taken.

Scientific and engineering evaluations should include six basic steps: 1) historic surveys; 2) direct observations; 3) investigation and model studies; 4) evaluation of viable alternatives; 5) documentation of previous steps; and only then, 6) restoration, repair, and retrofit. Some of these activities currently are undertaken. However, the other elements and interaction between activities should also be considered. Emergency response activities are also important.

A number of aforementioned elements of a comprehensive strategy would be greatly aided through the use of a GIS. A GIS would provide a central system for information archiving, data retrieving, juxtaposition, analysis, and strategy development. This system would also be a useful tool for emergency response activities.

More general technical studies about regional groundwater conditions, pipeline failure and leakage, strength of materials degraded by groundwater, seismic retrofit of minarets and joints between minarets and mosques, to name a few, are vital to adopting a strong preservation strategy for Cairo. The results of these studies would serve to minimize restoration effort and resources while at the same time greatly extending the monumental life of the structure.

The minarets of Cairo present an interesting study in and of themselves. The evolution of construction for these monuments and attempts at preservation have been documented. Consideration of the structural plan of most of these minarets and their observed state following the earthquake suggests that simple one-dimensional models may not be appropriate as they might be for the slender, high minarets found at the Mosque of Muhammad 'Ali al-Kabir and prevalent in places like Istanbul.

Minarets and other monuments should not be disassembled unless absolutely necessary. One case of disassembly was in process (Hasan Pasha Tāhir Mosque), one was planned (al-Ghūri Mosque), and one was being considered (Minaret of as-Sālih Negm ad-Din Ayyūb) during the team visit. Many alternatives exist to impose emergency restraint, to strengthen, and to retrofit minarets while conserving the original building materials.

Knowing the history of involvement by the Egyptian people and the individual stories of some of the monuments, it is obvious that preservation interest and action is not new and will last for generations to come. The resources available to this generation should be utilized and fully passed on to the next generation. Information compiled, problems studied, alternatives created and considered, decisions made, and results of all efforts should be archived and permanently stored.

6.3 Closing

Engineers, architects, and scientists have learned from the failures at Cairo. The damage points clearly to the importance of adequate maintenance and seismic retrofit as part of historic preservation activities. Weak links in structural stability for Islamic monuments have been documented without the widespread loss caused by larger earthquakes.

The experience of the Egyptian people is a prelude to the future of younger societies well beyond the paradigm of preserving cultural heritage and monuments. The preservation and sustained usefulness of our infrastructure is a multi-billion-dollar issue. The U.S. must design its public systems to last longer and withstand more severe and diverse effects. The long-term effects (up to two millennia) of many of these same hazards can be witnessed and studied in Cairo and elsewhere.

SECTION 7
REFERENCES

Ambraseys, N. N. and Finkel C. F. 1990. "The Marmara Sea Earthquake of 1509," Terra Nova, Vol 2, pp 167-174.

Antoniou, J., Bianca, S., El-Hakim, S., Lewcock, R., and Welbank, M. 1980. "The Conservation of the Old City of Cairo," Tech. Rpt. FMR/CC/CH/80/182, UNESCO, London, England.

Atil, E. 1981. Renaissance of Islam: Art of the Mamluks, Smithsonian Institution Press, Washington, DC, 286 pgs.

Aziz-Khalil, M. Fr. 1985. The Principal Ancient Coptic Churches of Old Cairo, The Fort of Babylon, and Ben Ezra Synagogue, trans. by I. H. El-Masri, Anba Reuiss Press, Cairo.

Bechtel Engineering 1992. "Post-Earthquake Assessment Report, Egypt Earthquake," November, Cairo, Egypt.

Behrens-Abouseif, Doris 1985. The Minarets of Cairo, The American University in Cairo Press, Cairo, Egypt.

________, 1989. Islamic Architecture in Cairo, An Introduction, The American University in Cairo Press, Cairo, Egypt.

Bergne P. 1978. "Cairo: Can the Medieval City be Saved?," Architectural Review, Vol 164, Aug., pp 113-126.

Cakmak, A., Davidson, R., Mullen, C., and Erdik, M. 1993. "Dynamic Analysis and Earthquake Response of Hagia Sophia," Structural Repair and Maintenance of Historic Buildings III, Computational Mechanics, Southampton, pp 67-84.

Creswell, K. A. C. 1959. "The Muslim Architecture of Egypt," 2 vols, Oxford, England.

Croci, G., Carluccio, G., and Viskovic, A. 1993. "The Structural Analysis and Restoration Projects for the St. Francis, St. Claire, and St. Mary of the Angels Basilica in Assissi," Structural Repair and Maintenance of Historic Buildings III, Computational Mechanics, Southampton, pp 375-382.

Croci, G., D'Ayala, D., and Conforto, M. 1992. "The Origin of Cracks and Failures in the History of Colosseum in Rome," Proc., Int'l Cong., Restoration Architect. Herit. and Bldgs., Canarias.

Egyptian Association of Friends of Antiquity, 1980. "Index to Mohammedan Monuments Appearing on the Special 1:5000 Scale Maps of Cairo," The American University in Cairo Press, Cairo, Egypt.

Elgamal, A., Amer, M., and Adalier, K. 1993. "Liquefaction During the October 12, 1992 Egyptian Dahshure Earthquake," Proc., 3rd Int'l Conf. Case Studies Geotech. Engr., St. Louis, MO.

Fitz, S., ed. 1993. Proc., Conservation of Historic Brick Structures, NATO-CCMS Pilot Study, published in Berlin, Germany.

Harris, C. M. 1975. Dictionary of Architecture and Construction, McGraw-Hill, New York, NY.

_________, 1977. Historic Architectural Sourcebook, McGraw-Hill, New York, NY.

Hefny, K. (ed.) 1982. "Groundwater Studies Project for Greater Cairo," Internal Report, Research Institute for Groundwater and Academy of Scientific Research and Technology, Cairo, Egypt, 190 pgs, (in Arabic).

Hoag, John D. 1975. Islamic Architecture, Electa Editrice, Milan, reprinted by Rizzoli, New York, NY, 1987.

Kamil, J. 1990. Coptic Egypt: History and Guide, 2nd. ed., American University Press, Cairo, Egypt.

Karaesmen, E. 1993. "Structural Behavior of Historic Masonry Domes of Major Importance: An Overview," Structural Repair and Maintenance of Historic Buildings III, Computational Mechanics, Southampton, pp 157-164.

Kebeasy, R. M. and Maamoun, M. 1981. "Seismicity and Earthquake Risk of the Proposed Site of Shoubra al-Khaimah Electric Power Station," Bull., Int'l Inst. Seismol. and Earthquake Energy, Vol 19, pp 21-33.

Khater, M. 1993. "Reconnaissance Report on the Cairo, Egypt Earthquake of October 12, 1992," NCEER Bulletin, Vol 7, No. 1, Jan.

Ministry of Public Works, 1902. "The Disintegration of Building Stones in Egypt," pamphlet, Survey Dept.

Petroski, Henry 1982. To Engineer Is Human, St. Martins Press, New York, NY.

Rodenbeck, J. 1992. "Cairo's Endangered Monuments," Insight Guide: Egypt, 3rd ed., Insight Guidebooks, APA, Singapore, pg. 101.

Said, R. 1975. "Subsurface Geology of Cairo Area," Memoire de L'Institue d'Egypte, Tome Soixante, Cairo, 70 pgs.

_________, 1981. The Geologic Evolution of the Nile River, Springer-Verlag, New York, NY, 151 pg.

Shata, Abdu A. 1988. "Geology of Cairo, Egypt," Bull. Assoc. Engr. Geol., Vol. XXV, No. 2, pp 149-183.

SPARE 1979a. "Map One: Al Azhar to the North Wall," Maadi Graphics, Maadi, Egypt.

_________, 1979b. Newsletter, No. 1, Nov.

_________, 1981. Newsletter, No. 3, Jan.

_________, 1982. Newsletter, No. 5, Jan.

________, 1984a. "Map Two: Sultan Hasan to Al-Azhar."

________, 1984b. Newsletter, No. 9, April.

________, 1990a. "Map Three: The Citadel to Ibn Tulun," Palm Press, Cairo, Egypt.

________, 1990b. Newsletter, No. 13, April.

________, 1992. Newsletter on the Earthquake in Cairo, 29 December.

Sykora, D., Hynes, M., and Karaesmen, E. 1993. "Report on an International Workshop on Preserving Historic Buildings of Major Importance," Misc. Paper in progress, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thenhaus, P., Sharp, R., Celebi, M., Ibrahim, A-B., and Van de Pol, H. 1993. "Reconnaissance Report on the 12 October 1992 Dahshur, Egypt, Earthquake," Open File Rpt 93-181, U.S. Geological Survey, Denver, CO.

Wight, J. K., Hryciw, R. D., and Naaman, A. E. 1992. "Field Investigation of Damage to Islamic Monuments Caused by the Egyptian Earthquake of October 12, 1992," Report UMCEE 92-31, Dept. Civil and Envir. Engr., Univ. of Michigan, Ann Arbor, MI.

Wyllie, L. A. Jr. and Lew, H. S. 1989. "Performance of Engineering Structures," Earthquake Spectra, Chptr. 6, Special Supplement, pp 70-92, Dec.

Youssef, N. et al. 1992. EERI Bulletin, Oakland, CA, Dec.

APPENDIX A
LIST OF PERSONS CONTACTED

The following is a list of persons that the team met or spoke with during their stay in Egypt. Addresses and phone numbers are also provided for convenience.

