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Report of an International Workshop on Preserving Historic Buildings of Major Importance

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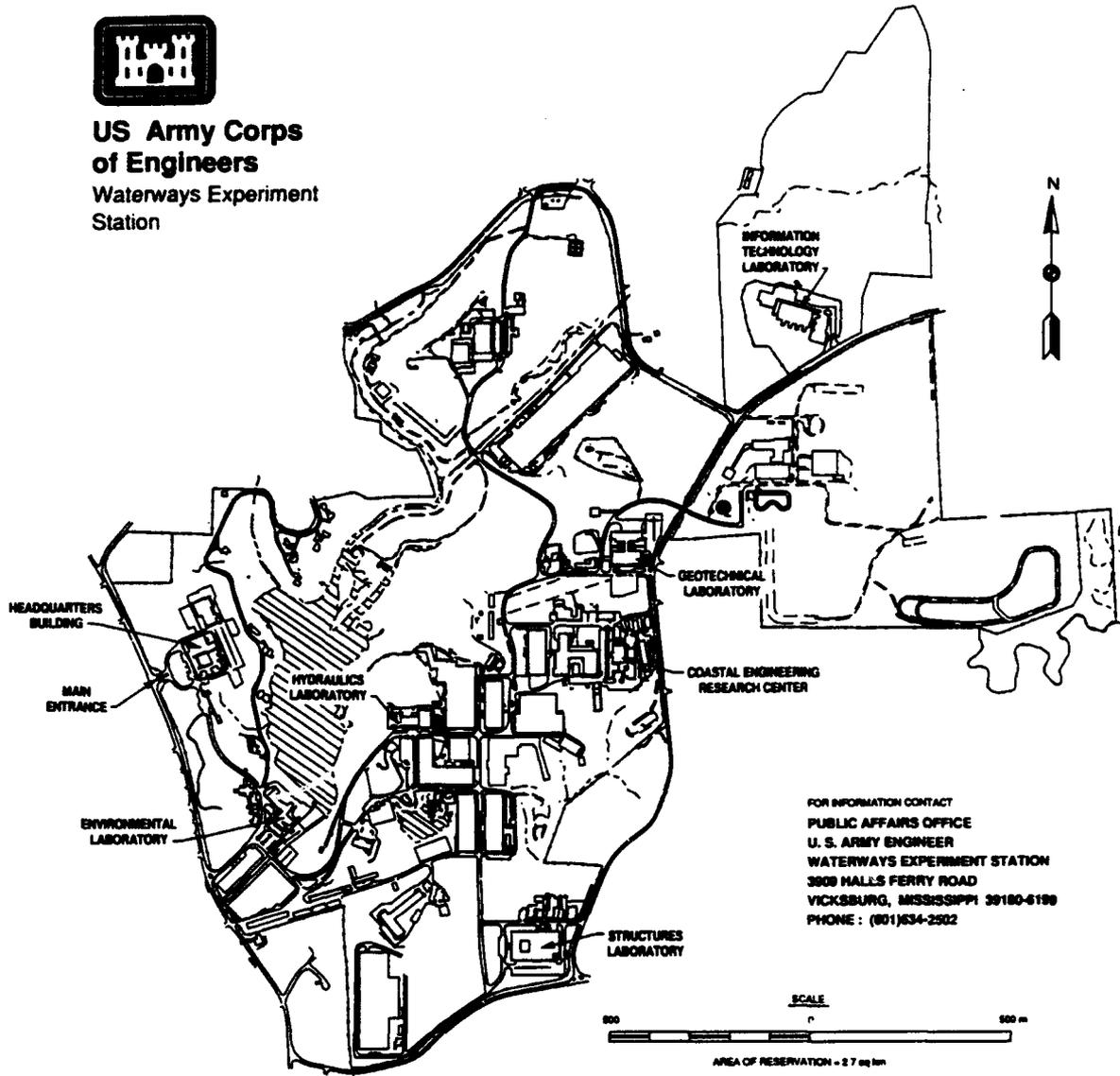
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EXECUTIVE SUMMARY

An international workshop was conducted to explore how recent advances in science and engineering may be exploited to evaluate the vulnerability of irreplaceable historic facilities to seismic hazards, to design remedial actions, and to develop an effective preservation methodology. The product of the workshop was a research plan 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.

The workshop participants consisted of an international team of 28 professionals with expertise in the fields of seismology, geophysics, geotechnical and structural engineering, architecture, and art history. The workshop was held in Istanbul, Turkey, because related Turkish authorities and professional counterparts offered to co-host this effort. This Turkish invitation provided a rare opportunity to discuss the development of a preservation methodology in the context of actual case histories of performance of two monumental structures—large-span masonry domed mosques which have been subjected to a 500-year history of environmental loading including significant seismic action.

This joint U.S.-Turkey opportunity provided a basis to develop a procedural model for evaluating the threat to irreplaceable historic construction; develop an effective preservation strategy; advance the state-of-the-art techniques in engineering seismology, engineering geophysics, and geotechnical and structural earthquake engineering; provide a forum for international technical transfer; and strengthen the bonds of friendship and cooperation between the two countries.

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PREFACE

This study was conducted by the US Army Engineer Waterways Experiment Station (WES) for the Geomechanical, Geotechnical, and Geo-environmental Systems Program, National Science Foundation (NSF) during FY92. Dr. Mehmet T. Tümay was the Program Director. The title of this project (MSS-9214843) was "Preserving Historic Buildings of Major Importance."

The Principal Investigator for this study was Dr. Mary Ellen Hynes, Chief, Earthquake Engineering and Seismology Branch (EESB), Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), WES. Dr. A. G. Franklin, Chief, EEGD, and Mr. David W. Sykora, EEGD, were invited participants. Messrs. Daniel Habeeb and Ezell Allen assisted in preparing the workshop preprint.

This report is a documentation of activities, presentations, ideas, and recommendations developed at the workshop to address the preservation objective. The technical papers prepared for this workshop are published in Appendix A and follow-up reports are presented in their entirety in Appendix D. Some of the key text and photographs from these documents were used directly in the body of this report. Primary contributors to this report were: Prof. A. Emin Aktan, University of Cincinnati, who wrote the section on the findings of the Structural Engineering working group; Mr. David Look, U.S. National Park Service, who wrote the section on the findings of the Art History and Architecture working group; and Prof. Ünal Öziş, Dokuz Eylül University, who wrote about the life of Sinan. Researchers and graduate students from METU (Ms. Nalan Boyaci, Mustafa Nalçakan, Ender Şenkaya, Serhat Yağci, and Ahmet Yakut) and Princeton University (Ms. Rachel Davidson) took notes and recorded the sessions. U.S. team participants provided additional comments incorporated in this report.

Overall direction at WES was provided by Dr. A. G. Franklin, Chief, EEGD, and Dr. William F. Marcuson III, Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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REPORT OF AN INTERNATIONAL WORKSHOP ON PRESERVING HISTORIC
BUILDINGS OF MAJOR IMPORTANCE

PART I: BACKGROUND

1. Recently, there has been much attention focused on preserving the infrastructure in a cost-effective manner to establish long-term safety and reliability. New strategies and technologies for evaluating, maintaining, and upgrading existing construction are being researched. A special aspect of the problem is preserving historic monuments of major importance. Architectural and structural designs, materials, and construction of most pre-20th century historic facilities cannot be replicated today without significant effort, if at all; art treasures that may be an integral part of these facilities are irreplaceable.

2. Historic buildings of major importance can be paralleled with critical structures, many of which are the responsibility of the Departments of Defense, Interior, and Energy in the United States. The level of detail for investigations, sophisticated analysis, performance evaluation, and remedial actions required for critical structures is a prime motivator for advances in the state of the art in engineering seismology, engineering geophysics, and geotechnical and structural engineering, and continues to be a challenge, particularly for seismic loading and remediation decisions. For such facilities, building codes are generally inappropriate and insufficient, and state-of-the-art, site-specific investigations are performed to assess facility survivability to future hazards under current and projected site and facility conditions and to design practical, effective remedial actions.

3. Preservation of important historic construction presents special difficulties, particularly when seismic effects are of concern. Fundamental changes have occurred in the architectural and structural systems in conjunction with the materials and construction processes over the centuries. The quality of steel, concrete, and masonry have individually improved. However, our capacity to: 1) understand the condition of an aged soil-foundation-structure system in terms of meaningful engineering indices, 2) to evaluate load transmission mechanisms, and 3) to assess the effects of local structural details on these mechanisms. Contemporary materials and

construction techniques generally prove incompatible with period counterparts unless specific studies are conducted to ensure compatibility. Therefore, traditional concepts of risk trade-offs and economic life are largely inapplicable due to values that transcend economics and the open-ended time frame for structure survival.

4. Achieving structural integrity of a deteriorated part of a building to withstand future seismic loads without damaging adjacent parts during the repair process is a challenge. Remediation strategies that are artistically acceptable may have large residual uncertainties in their effectiveness, as indicated by the lack of consistent performance of seismic retrofit strategies observed during the 1989 Loma Prieta earthquake in California (Mahin, 1991). Due to the fragility of architectural and artistic elements in historic construction, the site and structure condition evaluation options provided by the emerging technology of nondestructive testing are particularly desirable to estimate existing conditions and the effectiveness of remedial actions.

5. The level of preservation to be achieved can be categorized as partial preservation when only a key portion of a structure will be saved (often seen in U.S. cities to preserve the façades of old buildings such as post offices), functional preservation when remedial actions are required to maintain or restore facility functionality and may involve considerable structural intervention in place (e.g., rehabilitation of the Statue of Liberty), and heroic preservation when massive reconstruction effort is required to preserve the facility (e.g., base isolation preservation efforts at the Salt Lake City and County Building) and, in extreme cases, may include complete dismantling and relocation of the facility to a new, safer site (e.g., relocation of several temples and monuments in the Nile Valley, Egypt, that would have been inundated by reservoir and flood water retained by Aswan Dam).

6. Many examples of these levels of preservation exist in the activities of the U.S. National Park Service (NPS) and the Army Corps of Engineers (USACE) who have significant responsibility in the United States to preserve landmarks of our cultural heritage. The European Community (EC), North Atlantic Treaty Organization (NATO), and United Nations Economic, Scientific, and Cultural Organization (UNESCO) also have an interest in long-term preservation of historic sites outside the United States.

7. The decision about the level of preservation that is required and the conservatism in the remedial actions adopted, if required, are driven by the recognition of the facility as a national treasure and the determination of an acceptable level of damage to the critical elements of the structure. For this problem, communication is essential among the professional disciplines of science, engineering, architecture, archaeology, and history so that the treasured elements for preservation are properly identified, the level of accuracy required in engineering analyses and preservation designs is understood, and the potential future seismic threats and deteriorating facility condition are factored into the solutions.

Purpose and Objectives

8. The purpose of the workshop was to explore how recent advances in science and engineering for the evaluation of 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 construction. The primary objective of the workshop was to develop a research plan for formulating a procedural, analytical, and decision-making strategy for preservation of irreplaceable historic construction subjected to seismic hazards. This plan is embodied in a pilot study to serve as a model for future preservation projects. The decision strategy for historic preservation can be conceptualized as involving the following steps:

- Step 1: Estimate the past, present and future environmental loads on the structure, primarily seismic in this case.
- Step 2: Estimate the condition of the site and the structure under past, present and potential future loads.
- Step 3: Estimate the site-structure system response and damage that results from these loads.
- Step 4: Compare estimated damage with acceptable levels.
- Step 5: Develop and implement acceptable preservation remedial actions where needed.

9. The facilities proposed for the pilot study are large-span, domed, masonry mosques that represent the pinnacle of Ottoman building art. These are the Mihrimah Sultan and Selimiye mosque complexes constructed in the 1560's and 1570's in Istanbul and Edirne, Turkey, respectively. These

facilities, designed by the chief court architect and great master builder of the time, Sinan, represent a challenging class of construction, which significantly expanded the frontiers of engineering and architectural accomplishment. These two edifices have withstood severe earthquake shaking in the Istanbul-Marmara seismic disasters that occurred between 1756-1894, and lesser shaking before and after that time, with light to moderate structural damage. Like monuments in the United States and other countries, these structures have deteriorated with age due to environmental exposure.

10. Holding the workshop in Turkey provided an opportunity for the research team to visit the two sites, visually examine the structures, and begin the background data collection process. This joint U.S.-Turkish venture has tremendous potential to provide a procedural model for evaluating the threat to irreplaceable historic construction and developing an effective preservation strategy; advance the state-of-the-art techniques in engineering seismology, engineering geophysics, and geotechnical and structural earthquake engineering, particularly for their application to infrastructure problems; provide a forum for international technical transfer; and strengthen the bonds of friendship and cooperation between the two countries.

Agenda and Working Organization

11. The workshop was held during the period of May 29 to 31, 1992. The agenda for this period is provided in Table 1. Three plenary sessions were held, one on May 29 and two on May 31. Information about Ottoman-Islamic monuments was presented in the first plenary session and is summarized in Part II. The trip to Edirne was made on May 30. Technical presentations were made during the second plenary session and are summarized in Part III. The halls of the Istanbul Municipality Headquarters Building and the meeting rooms of the Kariye Hotel, Edirnekapi, Istanbul, were used for the plenary and working group sessions.

12. The participants of the workshop are listed in Tables 2 and 3, respective of the sponsoring country. Pictures of most of the participants are included in Figures 1 through 3. Mary Hynes and Erhan Karaesmen served as Principal Investigators and workshop coordinators. The list of technical presentations made is provided in Table 4.

13. Participants were placed into one of three working groups: Art History and Architecture; Geotechnical Engineering; Structural Engineering. Each group assembled three times during the workshop discussing generalities and impressions of site visits at Şehzade Mehmet, Edirnekapi Mihrimah, Süleymaniye Mosques, and the Hagia Sophia Museum (formerly Byzantium Church, then mosque) in Istanbul, the Alpulla Bridge, and the Selimiye Mosque in Edirne. Esin Atil, Liam Finn, and Mete Sözen served as chairpersons of the Art History and Architecture, Geotechnical Engineering, and Structural Engineering working groups, respectively.

Table 1
Workshop Agenda

Friday, May 29

PLENARY SESSION I: Opening Presentations

- o Dr. Mehmet Tümay, NSF
- o Dr. Ken Chong, NSF
- o Dr. Mary Ellen Hynes, WES

BREAK

PLENARY SESSION I: Opening Presentations (cont.)

- o Prof. Erhan Karaesmen, METU
- o Prof. Unal Oziş, Dokuz Eylül University, Turkey
- o Nurettin Sözen, Mayor of Istanbul

PLENARY SESSION II: International Preservation Efforts

- o Prof. Giorgio Croci, University of Rome, Italy

(Session continued on Sunday)

GENERAL DISCUSSION

VISIT TO ŞEHZADE MEHMET MOSQUE

VISIT TO SÜLEYMANIYE MOSQUE

LUNCH

VISIT TO MIHRIMAH SULTAN MOSQUE

WORKING GROUP MEETINGS

Saturday, May 30

TRAVEL TO EDIRNE, TURKEY

VISIT SELIMIYE MOSQUE

RETURN TO ISTANBUL

(continued)

Table 1 (continued)

Workshop Agenda

Sunday, May 31

PLENARY SESSION II: International Preservation Efforts (cont.)

- o Dr. Stephan Fitz, NATO, CCMS
- o Mr. David Look, US NPS
- o Prof. Ahmet Çakmak, Princeton University
- o Prof. Mete Sözen, University of Illinois

VISIT HAGIA SOPHIA

WORKING GROUP MEETINGS

PLENARY SESSION III: Presentation of Group Findings

- o Dr. Esin Atil, Smithsonian Institute
- o Prof. Liam Finn, University of British Columbia
- o Prof. Mete Sözen, University of Illinois
- o Dr. Mary Ellen Hynes, WES

Table 2
Representatives of U.S. National Science Foundation

Art

Esin Atil
Smithsonian Institute

Architecture

Howard Burns
Harvard University

Giorgio Croci
University of Rome
La Sapienza

David Look
National Park Service

Robert Mark
Princeton University

Geology/Seismology/Geotechnical Engr.

A. G. Franklin
U.S. Army Engineer
Waterways Experiment Station

Mary Ellen Hynes
U.S. Army Engineer
Waterways Experiment Station

David Sykora
U.S. Army Engineer
Waterways Experiment Station

Structural Materials

Oral Büyüköztürk
Massachusetts Institute of Technology

Soil-Structure Interaction

Liam Finn
University of British Columbia, CANADA

Structural Engineering

A. Emin Aktan
University of Cincinnati

Ahmet Çakmak
Princeton University

Rachel Davidson *
Princeton University

Mete Sözen
University of Illinois

Other

Jerry Comati
US Army Research and Development
Standardization Group (UK)

Stephan Fitz
Director, NATO CCMS Pilot Study

National Science Foundation

Ken Chong
Structural Systems and Construction
Processes Program

Mehmet Tümay
Geomechanical, Geotechnical, and
Geoenvironmental Systems Program

* Student

Table 3
Representatives of Turkish Scientific Community

Structural Engineering

Ersin Arioğlu
Private Consultant

Nalan Boyacı *
METU, Parlar Education and
Research Foundation

Coşkun Erkay
METU, Parlar Education and
Research Foundation

Uğur Ersoy
Middle East Technical University

Erhan Karaesmen (Prin. Inv.)
Middle East Technical University

Ihsan Mungan
Mimar Sinan University

Ender Şenkaya *
METU, Parlar Education and
Research Foundation

Turgut Tokdemir
Middle East Technical University

Serhat Yağci *
Middle East Technical University

Ahmet Yakut *
Middle East Technical University

Müfit Yorulmaz **
Istanbul Technical University

Tuğrul Tankut **
TUBITAK (Turkish Council of Scientific
and Technical Research)

Art History

Ekrem Akurgal
Ankara University (ret.)

Geotechnical Engineering

Nezihi Canitez **
Istanbul Technical University

Kirhan Dadaşbilge
STFA Group of Companies

Turan Durgunoğlu
Bosphorus University

Mustafa Nalçakan *
Middle East Technical University

Architecture/Preservation

Köksal Anadol
Private Consultant

Mete Ataç **
Turkish Association of Contractors

Ahmet Ersoy
Harvard University

Mete Göktuğ
Private Consultant

Cansen Kiliççote **
General Directorate of Foundation of
Historic Buildings

Nilgün Olgun **
General Directorate of Foundation of
Historic Buildings

Belkis Tunaligil **
Ministry of Public Works

Hydraulic Engineering

Ünal Özış
Dokuz Eylül University

* Graduate student

** Observer

Table 4
Presentations in Plenary Sessions

Presenter	Topic(s)
FRIDAY:	
Giorgio Croci	Study of Domed Basilica in Spain
SUNDAY:	
Stephan Fitz	Description of NATO Committee of Challenge for a Modern Society (CCMS)
David Look	History and Strategy of Preservation and Seismic Retrofit Activities of US National Park Service
Ahmet Çakmak	Studies of Dynamic Response of Hagia Sophia
Mete Sözen	Perspectives of Structural Modeling



Figure 1. Art History and Architecture Working Group
(left to right: Mete Goktug, David Look, Stephan Fitz, Köksal Anadol, Esin Atil (chairperson),
Nilgün Olgun, Howard Burns, Cansen Kiliccötte, Giorgio Croci, Ahmet Yakut)



Figure 2. Geotechnical Engineering Working Group
(left to right: Liam Finn, (chairperson), Jerry Comati, A. Gus Franklin, Mehmet Tümay
David Sykora, Unal Ozis, Mary Hynes, Turan Durgunoğlu, Kirhan Dadapbilge;
not shown: Nezihi Canitez and Mustafa Nalçakan)



Figure 3. Structural Engineering Working Group
(Front row, left to right: Emin Aktan, Ahmet Çakmak, Uğur Ersoy, Erhan Karaesmen, Rachel Davidson, Robert Mark;
Back row: Oral Büyükoztürk, Ken Chong, Mete Sözen (chairperson), Coşkur Erkay, Ihsan Mungan, Turgut Tokdemir,
Tuğrul Tankut, Serhat Yağcı; not shown: Nalan Boyacı, and Ender Şenkaya)

PART II: HISTORICAL BACKGROUND AND PHYSICAL DESCRIPTIONS

14. The focus of the workshop was Ottoman Islamic mosques with large masonry domes. Site visits were made to four such mosques (Şehzade Mehmet, Süleymaniye, and Mihrimah Sultan, in Istanbul, and Selimiye in Edirne). The two mosques highlighted in the workshop were the Mihrimah Sultan and Selimiye. A historical perspective of the Ottomans and their style of Islamic architecture and physical descriptions of the two subject mosques are provided below.

Ottoman Empire

15. Turks originated from the Oural-Altai region of the Central Asia and started to move west around the 9th century. Two main flows took place with the Seljouks first and the Ottomans later. Seljouks had a great influence on the architectural character of the beautiful medieval city of Isfahan, Persia. The Ottomans settled in Western Anatolia first and later in Istanbul and apparently merged traditional concepts of domes. Building techniques of the Ottomans were greatly improved during the sixteenth century, allowing the construction of masonry components in curved, sophisticated geometries. Istanbul thus became a center of Islamic architecture during this period.

16. Mosques with large domes were somewhat unique to Anatolia and southeastern Europe, especially Istanbul. The cool climate of this region mandated a large enclosed space to allow for congregational prayer. The large-domed mosque thus evolved to meet this need and large mosques became prestigious buildings.

17. In contrast, large congregational mosques of the Samarran style, such as those built in Cairo, Egypt, were hypo-style, having a courtyard surrounded with arcaded halls (riwāqs), the largest being the sanctuary on the qibla (wall facing Mecca) side (Behrens-Abouseif 1989). Domes in the warmer climates were typically reserved for mausoleums and, consequently, were much smaller and had decorative ribbing or decorative carvings on the exterior. One mosque with a large dome was built in Cairo during the Ottoman Period (Mosque of Muhammad 'Ali al-Kabir) but remains as an obvious inconsistency.

18. Historic domed structures are constructed from mortared brick and/or stone, materials long used and understood by mankind. Early Ottoman buildings with domes (14th and 15th century) were based either on the concept of a single dome of medium size covering the whole inner space or on a series of small domes one neighboring the other at the same level. In both solutions, static and dynamic loads are transmitted laterally to massive exterior walls or piers. Structural behavior of domed Ottoman structures under gravity loads is mostly governed by a mechanism of controlling thrust action around the main dome which generally lies in a compression state both for meridional and hoop stresses. Partial cupolas, which surround the main dome, help control thrust action when adequately formed and sized. Cupolas support the main dome laterally and transmit these loads to thick external walls. Main arches, however, are subjected to combined effect of flexure and torsion, transfer a considerable portion of upper level loads directly to interior piers.

19. Besides the main dome and central arches, other essential components in major domed buildings are drums of the main dome, strong inner piers, inclined short columns, separating windows of the main dome at its lower flank, bracing surrounding partial cupolas, pendentives filling the space between lower drum, arches and central piers, secondary arches, and auxiliary inner domes of smaller dimensions. The location and interaction of some of these elements are shown in Figure 4. The great master builder Sinan seems to have brilliantly played with all possible combination of neighboring and associating schemes of those components.

Sinan the Master Builder

20. Sinan, the great Turkish engineer and architect, was born towards the end of the 15th century, most likely in 1492, in the village Ağırnas near Kayseri in Central Anatolia. He was converted to Islam and recruited into the military during the reign of the Sultan Yavuz Selim I. He participated in several imperial war campaigns over 25 years, as an apprentice and later as a member of the Ottoman Army Engineering Corps. He visited the far reaches of the Ottoman Empire, from Cairo to the vicinity of Crimea, from Tabriz to the outskirts of Vienna. Thus, he had the opportunity to analyze and assimilate the art and the technology of construction of many cultures.

21. In 1538, Sinan was appointed by the Sultan Kanuni Süleyman as chief architect, thus becoming responsible for all construction activities in the entire Ottoman Empire. He held this position for 50 years through the reign of Süleyman and the Sultans Selim II and Murat III until his death in 1588. Sinan was responsible for the construction of about 500 edifices: more than 150 mosques of various sizes; more than 70 educational buildings; more than 50 public baths; more than 40 monumental tombs; several palaces, residences, caravanserais, hospices, hospitals, magazines, bridges, aqueducts. About 200 of these edifices presently exist in their original form and most of them are still in use. A summary of biographical information about Sinan is provided in Table 5.