Hazem El Abd
Chairman, Central Development Authority
Ministry of Development
New Communities, Housing, and Public Utilities
(VOI) 355-7919

Prof. Mohamed I. Amer
Dept. of Civil Engineering
Cairo University
Giza, Cairo, Egypt
(VOI) 570-2822, ext. 3012

Prof. Jere L. Bacharach
Dept. of History
University of Washington
Seattle, WA 98195
(VOI) 543-5790

Prof. Mohammed Ibrahim Bakr
Chairman, Eqyptian Antiquities Organization
(VOI) 20-2-341-5645

Father Agathon Anba Bishoy
Priest of Abu Sufein Church
P.O. Box 1085
Code 11737
Heliopolis, Cairo, Egypt
(VOI) 282-5375

Dr. Mark M. Easton
Cairo Director, American Research Center in Egypt
2, Midan Qasr el Doubara
Garden City, Cairo, Egypt
(VOI) 354-8239
(FAX) 355-3052

Mr. Jim Edinger
Area Engineer
U.S. Army Corps of Engineers
Maadi, Cairo, EGYPT
(VOI) 20-2-376-8221
(FAX) 20-2-352-5440

Mr. Adrian Hromiak
Deputy Area Engineer
U.S. Army Corps of Engineers
Maadi, Cairo, EGYPT
(VOI) 20-2-376-8221
(FAX) 20-2-352-5446

Prof. Roman Hryciw
Dept. of Civil and Environmental Engineering
University of Michigan
Ann Arbor, MI 48103

Mr. Ali Maher Mitwally
Undersecretary for Housing and Development Ministry
also,
Faculty of Arts, Archeology Section
Tanta University

Mr. Tamer Kafafi
Civil Engineer, U.S. Army Corps of Engineers
Cairo East Resident Office
(VOI) 376-8221

Prof. Antoine Naaman
Dept. of Civil and Environmental Engineering
University of Michigan
Ann Arbor, MI 48103

Prof. Bernard O'Kane
Art and Islamic Architecture
American University
Cairo, Egypt
(VOI) 354-2964
(FAX) 355-7565

Prof. Ali Radwan
Dean, Faculty of Archaeology
Cairo University
Giza, Cairo, Egypt
(VOI) 72-8108
(FAX) 72-6721

Ms. Marjorie Ransom
Counselor, Press and Cultural Affairs
US Embassy in Cairo
(VOI) 355-6393

Prof. Ahmed Rashed
Dept. of Civil Engineering
Cairo University
Giza, Cairo, Egypt
(VOI) 302-1866
(FAX) 303-6021

Mr. John Rodenbeck
(VOI) 351-8863

Prof. Abdul-Fattah El-Sabbahy
Asst. Prof. of Egyptology
Consultant to EAO
Helwan University
(VOI) 98-1838 (Univ.)
341-5645 (EAO)

Prof. Saleh A. Saleh
Chairman, Dept. of Conservation
Faculty of Archaeology
Cairo University
Giza, Cairo, Egypt
(VOI) 72-6721
(FAX) 72-8590

Prof. George Scanlon
Islamic History
American University
Cairo, Egypt
(VOI) 354-2964

Ms. Dalia M. Talaat
Cultural Affairs Specialist
U.S. Information Service
American Embassy
#8 Kamal El-Din Salah St.
Garden City, Cairo, EGYPT
(VOI) 20-2-357-2439
(FAX) 20-2-357-3591

Dr. Francis (Frank) B. Ward III
Cultural Affairs Officer
U.S. Embassy in Cairo
#8 Kamal El-Din Salah St.
Garden City, Cairo, EGYPT
(VOI) 20-2-357-3437
(FAX) 20-2-357-3591

Prof. Jim Wight
Dept. of Civil and Environmental Engineering
University of Michigan
Ann Arbor, MI 48103
(VOI) 313-763-3046

Nabih Youssef, Team Leader of EERI Reconnaissance Team
Nabih Youssef & Assoc
800 Wilshire Blvd, Suite 510
Los Angeles, CA 90017
(VOI) 213-362-0707
(FAX) 213-688-3018

APPENDIX B

FINDINGS BY GERMAN INSTITUTE OF ARCHEOLOGY

A condensed list of findings by a reconnaissance team from the German Institute of Archeology (GIA) based in Cairo is presented in Table B1. The GIA surveyed 17 monuments and presented the findings at a news conference at the office of the Egyptian Antiquities Organization (EAO) on November 5, 1992. The news conference had the following participants:

1. His Excellency, The Ministry of Culture, Dr. Faruk Hosni
2. Dr. Muhamed Bakr, Chairman, EAO
3. Prof. Rainer Stadelmann, Director, GIA
4. Ms. Nairy Hampikian, Archeologist, GIA
5. Mr. Achim Kzekelor, Architect-Engineer, GIA

The GIA also announced their intention to begin the restoration of a few of these moderately-damaged monuments. These include the Minaret of as-Sālih Negm ad-Din Ayyūb, and the Mosque, Mausoleum, and Māristan of al-Mansūr Qala'ūn. One of the two alternatives for restoration of the Minaret of as-Sālih Negm ad-Din Ayyūb includes disassembly.

TABLE B-1 Summary of Damage Reported by GIA

No.	Monument	EAO No.	Date	Level of Earthquake Damage[1]
1	Bāb al-Akhdar, Mosque of al-Husayni	28	17th cent.	Red
2	Mosque of Abū Bakr Muzhir	49	1479-1480	Blue
3	???	4	??	Yellow
4	Sabil-Kuttāb Ōda Bāshi	17	1673	Red
5	Maq'ad Mamay as-Saifi	-		Yellow
6	Bāb al-Futūh[2]	6	1087	Yellow
7	Bāb an-Nasr	7	1087	Blue
8	Palace al-Musāfirkhāna	20	1779-1788	Yellow
9	Isma'il Pasha	-	1828	Yellow
10	Mosque of ad-Dashtūti[2]	12	1506	Red
11	Sabil-Kuttāb Khalil Efendi al-Muqāti'gui	71	1632	Yellow
12	Sabil-Kuttāb as-Sayyid 'Ali ibn Heiza'	23	1646	Yellow
13	Bāb al-Bādistān	53	1511	Red
14	al-Hākim Bi-Amrillāh Mosque[2]	15	990-1013	Blue
15	Mausoleum and Madrasa of as-Sālih Negm ad-Din Ayyūb[2]	38	1243-1250	Red
16	Sabil al-Bazdār	27	17th cent.	Red
17	Wekālat Qāytbāy	75	1477	Red

[1] Yellow: verge of collapse
Red: serious damage which needs engineering intervention, recalculation
Blue: no serious damage

[2] Monuments observed by this reconnaissance team

APPENDIX C
GLOSSARY OF FOREIGN AND ARCHITECTURAL TERMS

ablaq masonry - striped masonry probably came to Cairo from Syria according to Creswell (Behrens-Abouseif 1989, p. 18).

amir - (Arabic: commander) a military or government officer beneath the rank of sultan (SPARE 1990a)

arcade - a line of counter-thrusting arches raised on columns or piers; a covered walk with a line of such arches along one or both long sides; (Harris 1977)

bāb - a gate (of the city or area of the city) or door (SPARE Map Three, 1990)

bayt - Arabic term for dwelling; used to designate the self-contained apartments within Umayyad mansions and Abbasid palaces (Hoag 1975)

caliph - leader of the Muslims in both a spiritual and political sense; in theory there should only be one, but in fact after the loss of power by the Abbasid caliph in the tenth century a Sunni Caliphate was established at Cordoba (925-1030) and a Shi'ite Caliphate by the Fatimids (915-1171); after the murder of the last Abbasid caliph at Baghdad in 1258 a shadow caliphate survived in Egypt until the Turkish conquest of 1517; the claim of the later Turkish sultans to the caliphate was not legitimate (Hoag 1975)

capital - the top-most member, usually decorated, of a column, pilaster, anta, etc.; it may carry an architrave or an arcade or be surmounted by an impost block (Harris 1977)

caravanserai - term for a fortified hostel along a trade route, also known as han and funduk (term of Greek origin used primarily in North Africa) (Hoag 1975)

Circassians - the people from the Caucasus Mountains, between the Black and Caspian Seas (SPARE 1990a)

dado - the middle portion of a pedestal between the base (or the plinth) and the surbase (or the cornice, cap, or entablement); the middle part (sometimes all parts) of a protective, ornamental paneling applied to the lower walls of a room above the baseboard (Harris 1975).

Dervish - (Persian: mendicant) a Muslim mystic, see *Sufi* (SPARE 1990)

dikka - bench used for recitations (Behrens-Abouseif 1989)

finial - an ornament which terminates the point of a spire, pinnacle, minaret, etc. (Harris 1977)

keel arch - arch with a profile resembling a ship's keel pointing upwards (Behrens-Abouseif 1989)

kufic - Arabic writing originating in Kufa, Mesopotamia; its angular characters are used decoratively in early Muslim architecture (Harris 1977)

haikal - domed apse in a Coptic Church (Kamil 1990) hypostyle hall - a large space with a flat roof supported by rows of columns (prevalent in ancient Egyptian and Achaemenid architecture); a structure whose roofing was supported, within the perimeter, by groups of columns or piers of more than one height (clerestory lights sometimes were introduced) (Harris 1977)

kibla - *qibla* (q.v.) (Hoag 1975)

khanqāh - a monastery, usually of a Sufi order of dervishes (Hoag 1975)

khutba - the Friday prayer spoken from the *minbar*; when not pronounced by the Caliph himself, his name was always mentioned (Hoag 1975)

kuttab - Quran school

imām - according to Shi'a doctrine, the only legitimate and authoritative religious leaders are the imāms, or descendants of 'Ali through his sons from Fātima, al-Hasan, and al-Husayn. The imāms, because of their ancestry, were considered by the Ismā'ilis to be divinely inspired and therefore infallible; the fatimid Caliphs were the imāms of the community (Behrens-Abouseif 1989)

liwan - (also *iwan*) a barrel-vaulted chamber, open at one end, usually off a central court (SPARE 1990a)

mabkhara - incense burner; perforated ornamental top of a minaret resembling an incense burner (Behrens-Abouseif 1989)

madrasa - an endowed theological school providing student lodgings, a prayer, hall, and sometimes classrooms; perhaps invented in the tenth century by the Ghaznavids to combat Shi'ism, it was adapted for the same purpose by the Persian and Turkish Seljuks, whence it spread to Syria (Hoag 1975)

Mamluk - (Arabic: possessed) a military slave (SPARE 1990a)

māristan - a hospital (SPARE 1984a)

masjid - literally a "place of prostration," a mosque (Hoag 1975); origin of the word mosque (Behrens-Abouseif 1989)

masjid jami - (abbreviated jami) congregational mosque (Behrens-Abouseif 1989).

mihrab - a niche in the *qibla* wall of a mosque indicating the direction of Mecca; first installed in the early eighth-century rebuilding of the mosque at Medina and perhaps of Eqyptian Christian origin (Hoag 1975)

minaret - tower from which the call to prayer is made; the term as well as the form may have been derived from a lighthouse (Hoag 1975)

minbar - a seat or pulpit, first used in Medina by Muhammad himself, which came to be installed to the right of the *mihrab* in all Friday mosques for the reading of the *khutba*; its use gradually became universal in all mosques (Hoag 1975)

mu'adhdhin - person who calls faithful to prayer via the minaret (Behrens-Abouseif 1985) *muqarnas* - Arabic term, derived from the Greek word for scales used in roof tiles, applied to what are called stalactite or honeycomb vaults; *muqarnas* unites have been found in ninth-century Nishapur, and so their earliest use may have been purely decorative; spreading throughout Islam in the late eleventh century, this element became characteristic of the Classic phase of Islamic architecture (Hoag 1975).

pasha - the highest, non-royal, rank in the Ottoman Empire

pendentive - one of a set of curved wall surfaces which form a transition between a dome (or its drum) and the supporting masonry; in medieval architecture and derivatives, one of a set of surfaces vaulted outward from a pier, corbel, or the like (Harris 1975).

pishtaq - rectangular screen rising above a roof line and framing a portal or an *iwan* (Hoag 1975), a perforated parapet (Look)

rising damp - moisture rising in a masonry wall cause by capillary action (Look)

qa'a - reception hall (Behrens-Abouseif 1989)

qibla - the direction of prayer; the wall of a mosque oriented toward Mecca (Hoag 1975)

riwaq - one of the porticos or arcades surrounding the sahn or central interior court of a mosque or a central shrine (Hoag 1975)

sabil - public drinking fountain (Hoag 1975)

sahn - interior central court of a mosque (Hoag 1975)

shiites - the followers of Ali who believe in the succession of twelve or more *imams* after him and reject the legitimacy of the Umayyad and Abbasid caliphs (Hoag 1975)

soffit - the exposed undersurface of any overhead component of a building, such as an arch, balcony, beam, cornice, lintel, or vault (Harris 1977)

squinch - corbeling, often arcuate, built at the upper corners of a structural bay to support its tangent, smaller dome or drum; a small arch across the corner of a square room which supports a superimposed mass; also called a sconce (Harris 1975).

Sufi - (Arabic: wearer of wool) a muslim mystic and ascetic who wore coarse woolen garments to show his disregard for the pleasures and vanities of this world (SPARE 1990a)

sultan - the absolute ruler of a Muslim state, theoretically appointed by the Caliph to exercise his sovereign authority

sunni - the major or Orthodox sect of Islam which in addition to the Koran and the *Hadith* (tradition preserved by the faithful) accepted as legitimate the Umayyad and Abbasid caliphates (Hoag 1975)

takiyyah, takiyya, or takiya - an institution where the Sufis lived, studied, and worshipped; appeared during the Ottoman Period; the plan of a takiyyah usually consisted of a courtyard surrounded by living cells that is independent of the mosque (Behrens-Abouseif 1989); a dervish convent (SPARE Map Two 1984); Ottoman Turkish name for a khanqāh (SPARE Map Three 1990) transept - the transverse portion of a church crossing the main axis at a right angle and producing a cruciform plan (Harris 1977)

voussoirs - a wedge-shaped masonry unit in an arch or vault whose converging sides are cut as radii of one of the centers of the arch or vault (Harris 1977)

wikala - Arabic term for caravansarai (SPARE 1990a)

ziyadah, ziyada - a court or series of courts around a mosque which serves to shelter it from immediate contact with secular buildings (Harris 1977); the outer enclosure of a mosque, probably an Abbasid innovation which reappears in certain of the imperial Ottoman foundations (Hoag 1975)

APPENDIX D
CHRONOLOGY OF TEAM ACTIVITIES

The following is a brief summary of the activities of the reconnaissance team while in Cairo, Egypt:

Sunday, October 25, 1992

Mr. Look arrived in Cairo and continued on to Luxor

Monday, October 26, 1992

Mr. Look visited Temple of Karnach
Mr. Look visited tombs in the Valley of the Kings and Valley of the Queens, the Mortuary Temples of Hatshepsut (Deir el Bahari) and Ramses II (Ramesseum), and the Colossi of Memnon
Mr. Look visited tombs of Horemheb, Amenophis II, Ramses VI, and Meneptah

Tuesday, October 27, 1992

Mr. Look traveled to Cairo
Mr. Look met with University of Michigan team to learn of their findings; also present were Jere Bacharach (University of Washington), Bernard O'Kane and George Scanlan (Department of Islamic Art and Architecture, American University in Cairo), and John Rodenbeck (SPARE)

Wednesday, October 28, 1992

Mr. Look coordinated team activities with USACE and U.S. Embassy in Cairo

Thursday, October 29, 1992

Mr. Look met with personnel of Cultural Attache and Office of Engineering at U.S. Embassy in Cairo
Mr. Look met Mark Easton (ARCE), Hassanein Rabie (Dean of Faculty of Arts at Cairo University and Marjorie Ransom (Counselor for Press and Cultural Affairs, U.S. Embassy) at a reception

Friday, October 30, 1992

Mr. Look visited stepped pyramid of Zoser
Mr. Look visited Abu Sufein Church and meets Nabih Youssef (EERI team leader), Kamal Nassif Ghali (Prof. of Concrete Structures, Ain Shams University), and Mandalon Mina (Engineer and Manager of local construction company)
Mr. Look visited Mosque of Ahmad idn Tūlūn
Mr. Look visited Mosque of Shaykhū
Mr. Look visited Khanqāh Shaykhū
Remaining team members arrived (Croci, Karaesmen, Karaesmen, and Sykora)

Saturday, October 31, 1992

Team met Nabih Youssef and he accompanied team to next meeting
Team met with representatives of Egyptian Ministry of Development, New Communities, Housing, and Public Utilities; Mr. Ali Maher accompanies team remainder of day
Team met with Dr. Abdul-Fattah El-Sabbahy, Dr. Gamal Mokhtar, and Ibraham Bakr, Chairman, EAO
Visited Hasan Pasha Tāhir Mosque
Visited Madrasa of Sarqhatmish

Sunday, November 1, 1992

Met with EAO, at Citadel to plan visits; Mahmoud Ramadan Abd El-Aziz is designated to accompany team to provide access to monuments
Visited Mosque of Muhammad 'Ali al-Kabir, Citadel
Visited al-Gawhara (Jewel) Palace, Citadel
Visited Saraya el-Adl, Citadel
Visited Mint, Citadel
Visited Abu Sufein Church; met with Bishop and church building committee
Visited Mosque of Muhammad as-Saghir
Visited Mosque of al-Ghūri
Visited Mosque and Sabil of al-Ashraf Barsbāy
Visited Mosque of as-Sālih Negm ad-Din Ayyūb
Visited Mosque, Māristan, and Mausoleum of al-Mansūr Qala'ūn
Visited Mausoleum of an-Nāsir Muhammad
Visited Mosque of Sultan Barqūq
Met with Mark Easton and Lou Staples (ARCE) and Jerry Rodenbeck (SPARE) at Intercontinental Hotel

Monday, November 2, 1992

Prof. Karaesmen departed early morning
Visited Mosque and Madrasa of Sultān Hasan
Visited al-Rifa'i Mosque
Visited Mosque of Ibrāhim Aghā Mustahfizān (Blue Mosque)
Visited the Mosque of ad-Dashtūti
Purchased related maps and books at American University in Cairo
Met with Mark Easton (ARCE) at ARCE office
Met with Frank Ward (Cultural Attache, U.S. Embassy in Cairo)
Met with Profs. Ali Radwan (Dean, Faculty of Archaeology) and Saleh A. Saleh (Chairman, Department of Conservation), Cairo University (meeting arranged by Ali Maher) at Marriott Hotel