22. Sinan's power can be described by study of four major works that were constructed in different periods of his life:

- a. Şehzade (Prince) Mehmed Mosque - (1545-1548)
- b. Süleymaniye Mosque - (1554-1557)
- c. Mihrimah Sultan Mosque - (1562-1565)
- d. Selimiye Mosque - (1572-1575)

The decade stretching from 1538 to 1548 was a period in which Sinan developed his architectural skills by utilizing well-tested schemes to broaden his outlook. Sinan's own evaluation of the Şehzade Mehmed Mosque as the last work of his "apprenticeship" period shows that he regarded his first ten years in the Office of Chief Court Architect as his period of search of maturation. To the beholder, the symmetrical formation of the Şehzade Mehmet Mosque was symbolic of the political power and social harmony to which the Ottoman State had arrived. Compared with Şehzade Mehmet Mosque, a higher level of structural challenge is achieved in the Süleymaniye Mosque of Istanbul which is considered as the summit of Sinan's work during his lifetime. In Süleymaniye, the radial symmetry is abolished intentionally for the sake of accordance between a majestic outside view and the hilly site suspended beautifully on the Golden Horn. The evolution of Sinan's approach to domed buildings is presented in Table 6.

23. The universal importance of Sinan's work with regard to architecture and to decorative arts has been recognized for many decades, leading to the proclamation by UNESCO of 1988 as the year of Sinan. However, his importance with regard to engineering, notably to civil engineering, has been less proclaimed. Appropriately for the role of architects during that

period and his list of accomplishments, Sinan described himself as a "skilled engineer" just after saying "wise architect".

The Mihrimah Mosque

24. The Mihrimah Sultan Mosque in Edirnekapi, Istanbul, was constructed in 1565 and named for the daughter of Emperor Süleyman the Magnificent. Pictures of the exterior of the mosque are shown in Figures 5 and 6. Cartographic and plan views are shown in Figures 7 and 8, respectively. This edifice is recognized to have an interior space of unique refinement. The spatial beauty of the temple is attributed to its daring structural system. The dome, shown in Figure 9, is known to have the largest dimensions (diameter of 21 m and height above the ground of 38 m) for an unbraced shell. There are no externally bracing partial cupolas in this extraordinary structure whose transmission of both lateral (seismic) and vertical (gravity) loads is ensured essentially by thin elegant arches flush with walls as shown in Figure 10 and attractive pendentives as shown in Figure 11. Paintings on the interior are from the 19th century.

25. The following descriptions of the Mihrimah Mosque are taken directly from Ulya Vogt-Göknil (1966):

"Four narrow, arcaded walls, interrupted by windows, and four spherical spandrels effect the transition from the cube-like central hall to the dome...In this building he [Sinan] attempted to improve on Byzantine structures (arcaded walls and pendentives)...Hard, sharply defined edges stress the various areas and transitional points...the vaulted corner arches have no visible means of support...There is no differentiation between vault, pilaster and walls. The spandrels and arches do not differ from one another; the surface of the vaults merges immediately into the shape of the dome. If we were to imagine that all those parts which fill in the shell were removed, the remaining arches and walls beneath would not form a skeleton that would stand up on its own. No single part of the system of walls could be subtracted—all the parts must be there for the building to have any unity."

Previous response to earthquakes

26. Istanbul is located in the second-most severe region of earthquake hazards in Turkey. At least ten large earthquakes have affected Istanbul. Some of the more pronounced events since the Ottoman Empire occurred in 1711, 1756, and 1894. Despite this historic record of damaging events, the Sehzade and Süleymaniye mosques are not believed to have incurred

significant damage. The Mihrimah Mosque has been damaged from earthquakes, however. The historic record of damage is unclear, but it is likely that very small cracks formed in the main structure and larger cracks and even a partial collapse in small cupolas surrounding the court garden occurred. Previous restorations make further determinations difficult.

Previous analytical studies

27. Various types of investigations and analyses have been applied to this mosque to develop a better behavioral understanding of the structural system. Two numerical models that include the whole skeleton have been developed within the framework of a comparative analysis logic (Karaesmen et al., Appendix A).

28. The first model was aimed at representing the structure as a collection of simple components without considering many architectural elements at the bottom of the four main arches. These elements are the secondary arches and small cupolas covering auxiliary prayer areas and also arched exterior walls of the building. Pendantives of the systems descend to unusually low levels, in a way magnifying the visual effect of these already elegant components. The pendantives initially were not considered to contribute significantly to the dynamic response. Therefore, the first model does not include this feature.

29. The results of preliminary numerical analysis have revealed that the full collapse of the columns and consequently of the building could be caused by a large earthquake. On the other hand, the period for the prevailing (first) mode of vibration was evaluated to be 2.1 sec which seemed long, even for this light looking structure formed by rather slender components. These results suggest that the contribution of the pendantives should not be underestimated. Similar observations were made relative to studies of the Şehzade Mehmet Mosque.

30. The second structural model was then created to incorporate more structural elements to better represent the behavior of the system. All bottom inner components and even one series of external cupolas next to the building with their columns, and bow string arches were inserted into the model. The total weight of the building was estimated to be 90,000 kN. The period for the first mode of vibration was calculated to be 1.6 sec. A seismic coefficient of about 11 percent was determined for the first mode.

The dynamic response calculations were found to be somewhat sensitive to geometry of the structure within the range of estimated dimensions.

31. Further analysis of this model provided indications where the zones of flexural effects and stresses would be maximized by seismic action when added to gravity loads. Associated directions of the complete quadratic combination (CQC) results of spectral analysis were determined by imposing the displacements of the first mode of vibration to the critical element solicited. The associated signs of the seismic action were taken into consideration for the evaluation of the most critical combined effect.

32. Zones of maximum tensile stresses were observed to be located in pendentives near the middle of the main arches. The principal tensile stress was computed to be in a direction such that formation of a crack parallel to the curved axis of the arch could be expected. Some small cracks and displacements, likely originating from static and dynamic soil behavior, are presently visible in the building. These features and the seismically hazardous past of the edifice require an extensive assessment study.

The Selimiye Mosque

33. The Selimiye Mosque was constructed on a plateau known as Saribayir or Kavak Meydani (Poplar Square) in Edirne and was completed in 1575. It is considered to be Sinan's masterpiece in terms of both architectural flair and engineering prowess. A picture of the mosque is shown in Figure 12. Cartographic views and a floor plan are shown in Figure 13 and 14, respectively. "The interior of the Selimiye...displays a well modulated expression of propriety and elegance. The intricately carved marble mihrab and minber are first-rate examples of their kind. So are the superb faience tiles covering the walls of the mihrab niche, the drum and cap of the minber, and the Sultan's balcony. They are among the best that came from the kilns of Isnik." (Kuran 1988)

34. The dome of this mosque has a diameter of 31.28 m that is supported by eight arches which, in turn, are supported by slender columns. Exterior views of the dome and buttresses are shown in Figure 15 and 16. Additional views of the exterior are shown in Figures 17 and 18. The dome rests on this series of arches through a thick curved drum and is braced horizontally by eight small external buttresses that transmit the lateral

action at least partially to the weight towers which are the continuation of eight internal pillars. The transmission of both thrust action and seismic effect apparently could not be achieved without the contribution of the lateral resistance of the four smaller segments of cupola constructed behind four of the eight main arches located orthogonally in plan. Four other main arches are vertically and laterally supported by other systems of arches occurring at the level of the third tier. These bottom arches are enlarged in thickness and they behave somewhat like vaults. At the same level, at the bottom parts of the four partial cupolas two perpendicular small arches are constructed participating in the flow mechanism of the load action in these four corners of the interior skeleton system.

35. The four slender minarets rise to a height of nearly 71 m and have three balconies apiece. The effects of the environment on these minarets is visible from the minaret balconies. The faces of individual limestone blocks, balcony railings, and interior steps have degraded non-uniformly and cracks are visible throughout. The exact mechanisms causing this degradation are not certain but are likely to be aging, weathering, and contraction/expansion.

36. Selimiye Mosque has been subjected to several strong seismic events during its lifespan of over four centuries. No structural damage from earthquakes has been reported. Some small local cracks at the flank of the main dome were created but were easily repaired by linking brick elements one to other by nailing. Cracks in the minarets may also be a result of seismic loading. Subsequent repair and maintenance work comprises only architectural details: tiling, plastering, painting.

Table 5
Biographical Facts on the Great Master Builder Sinan
Karaesmen et al. (Appendix A)

<u>Date</u>	<u>Activity</u>
-1492	Born in Ağırnas-Kayseri district (Mid-East part of Anatolia)
1512	Joined military training programs for gifted young people
1538	Nominated as Chief Court Architect (some selected Sinan's edifices during his chief court architect period could be summarized as follows:)
1547	Üsküdar Mihrimah Sultan Mosque
1548	Şehzade Mehmet Mosque
1550	Rüstem Paşa Mosque
1557	Süleymaniye Mosque
1557	Süleymaniye water supply system of Istanbul
1564	Kirkçeşme water supply system of Istanbul
1565	Edirnekapi Mihrimah Sultan Mosque
1568	Büyükçeşme Bridge
1575	Selimiye Mosque and Complex
1578	Ayazkapi Sokullu Mosque
1588	Died in Istanbul

Table 6

Evolution of Sinan's Structural Approaches in Domed Buildings (adapted from Karaesmen et al. 1993)

<p>I <u>Early Years</u> (1529-1537) and <u>Apprenticeship Years</u> (as chief court architect)</p>	<p>Ücbas, Muhsine Hatun, Haseki Sultan, Cavusbasi Yunus Bey Mosques</p>	
	<p>(small mosques [$D_{\text{dome}} < 14.5 \text{ m}$])</p>	
	<p>but, showing wide architectural and structural variety)</p>	
<p>II <u>End of Apprenticeship</u></p>	<p>> <u>Passage to</u></p>	<p>> <u>Maturity</u></p>
	<p>Series of Domes are coming (1544-1550)</p>	
	<p>Structural ingenuity</p>	<p>associated</p>
	<p>Functional rationality</p>	
	<p>Aesthetical elegance</p>	
	<p>(as visible in Şehzade Mosque in Istanbul)</p>	
<p>III <u>Masterly Years</u> 1550-1565</p>	<p>Süleymaniye 1557 and Edirnekapi Mihrimah 1565</p>	
<p>accomplishments</p>	<ul style="list-style-type: none"> - Effect of majesty amplified - Larger spaces, more slender and daring covers and supports - Both sophistication and abstraction in architectural and structural systems <p>(More subtle flow of curved lines)</p>	
<p>IV <u>Later Years</u> 1570-1575</p>	<p>Selimiye Mosque</p>	

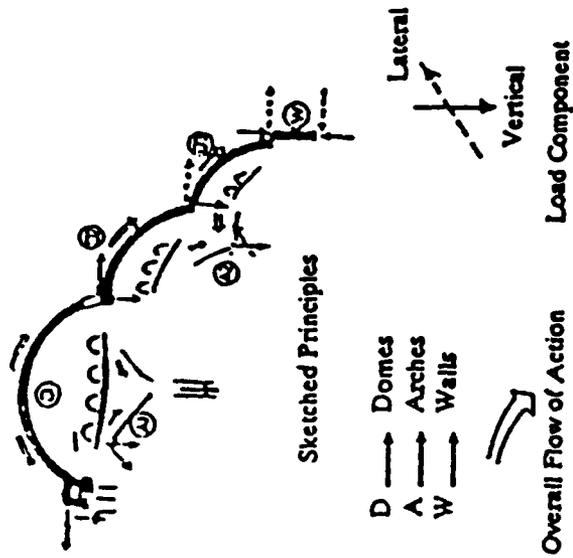
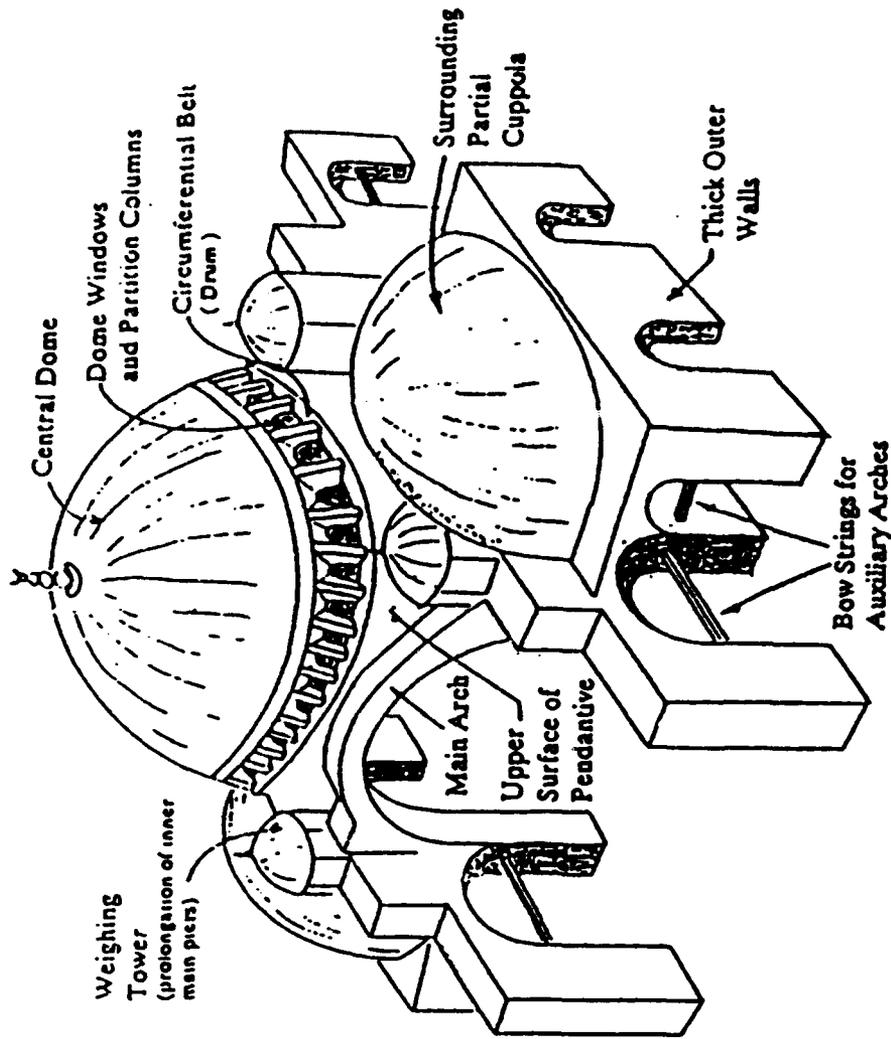


Figure 4. Typical components of Ottoman domed buildings showing flow mechanisms (Karaesmen et al., Appendix A)

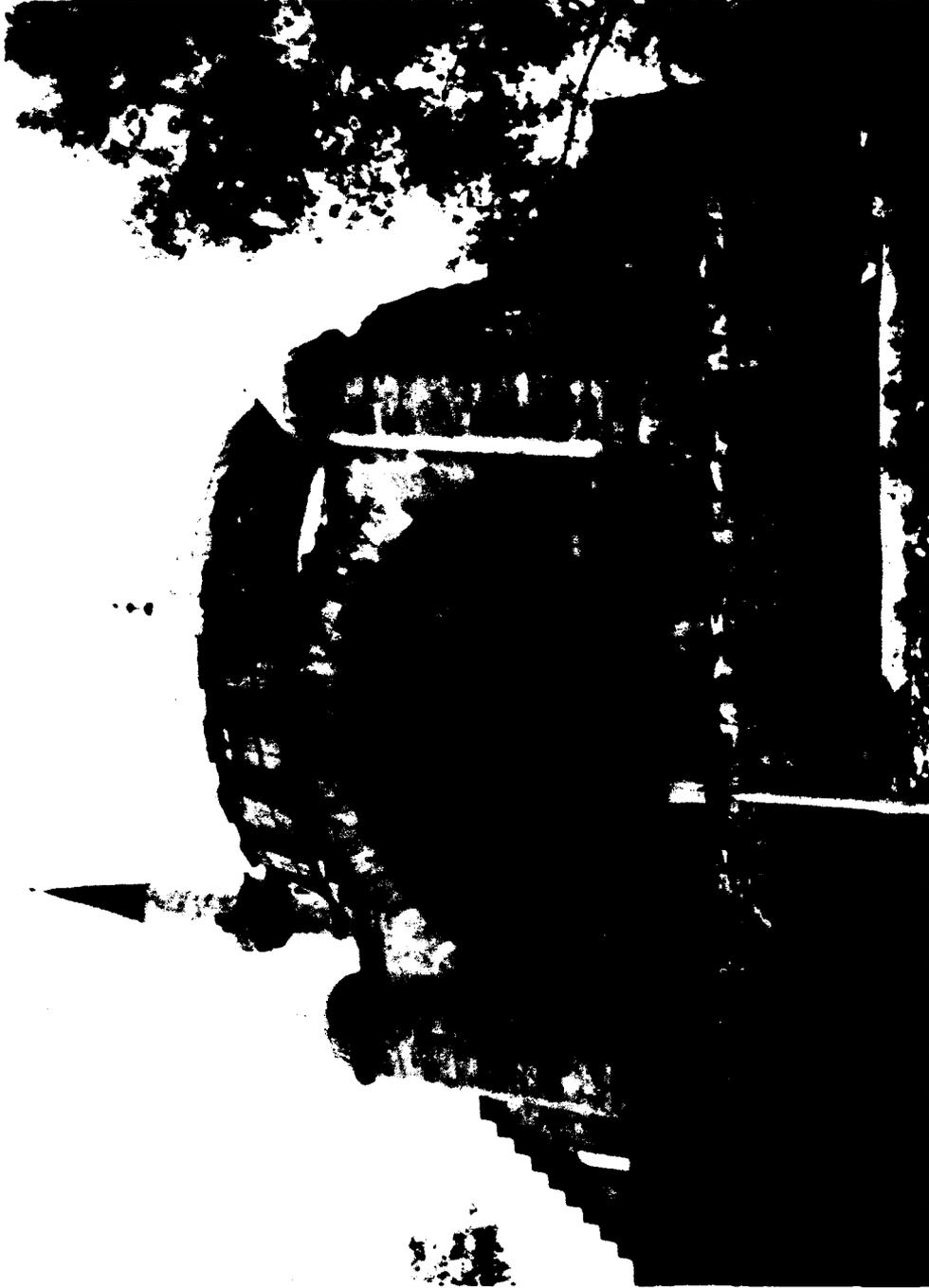


Figure 5. Mihrimah Mosque looking northwest



Figure 6. Court and auxiliary arches of Mihrimah Mosque looking south (Croci, Appendix D)

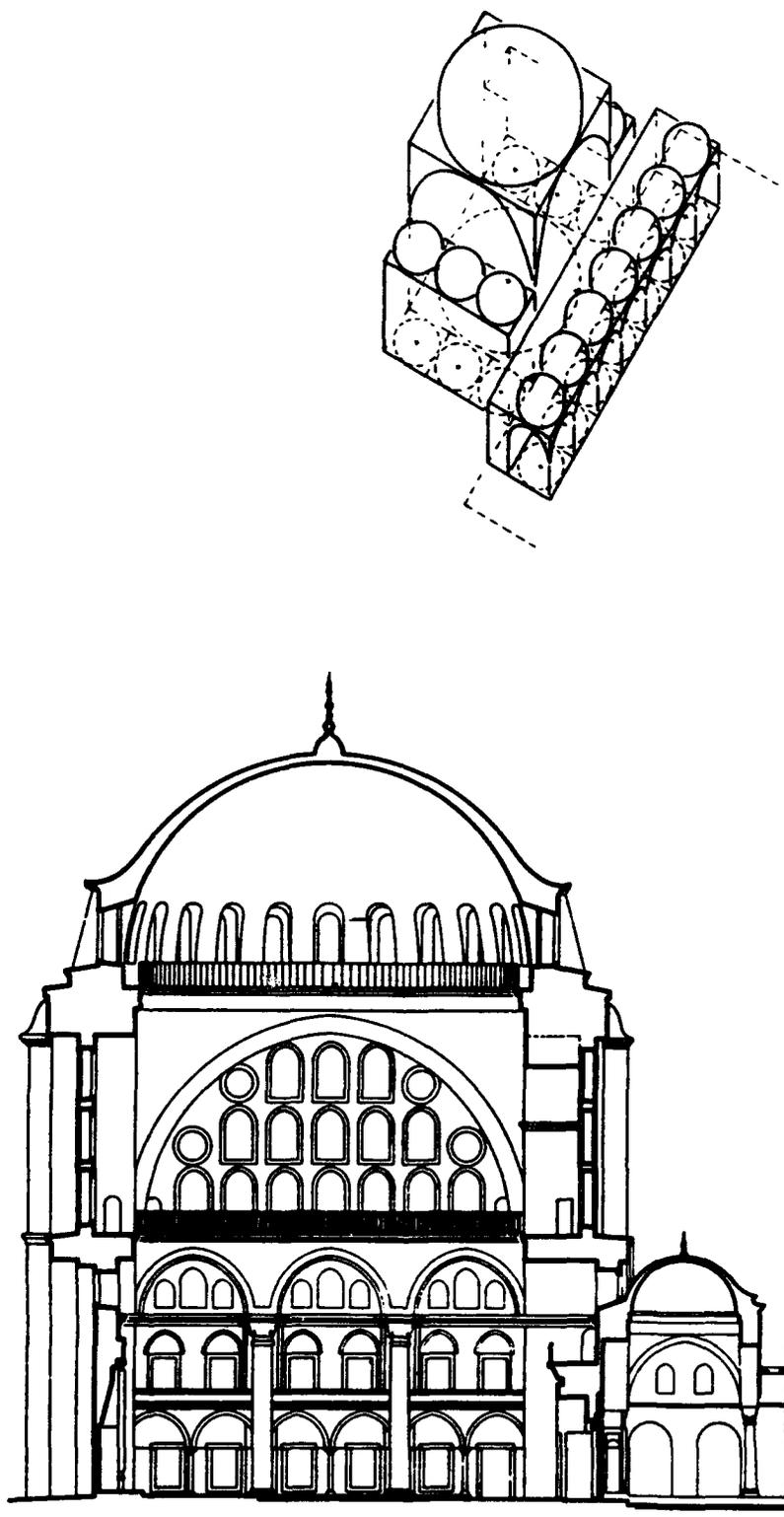


Figure 7. Section and perspective views of Mihrimah Mosque
(Vogt-Göknil 1966)

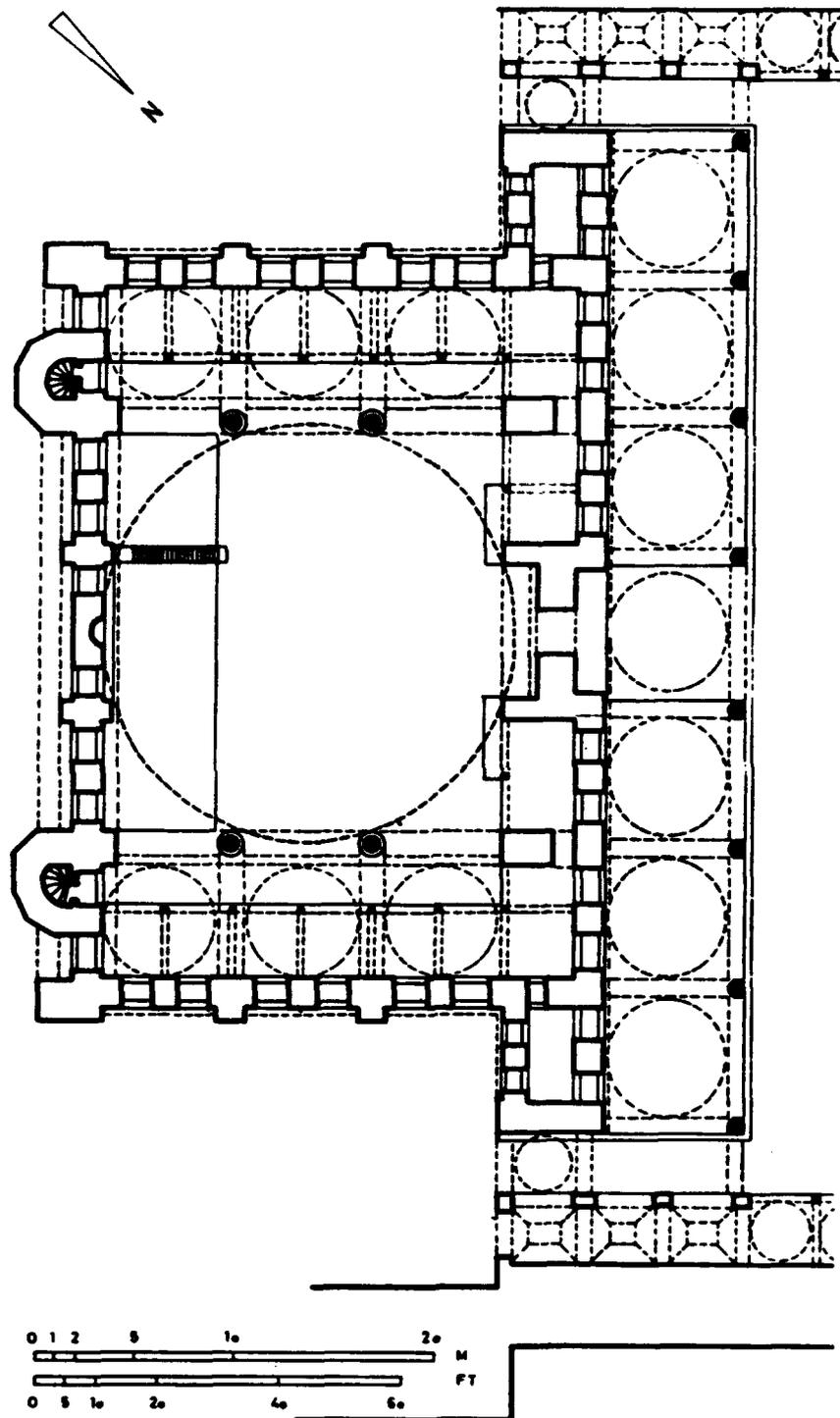


Figure 8. Floor plan of Mihrimah Mosque (Vogt-Göknil 1966)



Figure 9. Interior view of dome of Mihrimah Mosque (Crocì, Appendix D)

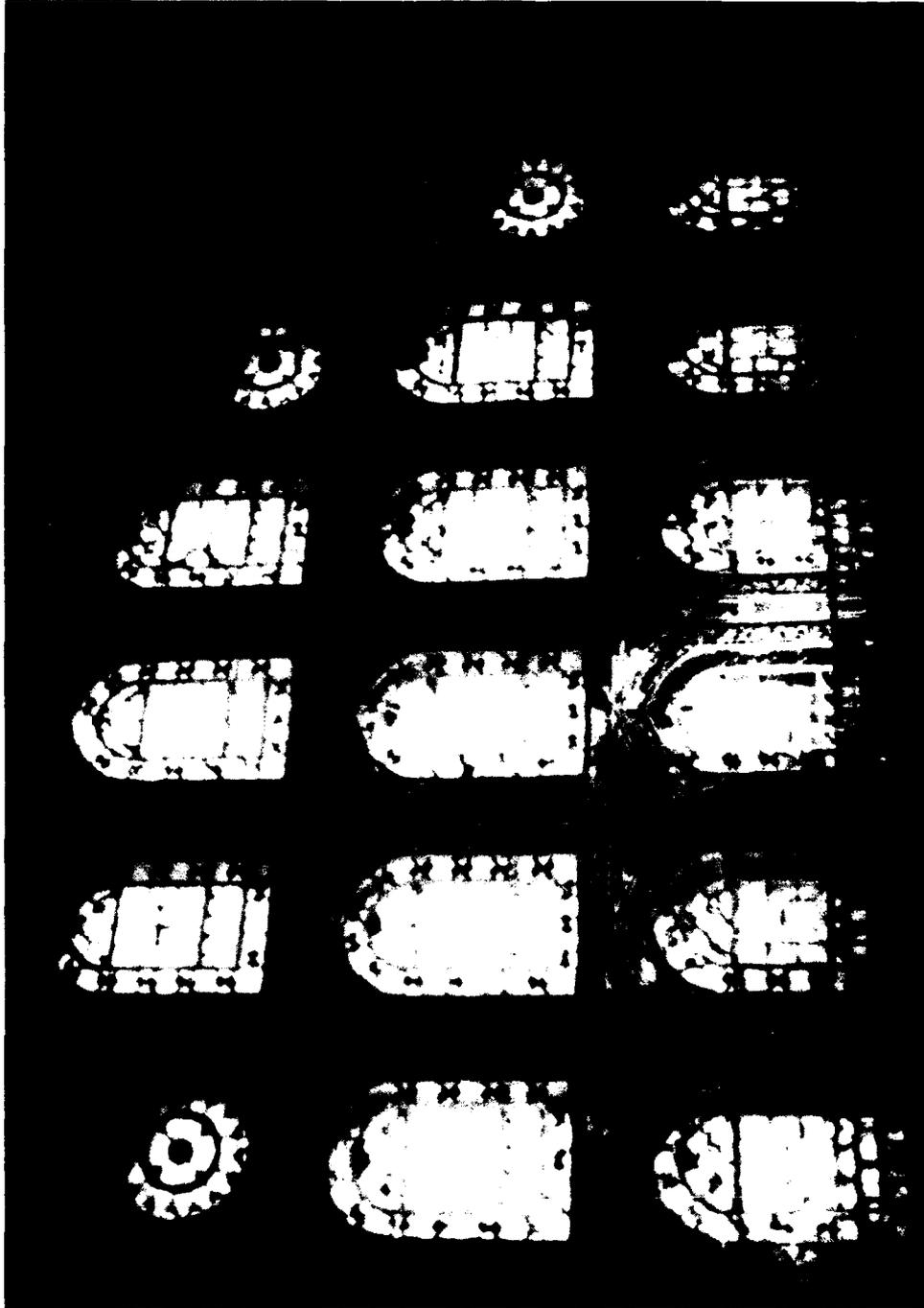


Figure 10. Southeast wall of Mihrimah Mosque looking
across from lower balcony

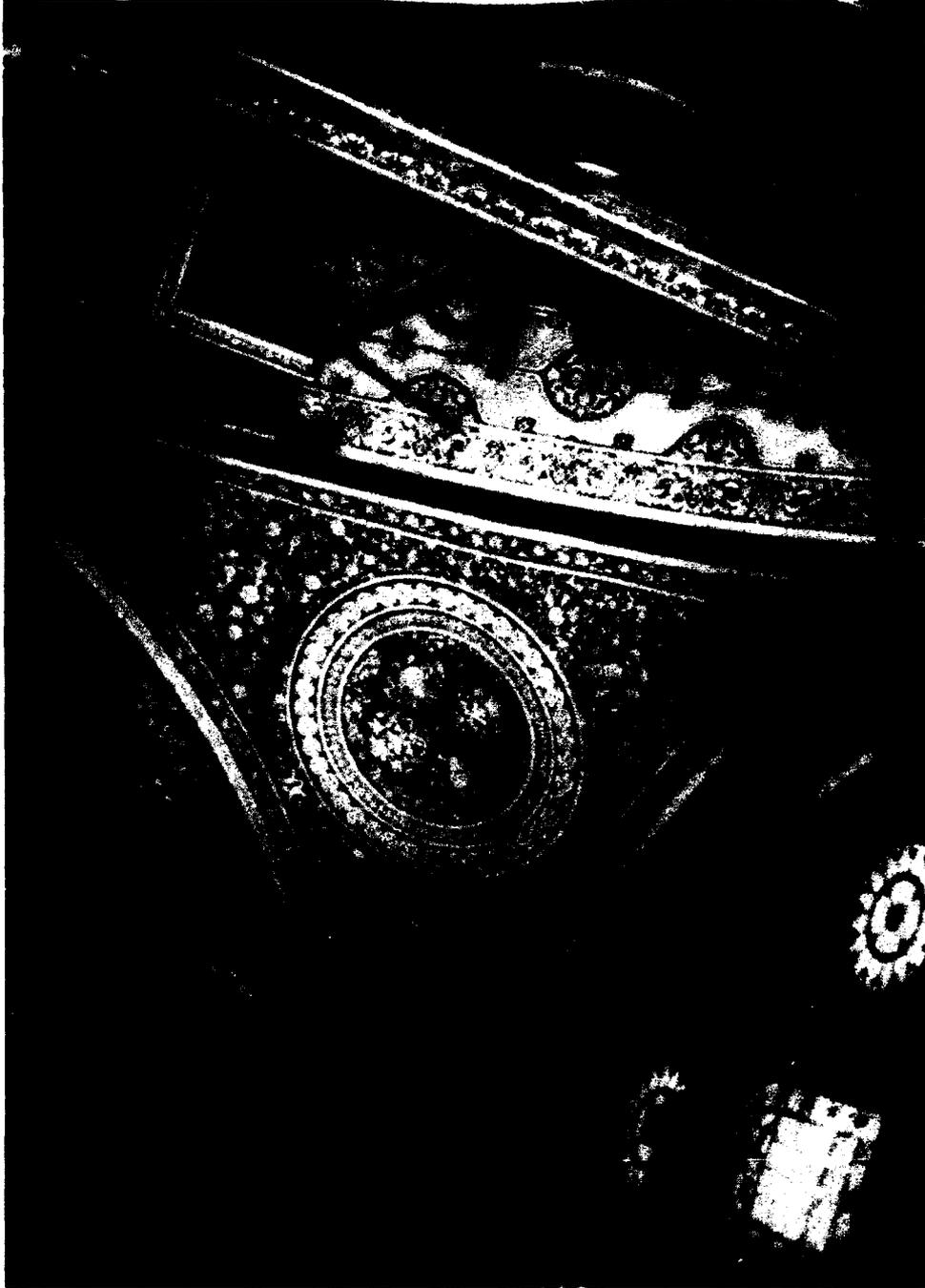


Figure 11. Pendant at southern corner of Mihrimah Mosque

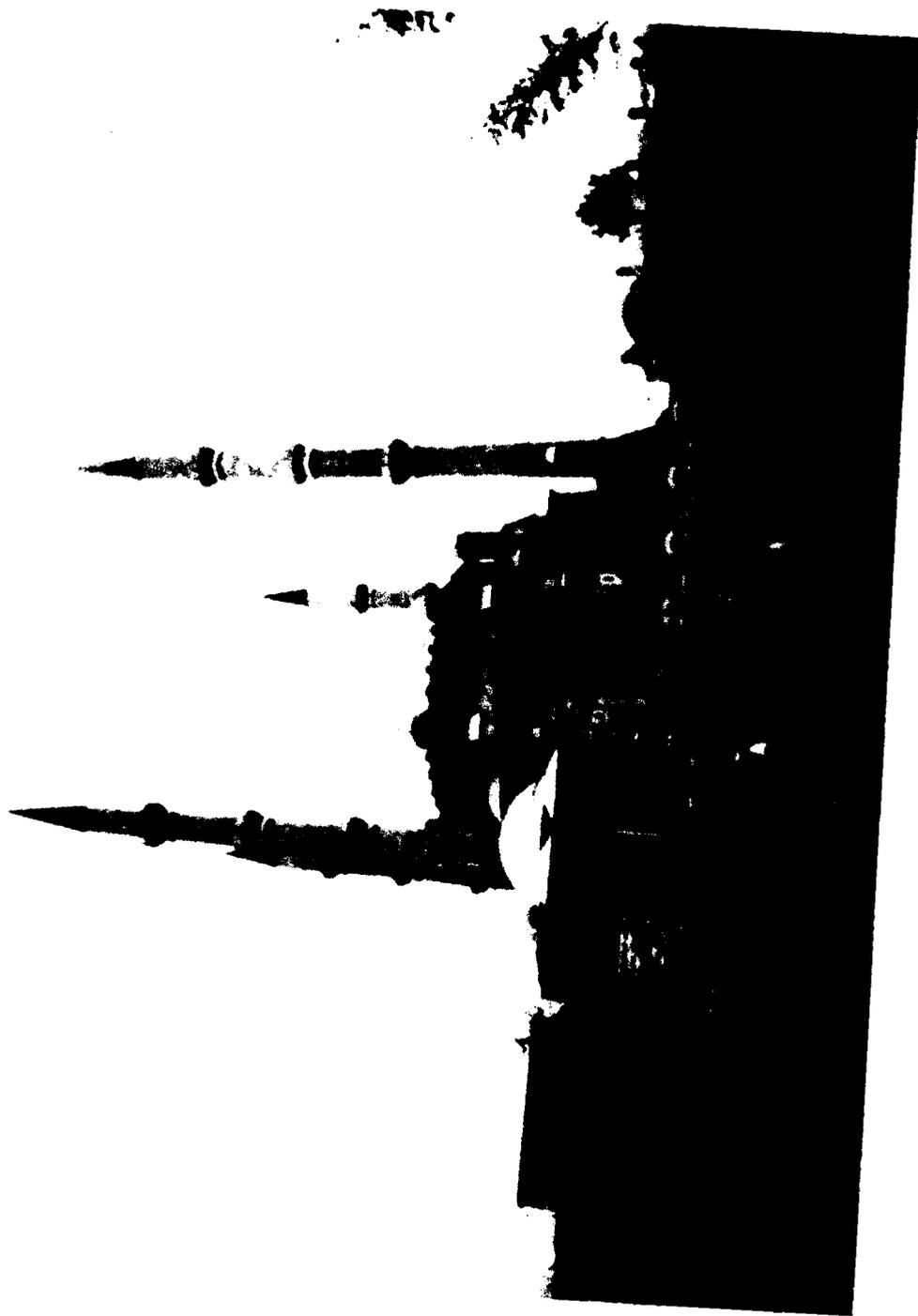


Figure 12. Selimiye Mosque looking north

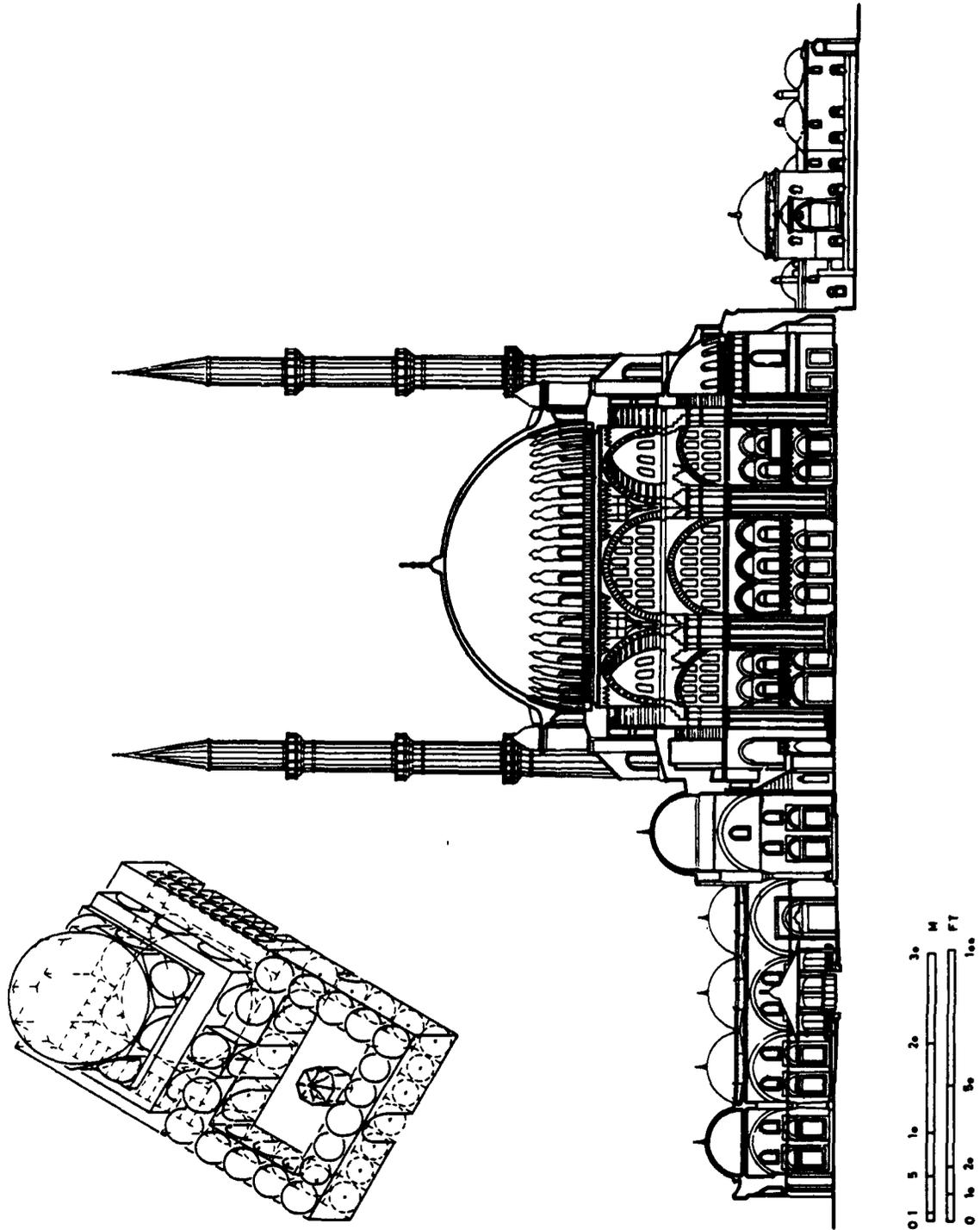


Figure 13. Section and perspective views of Selimiye Mosque (Vogt-Göknül 1966)

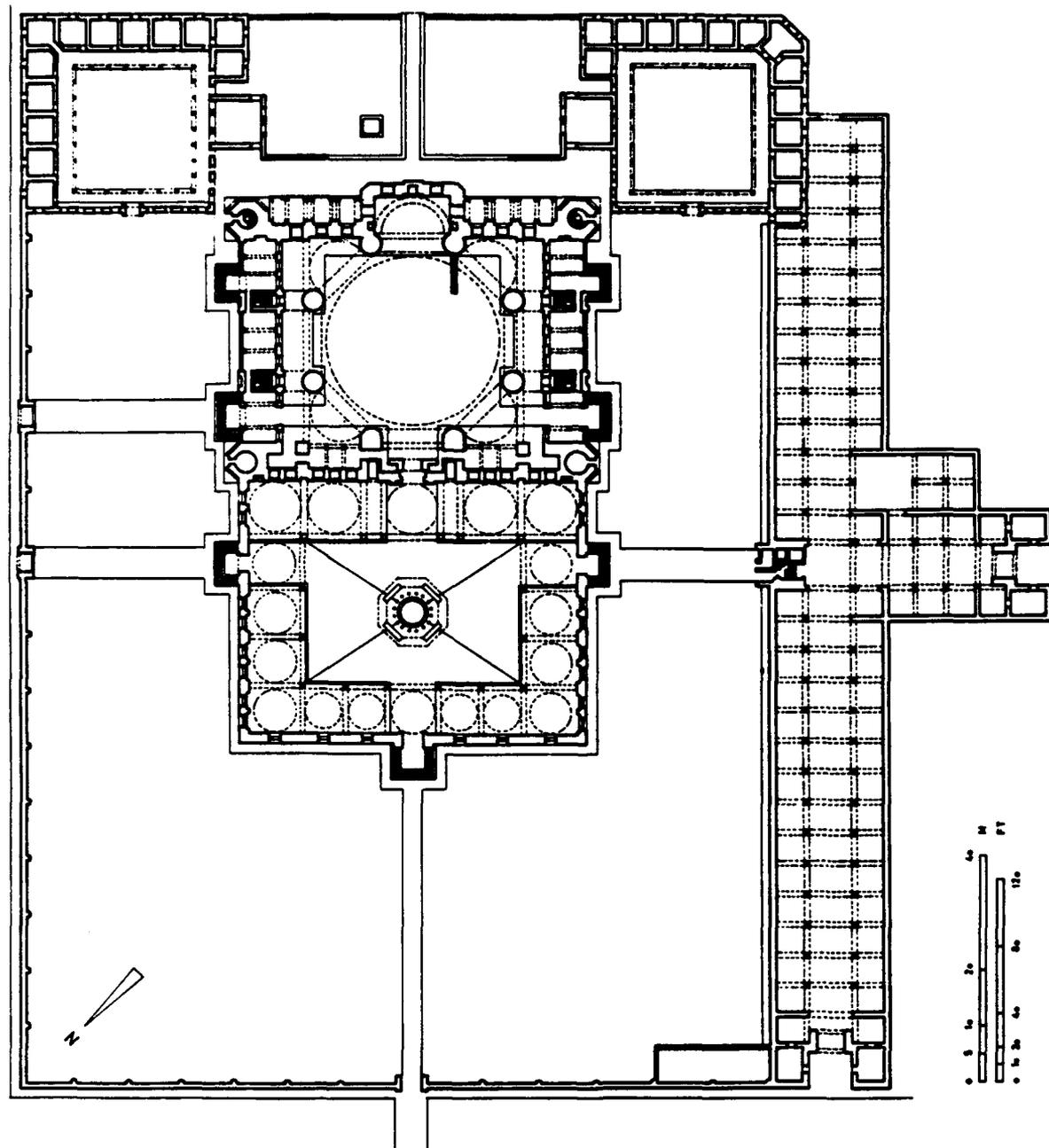


Figure 14. Plan view of Selimiye Mosque (Vogt-Göknıl 1966)

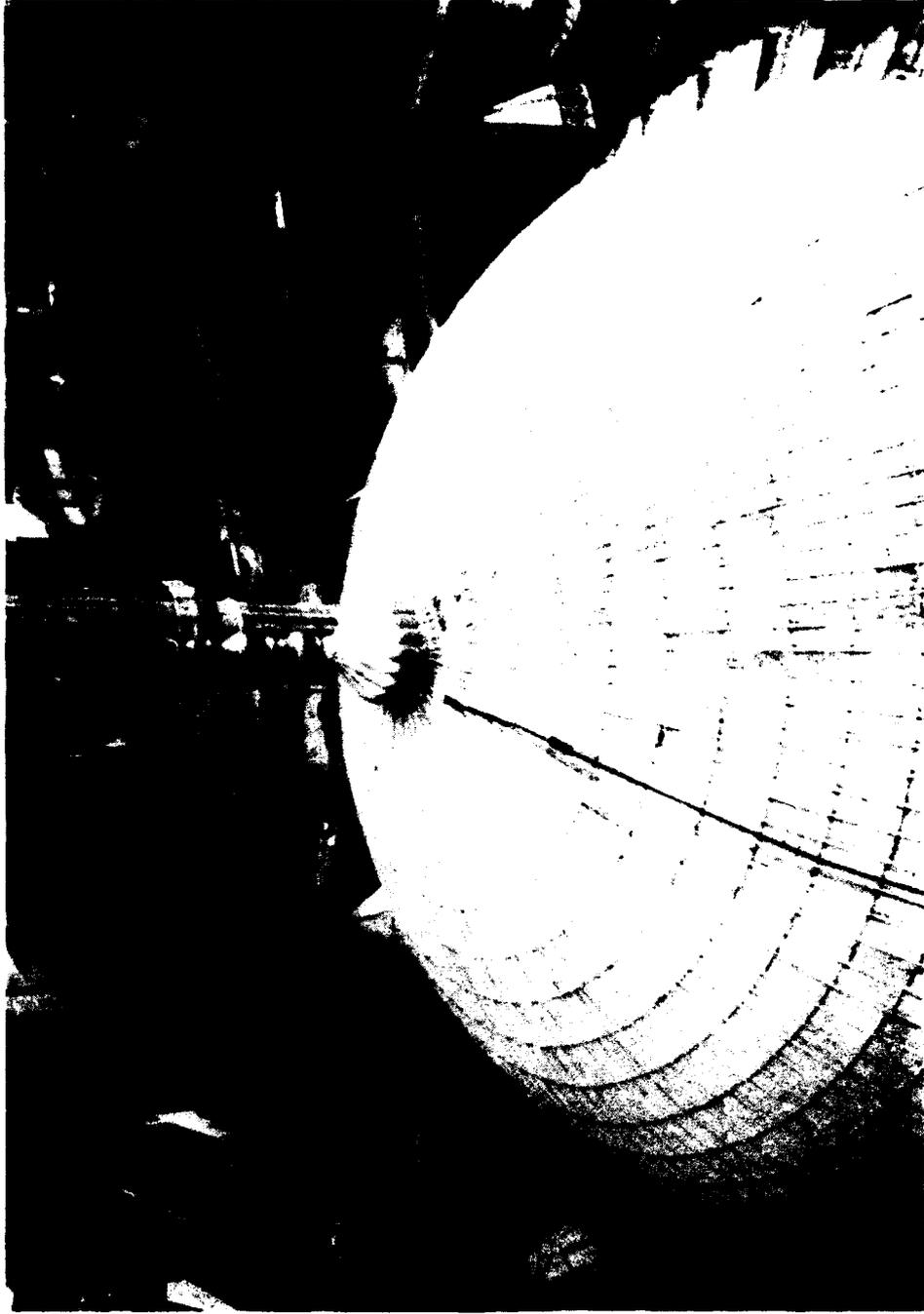


Figure 15. Exterior of dome of Selimiye Mosque looking west (Croci, Appendix D)