Tuesday, November 3, 1992

Prof. Croci departed early morning
Visited Bāb al-Futūh
Visited al-Hākim Bi-Amrillāh Mosque
Visited Bayt as-Sihaymi
Visited Palace of Amir Beshtāk
Visited Coptic Museum
Visited the el-Moalloqa (Hanging) Church

Wednesday, November 4, 1992

Coordinated exit interviews and final activities
Visited Museum of Islamic Art
Visited al-Azhar Mosque
Met with Jere Bacharach (University of Washington) at Marriott Hotel

Thursday, November 5, 1992

Mr. Look departed early morning
Mr. Sykora met with USACE-Cairo Area Office at their office
Mr. Sykora met with Profs. Mohamed Amer and Ahmed Rashed, (Department of Civil Engineering, Cairo University) at their office
Exit interview at U.S. Embassy; Frank Ward accompanies us to EAO
Exit interview at EAO
Mr. Sykora attended news conference of Minister of Culture, Chm., EAO, three researchers from German Institute of Archeology at EAO headquarters

Friday, November 6, 1992

Mr. Sykora departed early morning

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
LIST OF TECHNICAL REPORTS

The National Center for Earthquake Engineering Research (NCEER) publishes technical reports on a variety of subjects related to earthquake engineering written by authors funded through NCEER. These reports are available from both NCEER's Publications Department and the National Technical Information Service (NTIS). Requests for reports should be directed to the Publications Department, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Red Jacket Quadrangle, Buffalo, New York 14261. Reports can also be requested through NTIS, 5285 Port Royal Road, Springfield, Virginia 22161. NTIS accession numbers are shown in parenthesis, if available.

NCEER-87-0001 "First-Year Program in Research, Education and Technology Transfer," 3/5/87, (PB88-134275).

NCEER-87-0002 "Experimental Evaluation of Instantaneous Optimal Algorithms for Structural Control," by R.C. Lin, T.T. Soong and A.M. Reinhorn, 4/20/87, (PB88-134341).

NCEER-87-0003 "Experimentation Using the Earthquake Simulation Facilities at University at Buffalo," by A.M. Reinhorn and R.L. Ketter, to be published.

NCEER-87-0004 "The System Characteristics and Performance of a Shaking Table," by J.S. Hwang, K.C. Chang and G.C. Lee, 6/1/87, (PB88-134259). This report is available only through NTIS (see address given above).

NCEER-87-0005 "A Finite Element Formulation for Nonlinear Viscoplastic Material Using a Q Model," by O. Gyebi and G. Dasgupta, 11/2/87, (PB88-213764).

NCEER-87-0006 "Symbolic Manipulation Program (SMP) - Algebraic Codes for Two and Three Dimensional Finite Element Formulations," by X. Lee and G. Dasgupta, 11/9/87, (PB88-218522).

NCEER-87-0007 "Instantaneous Optimal Control Laws for Tall Buildings Under Seismic Excitations," by J.N. Yang, A. Akbarpour and P. Ghaemmaghami, 6/10/87, (PB88-134333). This report is only available through NTIS (see address given above).

NCEER-87-0008 "IDARC: Inelastic Damage Analysis of Reinforced Concrete Frame - Shear-Wall Structures," by Y.J. Park, A.M. Reinhorn and S.K. Kunnath, 7/20/87, (PB88-134325).

NCEER-87-0009 "Liquefaction Potential for New York State: A Preliminary Report on Sites in Manhattan and Buffalo," by M. Budhu, V. Vijayakumar, R.F. Giese and L. Baumgras, 8/31/87, (PB88-163704). This report is available only through NTIS (see address given above).

NCEER-87-0010 "Vertical and Torsional Vibration of Foundations in Inhomogeneous Media," by A.S. Veletsos and K.W. Dotson, 6/1/87, (PB88-134291).

NCEER-87-0011 "Seismic Probabilistic Risk Assessment and Seismic Margins Studies for Nuclear Power Plants," by Howard H.M. Hwang, 6/15/87, (PB88-134267).

NCEER-87-0012 "Parametric Studies of Frequency Response of Secondary Systems Under Ground-Acceleration Excitations," by Y. Yong and Y.K. Lin, 6/10/87, (PB88-134309).

NCEER-87-0013 "Frequency Response of Secondary Systems Under Seismic Excitation," by J.A. HoLung, J. Cai and Y.K. Lin, 7/31/87, (PB88-134317).

NCEER-87-0014 "Modelling Earthquake Ground Motions in Seismically Active Regions Using Parametric Time Series Methods," by G.W. Ellis and A.S. Cakmak, 8/25/87, (PB88-134283).

NCEER-87-0015 "Detection and Assessment of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 8/25/87, (PB88-163712).

NCEER-87-0016 "Pipeline Experiment at Parkfield, California," by J. Isenberg and E. Richardson, 9/15/87, (PB88-163720). This report is available only through NTIS (see address given above).

NCEER-87-0017 "Digital Simulation of Seismic Ground Motion," by M. Shinozuka, G. Deodatis and T. Harada, 8/31/87, (PB88-155197). This report is available only through NTIS (see address given above).

NCEER-87-0018 "Practical Considerations for Structural Control: System Uncertainty, System Time Delay and Truncation of Small Control Forces," J.N. Yang and A. Akbarpour, 8/10/87, (PB88-163738).

NCEER-87-0019 "Modal Analysis of Nonclassically Damped Structural Systems Using Canonical Transformation," by J.N. Yang, S. Sarkani and F.X. Long, 9/27/87, (PB88-187851).

NCEER-87-0020 "A Nonstationary Solution in Random Vibration Theory," by J.R. Red-Horse and P.D. Spanos, 11/3/87, (PB88-163746).

NCEER-87-0021 "Horizontal Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by A.S. Veletsos and K.W. Dotson, 10/15/87, (PB88-150859).

NCEER-87-0022 "Seismic Damage Assessment of Reinforced Concrete Members," by Y.S. Chung, C. Meyer and M. Shinozuka, 10/9/87, (PB88-150867). This report is available only through NTIS (see address given above).

NCEER-87-0023 "Active Structural Control in Civil Engineering," by T.T. Soong, 11/11/87, (PB88-187778).

NCEER-87-0024 "Vertical and Torsional Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by K.W. Dotson and A.S. Veletsos, 12/87, (PB88-187786).

NCEER-87-0025 "Proceedings from the Symposium on Seismic Hazards, Ground Motions, Soil-Liquefaction and Engineering Practice in Eastern North America," October 20-22, 1987, edited by K.H. Jacob, 12/87, (PB88-188115).

NCEER-87-0026 "Report on the Whittier-Narrows, California, Earthquake of October 1, 1987," by J. Pantelic and A. Reinhorn, 11/87, (PB88-187752). This report is available only through NTIS (see address given above).

NCEER-87-0027 "Design of a Modular Program for Transient Nonlinear Analysis of Large 3-D Building Structures," by S. Srivastav and J.F. Abel, 12/30/87, (PB88-187950).

NCEER-87-0028 "Second-Year Program in Research, Education and Technology Transfer," 3/8/88, (PB88-219480).

NCEER-88-0001 "Workshop on Seismic Computer Analysis and Design of Buildings With Interactive Graphics," by W. McGuire, J.F. Abel and C.H. Conley, 1/18/88, (PB88-187760).

NCEER-88-0002 "Optimal Control of Nonlinear Flexible Structures," by J.N. Yang, F.X. Long and D. Wong, 1/22/88, (PB88-213772).

NCEER-88-0003 "Substructuring Techniques in the Time Domain for Primary-Secondary Structural Systems," by G.D. Manolis and G. Juhn, 2/10/88, (PB88-213780).

NCEER-88-0004 "Iterative Seismic Analysis of Primary-Secondary Systems," by A. Singhal, L.D. Lutes and P.D. Spanos, 2/23/88, (PB88-213798).

NCEER-88-0005 "Stochastic Finite Element Expansion for Random Media," by P.D. Spanos and R. Ghanem, 3/14/88, (PB88-213806).

NCEER-88-0006 "Combining Structural Optimization and Structural Control," by F.Y. Cheng and C.P. Pantelides, 1/10/88, (PB88-213814).

NCEER-88-0007 "Seismic Performance Assessment of Code-Designed Structures," by H.H-M. Hwang, J-W. Jaw and H-J. Shau, 3/20/88, (PB88-219423).

NCEER-88-0008 "Reliability Analysis of Code-Designed Structures Under Natural Hazards," by H.H-M. Hwang, H. Ushiba and M. Shinozuka, 2/29/88, (PB88-229471).

NCEER-88-0009 "Seismic Fragility Analysis of Shear Wall Structures," by J-W Jaw and H.H-M. Hwang, 4/30/88, (PB89-102867).

NCEER-88-0010 "Base Isolation of a Multi-Story Building Under a Harmonic Ground Motion - A Comparison of Performances of Various Systems," by F-G Fan, G. Ahmadi and I.G. Tadjbakhsh, 5/18/88, (PB89-122238).

NCEER-88-0011 "Seismic Floor Response Spectra for a Combined System by Green's Functions," by F.M. Lavelle, L.A. Bergman and P.D. Spanos, 5/1/88, (PB89-102875).

NCEER-88-0012 "A New Solution Technique for Randomly Excited Hysteretic Structures," by G.Q. Cai and Y.K. Lin, 5/16/88, (PB89-102883).

NCEER-88-0013 "A Study of Radiation Damping and Soil-Structure Interaction Effects in the Centrifuge," by K. Weissman, supervised by J.H. Prevost, 5/24/88, (PB89-144703).