Figure 16. External buttresses at eastern corner of Selimiye Mosque
looking southeast



Figure 17. Southwest entry portal to Selimiye Mosque

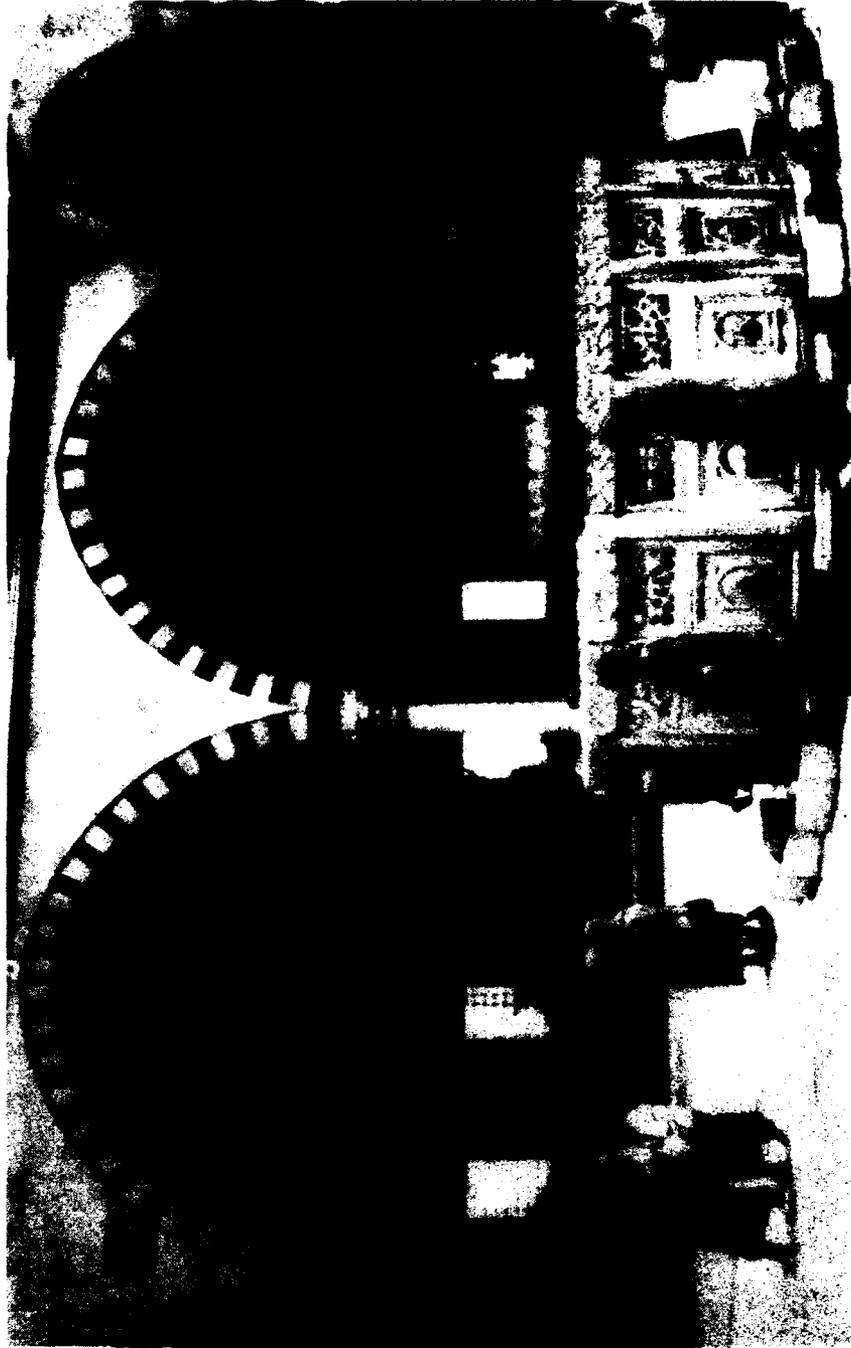


Figure 18. Court fountain of Selimiye Mosque looking north

PART III: PREVIOUS AND CURRENT PRESERVATION EFFORTS

37. The status of some other preservation efforts was highlighted in Plenary Session 2. Each of these presentors pointed to the fact that special problems and specific analyses can be expected for each study and that a number of assumptions are still required for most analyses because of the lack of knowledge regarding many aspects of construction and material behavior. Moreover, there tends to be little agreement among current researchers regarding some of these assumptions.

Ottoman Islamic Mosques

38. Structural engineers from Turkey pointed out that Sinan's designs are significantly different from other architects/engineers. For instance, Sinan used bracing with semi-domes or no bracing at all. Sinan's domes comply well with membrane theory. The exterior of the domes were typically protected with a layer of mud covered by lead skins which have prevented cracking of the dome. Sinan was in charge of restoring the Hagia Sophia (c. 537) before he was responsible for the design and construction of his mosques and it is likely that this magnificent edifice influenced his own work.

39. The static and dynamic structural response of a few Islamic mosques have been reported in recent conferences. The models and methods used to analyze these complex structural systems have been rather simple so far. Most investigators tend to begin with a simple model and add complexity as the behavior unfolds. Reasonable limits for many of the important assumptions have not been studied or validated and, therefore, are still quite varied.

St. Pablo Basilica, Spain

40. Prof. Croci described a sequence of analyses for the dome of the St. Pablo Basilica in Victoria, Spain. This structure was built about 500 years ago and has cracks more than 1 cm in width along the meridian of the dome. Tie bars were recently found in the dome. Also, endoscopy techniques were used to find that two domes actually exist, an inner and an outer dome. The results of the first structural stress analysis using principles of elasticity indicated that large stresses existed, oriented concentrically. A

more sophisticated analysis was then conducted to account for the cracks. Tensile forces were then calculated to exist on the inner face of the dome whereas compressive forces were calculated on the outer faces. This indicated that bending moments existed, a bad situation. A third analysis that took into account the bending moments shows low safety levels. Retrofit was made using tied cables around the exterior of the dome. This account shows the importance of conducting thorough investigations into the construction of the monument and the value of a staged type of analysis.

Hagia Sophia

41. The presentation by Prof. Cakmak of ongoing analysis of the Hagia Sophia brought up important issues about the assumptions necessary for present-day analysis. The Hagia Sophia was constructed during the period 532 to 537 AD. At the time of completion and for over 1000 years, it remained the largest four-point-supported dome in the world with a diameter of 31 to 32 m and a height of 56 m. (This monument was visited during the workshop.)

42. An anisotropic, finite element computer model is being used by Prof. Cakmak at Princeton University to calculate static and dynamic displacements and natural frequencies with measured values from in situ instrumentation. The construction sequence was modeled to replicate the increase in stresses and moments in load bearing members. All piers were assumed to be vertical and arches were assumed to be semi-circular. (Later visual inspection at the Hagia Sophia indicated that some piers are tilting significantly and some arches are clearly not semi-circular.) The results of analyses to date indicate that the mortar should be modeled separately (with a lower shear modulus) to get a suitable match between calculated and measured deformations. Dr. Livingston at the National Institute of Standards and Technology (NIST) studied the mortar used and found it to have a pozzolin base with a low density and exhibiting a slow curing time (6 to 18 months) and a high tensile strength. Therefore, it is likely that significant deformations occurred during construction.

43. Discussions of the presentation included constituents of material debonding and creep, the means to model inertial effects in the members, and the effects of architectural elements such as pendentives. Apparently no

cracking of the mortar has been observed in exposed parts. Architectural elements have not been included yet.

U.S. Seismic Retrofit Conferences

44. Two conferences on seismic retrofit have been sponsored by NPS and held in San Francisco, California. Mr. David Look organized these conferences and was the editor of the proceedings. The first conference, held in 1984, focused on the state-of-the-art of seismic retrofit (Look 1984). The second conference, held in 1991, focused on innovative solutions to solve retrofit problems (Look 1991). Each alternative was considered to provide life safety, but the adverse affects of each method were compared and contrasted.

45. Standards for evaluating solutions and applying standards to preservation projects already exist. For instance, the Venice Charter was produced in 1964 (International Charter for the Conservation and Restoration of Monuments and Sites 1964) although neither the U.S. nor Turkey accepted this charter. A draft statement of principles for the conservation of the Islamic Architectural Heritage (Lahore Statement 1980) were also developed. Documents from both the Venice Charter and the Lahore Conference are included in Appendix B. Standards for evaluating different solutions and guidelines for applying standards to preservation projects in the U.S. were developed by the U.S. Secretary of the Interior and are presented in Appendix C. All of these documents are specific about respecting the historic character of the monument. The basic concept is that the least intervention is the best alternative. Mr. Look stated that "It's better to maintain than restore; to restore than repair; to repair than reconstruct."

Efforts of NATO CCMS

46. The NATO CCMS uses scientific and technology cooperation to improve modern society. This includes safeguarding the environment and cultural heritage. The chronology of efforts has been as follows:

- o Conservation and restoration of monuments (1979-1986)
- o Preservation of historic stained glass (1982-1992)
- o Conservation of historic brick structures (1987-)

The NATO CCMS does not do research; rather, it is an umbrella organization. The main workload is spread among member countries and efforts are done on a voluntary basis. At times, CCMS will initiate research in certain fields so that other organizations will feel comfortable in conducting less risky follow-up studies. In Germany, data bases have been created that store information about the methods of preservation used on different projects and an inventory of damaged monuments.

47. Dr. Fitz is a Principal Investigator for the NATO CCMS Pilot Study on brick conservation. There are four aspects to this effort: 1) atlas of damage to historic brick structures; 2) diagnosis of damage; 3) development of analytical and test methods; and 4) evaluation and testing treatments. Some of the intermediate results relate to damage to bricks caused by air pollution, soluble salts, frost/thaw cycles, mechanical stress, and manufacturing techniques.

48. The presentation by Dr. Fitz pointed out the need to survey research that has been conducted in related areas. Results from the pilot study on conservation and restoration of monuments are directly applicable to efforts elsewhere. The approach and analytical methods of analysis used to study brick may have application to the similar study of stone.

Numerical Modeling Philosophy

49. Prof. Mete Sözen conveyed a fitting philosophy toward the application and use of numerical models to study historic monuments, including domed buildings. He made it clear that the expectations and limitations of the modeling effort must be known. Furthermore, the results must be used in a manner commensurate with the assumptions and details of the model. These issues are even more important when structural engineers are engaged in collaborative activities with experts in other fields, not to mention professionals from other engineering disciplines.

General Issues

50. A number of important and interesting general points of interest and specific issues were raised during the course of the two plenary sessions. One of the more important issues is that collaboration with other

organizations sponsoring preservation research is very important to minimize research effort. Organizations such as the NATO CCMS and UNESCO have been orchestrating efforts in these areas for some time. For instance, CCMS sponsored a committee from 1979 to 1986 to examine the conservation and restoration of monuments. Several conferences on seismic retrofit and historic preservation have been conducted over the past decade. In Germany, a data base of methods for preservation and damaged monuments has been constructed and is maintained. So, before any work is initiated, a thorough survey should be performed, appropriate reports should be obtained, and previous investigators should be contacted.

51. 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 the state-of-the-art capabilities. The problem is of 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.

52. The architects and art historians strongly suggested that a common vocabulary to describe aspects of preservation be adopted for this study. At least two documents have been published by others and would form a good basis for a comprehensive system. The general comments and discussions throughout the course of the plenary sessions supported the need for a common vocabulary.

53. There appeared to be an unspoken consensus that "the least is best" when describing the amount of preservation that should be performed. The structural engineers suggested that numerical modeling of proposed retrofits or reconstruction would be prudent to avoid irreversible mistakes.

54. Local experts, academicians, and artisans should be employed and trained in an apprenticeship program for all preservation efforts. These people would be led by an inter-disciplinary team of experts, preferably from around the world, who intend to transfer their understanding and resources for the sustainment of cultural heritage.

PART IV: FINDINGS OF SITE EXAMINATIONS AT SUBJECT MOSQUES

55. The examination of the Mihrimah and Selimiye Mosques was deemed to be an integral part of the workshop. Participants were grouped from different disciplines to form three teams to promote interaction for the site examinations. Observations were documented by photographs, personal notes, and recording of working group discussions. The observations for the Mihrimah Sultan Mosque were supplemented by additional observations made by Profs. Büyüköztürk, Croci, and Karaesmen (1992) several weeks later (Appendix D).

56. The site examinations made clear to the participants how the study of each monument is unique. General preservation strategies must be developed to account for a wide range of potential conditions. Many of the comments regarding the Mihrimah Mosque, for instance, are likely to be unique to that structure and site conditions.

57. The wall painting programs were found to have very little to do with the original 16th century decoration, neither in style and thematic repertoire, nor in technique and pigments (refer to Art History and Architectural group report in Appendix D). These new paintings, 1960's and 1970's for the Mihrimah Sultan and 1980's for the Selimiye, work to the detriment of the building as a whole. They overwhelm the interior with their garish colors whereas the original decoration blended harmoniously with the structure and accented specific components, as intended by the architect.* The paint in Selimiye, less than ten years old, is already flaking and falling off with the remnants of the older layer underneath.

The Mihrimah Mosque

58. Observations were made around the exterior grounds, within the mosque, both on the main level and on the lower balcony, inside the minaret, and on the roof. The current structural condition of the Mihrimah Mosque was judged to be critical and the need for restoration work is urgent, that is, work is necessary at once to prevent active decay and more significant damage.

59. There are many signs of deterioration in the masonry and mortar and structural cracks and distortions. The minaret also had some cracks in

* Comments of Esin Atil, Chairperson, Art History and Architecture Group

the central column that supports the stair. There are signs that groundwater, air pollution, and human occupation and use, and possibly, traffic-related vibrations and adjacent construction have led to an especially high rate of deterioration during the past decade. The groups tended to focus their attention on a few key issues—moisture at the base of masonry walls, concentric cracks in the dome, cracks and distortions in the walls and supporting and buttressing arches, a water well and tank, and the integrity of restoration efforts. These issues are addressed separately below.

Moisture in masonry walls

60. The lower 2-1/2 meters of the walls of this mosque were observed to have excessive moisture ("rising damp"). The source of the water for this capillary action is uncertain, particularly since this mosque sits on high ground. The combination of having a variation in moisture across the height of the wall and apparent previous repainting restoration of this lower portion have left a clear line of demarcation in wall painting as evident in Figure 19. This line might also be the consequence of cleaning procedures. The additional moisture is degrading the structural fiber of the masonry which will eventually begin to affect the structural stability of the walls.

61. The reduction of moisture in the masonry must be a high priority for all aspects of preservation—art, architecture, and engineering. To solve this problem, first the source of water must be determined. Given the terrain at the Mihrimah Mosque, this may be accomplished by conducting a very local groundwater study which must include pressure testing of pipes and holding tanks on the grounds, in surrounding buildings, and in nearby municipal sources. Second, active and passive techniques of isolating foundations from sources of groundwater should be studied and the best alternative adopted.

Cracks in dome and arches

62. Cracks in the inner surface of the dome (shown previously in Figure 9) have been observed; the most significant crack pattern being a circular line concentric with the dome. Important cracks are also present in the main arches that support the dome as shown in Figures 20 and 21. Studies to mitigate damage to the dome and arches should include:

- a. Archive research into original construction;
- b. Systematically collect information concerning damage and repairs, especially following the 1894 earthquake;

- c. Remove a small strip of lead cover of the dome to inspect cracks, establish thickness at key points and take samples of material if necessary;
- d. Survey key parts of the structure using methods such as endoscopy, sonic tests (non-destructive testing where there is plaster work to avoid damaging), investigation of materials, etc.;
- e. Establish a monitoring system for significant cracks to determine if cracks still moving;
- f. Continue mathematical model studies;
- g. Postulate and evaluate crack control methods;
- h. Initiate crack control and restoration work; and
- i. Continue periodic monitoring of the dome.

Cracks in walls

63. Cracks and deformations in the walls were apparent to all. From the lower balcony, significant cracks are found at numerous locations in the southeast and northwest walls, especially near the corners of the buildings as shown in Figure 22. The lower balcony along the southeast and southwest walls is distorted, bulging inward as shown in Figure 23. About 10 cm of horizontal bulging at mid-span was estimated for the southeast wall balcony.

64. Büyüköztürk, Croci, and Karaesmen (1992) have postulated mechanisms for the pattern of structural damage in the southeastern wall. This spacious wall has the weakest resistance to loads because it is thinner, it has an uninterrupted lateral span, and there are numerous window openings (refer to Figure 10). Most of the important cracks and deformations occur on this wall and many of these appear to be the consequence of seismic action. They have distinguished between normal and parallel actions on the wall.

65. Forces normal to southeast wall. The main resistance is offered by two central columns and the balcony which acts as a fixed end beam in the horizontal plane. A schematic of the forces and displacements are shown in Figure 24. The cracks visible over the arches are due to bending and shear and are concentrated at these points because of the reduced section of the balcony. Some ancient iron reinforcing bars are visible at this point.

66. Forces parallel to southeast wall. This component is taken up by the rows of cross vaults at the lower level of the northeast and southwest walls as shown in Figures 25 and 26. Cracks are clearly visible in the

vaults and are particularly evident in the corners where large gaps reveal the separation of the southeast wall from the northeast wall. The general concentration of cracks and spalling plaster in the southern corner also shows the serious state of the connection between these two walls. Irreversible deformation and relative movement of the blocks can also be observed.

67. Differential settlements may also be occurring along the southeast wall as evidenced by the pattern of cracks as shown in Figures 27 and 28. A well that is 15 to 20 m deep with an electric pump and a large polyester storage tank are located about 4 m from the southeast wall of the mosque. The combination of dewatering and the added weight of the tank on the foundation in this area may be causing differential settlement. Use of the well should be permanently discontinued and the tank and well should be removed. These actions may prevent further differential settlements and will certainly improve the aesthetics in the yard. Inconspicuous groundwater monitoring devices may be installed to evaluate the distribution and fluctuations in groundwater that would affect masonry.

Integrity of restoration efforts

68. The mosque should be restored to Sinan's original design. A number of alterations and additions have been made over the years, most of which detract from the original design by Sinan. They appear to be unnecessary and could be eliminated. If the owner does not wish to eliminate them, perhaps they can be redesigned and replaced with something more compatible with Sinan's original design. The following is a partial list of such alterations and additions that should be studied as part of the historic structures report and eliminated if possible:

- a. At the northeastern entrance there is a modern aluminum kiosk with unpleasing proportions. It effects and visually pollutes the building.
- b. Directly south of the minaret along what appears to be the property boundary line there is a modern concrete block wall constructed on top of the rear wall of the arcade. It is four to five meters long and one-and-a-half to two meters high. This later addition does not appear to have any useful function, detracts from the original design and should be eliminated, if possible.
- c. Outside the mosque at the southeastern corner of the property there are some additions and alterations in the area of the tombs that should be studied and eliminated, if possible, or redesigned to be more compatible with the historic resource.

69. On all facades of the mosques there are double windows, some of them with broken or missing glass. Water and birds have entered the spaces between the exterior and interior windows. Plants are now growing between the windows. Moisture stains on the wall indicate that the water is gravitating down through the wall. The moisture is having an adverse effect upon the mortar, cramping irons, plaster, and paintings. The missing panes in the exterior windows should be replaced immediately. Afterwards, vent the space between windows to allow that space to dry before reglazing the interior windows. The surrounding masonry should be allowed to dry out before repairing eroded mortar joints on the exterior and plaster finishes on the interior.

70. At the northeast corner of the mosque the lead roofing is missing, allowing water to enter this important connection point of the arches. The following actions should be taken:

- a. Cover this area of the roof immediately with temporary covering (tarp) to prevent any additional water from entering;
- b. Examine the condition of this section of the structure carefully while this area of the building is exposed; and
- c. Install lead roofing to match the original.

Evaluation strategy for Mihrimah Mosque

71. The following steps were developed to evaluate the Mihrimah Mosque following the site visit.

- a. Overall assessment of the structure—foundations, site conditions, structural condition, aesthetic and archaeological aspects, environmental conditions. Group reports would summarize the assessments.
- b. Workshop on findings and development of a final "state-of-the-art" document. This document would be the basis for planning and executing future work.
- c. Assessment of material properties and structural performance by testing and analyzing an expendable or "patient" structure. A report updating ideas on material properties and perhaps suggesting modifications in analytical methods would summarize this assessment.
- d. Global analysis of the performance of Mihrimah Mosque under past earthquakes, preferably those during which some damage was noted. This analysis would use the results of the earlier studies assembled above. The results of these studies may suggest necessary further research on material properties, modeling techniques, and methods of analysis.

- e. The entire program is attempted following stated objectives. The analysis of the response of Mihrimah Mosque to anticipated maximum credible shaking and interpretation of results from the point of view of seismic retrofitting. A report on anticipated performance of Mihrimah Mosque to the proposed seismic threat will summarize this attempt.
- f. Workshop to discuss the implication of the results of the previous studies for retrofitting the mosque. Discuss alternatives under aesthetic and economic constraints. A report on recommended remediation strategies for the Mihrimah Mosque is published.

The Selimiye Mosque

72. Observations were made around the exterior grounds, within the mosque, and inside the northern minaret to all three balconies. The current structural condition of the Selimiye Mosque is judged good although some important cracks and weak steps were observed in the minaret. The need for restoration work is important, but much less urgent than the need at the Mihrimah Mosque. Accordingly, comments were general and pertained to preservation strategies except for discussion about the northeast minaret.

73. Some of the surrounding market buildings designed by Sinan have been demolished in an attempt to landscape the area. Several appurtenant facilities within the complex of Selimiye have been left to complete deterioration. This includes a Turkish bath and house adjacent to this. These facilities are an important part of a complete preservation effort for the Selimiye Mosque.

74. The minarets have critical patterns of cracking and torsional dislocations around the spine as shown in Figure 29. Important and dangerous cracks are also visible on both faces of the cylindrical wall as shown in Figures 30 and 31. Indications of sliding between blocks is shown in Figure 32. All of the cracks and displacements are related to seismic actions and now lead to low safety levels. The minarets appear to be constructed of a soft, porous, and partially fossilized limestone that is undergoing continuous degradation.

75. Inside the northeast minaret are three sets of steps that rise to the three balconies. Although there were electric lights, they were spaced widely apart. With the light available, it was obvious that there were some cracked stone blocks and some of the blocks were shifted from their original position. The steps are well worn and a few have large pieces of stone

missing as shown in Figure 33. Some have iron anchor straps running across the top of the step from the central column to the exterior wall. These straps appear to work like stirrups in a global sense, providing shear resistance to deformation between the exterior wall and the internal column.

76. The exterior of the northeast minaret was observed from the first and third balcony levels. Again, cracked and shifted blocks exist. Some of the mortar joints were eroded away and allowing water to enter. Other deformations and sliding of the masonry were also observed.

77. The following investigations and analysis are recommended to properly study and restore the minarets:

- a. Survey and investigation of the damage and cracks present in the minarets;
- b. Conduct a systematic investigation of historical sources relating to damage and repair of the minarets;
- c. Establish a monitoring system for the cracks;
- d. Carry out dynamic tests; and
- e. Develop first approximation mathematical model.

78. The balcony railing was carved stone of a perforated design. The thickness was about 10 cm. The stone slabs met at angles with a staple shaped anchor holding the stones together. Molten lead had been poured around the wrought iron anchor to waterproof it. However, iron exposed to the weather rusts. The expanding rust has caused stone spalling and a large section of the stone balcony railing at the highest level was missing.

79. The following actions are recommended:

- a. The balcony railings should be immediately wrapped with structural grade nylon netting to prevent any loose pieces of stone from falling. If white nylon netting is used, it should not be too noticeable from the ground.
- b. All three balconies on all four minarets should be thoroughly inspected and the current damage recorded on a survey.
- c. All exposed wrought-iron straps should be cleaned of any rust and coated (primed and two coats of finish paint).
- d. All loose pieces of stone should be removed. If possible, they should be reinstalled using stainless steel pins and compatible mortar. If it is not possible to repair the balcony railing using the existing loose piece of stone, it will be necessary to replace

sections of the railing with stone that matches the original stone.



Figure 19. Northern entryway of Mihrimah Mosque
showing demarcation in paint on walls



Figure 20. Cracks on exterior of arches supporting dome
of Mihrimah Mosque (Croci, Appendix D)



Figure 21. Cracks in arch supporting balcony along southeast wall of Mihrimah Mosque (Croci, Appendix D)

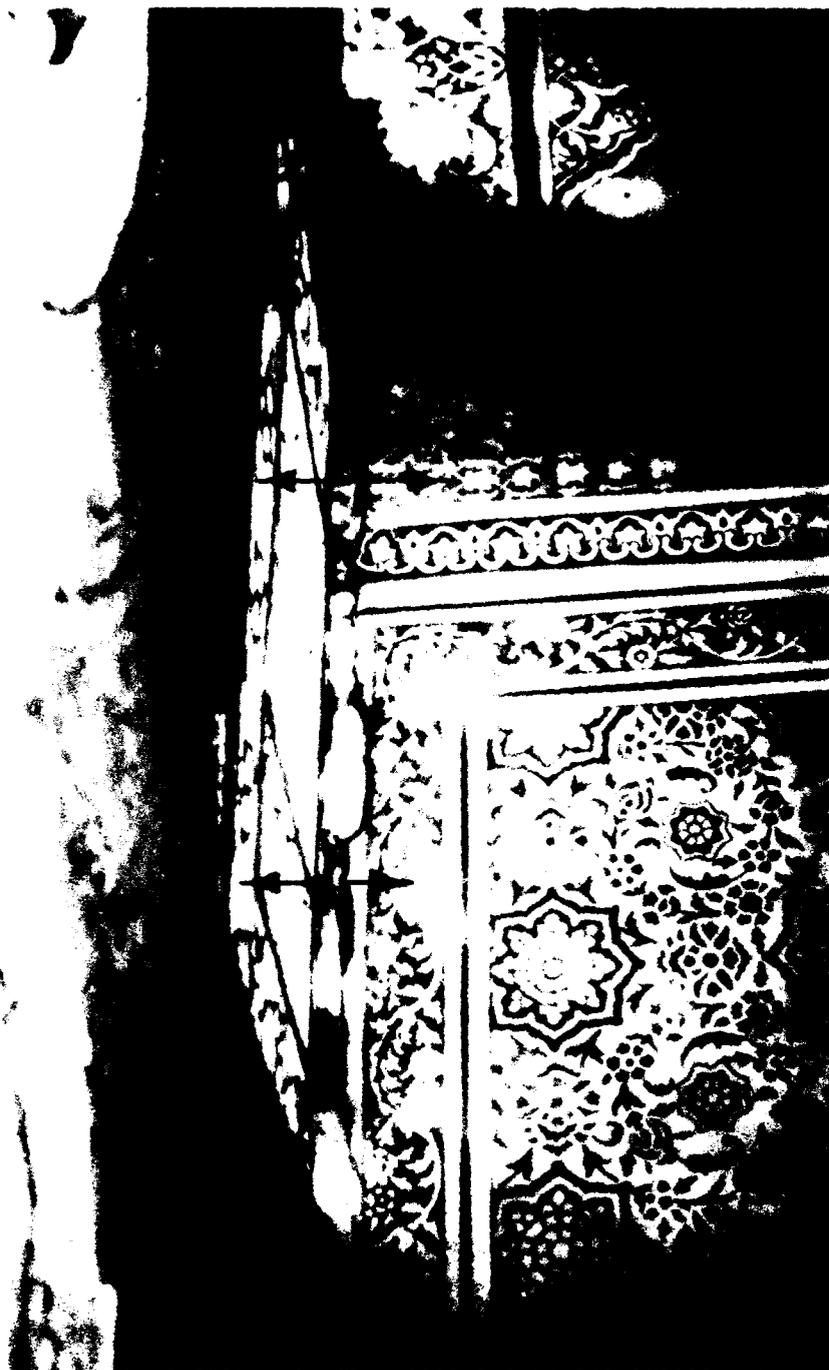
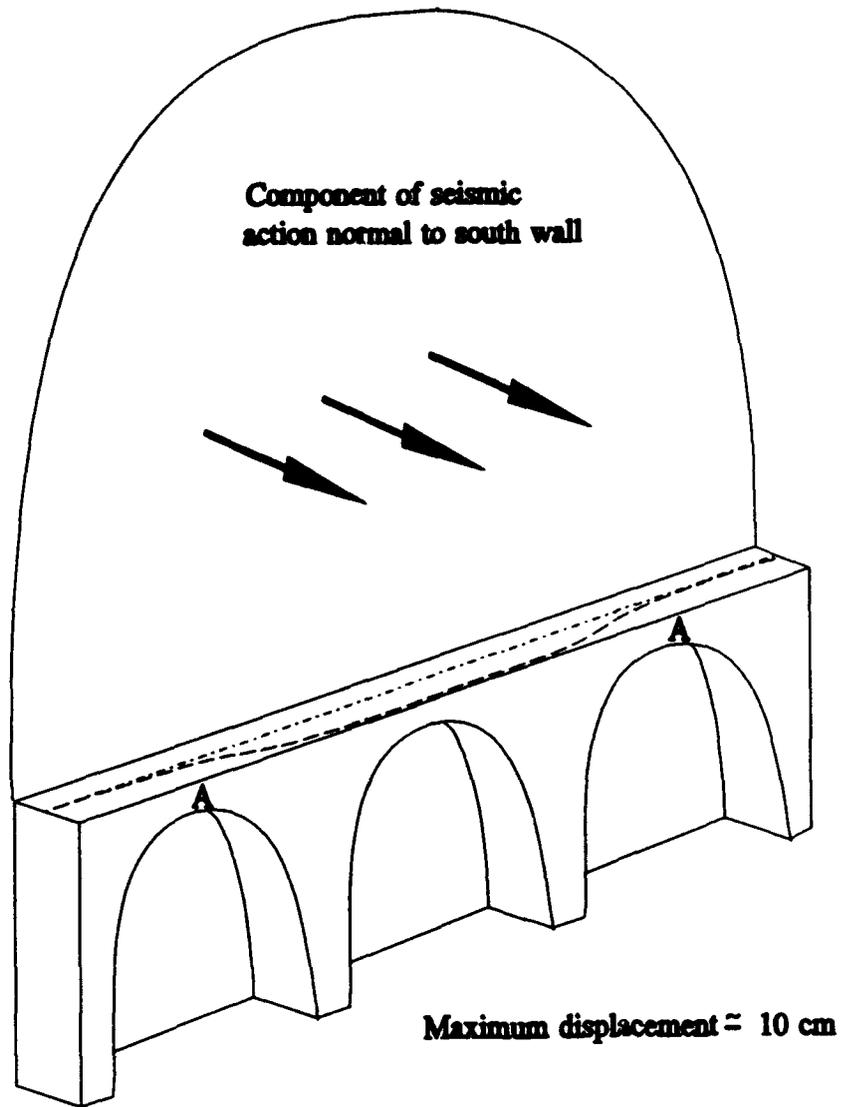


Figure 22. Separation of northwest wall from arches supporting dome of Mihrimah Mosque



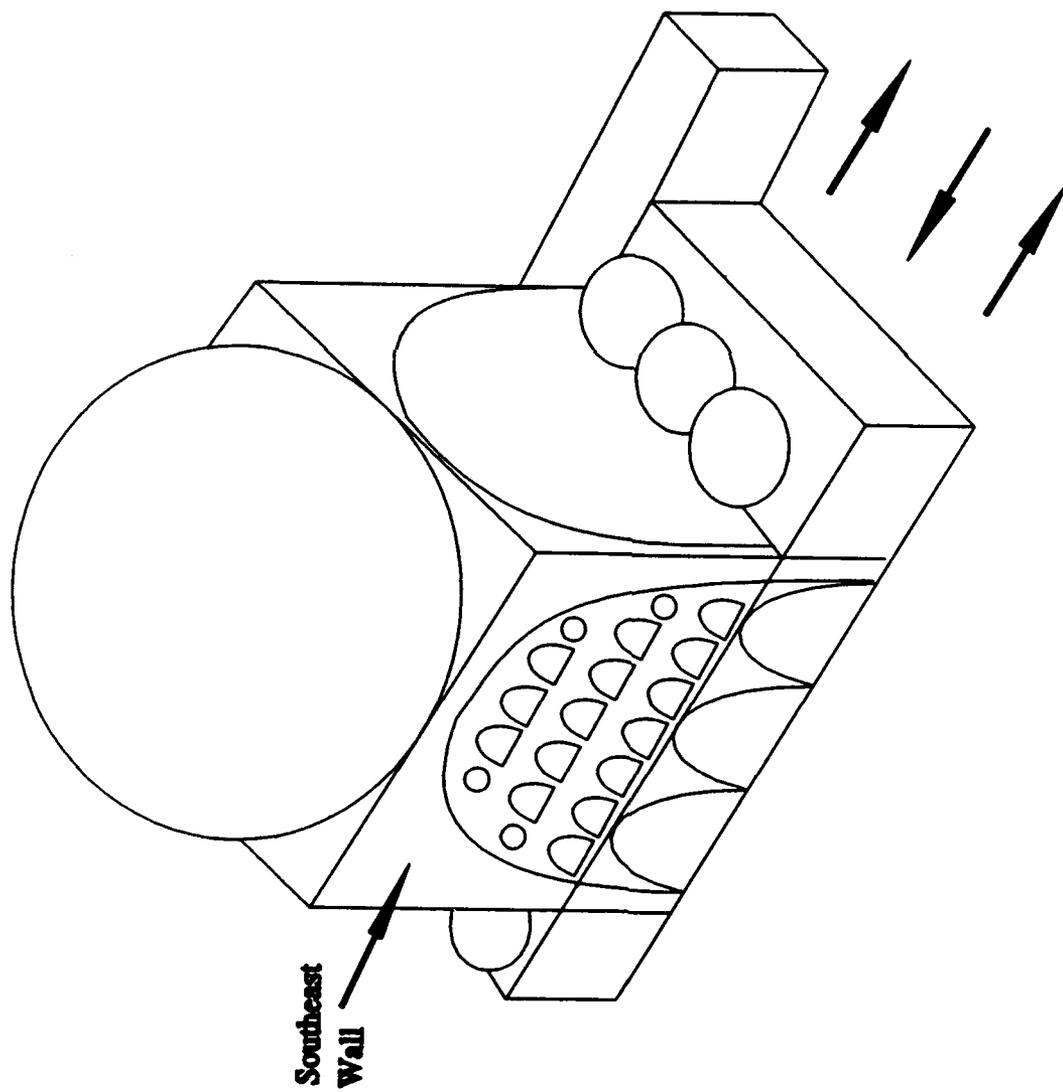
Figure 23. Balcony on southwest side of Mihrimah Mosque showing out-of-plane deformations (Crocì, Appendix D)

- - - - - = Neutral axis of balcony
- - - - - = Horizontal displacement



A = Critical points

Figure 24. Schematic of forces and displacements acting on southeast wall of Mihrimah Mosque (Büyükoztürk, Croci, and Karaesmen, Appendix D)



Component of seismic action parallel to south wall travels through the stiffest elements, these being the domed aisles along the east and west walls (shaded in diagram), thus subjecting them to higher loads.

Figure 25. Schematic of forces acting on Mihrimah Mosque in direction parallel to seismic action (Büyükköztürk, Croci, and Karaesmen, Appendix D)



Figure 26. Cracks in cross vaults of Mihrimah Mosque (Crocì, Appendix D)



Figure 27. Southeast exterior wall of Mihrimah Mosque showing cracks in recessed panel (in-fill wall)



Figure 28. Close-up view of cracks and deformation in southeast exterior wall of Mihrimah Mosque (Crocì, Appendix D)



Figure 29. Cracks in central column of northern minaret
of Selimiye Mosque (Croci, Appendix D)



Figure 30. Cracks on interior of northern minaret
of Selimiye Mosque (Croci, Appendix D)



Figure 31. Cracks on exterior of northern minaret of Selimiye Mosque



Figure 32. Sliding of masonry in northern minaret of Selimiye Mosque (Croci, Appendix D)



Figure 33. Worn masonry step in northern minaret of Selimiye Mosque

PART V: REPORTS FROM WORKING GROUPS

80. The recorder for each group submitted a report summarizing the activities, discussions, and recommendations of the respective participants. Some additional impressions were also submitted, incorporated into the following presentation, and included in Appendix D.

81. The engineering preservation of historic buildings in seismic zones consists of providing an adequate level of safety while preserving the historic character and fabric of the resource as much as possible. The Mihrimah and Selimiye Mosques are over 400 years old and have withstood many changes caused by nature, such as natural deterioration and damage caused by disasters (earthquakes, storms, etc.), and by humans, such as natural wear and tear caused by visitors, deliberate damage caused by vandalism and graffiti, and benign neglect caused by lack of proper and consistent maintenance. Each member of the interdisciplinary teams has much to contribute in understanding, evaluating, preserving, and retrofitting for seismic loads these important historic resources.

Art History and Architecture Group

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82. The Art History and Architecture working group agreed that it is important to know and understand the resource before the problems are defined and solutions proposed. Some of the questions to be asked are: What is to be preserved? What was the historic character and fabric of these resources when they were constructed (in the 16th century)? What was it like to experience them as they were originally intended to be used and experienced? The experience of the group when visiting the subject mosques was diminished as a consequence of a misunderstanding of the character of the resource, a lack of maintenance, misguided repairs, a lack of understanding of the architectural, engineering, and seismic problems, a lack of understanding of historic materials and their properties, and an attempt to satisfy the modern tastes and expectations of the tourists. For example, the recent cosmetic repair and repainting of the interior of the Selimiye Mosque appears to be not authentic but rather caters to the tastes of modern tourists. The modern materials also appear to be incompatible with the historic materials and finishes. The modern paint is flaking off and taking with it original material, thus resulting in a loss of evidence of the original paint and decorative scheme.

Compilation of information

83. In order to make a fully informed decision, additional information on each site is necessary in many different areas. Resources must be identified and retained. Identification also includes identification of the components of the resource that are the most important: significant spaces and features including skilled craftsmanship.

84. To compile and organize information for a monument, it is strongly recommended that a consistent format be adopted, such as the format for a historic structures report, or a modified version of it especially adapted to the construction of mosques. This will provide a framework for systematically collecting and organizing data for many structures and the computerization of this data. The following is a suggested format for a Historic Structure Report (HSR):

I. The first element is an administrative data section, prepared by or with the owner or manager, that contains:

- A. The name, number, management category, and proposed treatment of the structure;
- B. The proposed use of the structure;

- C. Identification of the planning document proposing the treatment and use, and any other documents bearing on the proposed management, furnishings, and use of the structure;
- D. A justification of the proposed treatment (stabilization, preservation, restoration, rehabilitation, or reconstruction) in terms of the application of the Secretary of the Interior's Standards for Historic Preservation Projects (the Venice Charter or other criteria adopted by the joint U.S.-Turkey Team) and the characteristics and limitations of the resource;
- E. Any recommended change in the proposed treatment or use based on the degree of documentary or physical evidence, the condition of the historic structure, or other professional findings in the completed analysis section; and
- F. Recommendations for the documentation, cataloging, conservation, and storage of any objects, documents, records, photographs, negatives, and tapes collected or produced as a result of the study.

II. The second element is a physical history and analysis section, prepared by appropriate cultural resources specialists, usually an historian and an historical architect and/or engineer, that contains:

- A. A statement of the anthropological/archeological/ historical, or architectural/engineering significance of the structure and its setting (including associated above-ground and subsurface features and their relationship to national, regional, or local history);
- B. A narrative and graphic description of the appearance, occupation, and use of the structure and its setting during significant periods or later time, based on a documentary and oral historical evidence, physical evidence from architectural fabric investigation, and any archeological investigation; all sources of information and data must be cited;
- C. A description and record of existing conditions, using measured drawings and photography prepared to Historic American Building Standards/Historic American Engineering Record standards (or other documentation standards adopted by the joint U.S.-Turkey Team);
- D. An evaluation of the impact of the proposed use on the integrity of the structure, including the effect of compliance with regulations for human safety, energy conservation, handicapped access, etc;
- E. An engineering report on safety and load-bearing limits of the structure as warranted by the proposed use or apparent conditions;
- F. An identification and analysis of significant material, structural, natural, environmental, and human factors affecting preservation of the structure and recommended measures to deal with them, including any constraints on proposed use;

- G. The recommended steps for preservation, rehabilitation, restoration, or reconstruction; a discussion of the basis for such recommendations; and preliminary drawings and engineering designs;
- H. An analysis of the impact of the proposed action on the structure and its contents (if any) in accordance of the Secretary's Standards (or other adopted standards) and on other affected cultural resources and the historic scene, with recommendations to avoid or mitigate any potential adverse effects;
- I. An updated package providing cost estimates to carry out recommendations, prepared and reviewed by the appropriate specialists; and
- J. A recommendation for further study in support of the proposed treatment project, if necessary, with suggested sources.

III. The third and last element is an appendix that contains:

- A. A record of all fabric analyses performed (paint, mortar, etc.) listing basic data with specific recommendation for treatment;
- B. An assessment of future anthropological/archeological, historic and/or architectural/engineering research potential;
- C. Records of any documentary data such as furnishings evidence, found during the investigation that are pertinent to the structure or setting but not to the treatment project for which the report was funded; comprehensive collections of data should be undertaken under separately funded studies; and
- D. An annotated bibliography of sources.

85. Data obtained during treatment and not previously included in the HSR should be presented as an addendum to the report. Further addenda are appropriate whenever new data become available. During the course of research for a HSR, it may be economical or desirable to gather data not specifically needed to support the treatment project. Such data on a structure, its occupants, its grounds, and/or its furnishings may be desired for interpretation or other purposes. When such is the case, the owner or manager should program for a Historic Resources Study, Cultural Landscape Report, and/or Historic Furnishings Report in conjunction with the HSR. Once the necessary data is collected and compile, the methodology of study precedes to diagnosis and decisions.

Study of Problems

86. Once the resources have been defined, the problems are then defined and analyzed. Problems may have single or multiple causes. Archival and historic research may reveal much information about the history of the

structure. This may include, but should not be limited to, historic documents and accounts in the hands of the owner, in the building, in local, regional and national archives and libraries, or elsewhere; contemporary and secondary accounts of newspapers, magazines, and other published sources such as travel and tour guides; photographic, pictorial, or graphic (drawings and specifications) information; previous physical and archeological evidence and reports; previous architectural and engineering studies and reports; soils reports; and topographical and geological maps. These efforts may not be the first and probably will not be the last to study and conserve a historic resource, especially one that is over 400 years old. It is also important that a detailed record of findings and any work that is proposed and/or accomplished be kept for future generations.

87. Paint research needs to be done by a qualified paint conservators and experts in 16th century Turkish painting to determine the composition of the original paint, the substrate, and the chronology of paint, the original design of the painting and decorative scheme, and how to conserve the original decorative paint design where the original design exists and how to restore and recreate where necessary the original design with paints that will be compatible with the existing layers of paint.

Preservation standards

88. To evaluate solutions, it is suggested that criteria be developed and adopted before solutions are developed. What criteria or standards should be used to evaluate alternate proposed solutions? Only proposed solutions that provide an adequate level of life safety should be considered. Of those solutions, the one that has the least adverse effect upon the character and fabric of the resource is likely to be the best choice.

89. In 1964 the Second International Congress of Architects and Technicians of Historic Monuments adopted what is commonly known as the Venice Charter (1964) which is reproduced in Appendix B. Neither the United States nor Turkey signed this document but the Venice Charter is frequently recognized as the international standard for evaluating the preservation of historic monuments. Besides traditional rules, no officially formulated or adopted standards or criteria for the preservation of historic structures are used in Turkey. Therefore, a set of standards applicable to historic mosques is needed and highly recommended.

90. The United States adopted its own standards: The Secretary of the Interior's Standards for Preservation Projects (reproduced in Appendix C). These standards provide definitions for the treatments of acquisition, protection, stabilization, preservation, rehabilitation, restoration, and reconstruction and standards for each treatment and were revised in 1990. Some of the definitions appropriate to this workshop are:

Acquisition is the act or process of acquiring fee title or interest other than fee title of real property (including the acquisition of development rights or remainder interest). If the current owner of a property cannot or does not want to care for the resource or wants to demolish it, it may be necessary to acquire the property to save it.

Protection is the act or process of applying measures designed to affect the physical condition of a property by defending or guarding it from deterioration, loss or attack, or to cover or shield the property from danger or injury. In the case of buildings and structures, such treatment is generally of a temporary nature and anticipates future historic preservation treatment; in the case of archeological sites, the protective measure may be temporary or permanent.

Stabilization is the act or process of applying measures designed to reestablish a weather resistant enclosure and the structural stability of an unsafe or deteriorated property while maintaining the essential form as it exists at present.

Preservation is the act or process of applying measures to sustain the existing form, integrity, and material of a building or structure, and the existing form and vegetative cover of a site. It may include initial stabilization work, where necessary, as well as ongoing maintenance of the historic building materials.

Rehabilitation is the act or process of returning a property to a state of utility through repair or alteration which makes possible an efficient contemporary use while preserving those portions or features of the property which are significant to its historical, architectural, and cultural values

Restoration is the act or process of accurately recovering the form and details of a property and its setting as it appeared at a particular period of time by means of the removal of later work or by replacement of missing earlier work

Reconstruction is the act or process of reproducing by new construction the exact form and detail of a vanished building, structure, or object, or a part thereof, as it appeared at a specific period of time.

91. Both the Venice Charter and the Standards for Preservation Projects require that the historic character and fabric of the resource be respected and preserved. There are some basic principles that underlie these

criteria. These are the principles of minimal intervention, reversibility, compatibility, and authenticity which are extremely valid for restoration and preservation of architectural decoration, be it carved marble, inlaid woodwork, glazed tile, or wall painting.

92. Principle of minimal intervention. This principle states that the historic fabric never increases (with few exceptions). Each time work is done on a building there is usually a net loss of historic fabric; therefore, the less done to a building, usually the less the resource loss to the historic fabric. There are two exceptions. One exception to this principle is when original or early historic fabric which had been previously removed for whatever reason is returned to its original location and reinstalled in an appropriate manner. The other exception is when new material added to a historic resource gains its own significance through time and events. This is more rare and usually takes a considerable passage of time.

93. In evaluating various proposals, the solution that has the least adverse effect upon the historic character and fabric of the resources should be given the highest priority. Changes to a building can usually be categorized as additive or subtractive. When materials are added to a resource, the character and integrity of the resource may or may not be effected. When materials are removed from a resource, there is almost always a net loss of both historic fabric and integrity and usually a loss of historic character also. If it is the removal of an inappropriate prior addition, it may be restorative in nature. Treatments that are additive in nature are usually more tolerable and acceptable, if it is reversible, because they can usually be removed at some future date. On the other hand, treatments that are subtractive in nature are usually not very reversible especially as the amount and significance of the materials removed increases.