NCEER-88-0014 "Parameter Identification and Implementation of a Kinematic Plasticity Model for Frictional Soils," by J.H. Prevost and D.V. Griffiths, to be published.

NCEER-88-0015 "Two- and Three- Dimensional Dynamic Finite Element Analyses of the Long Valley Dam," by D.V. Griffiths and J.H. Prevost, 6/17/88, (PB89-144711).

NCEER-88-0016 "Damage Assessment of Reinforced Concrete Structures in Eastern United States," by A.M. Reinhorn, M.J. Seidel, S.K. Kunnath and Y.J. Park, 6/15/88, (PB89-122220).

NCEER-88-0017 "Dynamic Compliance of Vertically Loaded Strip Foundations in Multilayered Viscoelastic Soils," by S. Ahmad and A.S.M. Israil, 6/17/88, (PB89-102891).

NCEER-88-0018 "An Experimental Study of Seismic Structural Response With Added Viscoelastic Dampers," by R.C. Lin, Z. Liang, T.T. Soong and R.H. Zhang, 6/30/88, (PB89-122212). This report is available only through NTIS (see address given above).

NCEER-88-0019 "Experimental Investigation of Primary - Secondary System Interaction," by G.D. Manolis, G. Juhn and A.M. Reinhorn, 5/27/88, (PB89-122204).

NCEER-88-0020 "A Response Spectrum Approach For Analysis of Nonclassically Damped Structures," by J.N. Yang, S. Sarkani and F.X. Long, 4/22/88, (PB89-102909).

NCEER-88-0021 "Seismic Interaction of Structures and Soils: Stochastic Approach," by A.S. Veletsos and A.M. Prasad, 7/21/88, (PB89-122196).

NCEER-88-0022 "Identification of the Serviceability Limit State and Detection of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 6/15/88, (PB89-122188). This report is available only through NTIS (see address given above).

NCEER-88-0023 "Multi-Hazard Risk Analysis: Case of a Simple Offshore Structure," by B.K. Bhartia and E.H. Vanmarcke, 7/21/88, (PB89-145213).

NCEER-88-0024 "Automated Seismic Design of Reinforced Concrete Buildings," by Y.S. Chung, C. Meyer and M. Shinozuka, 7/5/88, (PB89-122170). This report is available only through NTIS (see address given above).

NCEER-88-0025 "Experimental Study of Active Control of MDOF Structures Under Seismic Excitations," by L.L. Chung, R.C. Lin, T.T. Soong and A.M. Reinhorn, 7/10/88, (PB89-122600).

NCEER-88-0026 "Earthquake Simulation Tests of a Low-Rise Metal Structure," by J.S. Hwang, K.C. Chang, G.C. Lee and R.L. Ketter, 8/1/88, (PB89-102917).

NCEER-88-0027 "Systems Study of Urban Response and Reconstruction Due to Catastrophic Earthquakes," by F. Kozin and H.K. Zhou, 9/22/88, (PB90-162348).

NCEER-88-0028 "Seismic Fragility Analysis of Plane Frame Structures," by H.H-M. Hwang and Y.K. Low, 7/31/88, (PB89-131445).

NCEER-88-0029 "Response Analysis of Stochastic Structures," by A. Kardara, C. Bucher and M. Shinozuka, 9/22/88, (PB89-174429).

NCEER-88-0030 "Nonnormal Accelerations Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 9/19/88, (PB89-131437).

NCEER-88-0031 "Design Approaches for Soil-Structure Interaction," by A.S. Veletsos, A.M. Prasad and Y. Tang, 12/30/88, (PB89-174437). This report is available only through NTIS (see address given above).

NCEER-88-0032 "A Re-evaluation of Design Spectra for Seismic Damage Control," by C.J. Turkstra and A.G. Tallin, 11/7/88, (PB89-145221).

NCEER-88-0033 "The Behavior and Design of Noncontact Lap Splices Subjected to Repeated Inelastic Tensile Loading," by V.E. Sagan, P. Gergely and R.N. White, 12/8/88, (PB89-163737).

NCEER-88-0034 "Seismic Response of Pile Foundations," by S.M. Mamoon, P.K. Banerjee and S. Ahmad, 11/1/88, (PB89-145239).

NCEER-88-0035 "Modeling of R/C Building Structures With Flexible Floor Diaphragms (IDARC2)," by A.M. Reinhorn, S.K. Kunnath and N. Panahshahi, 9/7/88, (PB89-207153).

NCEER-88-0036 "Solution of the Dam-Reservoir Interaction Problem Using a Combination of FEM, BEM with Particular Integrals, Modal Analysis, and Substructuring," by C-S. Tsai, G.C. Lee and R.L. Ketter, 12/31/88, (PB89-207146).

NCEER-88-0037 "Optimal Placement of Actuators for Structural Control," by F.Y. Cheng and C.P. Pantelides, 8/15/88, (PB89-162846).

NCEER-88-0038 "Teflon Bearings in Aseismic Base Isolation: Experimental Studies and Mathematical Modeling," by A. Mokha, M.C. Constantinou and A.M. Reinhorn, 12/5/88, (PB89-218457). This report is available only through NTIS (see address given above).

NCEER-88-0039 "Seismic Behavior of Flat Slab High-Rise Buildings in the New York City Area," by P. Weidlinger and M. Ettouney, 10/15/88, (PB90-145681).

NCEER-88-0040 "Evaluation of the Earthquake Resistance of Existing Buildings in New York City," by P. Weidlinger and M. Ettouney, 10/15/88, to be published.

NCEER-88-0041 "Small-Scale Modeling Techniques for Reinforced Concrete Structures Subjected to Seismic Loads," by W. Kim, A. El-Attar and R.N. White, 11/22/88, (PB89-189625).

NCEER-88-0042 "Modeling Strong Ground Motion from Multiple Event Earthquakes," by G.W. Ellis and A.S. Cakmak, 10/15/88, (PB89-174445).

NCEER-88-0043 "Nonstationary Models of Seismic Ground Acceleration," by M. Grigoriu, S.E. Ruiz and E. Rosenblueth, 7/15/88, (PB89-189617).

NCEER-88-0044 "SARCF User's Guide: Seismic Analysis of Reinforced Concrete Frames," by Y.S. Chung, C. Meyer and M. Shinozuka, 11/9/88, (PB89-174452).

NCEER-88-0045 "First Expert Panel Meeting on Disaster Research and Planning," edited by J. Pantelic and J. Stoyle, 9/15/88, (PB89-174460).

NCEER-88-0046 "Preliminary Studies of the Effect of Degrading Infill Walls on the Nonlinear Seismic Response of Steel Frames," by C.Z. Chrysostomou, P. Gergely and J.F. Abel, 12/19/88, (PB89-208383).

NCEER-88-0047 "Reinforced Concrete Frame Component Testing Facility - Design, Construction, Instrumentation and Operation," by S.P. Pessiki, C. Conley, T. Bond, P. Gergely and R.N. White, 12/16/88, (PB89-174478).

NCEER-89-0001 "Effects of Protective Cushion and Soil Compliancy on the Response of Equipment Within a Seismically Excited Building," by J.A. HoLung, 2/16/89, (PB89-207179).

NCEER-89-0002 "Statistical Evaluation of Response Modification Factors for Reinforced Concrete Structures," by H.H-M. Hwang and J-W. Jaw, 2/17/89, (PB89-207187).

NCEER-89-0003 "Hysteretic Columns Under Random Excitation," by G-Q. Cai and Y.K. Lin, 1/9/89, (PB89-196513).

NCEER-89-0004 "Experimental Study of 'Elephant Foot Bulge' Instability of Thin-Walled Metal Tanks," by Z-H. Jia and R.L. Ketter, 2/22/89, (PB89-207195).

NCEER-89-0005 "Experiment on Performance of Buried Pipelines Across San Andreas Fault," by J. Isenberg, E. Richardson and T.D. O'Rourke, 3/10/89, (PB89-218440). This report is available only through NTIS (see address given above).

NCEER-89-0006 "A Knowledge-Based Approach to Structural Design of Earthquake-Resistant Buildings," by M. Subramani, P. Gergely, C.H. Conley, J.F. Abel and A.H. Zaghw, 1/15/89, (PB89-218465).

NCEER-89-0007 "Liquefaction Hazards and Their Effects on Buried Pipelines," by T.D. O'Rourke and P.A. Lane, 2/1/89, (PB89-218481).

NCEER-89-0008 "Fundamentals of System Identification in Structural Dynamics," by H. Imai, C-B. Yun, O. Maruyama and M. Shinozuka, 1/26/89, (PB89-207211).

NCEER-89-0009 "Effects of the 1985 Michoacan Earthquake on Water Systems and Other Buried Lifelines in Mexico," by A.G. Ayala and M.J. O'Rourke, 3/8/89, (PB89-207229).

NCEER-89-R010 "NCEER Bibliography of Earthquake Education Materials," by K.E.K. Ross, Second Revision, 9/1/89, (PB90-125352).

NCEER-89-0011 "Inelastic Three-Dimensional Response Analysis of Reinforced Concrete Building Structures (IDARC-3D), Part I - Modeling," by S.K. Kunnath and A.M. Reinhorn, 4/17/89, (PB90-114612).

NCEER-89-0012 "Recommended Modifications to ATC-14," by C.D. Poland and J.O. Malley, 4/12/89, (PB90-108648).

NCEER-89-0013 "Repair and Strengthening of Beam-to-Column Connections Subjected to Earthquake Loading," by M. Corazao and A.J. Durrani, 2/28/89, (PB90-109885).

NCEER-89-0014 "Program EXKAL2 for Identification of Structural Dynamic Systems," by O. Maruyama, C-B. Yun, M. Hoshiya and M. Shinozuka, 5/19/89, (PB90-109877).

NCEER-89-0015 "Response of Frames With Bolted Semi-Rigid Connections, Part I - Experimental Study and Analytical Predictions," by P.J. DiCorso, A.M. Reinhorn, J.R. Dickerson, J.B. Radziminski and W.L. Harper, 6/1/89, to be published.

NCEER-89-0016 "ARMA Monte Carlo Simulation in Probabilistic Structural Analysis," by P.D. Spanos and M.P. Mignolet, 7/10/89, (PB90-109893).

NCEER-89-P017 "Preliminary Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 6/23/89, (PB90-108606).

NCEER-89-0017 "Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 12/31/89, (PB90-207895). This report is available only through NTIS (see address given above).

NCEER-89-0018 "Multidimensional Models of Hysteretic Material Behavior for Vibration Analysis of Shape Memory Energy Absorbing Devices, by E.J. Graesser and F.A. Cozzarelli, 6/7/89, (PB90-164146).

NCEER-89-0019 "Nonlinear Dynamic Analysis of Three-Dimensional Base Isolated Structures (3D-BASIS)," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 8/3/89, (PB90-161936). This report is available only through NTIS (see address given above).

NCEER-89-0020 "Structural Control Considering Time-Rate of Control Forces and Control Rate Constraints," by F.Y. Cheng and C.P. Pantelides, 8/3/89, (PB90-120445).

NCEER-89-0021 "Subsurface Conditions of Memphis and Shelby County," by K.W. Ng, T-S. Chang and H-H.M. Hwang, 7/26/89, (PB90-120437).

NCEER-89-0022 "Seismic Wave Propagation Effects on Straight Jointed Buried Pipelines," by K. Elhmadi and M.J. O'Rourke, 8/24/89, (PB90-162322).

NCEER-89-0023 "Workshop on Serviceability Analysis of Water Delivery Systems," edited by M. Grigoriu, 3/6/89, (PB90-127424).

NCEER-89-0024 "Shaking Table Study of a 1/5 Scale Steel Frame Composed of Tapered Members," by K.C. Chang, J.S. Hwang and G.C. Lee, 9/18/89, (PB90-160169).

NCEER-89-0025 "DYNA1D: A Computer Program for Nonlinear Seismic Site Response Analysis - Technical Documentation," by Jean H. Prevost, 9/14/89, (PB90-161944). This report is available only through NTIS (see address given above).

NCEER-89-0026 "1:4 Scale Model Studies of Active Tendon Systems and Active Mass Dampers for Aseismic Protection," by A.M. Reinhorn, T.T. Soong, R.C. Lin, Y.P. Yang, Y. Fukao, H. Abe and M. Nakai, 9/15/89, (PB90-173246).

NCEER-89-0027 "Scattering of Waves by Inclusions in a Nonhomogeneous Elastic Half Space Solved by Boundary Element Methods," by P.K. Hadley, A. Askar and A.S. Cakmak, 6/15/89, (PB90-145699).

NCEER-89-0028 "Statistical Evaluation of Deflection Amplification Factors for Reinforced Concrete Structures," by H.H.M. Hwang, J-W. Jaw and A.L. Ch'ng, 8/31/89, (PB90-164633).

NCEER-89-0029 "Bedrock Accelerations in Memphis Area Due to Large New Madrid Earthquakes," by H.H.M. Hwang, C.H.S. Chen and G. Yu, 11/7/89, (PB90-162330).

NCEER-89-0030 "Seismic Behavior and Response Sensitivity of Secondary Structural Systems," by Y.Q. Chen and T.T. Soong, 10/23/89, (PB90-164658).

NCEER-89-0031 "Random Vibration and Reliability Analysis of Primary-Secondary Structural Systems," by Y. Ibrahim, M. Grigoriu and T.T. Soong, 11/10/89, (PB90-161951).

NCEER-89-0032 "Proceedings from the Second U.S. - Japan Workshop on Liquefaction, Large Ground Deformation and Their Effects on Lifelines, September 26-29, 1989," Edited by T.D. O'Rourke and M. Hamada, 12/1/89, (PB90-209388).

NCEER-89-0033 "Deterministic Model for Seismic Damage Evaluation of Reinforced Concrete Structures," by J.M. Bracci, A.M. Reinhorn, J.B. Mander and S.K. Kunnath, 9/27/89.

NCEER-89-0034 "On the Relation Between Local and Global Damage Indices," by E. DiPasquale and A.S. Cakmak, 8/15/89, (PB90-173865).

NCEER-89-0035 "Cyclic Undrained Behavior of Nonplastic and Low Plasticity Silts," by A.J. Walker and H.E. Stewart, 7/26/89, (PB90-183518).

NCEER-89-0036 "Liquefaction Potential of Surficial Deposits in the City of Buffalo, New York," by M. Budhu, R. Giese and L. Baumgrass, 1/17/89, (PB90-208455).

NCEER-89-0037 "A Deterministic Assessment of Effects of Ground Motion Incoherence," by A.S. Veletsos and Y. Tang, 7/15/89, (PB90-164294).

NCEER-89-0038 "Workshop on Ground Motion Parameters for Seismic Hazard Mapping," July 17-18, 1989, edited by R.V. Whitman, 12/1/89, (PB90-173923).

NCEER-89-0039 "Seismic Effects on Elevated Transit Lines of the New York City Transit Authority," by C.J. Costantino, C.A. Miller and E. Heymsfield, 12/26/89, (PB90-207887).

NCEER-89-0040 "Centrifugal Modeling of Dynamic Soil-Structure Interaction," by K. Weissman, Supervised by J.H. Prevost, 5/10/89, (PB90-207879).

NCEER-89-0041 "Linearized Identification of Buildings With Cores for Seismic Vulnerability Assessment," by I-K. Ho and A.E. Aktan, 11/1/89, (PB90-251943).

NCEER-90-0001 "Geotechnical and Lifeline Aspects of the October 17, 1989 Loma Prieta Earthquake in San Francisco," by T.D. O'Rourke, H.E. Stewart, F.T. Blackburn and T.S. Dickerman, 1/90, (PB90-208596).

NCEER-90-0002 "Nonnormal Secondary Response Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 2/28/90, (PB90-251976).

NCEER-90-0003 "Earthquake Education Materials for Grades K-12," by K.E.K. Ross, 4/16/90, (PB91-251984).

NCEER-90-0004 "Catalog of Strong Motion Stations in Eastern North America," by R.W. Busby, 4/3/90, (PB90-251984).

NCEER-90-0005 "NCEER Strong-Motion Data Base: A User Manual for the GeoBase Release (Version 1.0 for the Sun3)," by P. Friberg and K. Jacob, 3/31/90 (PB90-258062).

NCEER-90-0006 "Seismic Hazard Along a Crude Oil Pipeline in the Event of an 1811-1812 Type New Madrid Earthquake," by H.H.M. Hwang and C-H.S. Chen, 4/16/90(PB90-258054).

NCEER-90-0007 "Site-Specific Response Spectra for Memphis Sheahan Pumping Station," by H.H.M. Hwang and C.S. Lee, 5/15/90, (PB91-108811).

NCEER-90-0008 "Pilot Study on Seismic Vulnerability of Crude Oil Transmission Systems," by T. Ariman, R. Dobry, M. Grigoriu, F. Kozin, M. O'Rourke, T. O'Rourke and M. Shinozuka, 5/25/90, (PB91-108837).

NCEER-90-0009 "A Program to Generate Site Dependent Time Histories: EQGEN," by G.W. Ellis, M. Srinivasan and A.S. Cakmak, 1/30/90, (PB91-108829).

NCEER-90-0010 "Active Isolation for Seismic Protection of Operating Rooms," by M.E. Talbott, Supervised by M. Shinozuka, 6/8/9, (PB91-110205).

NCEER-90-0011 "Program LINEARID for Identification of Linear Structural Dynamic Systems," by C-B. Yun and M. Shinozuka, 6/25/90, (PB91-110312).

NCEER-90-0012 "Two-Dimensional Two-Phase Elasto-Plastic Seismic Response of Earth Dams," by A.N. Yiagos, Supervised by J.H. Prevost, 6/20/90, (PB91-110197).

NCEER-90-0013 "Secondary Systems in Base-Isolated Structures: Experimental Investigation, Stochastic Response and Stochastic Sensitivity," by G.D. Manolis, G. Juhn, M.C. Constantinou and A.M. Reinhorn, 7/1/90, (PB91-110320).

NCEER-90-0014 "Seismic Behavior of Lightly-Reinforced Concrete Column and Beam-Column Joint Details," by S.P. Pessiki, C.H. Conley, P. Gergely and R.N. White, 8/22/90, (PB91-108795).

NCEER-90-0015 "Two Hybrid Control Systems for Building Structures Under Strong Earthquakes," by J.N. Yang and A. Danielians, 6/29/90, (PB91-125393).

NCEER-90-0016 "Instantaneous Optimal Control with Acceleration and Velocity Feedback," by J.N. Yang and Z. Li, 6/29/90, (PB91-125401).

NCEER-90-0017 "Reconnaissance Report on the Northern Iran Earthquake of June 21, 1990," by M. Mehrain, 10/4/90, (PB91-125377).

NCEER-90-0018 "Evaluation of Liquefaction Potential in Memphis and Shelby County," by T.S. Chang, P.S. Tang, C.S. Lee and H. Hwang, 8/10/90, (PB91-125427).