94. Principle of reversibility. This principle states that nothing should be done to a resource that cannot be undone at a future date with little or no damage. Preservation work on historic monuments is usually not the first and is not likely to be the last. Preservation methods and procedures tend to improve as time progresses. Previous treatments done to historic resources may now be causing more harm than good. To halt the damage or deterioration caused by a previous treatment, it may be necessary to do radical surgery which may result in a loss of historic fabric. By designing

treatments to a resource that are easily reversibility with little or no damage, the future loss of historic fabric is being prevented or diminished.

95. Principle of compatibility. Anything that is done to a historic resource should be compatible or harmonious with the historic character and fabric. Compatibility of materials is very objective and is based upon the matching of physical characteristics or properties, for example, weight, strength, coefficient of expansion and contraction, porosity, absorption rates, etc. The properties of the new materials need to be compatible with that of the historic materials so that the new materials do not damage the historic materials. Compatibility of historic character, on the other hand, is more subjective and is based upon similarity of visual characteristics such as color, textures, size, scale, mass, proportion, configuration, rhythm, ratio of solids to voids, ornamentation, details, etc. If few or none of the characteristics of the new material harmonize with the historic materials, the effect may be very jarring and detract from the artistic and architecture expression of the historic resource. If all of the visual characteristics are matched, it becomes very difficult to distinguish between what is historic and what is new.

96. Principle of authenticity. Authenticity relates to integrity. Even a very fine replica can never be the "real thing." The original fabric of a resource is authentic and therefore has significance. It may be much less expensive to demolish the original resource and construct a replica with new materials and technology that looks just like the original resource, but a replica is always a replica. When the original material is lost, the original craftsmanship and the patina of time are lost. Replacements of missing parts of the design must be based on physical or photographic documentation, not conjecture. Even in a restoration effort, the replacement of missing parts must be compatible and accurate replication but also must be distinguishable from the original so that the restoration does not falsify the artistic or historic evidence. This is frequently done by thorough documentation of the work and by labeling the new materials in an inconspicuous location, usually on the back.

97. Alternate solutions need to be developed and evaluated for their effect upon the historic character and fabric of the resource. Not all solutions are equally destructive to a building. By developing alternate solutions and evaluating them as to their effect upon the historic character

and fabric, the adverse effects upon the resource can be diminished. The main focus of the NPS conference on the Seismic Retrofit of Historic Buildings is to look at various alternative solutions and to analyze the decision making process of selecting the solution that has the least adverse effect upon the resource. For example in the recent conference, Sparacio (1991) discussed several projects and how the historic fabric and artistic features were saved and preserved. In addition, Elsesser et al. (1991) described the various proposed solutions developed and evaluated for five historic building damaged by the Loma Prieta Earthquake and examined the decision making process for selecting final solution from a variety of proposals.

98. Historic buildings should be studied and retrofitted if necessary. Various approaches and methods have been used effectively to retrofit historic buildings. There are several effective methods of retrofitting historic buildings. By developing and evaluating several (at least two) alternative retrofit solutions, the least destructive method to the historic character and fabric of a particular building can be selected. A thorough understanding of the resource and its significance is also very important. Identification of what are the most important spaces and features of a building helps the designer determine what to avoid and where retrofit elements may be added with the least effect on the resource. As stated before, this does not mean that all other spaces and features of historic buildings are fair game for demolition. The cumulative effect of loss of historic materials must be considered, even if it is replaced in kind.

Role of Maintenance and Repair

99. It is very important to establish a sound maintenance program of each historic structure. When a building is constructed, there is an investment made in time, labor, and materials. Proper cleaning and maintenance protect that investment and do more for preservation than any other treatments. When maintenance is deferred, it usually costs at least three times as much to later correct the damage done by deferring the work. For example, if a leaking roof is not repaired or replaced in a timely manner, it may be necessary to repair or replace the roof sheathing, the roof framing members, the plaster ceilings and the flooring of rooms below the leak. At a minimum, maintenance should include periodic inspection to find and document problems as soon as possible and to provide repairs before a small job becomes a big job.

100. If a building is well cleaned and maintained, it seldom needs to be repaired or restored. If surfaces are cleaned on a routine and continuous basis, seldom is it necessary to use harsh or abrasive measures to clean the surface. If soil, oils, stains, and pollutants are removed periodically, they do less damage to the resource. The traditional practice of removing shoes before entering a mosque is a wonderful preservation action. Soil, especially sand particles, are very abrasive to materials. If not removed, the sharp particles will cut fibers in carpets and wear away hard surfaces—even stone—as noticed at nearly all the monuments visited. Maintenance includes the protection of historic materials through treatments such as rust removal, caulking, and the re-application of protective coatings (priming and painting). These coatings not only provide color and pattern but repel water and provide a maintainable and renewable surface. If the coating is maintained, the surface beneath can be preserved almost indefinitely.

101. While inspecting earthquake damage, frequently two or three adjacent identical or very similar buildings that were obviously constructed about the same time are encountered. Two of them may be in good condition with little or no earthquake damage while the third one may have extensive damage. Usually the monument that incurred extensive damage had the poorest maintenance and resulting deterioration. Deteriorated materials (rotted or insect infested wooden members, rusted metal anchors or fasteners, etc.) do not have their original capacity to function in a building. When a building is stressed with seismic loads, the first localized failure usually occurs where there is deterioration. Localized failure can lead to catastrophic failure. Therefore, good maintenance is the best investment to protect the resource. It is always better to preserve and maintain than to repair.

102. If the material is damaged, it may be necessary to repair. Guidance for the repair of historic materials such as masonry, wood, and architectural metals again begins with the least degree of intervention possible such as patching, piecing-in, slicing, or otherwise reinforcing or upgrading them according to recognized preservation methods. Repairs should always be in kind, that is, repair wood, stone, or metal with the same kind of wood, stone, or metal, respectively.

Consolidation

103. Consolidation of materials can sometimes extend the useful life of a material. If the consolidation is reversible, consolidation is a useful

and safe treatment. If consolidation is irreversible, it should only be used as a last resort and only in the areas of severe deterioration. If the material is so deteriorated that it must be repaired, even irreversible consolidation may be permissible under certain circumstances.

104. Sometimes consolidation can postpone replacement. The practicality of consolidation or repair of museum objects and architectural elements are somewhat different. A museum object can be cleaned and conserved (arrested deterioration) and then placed on display or in storage in a controlled environment. For architectural elements on the interior of a building, this is sometimes possible even if the environment cannot be totally controlled. For the exterior of buildings, this is not always possible. For example, if the architectural element must function to shed water, such as a roof, repair or consolidation of the material may only extend the useful life of the material a short time. When it fails, many other materials may be at jeopardy. Therefore, some elements, such as roofing, are more subject to replacement. Although using the same kind of material is always the preferred option, a substitute material is acceptable if the original material is not available and if the form and design as well as the substitute material itself convey the visual appearance of the remaining parts of the feature and finish. It is almost always better to repair than to replace.

105. If elements of the building are missing or so deteriorated that they cannot be repaired, it may be necessary to replace them. If the essential form and detailing are still evident so that the physical evidence can be used to re-establish the feature as an integral part, then its replacement is appropriate. If there is no physical or archeological evidence, the design of the replacement elements may be based on photographic or pictorial documentation and, in some cases, on written description. Replacement should not be based on conjecture. Like the guidance for repair, the preferred option is always replacement of the element in kind, that is, with the same material. Because this approach may not always be technically or economically feasible, provisions are made to consider the use of a compatible substitute material. This is especially true if the original material is causing a problem. For example, if the original wrought iron anchors are oxidizing and the expanding rust is causing the surface of the stone to spall, then the use of stainless steel as a substitute material may be considered.

Discussion of working group

106. Much of the discussion focused on what additional information is needed, how to obtain the information, whether the information exists, and what research was necessary to make a fully informed decision. The Turkish Foundation of Historic Monuments is known to have some archival records on the various mosques. An initial data survey should be conducted to assess the magnitude and potential rewards of this effort.

107. The primary information research effort conducted for each mosque would have to be done to locate and collect all of the information that exists on any particular mosque. There is no computer system or index of the information or where it is located. Eventually a computer system might be available to manipulate this data once it is compiled. It was suggested that universities with departments of history, architecture, and engineering be contacted to ask their contribution of resources and research students to work on the various research projects. This would be a learning experience for the students and an inexpensive but probably slow way to locate and collect data. Students could also be used to search periodicals for information on earthquake damage and do measured drawings of the existing conditions of the mosque.

108. The outcome of the information study would be a series of reports. The pertinent information in the reports should be incorporated into the historic structures report. Drafts of the study/research reports should be distributed to all team members and other relevant parties, such as the Foundation and local, regional, and national government agencies. The reports will be used to help each team member learn about and understand the resource and its problems. For example, the archival and historical research will help the team members to understand previous damage, repairs, and alterations to the resources. Destructive and non-destructive testing will help the team members understand the problems of the buildings and the extent and seriousness of the problems.

109. There was also considerable discussion about two problems effecting the Mihrimah Mosque—air pollution and a proposed expressway adjacent (to the east). High concentrations of air pollution in Istanbul is causing a slow deterioration of the stone and other materials. The preservation community should join forces with the environmental community to urge stronger environmental protection laws and regulations to greatly reduce the air

pollution. The vibrations from construction of the proposed expressway, and later from the thousands of cars, buses, and trucks that traveled the road each day, would have an adverse and serious effect upon the mosque. The demolition of thousands of historic buildings and archeological sites in its path would be an enormous loss to the whole society. The preservation community should testify against this proposal for the reasons stated above. It may be necessary to pass stronger preservation laws to prevent the destruction or damage to historic and archeological sites.

Recommendations

110. Before doing any cosmetic work is very important to study all of the problems and make structural repairs. Once these repairs have been made, the structure should be monitored to be certain that all problems been corrected prior to doing repairs and restoration of decorative finishes. The following series of recommendations are suggested:

- a. The biography of the buildings are most likely available at the Vakiflar Archives (Ministry of Pious Foundations/Endowments). Departments of engineering, conservation, history, and art history in Turkish universities and museums can provide students and interns who can work in teams with the Vakiflar personnel to prepare this document.
- b. It is most desirable to work up a model or map of the building to see how the proposed restoration will look. Computer-aided "walk through" modeling may be of great assistance. Decorative motifs and color samples should be included. This model should be carefully studied by art historians and other specialists in the decorative arts.
- c. Materials chosen should be checked by engineers, chemists, and conservators to determine reversibility, suitability, and compatibility.
- d. Most importantly, aesthetics should be considered. These buildings are being preserved not for sheer exercise of conservation techniques and practices, but to preserve the experience of the past—to preserve the cultural heritage of mankind. The integrity of the building must be honored—structurally and decoratively—to fully appreciate and understand the achievements of their age, their social, economic, and aesthetic milieu. Therefore, one cannot concentrate on one single structure, but the entire külliye (complex of buildings around a central mosque) must be considered as life revolved around these buildings that provided diverse areas for prayer, education, health facilities, and social interaction.

If we are to learn from the past, its story must be faithfully preserved, its originality retained, and its aesthetic experience honored.

Geotechnical Engineering Group

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Recommendations for a pilot study

111. A procedure for conducting geological, seismological, and geotechnical engineering evaluations for a pilot study that could be generally applied to other preservation studies for historic monuments was developed and is presented below.

112. Geology. Definition of regional and local geologic conditions normally represents the first phase of a geotechnical analysis. Included in this category is hydrogeology. The two main components for a pilot study are:

a. Define the general geology of each site in terms of the depth to sound bedrock and the three-dimensional stratigraphy and structure of the site.

b. Define the hydrogeology of each site.

113. Seismology. The next logical step is to conduct a seismologic study to define the seismic hazard. Normally for critical structures, the Maximum Credible Earthquake event (MCE) is used. Specific comments regarding seismological studies related to the MCE proposed by Krinitzsky are presented in Appendix D. However, it may be impossible to retrofit for the MCE without destroying the historic fiber of the structure. In this case, it is better to retrofit for a lesser earthquake than do nothing.

a. Conduct an adequate assessment of future seismic demand on the targeted structures.

b. This assessment needs to be in terms of the MCE affecting the site. This earthquake will be established by determining the maximum earthquake that can be produced by the causative mechanisms in each seismic zone and estimating the intensity of shaking at the site resulting from it. The greatest intensity of shaking taking all relevant sources into account will be the seismic demand on the structure.

c. Determine intensity of shaking from past earthquakes. A key element in defining site intensities is selection of proper attenuation functions for the Turkish seismic environment.

d. Consideration also needs to be given to the consequences of ground rupture, tectonic uplift or subsidence, and tsunamis.

114. Geotechnical investigations. A number of traditional and innovative techniques to interpret the stratigraphy and define material properties can be used for the pilot study. These techniques include non-destructive, non-invasive geophysical methods such as ground-penetrating radar, minimal-invasive exploration methods like cone penetrometer testing, and drilling and sampling. A system of selecting and implementing these methods is prescribed below:

a. Review available written records of construction, excavation, topographic surveys, records of past repairs, inspection of accessible galleries or tunnels.

b. Obtain or create accurate surface topographic maps.

c. Begin with the least invasive techniques. A first logical step is to define the foundation geometry by non-destructive evaluation techniques. Ground penetrating radar has been suggested as a reliable, cost-effective technique of this kind.

d. Soil stratification, soil type, and relevant properties can be estimated by in-situ techniques such as the cone penetration test, the standard penetration test, and pressuremeter tests.

e. The dynamic moduli of the foundation soils can be established by geophysical methods such as uphole, downhole, and crosshole surveys of shear and compression waves. Low-strain damping may also be measured.

f. A program of retrieving good quality samples should be executed as it seems feasible based on the previous investigations. These samples would allow determination of the strain dependence of moduli and the variation of damping ratio with shear strain. Stress-strain-strength information from

triaxial tests as well as low strain moduli from resonant column tests can also be obtained.

115. Suggestions for other disciplines. The geotechnical engineering group had some specific recommendations regarding structural engineering interests based on observations made during the site visits:

a. Make comparisons between past seismic shaking and anticipated future shaking.

b. A crack survey should be made with an attempt to determine the relative sense of movement of the different parts of the structure. This appears to be particularly relevant to the Mihrimah Mosque site.

c. Dynamic analysis procedures should be validated by using them to assess the performance in past earthquakes. Comparisons between predicted and reported performance should be useful in improving the modeling of seismic response.

Needed research

116. Probably the most important research effort defined by this group is the synthesis and systemization of appropriate exploration techniques, particularly non-destructive and non-invasive techniques. These techniques must also be adapted to assist in defining the dimensions of foundations (footings, pile caps, etc.) and the evaluating the potential for voids formed by constructing over existing systems such as canals, cisterns, or baths.

Structural Engineering Group

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117. The main objectives of an evaluation and restoration activity for structural engineers would involve the development of engineering methodologies for evaluation deterioration, monitoring the safety of irreplaceable structures, development and evaluation of materials and technologies for restoration, and development of design and construction methods for remedial actions. The success of any restoration measures depends on the accuracy with which the structural vulnerability and the cause and extent of the deterioration has been evaluated and the quality of the judgement that has been used in selecting an appropriate restoration method.

118. The workshop provided a glimpse to the structural engineers about the potential rewards of multi-disciplinary interaction with researchers in the areas of art, art history, architecture, chemical and environmental engineering, etc. On the other hand, the structural engineers experienced considerable difficulty in effectively interacting with the researchers from other disciplines within the short duration of the workshop. There was not sufficient time for the personality and disciplinary barriers to be eliminated. A lack of common definitions and terminology made communication and understanding of the issues considered important by different disciplines quite difficult.

119. The concerns of the structural engineering group focused on structural identification, computer modeling, and degradation of building materials. The value of non-destructive tests to evaluate the structure and material degradation was also discussed. Deterioration of the observed structures occurs mainly as a result of mechanical and environmental effects. In this respect, understanding of time-dependent factors, including construction, load, and maintenance histories and their effect on structural system behavior and material deterioration are essential.

Structural engineering research and application needs

120. Four basic categories of research and application needs were identified. These are: fact finding, evaluation of structural materials, behavior modes, and preservation (repair and retrofit) strategies. Research and application is needed to accomplish tasks within each category as described separately below.

121. Fact finding. This category involves finding and documenting archival facts about a subject facility. This includes information about construction, past loadings, repair history, and other pertinent facts. Some specific details are:

- o Establishing the dimensions. This includes the 3-D global geometry and local geometries, e.g., section dimensions as well as existence and details of any reinforcing within a masonry section,
- o Condition survey of the structure and the foundation,
- o Geotechnical information as it relates to structural issues, and
- o Basic material properties and the variation in these throughout the structure and foundation. In-situ tests as well as sampling and laboratory testing of the materials is required. Effective and quantitative NDE techniques were considered.

122. Evaluation of structural materials. Deterioration of the materials can be defined as any adverse changes of normal mechanical, physical, and chemical properties either on the surface or in the whole body of the material generally through separation of its components. It can be caused by either physical or chemical factors, or both. Physical factors have to do with forces such as temperature variations, foundation displacement, seismic forces, vibrations and water surges. Chemical factors are commonly associated with the intrusion of polluted air and aggressive waters containing organic or inorganic acids, sulfates, and other salts. Alkali-stone reactions can cause physical damage and mechanical deterioration.

123. The importance of examining local effects in the initiation and progression of deterioration can not be over-emphasized. Identification of critical regions by careful inspection and, preferably with the use of non-destructive evaluation probes, to identify critical deterioration regions will be essential. Large-scale system analysis approaches to assess the overall structural characteristics under different mechanical effects will be useful after material and composite component behavior at the local level is

realistically represented in the mathematical models. Local behaviors such as mortar-masonry interaction and cracking such as those at the pendentives will critically influence the predictions based on system or global level structural model. Assessment of mortar and masonry characteristics and studies on experimental and analytical models representing local deterioration mechanisms will be needed.

124. Behavior modes. This category involves analytical representations of the structure-foundation behavior under different types of short-and-long term loading conditions. This includes:

- o Establishing structural index values for loads, stress, stiffness, and stability for checking global stresses and deformations.
- o Modeling and static and dynamic analyses based on models that may range in sophistication and detail between linear 2-D macroscopic to nonlinear 3-D microscopic (FE).

125. Strategies. Preservation strategies that would use the results of behavior analyses and recognize the multi-disciplinary nature of the problem have to be formulated.

Recommended features of future research

126. Research should be formulated to foster uninhibited multi-disciplinary interaction. This requires more than just bringing researchers from different disciplines together, multi-disciplinary interaction should be designed into the research.

127. Fundamental research is needed to improve the reliability in the estimated structural behavior and distresses. These would include the study of constitutive material and bonding, element and subassembly behavior in the laboratory under generalized (3-D) load/displacement histories and environmental/chemical parameters, structural identification, and deterioration mechanisms (i.e., accelerated testing for the effects of environmental attack).

128. Research should incorporate several prediction tournaments. It is recommended to assign similar research and applications to several teams and to correlate the results provided by the different teams. For example, different teams may be assigned to evaluate structural conditions by different NDE approaches, and the results may be correlated. Another example would be providing the same data about the structure to various teams for analytical modeling and behavior prediction, and correlating the predictions. Similar

"round robin" type studies may even extend to interpreting results of analyses conducted by others and developing preservation strategies.

129. Another possible enhancement of the multi-national, multi-disciplinary research could be through global competitions. For example, currently a US-Turkish team composed of Princeton University and Kandilli researchers is investigating the Hagia Sophia. A second team of Japanese and separate Turkish researchers who are essentially looking into the same problem have been identified. Both teams have measured certain characteristics of the structure and are developing analytical models. Considerable benefit is expected by correlating their findings and syntheses.

130. A six-point research outline proposed for a Mihrimah-specific preservation study during the closing day of the workshop has been found as an excellent starting point for formulating a multi-national, multi-disciplinary proposal. High-risk loading tests and material sampling/testing may be conducted by taking advantage of an "expendable" domed facility of the same period such as a bath. The round-robin type efforts may include studies on such an expendable dome, i.e., a correlation between observed load-test behavior and the predictions prior to the test carried out by various research teams.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

131. Conclusions and recommendations derived from the workshop are presented below. These conclusions are based upon presentations during the plenary sessions, findings of the working groups, and comments by individual researchers, both documented and undocumented, but are guided by the thoughts and feelings of the editors of this report.

Preservation Strategy

132. An ultimate goal for a country dedicated to preserving cultural heritage in the form of historic monuments is to adopt, use, and enforce a comprehensive preservation strategy. It is important to include ministry officials (in this case, of the Republic of Turkey) in the formulation process so that the methodology will be thoroughly understood and the needs and concerns of the country are adequately met.

133. A suitable preservation strategy must be flexible and wide ranging in addressing potential site conditions. This strategy must consider the full spectrum of factors related to preservation, including art, art history, architecture, seismology, geotechnical engineering, structural engineering, and seismic retrofit.

134. The involvement of an international, multi-disciplinary group of experts for workshops was both enlightening and invigorating. To be most effective, however, each participant must recognize and respect the priorities, interests, perspectives, goals, and objectives of others and other disciplines. Some actions can be made to improve effective communication, including adopting a common inter-disciplinary vocabulary and involving more inter-disciplinary interaction in working group meetings. The consensus of opinion was that the framework used for this workshop should be continued in guiding future research endeavors and conducting periodic workshops.

135. Developing a framework of collaborative international and inter-disciplinary research is a more difficult task. Some restrictions and limitations on international travel and global communication will always exist and hinder a truly collaborative effort. One plausible model has three primary components of activity. The first activity are teams of experts within a certain discipline and from related disciplines performing research

to solve specific problems. The work could be done using a collaborative effort deemed appropriate by the group. In addition, more cooperation among researchers is vital to the overall success of such studies. For example, the experience gained by the investigators of the Hagia Sophia should be an integral part of similar studies.

136. An international, inter-disciplinary technical panel would comprise the second activity. This panel would be independent from the research teams and review and critique the studies periodically to ensure that the defined objectives were being met in an appropriate manner and that the findings of one study would be directly related to the needs of other groups to meet the overall preservation objective of the project.

137. The third component is a central research coordination activity. It would be responsible for coordinating activities. The responsibilities of this group would also include the collection, merging, and dissemination of information and the facilitation of the technical panel. This group would serve as the point of contact for all efforts.

138. The list of experts for such an effort is not complete. Many more researchers and preservation organizations need to be considered for the various components of this effort. Many other countries should also be represented, if possible, to bring together the most broad base of experience and study to best affect the heritage of all.

Pilot Study

139. Once a target structure is selected, then the following plan may be used to assess the structure:

- a. Overall assessment of the structure,
- b. Interpretation of findings,
- c. Apply technology to assess performance of expendable structure (e.g., bath); reassess technology, and
- d. Implementation of state-of-the-art technology to analyze past performance and potential future response of the target structure.

Apprenticeship programs for professionals, workmen, and craftsmen should be an integral part of these steps.

Basic Research Required

140. Several problems were identified that require some degree of research to solve and integrate the results into a preservation strategy. This includes: defining a charter for preservation activities; defining criteria that relate performance of structure with damage to art and architectural elements; synthesis and systemization of non-destructive geophysical and geotechnical techniques for subsurface exploration, the modeling of minarets and interaction with mosques; retrofit strategies for unique structures and architectural elements.

141. All attempts should be made to thoroughly examine international technical journals and proceedings, and report lists of organizations dealing with preservation to be certain that no duplication is made. Although this seems like a basic recommendation, it merits stating. Preservation of historic monuments is not new, but many problems still remain. Our task as researchers is to determine what problems have not been solved and derive a plan to solve them.