NCEER-90-0019 "Experimental and Analytical Study of a Combined Sliding Disc Bearing and Helical Steel Spring Isolation System," by M.C. Constantinou, A.S. Mokha and A.M. Reinhorn, 10/4/90, (PB91-125385).

NCEER-90-0020 "Experimental Study and Analytical Prediction of Earthquake Response of a Sliding Isolation System with a Spherical Surface," by A.S. Mokha, M.C. Constantinou and A.M. Reinhorn, 10/11/90, (PB91-125419).

NCEER-90-0021 "Dynamic Interaction Factors for Floating Pile Groups," by G. Gazetas, K. Fan, A. Kaynia and E. Kausel, 9/10/90, (PB91-170381).

NCEER-90-0022 "Evaluation of Seismic Damage Indices for Reinforced Concrete Structures," by S. Rodriguez-Gomez and A.S. Cakmak, 9/30/90, PB91-171322).

NCEER-90-0023 "Study of Site Response at a Selected Memphis Site," by H. Desai, S. Ahmad, E.S. Gazetas and M.R. Oh, 10/11/90, (PB91-196857).

NCEER-90-0024 "A User's Guide to Strongmo: Version 1.0 of NCEER's Strong-Motion Data Access Tool for PCs and Terminals," by P.A. Friberg and C.A.T. Susch, 11/15/90, (PB91-171272).

NCEER-90-0025 "A Three-Dimensional Analytical Study of Spatial Variability of Seismic Ground Motions," by L-L. Hong and A.H.-S. Ang, 10/30/90, (PB91-170399).

NCEER-90-0026 "MUMOID User's Guide - A Program for the Identification of Modal Parameters," by S. Rodriguez-Gomez and E. DiPasquale, 9/30/90, (PB91-171298).

NCEER-90-0027 "SARCF-II User's Guide - Seismic Analysis of Reinforced Concrete Frames," by S. Rodriguez-Gomez, Y.S. Chung and C. Meyer, 9/30/90, (PB91-171280).

NCEER-90-0028 "Viscous Dampers: Testing, Modeling and Application in Vibration and Seismic Isolation," by N. Makris and M.C. Constantinou, 12/20/90 (PB91-190561).

NCEER-90-0029 "Soil Effects on Earthquake Ground Motions in the Memphis Area," by H. Hwang, C.S. Lee, K.W. Ng and T.S. Chang, 8/2/90, (PB91-190751).

NCEER-91-0001 "Proceedings from the Third Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures for Soil Liquefaction, December 17-19, 1990," edited by T.D. O'Rourke and M. Hamada, 2/1/91, (PB91-179259).

NCEER-91-0002 "Physical Space Solutions of Non-Proportionally Damped Systems," by M. Tong, Z. Liang and G.C. Lee, 1/15/91, (PB91-179242).

NCEER-91-0003 "Seismic Response of Single Piles and Pile Groups," by K. Fan and G. Gazetas, 1/10/91, (PB92-174994).

NCEER-91-0004 "Damping of Structures: Part 1 - Theory of Complex Damping," by Z. Liang and G. Lee, 10/10/91, (PB92-197235).

NCEER-91-0005 "3D-BASIS - Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures: Part II," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 2/28/91, (PB91-190553).

NCEER-91-0006 "A Multidimensional Hysteretic Model for Plasticity Deforming Metals in Energy Absorbing Devices," by E.J. Graesser and F.A. Cozzarelli, 4/9/91, (PB92-108364).

NCEER-91-0007 "A Framework for Customizable Knowledge-Based Expert Systems with an Application to a KBES for Evaluating the Seismic Resistance of Existing Buildings," by E.G. Ibarra-Anaya and S.J. Fenves, 4/9/91, (PB91-210930).

NCEER-91-0008 "Nonlinear Analysis of Steel Frames with Semi-Rigid Connections Using the Capacity Spectrum Method," by G.G. Deierlein, S-H. Hsieh, Y-J. Shen and J.F. Abel, 7/2/91, (PB92-113828).

NCEER-91-0009 "Earthquake Education Materials for Grades K-12," by K.E.K. Ross, 4/30/91, (PB91-212142).

NCEER-91-0010 "Phase Wave Velocities and Displacement Phase Differences in a Harmonically Oscillating Pile," by N. Makris and G. Gazetas, 7/8/91, (PB92-108356).

NCEER-91-0011 "Dynamic Characteristics of a Full-Size Five-Story Steel Structure and a 2/5 Scale Model," by K.C. Chang, G.C. Yao, G.C. Lee, D.S. Hao and Y.C. Yeh," 7/2/91, (PB93-116648).

NCEER-91-0012 "Seismic Response of a 2/5 Scale Steel Structure with Added Viscoelastic Dampers," by K.C. Chang, T.T. Soong, S-T. Oh and M.L. Lai, 5/17/91, (PB92-110816).

NCEER-91-0013 "Earthquake Response of Retaining Walls; Full-Scale Testing and Computational Modeling," by S. Alampalli and A-W.M. Elgamal, 6/20/91, to be published.

NCEER-91-0014 "3D-BASIS-M: Nonlinear Dynamic Analysis of Multiple Building Base Isolated Structures," by P.C. Tsopelas, S. Nagarajaiah, M.C. Constantinou and A.M. Reinhorn, 5/28/91, (PB92-113885).

NCEER-91-0015 "Evaluation of SEAOC Design Requirements for Sliding Isolated Structures," by D. Theodossiou and M.C. Constantinou, 6/10/91, (PB92-114602).

NCEER-91-0016 "Closed-Loop Modal Testing of a 27-Story Reinforced Concrete Flat Plate-Core Building," by H.R. Somaprasad, T. Toksoy, H. Yoshiyuki and A.E. Aktan, 7/15/91, (PB92-129980).

NCEER-91-0017 "Shake Table Test of a 1/6 Scale Two-Story Lightly Reinforced Concrete Building," by A.G. El-Attar, R.N. White and P. Gergely, 2/28/91, (PB92-222447).

NCEER-91-0018 "Shake Table Test of a 1/8 Scale Three-Story Lightly Reinforced Concrete Building," by A.G. El-Attar, R.N. White and P. Gergely, 2/28/91, (PB93-116630).

NCEER-91-0019 "Transfer Functions for Rigid Rectangular Foundations," by A.S. Veletsos, A.M. Prasad and W.H. Wu, 7/31/91.

NCEER-91-0020 "Hybrid Control of Seismic-Excited Nonlinear and Inelastic Structural Systems," by J.N. Yang, Z. Li and A. Danielians, 8/1/91, (PB92-143171).

NCEER-91-0021 "The NCEER-91 Earthquake Catalog: Improved Intensity-Based Magnitudes and Recurrence Relations for U.S. Earthquakes East of New Madrid," by L. Seeber and J.G. Armbruster, 8/28/91, (PB92-176742).

NCEER-91-0022 "Proceedings from the Implementation of Earthquake Planning and Education in Schools: The Need for Change - The Roles of the Changemakers," by K.E.K. Ross and F. Winslow, 7/23/91, (PB92-129998).

NCEER-91-0023 "A Study of Reliability-Based Criteria for Seismic Design of Reinforced Concrete Frame Buildings," by H.H.M. Hwang and H-M. Hsu, 8/10/91, (PB92-140235).

NCEER-91-0024 "Experimental Verification of a Number of Structural System Identification Algorithms," by R.G. Ghanem, H. Gavin and M. Shinozuka, 9/18/91, (PB92-176577).

NCEER-91-0025 "Probabilistic Evaluation of Liquefaction Potential," by H.H.M. Hwang and C.S. Lee," 11/25/91, (PB92-143429).

NCEER-91-0026 "Instantaneous Optimal Control for Linear, Nonlinear and Hysteretic Structures - Stable Controllers," by J.N. Yang and Z. Li, 11/15/91, (PB92-163807).

NCEER-91-0027 "Experimental and Theoretical Study of a Sliding Isolation System for Bridges," by M.C. Constantinou, A. Kartoum, A.M. Reinhorn and P. Bradford, 11/15/91, (PB92-176973).

NCEER-92-0001 "Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes, Volume 1: Japanese Case Studies," Edited by M. Hamada and T. O'Rourke, 2/17/92, (PB92-197243).

NCEER-92-0002 "Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes, Volume 2: United States Case Studies," Edited by T. O'Rourke and M. Hamada, 2/17/92, (PB92-197250).

NCEER-92-0003 "Issues in Earthquake Education," Edited by K. Ross, 2/3/92, (PB92-222389).

NCEER-92-0004 "Proceedings from the First U.S. - Japan Workshop on Earthquake Protective Systems for Bridges," Edited by I.G. Buckle, 2/4/92.

NCEER-92-0005 "Seismic Ground Motion from a Haskell-Type Source in a Multiple-Layered Half-Space," A.P. Theoharis, G. Deodatis and M. Shinozuka, 1/2/92, to be published.

NCEER-92-0006 "Proceedings from the Site Effects Workshop," Edited by R. Whitman, 2/29/92, (PB92-197201).

NCEER-92-0007 "Engineering Evaluation of Permanent Ground Deformations Due to Seismically-Induced Liquefaction," by M.H. Baziar, R. Dobry and A-W.M. Elgamal, 3/24/92, (PB92-222421).

NCEER-92-0008 "A Procedure for the Seismic Evaluation of Buildings in the Central and Eastern United States," by C.D. Poland and J.O. Malley, 4/2/92, (PB92-222439).