REFERENCES

- Behrens-Abouseif, D. 1989. Islamic Architecture in Cairo. An Introduction. The American University in Cairo Press, Cairo, Egypt.
- Elsesser, E., Naaseh, S., Walters, M., Sattary, V., and Whittaker, A. 1991. Proc., 2nd Conf., Seismic Retrofit Historic Bldgs., D. Look, ed., Assoc. Preservation Technology, San Francisco, CA, pp 4-1 to 4-40.
- International Charter for the Conservation and Restoration of Monuments and Sites, 1964. "Decisions and Resolutions," Venice, Italy.
- Kuran, Aptullah 1988. SINAN: The Grand Old Master of Ottoman Architecture
- Lahore Statement 1980. Proc., Symp. Conservation & Restoration Islamic Cultural Architectural Heritage. Lahore.
- Look, D. W., ed. 1984. Proc., Seismic Retrofit Historic Bldgs., San Francisco, CA.
- Look, D. W., ed. 1991. Proc., 2nd Conf., Seismic Retrofit Historic Bldgs., Assoc. Preservation Technology, San Francisco, CA.
- Mahin, S. A. 1991. "The Loma Prieta Earthquake: Implications of Structural Damage," Proc., 2nd Int'l Conf., Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics. St. Louis, MO, March.
- Sparacio, R. 1991. Proc., 2nd Conf., Seismic Retrofit Historic Bldgs., D. Look, ed., Assoc. Preservation Technology, San Francisco, CA, pp 3-1 to 3-14.
- U.S. Secretary of the Interior, 1990. Standards for Historic Preservation Projects, 1st rev., Washington, DC.
- Vogt-Göknil, Ulya 1966. Living Architecture: Ottoman. Grosset & Dunlap, New York, NY.

APPENDIX A
SUBMITTED PAPERS

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**STUDIES ON DEVELOPMENT OF AN ASSESSMENT METHODOLOGY
FOR HISTORIC MASONRY DOMED EDIFICES IN SEISMIC ZONES
WITH EMPHASIS ON TWO CASES OF THE LAST MASTERWORKS
OF THE GREAT ARCHITECT AND MASTERBUILDER, SINAN**

(Summarized introduction on Sinan and his work,
for the Istanbul meeting on 29 May 1992)

**SINAN, THE ENGINEER
BEYOND THE ARCHITECT AND THE ARTIST**

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ON SINAN'S LIFE

Sinan, the great turkish engineer and architect, was born towards the end of the XV. century, most probably in 1492, in the village Ağırnas near Kayseri in Central Anatolia. He has been converted and recruited in 1512/13 during the reign of the Sultan Yavuz Selim I. He participated in 10 imperial war campaigns during 25 years, as a member of the ottoman army, advancing ultimately to the rank of Haseki. He saw many locations, from Cairo to the vicinity of Crimea, from Tabriz to the outskirts of Vienna; and got the opportunity to analyse and assimilate the art and the technology of construction in east and west.

He has been appointed in 1538 by the Sultan Kanuni Süleyman, the magnificent, as chief architect, becoming thus responsible for all construction activities in the entire ottoman empire. He held this position for 50 years, also during the reigns of the Sultans Selim II. and Murat III., until his death on 9 April 1588. This exceptionally long duration in such a high position, indicates also the great administrative skills of Sinan.

ON SINAN'S WORK

During the last years of his long life, he dictated to his collaborator Nakkaş Sâi Mustafa Çelebi, the story of his life and the list of the edifices constructed or thoroughly repaired by himself. According to these manuscripts, bearing the titles "Tezkiretü'l bünyan", "Tezkiretü'l ebniye", "Tuhfetü'l mimarin", which can be considered as modified and somewhat enlarged copies of his original dictate, he was responsible for the construction of about 500 edifices; among them are more than 150 mosques of various sizes, more than 70 educational buildings, more than 50 public baths, more than 40 monumental tombs, as well as several palasts, residences, caravanserais, hospices, hospitals, magazines, bridges, aqueducts. About 200 of these edifices maintained their original form until present and most of them are still in use.

ON SINAN'S ENGINEERING

The universal importance of Sinan's work with regard to architecture and to decorative arts has been recognised since many decades, leading to the proclamation of 1988 as "Sinan-year" by UNESCO. However, his importance with regard to engineering, notably to civil engineering,

has been far less assessed, and the current research project is anticipated to be of paramount importance in this respect.

Sinan expressed in "Tezkiretü'l bünyan" certain details and conversations related to the construction of seven edifices, which he considered as his most important ones. These are three large mosques (Şehzade; Süleymaniye; Selimiye), two bridges (Kanuni Süleyman on the estuary of the Büyük Çekmece lake; Sokollu Mehmet Paşa on Drina), two hydraulic systems (well and water lifting devices in the Iskender Çelebi garden in Istanbul; the Kırkçeşme water conveyance system to Istanbul, including the spectacular Uzun, Eğri, Mağlova, Güzelce aqueducts).

Since bridges and hydraulic structures are mainly subjects of civil engineering, and since the civil engineering aspect of tall buildings like the aforementioned mosques is at least as important as that of architecture, Sinan should be considered as an engineer even before as an architect.

In fact, Sinan described himself in "Tuhfetü'l mimarin", as a "skilled engineer" (mühendis züfünun) just after saying "wise architect" (mimar'ı akil).

ON PRESERVATION OF SINAN'S EDIFICES

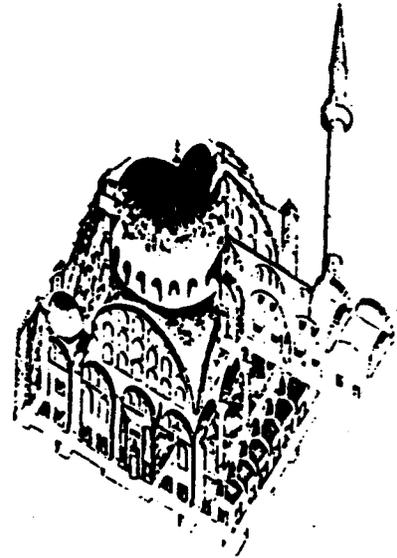
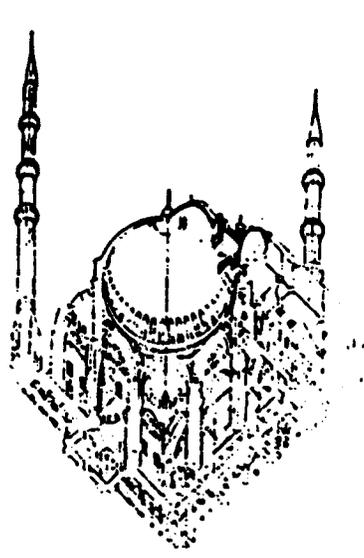
In "Tezkiretü'l ebniye", Sinan ended the section on his life with the following sentences:

"I hope
until the time ends and
the earth stops
wise people who see my edifices
knowing the seriousness of my work
look at them with indulgence
and think of me with well-intended prayers
If God wishes".

We hope, too, that every effort has to be spent in order to preserve the remaining 200 edifices of Sinan, which have endured more than four centuries, in order that future generations would comply with his wishes.

SHORT BIOGRAPHY OF Prof.Dr. Onal ÖZİŞ

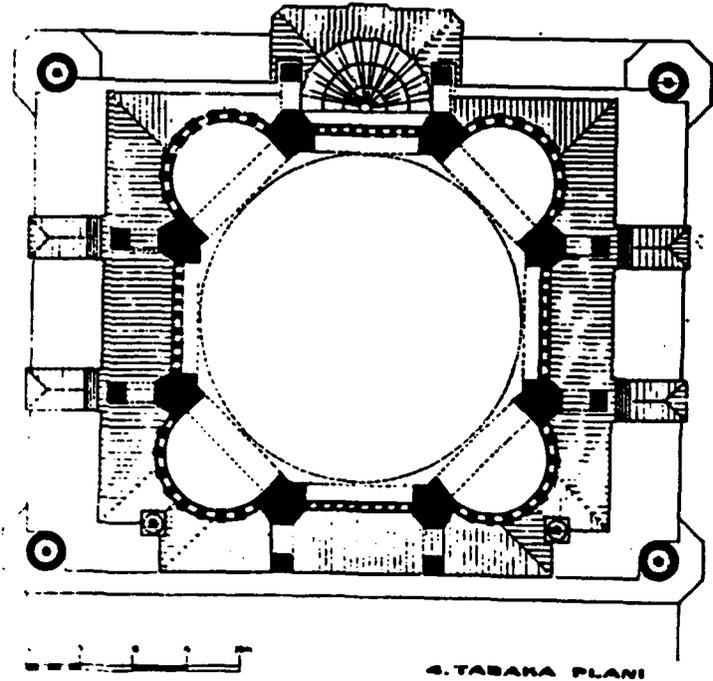
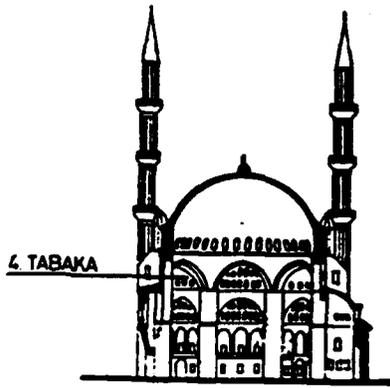
Onal Özış was born in 1934 in Istanbul and studied there at the Galatasaray Lyceum. He graduated as an M.S. in civil engineering from the Munich Technical Highschool in 1957. He received his Ph.D. degree from the same institution in 1961. He worked with several Turkish, German, Swiss, U.S. private and public corporations on various fields of civil engineering, primarily as planning and project engineer and consultant for 13 years, before joining the Ege University academic staff in 1970. He became associate professor during the same year, professor in 1976; and since 1982, he is working at the then newly founded Dokuz Eylül University. He is the author of about 200 publications in Turkish, German, English, and French, on ancient and modern hydraulic works, operational hydrology, karst water resources, water power development.



Selimiye mosque (Edirne) axonometric section (dome diameter 31.2 m)

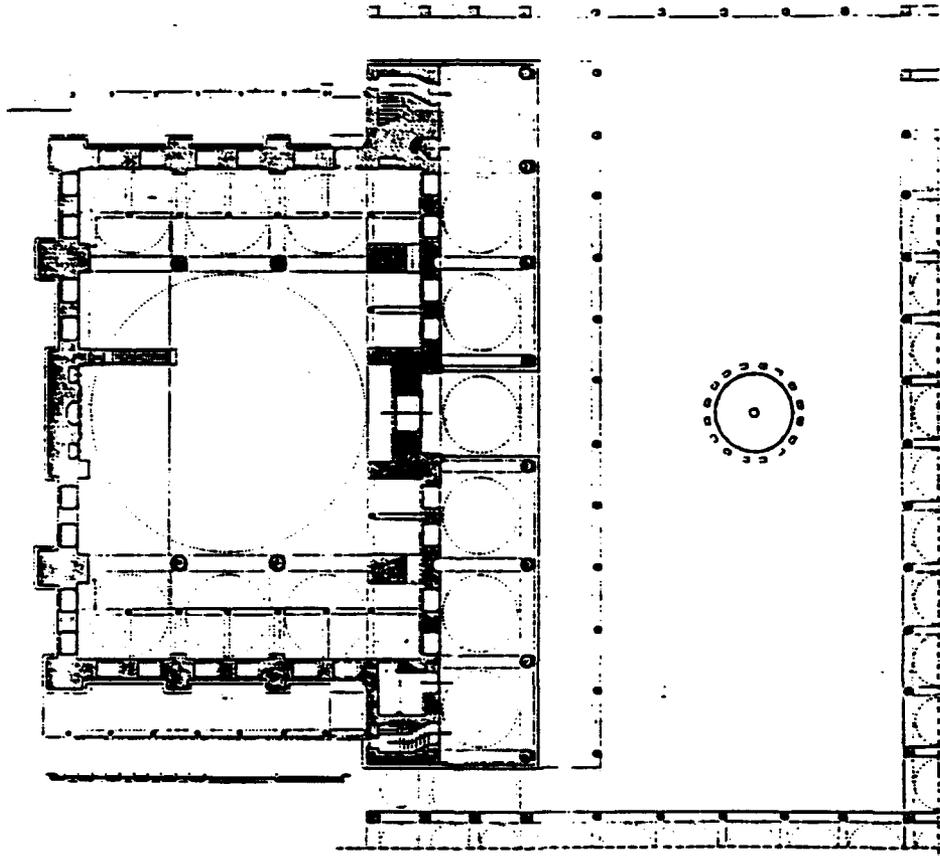
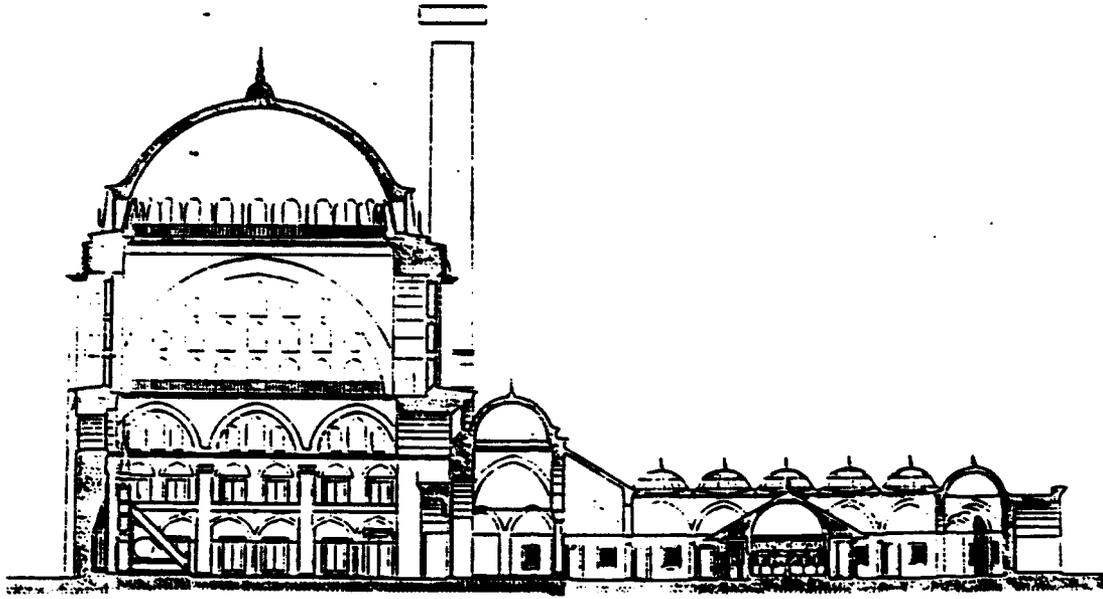
Mihrimah mosque (Edirnekapi) axonometric section (dome diameter 19.3 m)

(A.R. Burelli 1990, vision and representation of urban space. Roma, "Environmental Design" v.5, n.5-6. pp. 42-51).



Selimiye mosque (Edirne): (a) vertical section, (b) horizontal section (layout at the arch & trompe level)

(H. Güngör 1988, Mimar Sinan'ın üç büyük caminde mekân-strüktür ilişkisi. İstanbul, "Mimar Sinan dönemi Türk mimarlığı ve sanatı", T. İş Bankası Kültür Yayınları n. 288-41 s. 135-168).



Mihrimah mosque (Edirnekapı): (a) vertical section; (b) layout
(A.S. Ülgen, F.Yenişehirlioğlu, E. Madran, 1989, "Mimar Sinan Yapıları-
Katalog+Çizimler", Ankara, Türk Tarih kurumu, n. VI-32).

Preservation Strategies Used in the Pacific Rim

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The Western Region of the National Park Service is an integral part of the Pacific Rim and its associated areas of seismic and volcanic activity. Our region consists of seven states (Arizona, California, Hawaii, Idaho, Nevada, Oregon, and Washington), three territories (American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands), and three new republics (the Federated States of Micronesia, the Republic of the Marshall Islands, and the Republic of Palau) which were formerly the Trust Territories of the Pacific Islands. It stretches from Canada to Mexico and from the Rocky Mountains to Micronesia. Each year we review thousands of historic preservation projects for this vast region; most of these projects include seismic retrofit.

According to the author of Between Two Earthquakes, Sir Bernard Feilden, "we are always between two earthquakes" except, of course, for the minute or two of an actual seismic event. Recorded history of North America is less than 500 years, a very short period in geological time. Recorded history of this part of the world is several thousand years and the seismic activity is well documented. I was very impressed with the chronology and collected data on earthquakes and tsunamis. It is not a matter of "If the next earthquake will occur" but "When and where will the next occur?" But more importantly, "What have we done to prepare for it?"

The Loma Prieta Earthquake lasted only 15 seconds and it was not the "Big One." It was only 7.1 on the Richter Scale. Although it occurred at 5:04 PM on October 17, 1989, during the afternoon rush hour traffic, only 65 people died and there was billions of dollars in damage. Most of the death occurred at the collapse of the Cypress expressway, built in the 1950s, not in or near historic buildings. The Bay Area is still feeling the economic effects. Although many more modern buildings were damaged than historic buildings, there was damage reported on 472 historic buildings in a 7 county area. Of these over 90 have been demolished.

Of those historic buildings that have been retrofitted, most performed well or with minor damage. In 1984 the first National Park Service conference on the Seismic Retrofit of Historic Buildings looked at the State of the Art of the retrofitting historic buildings in a manner that is sensitive to the character and fabric of the historic resource while assuring an adequate level of safety. We have seen that the technology exists to retrofit buildings and it is reasonably effective during an earthquake.

The purpose of our second technical conference in November 1991 was to encourage the seismic retrofit of historic buildings

while preserving their historic character and materials. The conference provided a forum for experts from all related disciplines to exchange information. The second conference, therefore, built upon the first. It is with great pleasure that I present this conference with two copies of the workbook for our conference: one copy for the Turkish Team and one copy for the American Team (Enclosures 1 and 2). I also have order forms if anyone would like to order his/her own personal copy.

The preservation and seismic retrofit of historic buildings is a multi-disciplinary field consisting of history, art history, architectural history, historic archeology, industrial archeology, architecture, engineering, seismology, preservation, conservation, and other appropriate disciplines depending upon the type of resource. Most successful projects are the result of a team approach; therefore, it is wise to assemble a team of experts in all of the appropriate fields. To improve communication it is important that we speak to each other and that we know and use each other's terminology correctly. Therefore, for our conference in San Francisco we compiled a glossary of architectural, engineering, seismic, and preservation terms to help us understand each other. You may wish to use this glossary, delete terms not related to this project, and expand it to include terms germane to your building construction.

It is not enough to just assemble a good team and to communicate effectively. The team must work together and each team member must be aware of what each other team member is doing and the results of their work. Each member must have the opportunity to provide their professional advice at each decision, otherwise the teams expertise is not used to its fullest potential.

Our office has reviewed hundreds of projects, most of them included seismic retrofit. When analyzing poor projects, a breakdown in communication is usually found. Frequently, there is a phenomena known as "chapterization." The historians, architectural historians, historic and industrial archeologists do their research and write their reports. They are paid and make their exit and are usually never asked for advice during the progress of the project. The reports are shelved and frequently never read, usually because their existence is known only by a few people. The building is designated a historic building or monument but frequently the people who did the original research and/or people who are experts on a particular building are not present or available when proposed solutions are discussed and decisions are made. There may also be some passage of time before the next "chapter" is written.

The architects and engineers are hired and they do their job. Decisions are made without the benefit of the whole team's input. Different alternative approaches are not explored, developed, or evaluated. The drawings and specification are reviewed by the city or other review offices and revisions made. The work is done and, unfortunately in many cases, there is usually an enormous loss of historic fabric and character. The only way such a fragmented team approach can possibly work is when the Team Leader is a Renaissance

person with extensive expertise in every field. With today's specialization, it takes most of us all or most of our lives to become an expert in just one field. The Team Leader who has extensive expertise in several fields is very rare if he or she exists at all. In most cases, a good Team Leader is usually a generalist who can coordinate and facilitate the exchange of information and collective decision making. Unfortunately, we tend to hire experts and then underutilize or ignore them when we decide the fate of the resource.

That's no way to treat our irreplaceable cultural resources. Our heritage is worth saving and we must take the extra steps and precautions to ensure that these irreplaceable cultural resources survive for future generations. In each case the questions should be asked "Why is this building significant?" and "What are the most significant spaces and features that must be avoided during the retrofit?" In addition to saving lives, what can be done to ensure the survival of the resource and it's invaluable features and contents. This doesn't mean that everything that is not highly significant is a candidate for the dumpster because the cumulative effect of other losses of historic fabric can also be significant. If each generation "hacks" away at our heritage, our grandchildren and their grandchildren will have little to pass on to the next generation and we as a nation will loose our identity. It is our responsibility to pass on to the next generation our cultural heritage with as much integrity as possible. It is not a renewable resource. Once it is gone, it is gone forever. On the other hand, it does not mean that nothing can be touched.

In America we have a saying: "There is more than one way to skin a cat." I have never skinned a cat but what this saying means is there are usually more than one way to solve most problems. We are all creatures of habit and tend to repeat tried and proven solutions. We all know that a diaphragm can be installed on the floor or it can be installed on the ceiling of the story below. Both behave the same during an earthquake. If there are fine marble or parquet flooring, then maybe it is less destructive to install the diaphragm on the ceiling of the story below. If the ceiling has very ornate plaster decoration, then maybe it is less destructive to install the diaphragm on the floor of the story above if the floor surface is not significant. If, however, both the floor of the story above and the ceiling of the story below are significant, then a decision must be made as to which can be carefully disassembled and reinstalled after the diaphragm is constructed.

Not all solutions are equally destructive to a building. By developing alternate solutions and evaluating them as to their effect upon the historic character and fabric, we can diminish the adverse effect upon the resource. The main focus of our second conference was to look at various alternative solutions and to analyze the decision making process of selecting the solution that has the least adverse effect upon the resource. For example, Prof. Renato Sparacio discussed several projects and how the historic fabric and artistic features were saved and preserved. The paper

by Eric Elsesser described the various proposed solutions developed and evaluated for five historic buildings damaged by the Loma Prieta Earthquake and examined the decision making process for selecting final solution from a variety of proposals.

We encourage the retrofit of historic buildings. Various approaches and methods have been used effectively to retrofit historic buildings. Just as there are no inappropriate materials, only inappropriate places or situations for almost any material. Likewise, there are several effective methods of retrofitting historic buildings. By developing and evaluating several (at least two) alternative retrofit solutions, one can determine which method is the least destructive to the historic character and fabric of a particular building. A thorough understanding of the resource and its significance is also very important. What is it that we are trying to save? Identification of what are the most important spaces and features of a building helps the designer determine what to avoid and where retrofit elements may be added with the least effect on the resource. As stated before, this does not mean that all other spaces and features of historic buildings are fare game for demolition. We must also look at the cumulative effect of loss of historic materials even if it is replaced in kind. If the handle on our grandfather's ax has been replaced three times and the blade twice, do we still have our grandfather's ax? This is a tricky question. If my grandfather replaced the handles and blades, then it still his my grandfather's ax. However, if I or anyone else replaced the handle and blade, then it is no longer my grandfather's ax.

What criteria or standards should be used to evaluate alternate proposed solutions? We will assume that all proposed solutions provide an adequate level of life safety. If not, those that do not provide an adequate life safety and cannot be modified to provide an adequate level should be eliminated. Of those solutions which provide an adequate level of life safety, the solution that has the least adverse effect upon the character and fabric of the resource shoule be chosen. In 1964 the Second International Congress of Architects and Technicians of Historic Monuments adopted what is commonly known as the Venice Charter. Neither the United States nor Turkey signed this document but the Venice Charter is frequently recognized as the international standard for evaluating the preservation of historic monuments (Enclosure 3). The United States adopted its own standards: The Secretary of the Interior's Standards for Preservation Projects (Enclosure 4). At the time of writing this paper, I did not know what standards Turkey uses to evaluate projects. During this conference, I did not learn of any standards that Turkey has adopted for the preservation of historic structures; therefore, I highly recommend that we develop a set of standards applicable to historic mosques.

I have brought copies of the Venice Charter and the Secretary's Standards for those who would like copies. The Secretary's Standards provide definitions for the treatments of acquisition, protection, stabilization, preservation, rehabilitation, restora-

tion, and reconstruction and standards for each treatment. The Standards for Rehabilitation was revised in 1990 and is located at the end.

Acquisition is defined as the act or process of acquiring fee title or interest other than fee title of real property (including the acquisition of development rights or remainder interest). If the current owner of a property cannot or does not want to care for the resource or wants to demolish it, it may be necessary to acquire the property to save it.