NCEER-92-0009 "Experimental and Analytical Study of a Hybrid Isolation System Using Friction Controllable Sliding Bearings," by M.Q. Feng, S. Fujii and M. Shinozuka, 5/15/92, (PB93-150282).

NCEER-92-0010 "Seismic Resistance of Slab-Column Connections in Existing Non-Ductile Flat-Plate Buildings," by A.J. Durrani and Y. Du, 5/18/92.

NCEER-92-0011 "The Hysteretic and Dynamic Behavior of Brick Masonry Walls Upgraded by Ferrocement Coatings Under Cyclic Loading and Strong Simulated Ground Motion," by H. Lee and S.P. Prawel, 5/11/92, to be published.

NCEER-92-0012 "Study of Wire Rope Systems for Seismic Protection of Equipment in Buildings," by G.F. Demetriades, M.C. Constantinou and A.M. Reinhorn, 5/20/92.

NCEER-92-0013 "Shape Memory Structural Dampers: Material Properties, Design and Seismic Testing," by P.R. Witting and F.A. Cozzarelli, 5/26/92.

NCEER-92-0014 "Longitudinal Permanent Ground Deformation Effects on Buried Continuous Pipelines," by M.J. O'Rourke, and C. Nordberg, 6/15/92.

NCEER-92-0015 "A Simulation Method for Stationary Gaussian Random Functions Based on the Sampling Theorem," by M. Grigoriu and S. Balopoulou, 6/11/92, (PB93-127496).

NCEER-92-0016 "Gravity-Load-Designed Reinforced Concrete Buildings: Seismic Evaluation of Existing Construction and Detailing Strategies for Improved Seismic Resistance," by G.W. Hoffmann, S.K. Kunnath, A.M. Reinhorn and J.B. Mander, 7/15/92.

NCEER-92-0017 "Observations on Water System and Pipeline Performance in the Limón Area of Costa Rica Due to the April 22, 1991 Earthquake," by M. O'Rourke and D. Ballantyne, 6/30/92, (PB93-126811).

NCEER-92-0018 "Fourth Edition of Earthquake Education Materials for Grades K-12," Edited by K.E.K. Ross, 8/10/92.

NCEER-92-0019 "Proceedings from the Fourth Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures for Soil Liquefaction," Edited by M. Hamada and T.D. O'Rourke, 8/12/92, (PB93-163939).

NCEER-92-0020 "Active Bracing System: A Full Scale Implementation of Active Control," by A.M. Reinhorn, T.T. Soong, R.C. Lin, M.A. Riley, Y.P. Wang, S. Aizawa and M. Higashino, 8/14/92, (PB93-127512).

NCEER-92-0021 "Empirical Analysis of Horizontal Ground Displacement Generated by Liquefaction-Induced Lateral Spreads," by S.F. Bartlett and T.L. Youd, 8/17/92, (PB93-188241).

NCEER-92-0022 "IDARC Version 3.0: Inelastic Damage Analysis of Reinforced Concrete Structures," by S.K. Kunnath, A.M. Reinhorn and R.F. Lobo, 8/31/92.

NCEER-92-0023 "A Semi-Empirical Analysis of Strong-Motion Peaks in Terms of Seismic Source, Propagation Path and Local Site Conditions, by M. Kamiyama, M.J. O'Rourke and R. Flores-Berrones, 9/9/92, (PB93-150266).

NCEER-92-0024 "Seismic Behavior of Reinforced Concrete Frame Structures with Nonductile Details, Part I: Summary of Experimental Findings of Full Scale Beam-Column Joint Tests," by A. Beres, R.N. White and P. Gergely, 9/30/92.

NCEER-92-0025 "Experimental Results of Repaired and Retrofitted Beam-Column Joint Tests in Lightly Reinforced Concrete Frame Buildings," by A. Beres, S. El-Borgi, R.N. White and P. Gergely, 10/29/92.

NCEER-92-0026 "A Generalization of Optimal Control Theory: Linear and Nonlinear Structures," by J.N. Yang, Z. Li and S. Vongchavalitkul, 11/2/92, (PB93-188621).

NCEER-92-0027 "Seismic Resistance of Reinforced Concrete Frame Structures Designed Only for Gravity Loads: Part I - Design and Properties of a One-Third Scale Model Structure," by J.M. Bracci, A.M. Reinhorn and J.B. Mander, 12/1/92.

NCEER-92-0028 "Seismic Resistance of Reinforced Concrete Frame Structures Designed Only for Gravity Loads: Part II - Experimental Performance of Subassemblages," by L.E. Aycardi, J.B. Mander and A.M. Reinhorn, 12/1/92.

NCEER-92-0029 "Seismic Resistance of Reinforced Concrete Frame Structures Designed Only for Gravity Loads: Part III - Experimental Performance and Analytical Study of a Structural Model," by J.M. Bracci, A.M. Reinhorn and J.B. Mander, 12/1/92, (PB93-227528, A09, MF-A01).

NCEER-92-0030 "Evaluation of Seismic Retrofit of Reinforced Concrete Frame Structures: Part I - Experimental Performance of Retrofitted Subassemblages," by D. Choudhuri, J.B. Mander and A.M. Reinhorn, 12/8/92.

NCEER-92-0031 "Evaluation of Seismic Retrofit of Reinforced Concrete Frame Structures: Part II - Experimental Performance and Analytical Study of a Retrofitted Structural Model," by J.M. Bracci, A.M. Reinhorn and J.B. Mander, 12/8/92.

NCEER-92-0032 "Experimental and Analytical Investigation of Seismic Response of Structures with Supplemental Fluid Viscous Dampers," by M.C. Constantinou and M.D. Symans, 12/21/92, (PB93-191435).

NCEER-92-0033 "Reconnaissance Report on the Cairo, Egypt Earthquake of October 12, 1992," by M. Khater, 12/23/92, (PB93-188621).

NCEER-92-0034 "Low-Level Dynamic Characteristics of Four Tall Flat-Plate Buildings in New York City," by H. Gavin, S. Yuan, J. Grossman, E. Pekelis and K. Jacob, 12/28/92, (PB93-188217).

NCEER-93-0001 "An Experimental Study on the Seismic Performance of Brick-Infilled Steel Frames With and Without Retrofit," by J.B. Mander, B. Nair, K. Wojtkowski and J. Ma, 1/29/93.

NCEER-93-0002 "Social Accounting for Disaster Preparedness and Recovery Planning," by S. Cole, E. Pantoja and V. Razak, 2/22/93, to be published.

NCEER-93-0003 "Assessment of 1991 NEHRP Provisions for Nonstructural Components and Recommended Revisions," by T.T. Soong, G. Chen, Z. Wu, R-H. Zhang and M. Grigoriu, 3/1/93, (PB93-188639).

NCEER-93-0004 "Evaluation of Static and Response Spectrum Analysis Procedures of SEAOC/UBC for Seismic Isolated Structures," by C.W. Winters and M.C. Constantinou, 3/23/93, (PB93-198299).

NCEER-93-0005 "Earthquakes in the Northeast - Are We Ignoring the Hazard? A Workshop on Earthquake Science and Safety for Educators," edited by K.E.K. Ross, 4/2/93.

NCEER-93-0006 "Inelastic Response of Reinforced Concrete Structures with Viscoelastic Braces," by R.F. Lobo, J.M. Bracci, K.L. Shen, A.M. Reinhorn and T.T. Soong, 4/5/93.

NCEER-93-0007 "Seismic Testing of Installation Methods for Computers and Data Processing Equipment," by K. Kosar, T.T. Soong, K.L. Shen, J.A. HoLung and Y.K. Lin, 4/12/93, (PB93-198299).

NCEER-93-0008 "Retrofit of Reinforced Concrete Frames Using Added Dampers," by A. Reinhorn, M. Constantinou and C. Li, to be published.

NCEER-93-0009 "Seismic Applications of Viscoelastic Dampers to Steel Frame Structures," by K.C. Chang and T.T. Soong, to be published.

NCEER-93-0010 "Seismic Performance of Shear-Critical Reinforced Concrete Bridge Piers," by J.B. Mander, S.M. Waheed, M.T.A. Chaudhary and S.S. Chen, 5/12/93, (PB93-227494, A08, MF-A02).

NCEER-93-0011 "3D-BASIS-TABS: Computer Program for Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures," by S. Nagarajaiah, C. Li, A.M. Reinhorn and M.C. Constantinou, 8/2/93.

NCEER-93-0012 "Effects of Hydrocarbon Spills from an Oil Pipeline Break on Ground Water," by O.J. Helweg and H.H.M. Hwang, 8/3/93.

NCEER-93-0013 "Simplified Procedures for Seismic Design of Nonstructural Components and Assessment of Current Code Provisions," by M.P. Singh, L.E. Suarea, E.E. Matheu and G.O. Maldonado, 8/4/93.

NCEER-93-0014 "An Energy Approach to Seismic Analysis and Design of Secondary Systems," by G. Chen and T.T. Soong, 8/6/93.

NCEER-93-0015 "Proceedings from School Sites: Becoming Prepared for Earthquakes - Commemorating the Third Anniversary of the Loma Prieta Earthquake, Edited by F.E. Winslow and K.E.K. Ross, 8/16/93, to be published.

NCEER-93-0016 "Reconnaissance Report of Damage to Historic Monuments in Cairo, Egypt Following the October 12, 1992 Dahshur, Earthquake," by D. Sykora, D. Look, G. Croci, E. Karaesmen and E. Karaesmen, 8/19/93.