Protection is defined as the act or process of applying measures designed to affect the physical condition of a property by defending or guarding it from deterioration, loss or attack, or to cover or shield the property from danger or injury. In the case of buildings and structures, such treatment is generally of a temporary nature and anticipates future historic preservation treatment; in the case of archeological sites, the protective measures may be temporary or permanent.

Stabilization is defined as the act or process of applying measures designed to reestablish a weather resistant enclosure and the structural stability of an unsafe or deteriorated property while maintaining the essential form as it exists at present.

Preservation is defined as the act or process of applying measures to sustain the existing form, integrity, and material of a building or structure, and the existing form and vegetative cover of a site. It may include initial stabilization work, where necessary, as well as ongoing maintenance of the historic building materials.

Rehabilitation is defined as the act or process of returning a property to a state of utility through repair or alteration which makes possible an efficient contemporary use while preserving those portions or features of the property which are significant to its historical, architectural, and cultural values

Restoration is defined as the act or process of accurately recovering the form and details of a property and its setting as it appeared at a particular period of time by means of the removal of later work or by replacement of missing earlier work

Reconstruction is defined as the act or process of reproducing by new construction the exact form and detail of a vanished building, structure, or object, or a part thereof, as it appeared at a specific period of time.

Both the Venice Charter and the Secretary of the Interior's Standards for Preservation Projects require that the historic character and fabric of the resource be respected and preserved. There are some basic principles that underlie these criteria. These are the principles of minimal intervention, reversibility, compatibility, and authenticity.

The principle of minimal intervention states that we will never have any more historic fabric, with few exceptions, than we have today and that each time we do work on a building there is usually a net loss of historic fabric; therefore, the less we do to a building usually means the less the resource loses historic fabric. There are two exceptions. One exception to this principle

is when original or early historic fabric which had been previously removed for whatever reason is returned to its original location and reinstalled in an appropriate manner. The other exception is when new material added to a historic resource gains its own significance through time and events. This is more rare and usually takes a considerable passage of time.

In evaluating various proposals we should try to assess which solution(s) has the least adverse effect upon the historic character and fabric of the resources. Changes to a building can usually be categorized as additive or subtractive. When materials are added to a resource, the character and integrity of the resource may or may not be effected. When materials are removed from a resource, there is almost always a net loss of both historic fabric and integrity and usually a loss of historic character also. If it is the removal of an inappropriate prior addition, it may be restorative in nature. Treatments that are additive in nature are usually more tolerable and acceptable, if it is reversible, because they can usually be removed at some future date. On the other hand, treatments that are subtractive in nature are usually not very reversible especially as the amount and significance of the materials removed increases.

The principle of reversibility states that nothing should be done to a resource that cannot be undone at a future date with little or no damage. We are usually not the first people to work on a historic resource and probably not the last. With the passage of time, we often learn how to do things better. Previous treatments done to historic resources may now be causing more harm than good. To halt the damage or deterioration caused by a previous treatment it may be necessary to do radical surgery which may result in a loss of historic fabric. By designing treatments to a resource that are easily reversible with little or no damage we are preventing or diminishing the future loss of historic fabric.

Anything that is done to a historic resource should be compatible or harmonious with the historic character and fabric. Compatibility of materials is very objective and is based upon the matching of physical characteristics or properties, for example, weight, strength, coefficient of expansion and contraction, porosity, absorption rates, etc. The properties of the new materials need to be compatible with that of the historic materials so that the new materials do not damage the historic materials. Compatibility of historic character, on the other hand, is more subjective and is based upon similarity of visual characteristics such as color, textures, size, scale, mass, proportion, configuration, rhythm, ratio of solids to voids, ornamentation, details, etc. If few or none of the characteristics of the new material harmonize with the historic materials, the effect may be very jarring and detract from the artistic and architecture expression of the historic resource. If all of the visual characteristics are matched, it becomes very difficult to distinguish between what is historic and what is new.

Authenticity relates to integrity. Even a very fine replica can never be the "real thing." The original fabric of a resource is authentic and therefore has significance. It may be much less expensive to demolish the original resource and construct a replica with new materials and technology that looks just like the original resource, but a replica is always a replica. When the original material is lost, we lose the original craftsmanship and the patina of time. Replacements of missing parts of the design must be based on physical or photographic documentation, not conjecture. Even in a restoration, the replacement of missing parts must be compatible and an accurate replication but also must be distinguishable from the original so that the restoration does not falsify the artistic or historic evidence. This is frequently done by thorough documentation of the work and by labeling the new materials in an inconspicuous location, usually on the back.

Before we preserve anything, we need to know and understand the resource. Therefore, we must identify the resource and retain it. Identification also includes identification of the components of the resource that are the most important: significant spaces and features including skilled craftsmanship.

When a building is constructed, there is an investment made in time, labor, and materials. Proper cleaning and maintenance protect that investment and do more for preservation than any other treatments. When maintenance is deferred, it usually costs at least three times as much to later correct the damage done by deferring the work. For example, if a leaking roof is not repaired or replaced in a timely manner, it may be necessary to repair or replace the roof sheathing, the roof framing members, the plaster ceilings and the flooring of rooms below the leak. At a minimum, maintenance should include period inspection to find and document problems as soon as possible and to provide repairs before a small job becomes a big job.

If a building is well cleaned and maintained, it seldom needs to be repaired or restored. If surfaces are cleaned on a routine and continuous basis, seldom is it necessary to use harsh or abrasive measures to clean the surface. If soil, oils, stains, and pollutants are removed periodically, they do less damage to the resource. I am very pleased to see people remove their shoes before entering mosques. Soil, especially sand particles, are very abrasive to materials. If not removed, the sharp particles will cut fibers in carpets and wear away hard surfaces even stone. We have all seen steps that have been severely worn away by countless footsteps. Maintenance includes the protection of historic materials through treatments such as rust removal, caulking, and the re-application of protective coatings (priming and painting). These coatings not only provide color and pattern but repel water and provide a maintainable and renewable surface. If the coating is maintained, the surface beneath can be preserved almost indefinitely.

While inspecting earthquake damage, we frequently encounter two or three adjacent identical or very similar buildings that were obviously constructed about the same time. Two of them may be in

good condition with little or no earthquake damage while the third one may have extensive damage. On investigating the difference, we usually find that the one with the extensive damage had poor maintenance and resulting deterioration. Deteriorated materials (rotted or insect infested wooden members, rusted metal anchors or fasteners, etc.) do not have their original capacity to function in a building. When a building is stressed with seismic loads, the first localized failure usually occurs where there is deterioration. Localized failure can lead to catastrophic failure. Therefore, good maintenance is the best investment to protect the resource. It is always better to preserve and maintain than to repair.

If the material is damaged, it may be necessary to repair. Guidance for the repair of historic materials such as masonry, wood, and architectural metals again begins with the least degree of intervention possible such as patching, piecing-in, slicing, or otherwise reinforcing or upgrading them according to recognized preservation methods. Repairs should always be in kind, that is, repair wood, stone, or metal with the same kind of wood, stone, or metal, respectively.

Consolidation of materials can sometimes extend the useful life of a material. If the consolidation is reversible, consolidation is a useful and safe treatment. If consolidation is irreversible, it should only be used as a last resort and only in the areas of severe deterioration. If the material is so deteriorated that it must be repaired, even irreversible consolidation may be permissible under certain circumstances.

Sometimes consolidation can postpone replacement. The practicality of consolidation or repair of museum objects and architectural elements are somewhat different. A museum object can be cleaned and conserved (arrested deterioration) and then placed on display or in storage in a controlled environment. For architectural elements on the interior of a building, this is sometimes possible even if the environment cannot be totally controlled. For the exterior of buildings, this is not always possible. For example, if the architectural element must function to shed water, such as a roof, repair or consolidation of the material may only extend the useful life of the material a short time. When it fails, many other materials may be at jeopardy. Therefore, some elements, such as roofing, are more subject to replacement. Although using the same kind of material is always the preferred option, a substitute material is acceptable if the original material is not available and if the form and design as well as the substitute material itself convey the visual appearance of the remaining parts of the feature and finish. It is almost always better to repair than to replace.

If elements of the building are missing or so deteriorated that they cannot be repaired, it may be necessary to replace them. If the essential form and detailing are still evident so that the physical evidence can be used to re-establish the feature as an integral part, then its replacement is appropriate. If there is no physical or archeological evidence, the design of the replacement

elements may be based on photographic or pictorial documentation and, in some cases, on written description. Replacement should not be based on conjecture. Like the guidance for repair, the preferred option is always replacement of the element in kind, that is, with the same material. Because this approach may not always be technically or economically feasible, provisions are made to consider the use of a compatible substitute material. This is especially true if the original material is causing a problem. For example, if the original wrought iron anchors are oxidizing and the expanding rust is causing the surface of the stone to spall, then the use of stainless steel as a substitute material may be considered.

I strongly recommend that this project develop and/or adopt standards or criteria for evaluation based on the above mentioned factors at the beginning of the project, not at the end. It is too late to decide on how to evaluate proposals after they have been developed. At that point, vested interests in particular solution(s) might influence our unbiased judgment of the standards or criteria.

The last two days we have made site visits to the Mirimah Sultan Mosque in Istanbul and the Selimiye Mosque in Edirne. We have noted some problems and each team will be making some recommendations. It is very difficult to make accurate and specific recommendations based on a short walk around and walk through these magnificent and complex resources. These site visits were absolutely essential to start thinking and understanding these resources but these resources deserve more than our "knee-jerk" reaction. In order to make a fully informed decision, it is necessary to compile additional information: archival, historical, curatorial (both preservation and conservation), architectural, engineering (structural, geotechnical, seismic), financial, etc. This data must be organized consistently in a rational and logical manner to be useful to all of the teams. In the United States we use the historical structures report for organizing this data.

Each Historic Structure Report should include three elements.

1. The first element is an administrative data section, prepared by or with the owner or manager, that contains:
 - a. The name, number, management category, and proposed treatment of the structure;
 - b. The proposed use of the structure;
 - c. Identification of the planning document proposing the treatment and use, and any other documents bearing on the proposed management, furnishings, and use of the structure;
 - d. A justification of the proposed treatment (stabilization, preservation, restoration, rehabilitation, or reconstruction) in terms of the application of the Secretary of the Interior's Standards for Historic Preservation Projects and the characteristics and limitations of the resource;
 - e. Any recommended change in the proposed treatment or use based on the degree of documentary or physical evidence, the condition of the historic structure, or other

- professional findings in the completed analysis section;
and
- f. Recommendations for the documentation, cataloging, conservation, and storage of any objects, documents, records, photographs, negatives, and tapes collected or produced as a result of the study.
2. The second element is a physical history and analysis section, prepared by appropriate cultural resources specialists, usually an historian and an historical architect and/or engineer, that contains:
- a. A statement of the anthropological/archeological/historical, or architectural/engineering significance of the structure and its setting (including associated above-ground and subsurface features and their relationship to national, regional, or local history);
 - b. A narrative and graphic description of the appearance, occupation, and use of the structure and its setting during significant periods or later time, based on a documentary and oral historical evidence, physical evidence from architectural fabric investigation, and any archeological investigation; all sources of information and data must be cited;
 - c. A description and record of existing conditions, using measured drawings and photography prepared to Historic American Building Standards/Historic American Engineering Record standards;
 - d. An evaluation of the impact of the proposed use on the integrity of the structure, including the effect of compliance with regulations for human safety, energy conservation, handicapped access, etc;
 - e. An engineering report on safety and load-bearing limits of the structure as warranted by the proposed use or apparent conditions;
 - f. An identification and analysis of significant material, structural, natural, environmental, and human factors affecting preservation of the structure and recommended measures to deal with them, including any constraints on proposed use;
 - g. The recommended steps for preservation, rehabilitation, restoration, or reconstruction; a discussion of the basis for such recommendations; and preliminary drawings and engineering designs;
 - h. An analysis of the impact of the proposed action on the structure and its contents (if any) in accordance of the Secretary's Standards and on other affected cultural resources and the historic scene, with recommendations to avoid or mitigate any potential adverse effects;
 - i. An updated package estimating detail providing cost estimates to carry out recommendations, prepared and reviewed by the appropriate specialists; and

- j. A recommendation for further study in support of the proposed treatment project, if necessary, with suggested sources.
3. The third and last element is an appendix that contains:
 - a. A record of all fabric analyses performed (paint, mortar, etc.) listing basic data with specific recommendation for treatment;
 - b. An assessment of future anthropological/archeological, historic and/or architectural/engineering research potential;
 - c. Records of any documentary data such as furnishings evidence, found during the investigation that are pertinent to the structure or setting but not to the treatment project for which the report was funded; comprehensive collections of data should be undertaken under separately funded studies; and
 - d. An annotated bibliography of sources.

Data obtained during treatment and not previously included in the Historic Structure Report (HSR) should be presented in an addendum to the report. Further addenda are appropriate whenever new data become available. During the course of research for a HSR, it may be economical or desirable to gather data not specifically needed to support the treatment project. Such data on a structure, its occupants, its grounds, and/or its furnishings may be desired for interpretation or other purposes. When such is the case, the owner or manager should program for a Historic Resources Study, Cultural Landscape Report, and/or Historic Furnishings Report in conjunction with the HSR.

I strongly recommend that the format of the Historic Structures Report be adopted as is or tailored to these particular resources as a part of the methodology. If there are parts of the outline that are not relevant, they can be revised, deleted, or noted as not applicable for a particular resource. If there are other categories of data not addressed by the outline, these can be added. By adopting a consistent format for the treatment of all mosques the data can later be systematically entered into a computer. Considering that the Foundation is responsible for over 7,000 mosques in Turkey, the use of the computer is the only way to manage such a large data base.

In conclusion, I would like to make the following points.

If we retrofit a historic building before an earthquake, it is usually much less expensive than after an earthquake because after an earthquake, we also have to repair the earthquake damage. Therefore, the retrofit of historic buildings is an investment in the future of the resources.

The seismic retrofit of historic structures sometimes requires the alteration of foundations or the addition of foundations for new structural elements if the existing foundations are found to be inadequate to carry additional loads. Any excavations should be carried out in accordance with scientific standards for archeological investigation and documentation. Frequently historic monuments were built upon the site of previous occupation. In some cases

there are several layers of evidence of civilization. Even if the historic monument was built upon a site that had no previous occupation, the excavation may uncover evidence about the construction of the resource or the people who built it. If this evidence is destroyed and not recorded, this information may be lost for all time.

We are always between two earthquakes and as each day passes we move closer to the next earthquake. Time is running out and we must take action to protect life and property. If we retrofit historic buildings in a sensitive manner, we will not only save thousands of lives and billions of dollars, but we will also save our cultural heritage.

I strongly recommend that we consider the whole resource and all of its problems. Taking a piece-meal approach is seldom satisfactory. We must consider both the preservation of the resource and its seismic retrofit. We must adopt or develop standards or criteria for the evaluation of various proposals so that we preserve as much as possible of the resource's historic character and fabric. Our strategy must include a methodology that organizes and manages a great deal of data in a consistent and professional manner.

Our cultural heritage is worth saving. When we share information, everyone benefits. Therefore, I look forward to this conference and the free exchange of knowledge and ideas.

OVERVIEW OF DOMED HISTORIC STRUCTURES
IN SEISMIC ZONES
(With Emphasis on Sinan's Major Works)

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1. INTRODUCTION - BACKGROUND INFORMATION

1.1. "Dome" in General:

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. Indeed, in all domed edifices, mostly temples, the main dome constitutes the ritual center as well as the axis of architectural-engineering prestige. The word "dome" is even used in some languages as diminutive equivalent of the "temple". There is no other structural element or component with such a representative characteristic.

Historic Domed structures are mainly constructed by mortared brick with which the mankind was familiarised from the very early ages. But, construction of major domes was attempted much later. Difficulty of controlling three-dimensional thrust action under gravity loads and the obligation of ensuring a good compatibility between the dome itself with its associating, supporting structural components under seismic loads constituted main obstacles to construct wide spanning masonry domes of revolution-shell form, apparently.

1.2. Object and Scope:

In this study general evolution of the domical art is summarized and more specifically Ottoman Domes are investigated. As known, muslim countries are mainly concentrated in southern and eastern Mediterranean and middle eastern regions as well as in northern

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and southern flanks of Himalaya and Pamir chains of mountains. Most of these regions are heavily earthquake prone, and islamic approach recognizes an absolute priority to domed forms in temples.

Therefore, the study of islamic dome and especially Ottoman dome, in its most developed form, constitutes a meaningful work for understanding the engineering reality of major domed structures in seismic zones.

2. SINAN'S DOMED STRUCTURES: A SUMMIT IN DOMICAL ART

2.1. Pre-Ottoman Tradition:

Turks are originated from the Overall-Altai region of the Central Asia. They started to move to western lands through 9 th. century A.D.. Two main flows had taken place with Seljouks first and Ottoman's later. They had likely brought their ancestral familiarization with cylindrical and spherical forms from the origin lands to Anatolia. Seljouks had also influenced architectural character of this beautiful medieval city of Ispahan in their passage through Persian lands.

There were meaning products of space forms in Byzantine tradition, too, with grandiose example of the Haghia Sophia. The Ottomans, being settled in Western Anatolia first and in Istanbul later, apparently merged the two traditional familiarization with the domes. Since then, Istanbul and Edirne became museums of dome collections.

2.2. Sinan's Insight Into Domed Structures:

Early Ottoman buildings with domes (14 th. and 15 th. century) were based either on the concept of a single dome of medium size covering the whole inner space or on the series of small domes one neighbouring the other at the same level. In both solutions, thrust and seismic actions would thus be laterally transmitted to massive exterior walls or piers.

Sinan (1492-1588) developed his structural ingenuity first as a military engineer. He later served, for almost half a century, as the chief architect of the Empire, during which he was involved

directly or indirectly in the construction of nearly five hundred works including mosques, bridges, hydraulic infrastructures, hospitals, palaces, schools, etc. A summary biographical information of Masterbuilder Sinan is given in Tables 1-2.

On the other hand, building techniques of Ottomans' had been also greatly improved during the sixteenth century by allowing the construction of masonry components in any curved, sophisticated geometry. Within the social context, mosques with large domes were considered as the prestige buildings. Domed structures had become, thus, engineering summits and social targets to be reached.

Sinan's evolution based on, both, an immense individual talent and on engineering progress of the rising Ottoman State. Sinan's power could be very summarisingly described by study of four major works that had been constructed in different periods of his life.

- * Şehzade (Prince) Mehmed Mosque - (1545-1548)
(marking the passage to maturity)

- * Süleymaniye Mosque - (1554-1557)
(A majestic example of the maturity period)

- * Mihrimah Sultan Mosque - (1562-1565)

(First example of masterpieces of the latest period,
marking the challenge of avoiding external bracings)

- * Selimiye Mosque - (1572-1575)
(The second example of the latest period and uncomparable
summit of the domical art)

2.3. Summary on Major Building Works of Great Masterbuilder Sinan:

Structural behaviour of domed Ottoman edifices under gravity loads is mostly governed by a mechanism of controlling thrust action around the main dome which generally lies in compression state both for meridional and hoop stresses. Surrounding partial

cupolas when adequately formed and sized, contribute to this control, supporting the main dome laterally and transmitting all loads to thick external walls whereas main arches, subjected to combined effect of flexure and torsion, transfer a considerable portion of upper level loads directly to interior piers.

Besides main dome and central arches, other essential components in major domed buildings are as described in Figure-1: drums of the main dome; strong inner piers; inclined short columns; separating windows of the main dome at its lower flank; bracing surrounding partial cupolas; pendentives filling the space between lower drum, arches and central piers; secondary arches and auxiliary inner domes of smaller dimensions. The great Masterbuilder Sinan seems to have brilliantly played with all possible combination of neighbouring and associating schemes of those components.

2.3.1. Şehzade Mehmet Mosque:

The decade stretching 1538 to 1548 was a period in which Sinan developed his architectural skills by utilizing well-tested schemes to boarden his outlook. Sinan's own evaluation of the Şehzade Mehmed Mosque as the last work of his "apprenticeship" period shows that he regarded his first ten years in the Office of Chief Court Architect as his period of search of maturation. The Şehzade Mehmed Mosque was a striking monument at the end of the first phase of a promising career. It appealed to the eye, satisfied the mind, and elevated the spirit. The Şehzade Mehmed Mosque creates, in the viewer, the impression of a visual movement flowing downwards from the central dome to the foundations. To the beholder, the symmetrical formation of the Şehzade Mehmed Mosque was symbolic to the political power and social harmony that the Ottoman State had arrived. The Şehzade Mehmed Mosque, displaying an ideal centrally planned scheme, constitutes a turning point. It represents a harmonious symmetry and the externalization of the inner spatial order (Figure 2).

The Şehzade Mehmed Mosque consists of two adjoining square masses -one closed, the other open- riveted together by two minarets. The domical superstructure of the closed square is composed of a central dome braced by four partial cupolas, which are in touch with the external walls of the edifice either directly or through eight smaller partial cupolas surrounding them from one side and

the other, two for each. Architectural effect thus created is really extraordinary both by the immensity of inner spaces and the spiritual grace of the elements covering them.

Overall building shape and features of structural components of this edifice conform to general classical system of Ottoman domed edifices described in Figure 1. The central dome has a partial spherical form with a varying thickness approximated to 50 cm. in average . The diameter of the sectional circle resting on the drum is 19.50 m. Four partial cupolas surround the drum and each of them is supported at lower levels by two smaller partial cupolas as described in the load transmission pattern sketch in Figure 1.

The temple was analytically investigated in several ways. The main dome alone was analyzed first, being considered as formed by partial spherical slices clamped on the drum. Since the fulfilment of compatibility conditions between the dome and other neighbouring elements is leading to unrealistic structural considerations, other models were needed.

The model reflecting the whole structure as presented in Figure 3 was adopted with an idealization approach of assembling 240 shell elements and 200 frame elements. The total load of the system including the snow was evaluated as 160.000 kN. Seismic action was approximated to 16.000 kN of lateral load and its investigation was based on the spectral analysis with consideration of spectrum features of the soil on which the edifice was settled. Numerical results revealed interesting features for overall comprehension of the load transmission mechanism. As for the earthquake aspect, the following points were strikingly observed:

- i) Maximum shear stress under seismic action was evaluated 0.3 N/mm^2 in the short partition columns of windows on the lower flank of the main dome. For local limestones, this stress reveals rather close to allowable limit evaluated as 0.42 N/mm^2 . This finding shows the already underlined critical importance of these short partition columns
- ii) Skeleton elements of the central space (main dome, drum, four main arches and four pendentives) were connected to

thick outer walls by surrounding bracing partial cupolas and also a series of smaller inner cupolas and arches at lower levels. Bow string arches which were constructed in these areas (Figure 1) contributed to transmission of the lateral seismic action from the main central pier to the thick outer wall. 28 % of the total lateral load was carried by these elements, showing cleverness of the design and construction of the overall skeleton where all components had a structural significance as well as functional and esthetical meaning.

- iii) Combination of gravity and seismic loads at the base of the heavy looking inner piers resulted in a flexural moment value of 24 000 kN-m. Design check of the base section with various considerations (section fully plain or partially hollow -loosely filled with waste material-) has shown that the system is not so overdesigned as it would appear at the first glance.

2.3.2. Süleymaniye Mosque:

Compared with Şehzade Mehmet Mosque, higher level of structural challenge is arrived in the Süleymaniye Mosque of Istanbul which is considered as the summit of Sinan's masterly period. In Süleymaniye, the radial symmetry is abolished intentionally for the sake of accordance between a majestic outside view and the hilly site suspended beautifully on the Golden Horn. There is only a bi-axial symmetry in the system and consequently the load transmission mechanism is highly complex and daring especially with regard to the seismic conditions of Istanbul.

The Süleymaniye comprises a vast, multi-domed prayer hall, 61 meters long by 70 meters wide, preceeded by a courtyard with a minaret demarcating each of its four corners. The central dome, 26.20 meters in diameter and 49.50 meters high at the crown, rises above four big pillars, and is shouldered, on the longitudinal axis, by two partial domes while the gravity and seismic action are resisted in perpendicular direction by merely arches. Within this description, the load bearing and transmitting mechanism reminds that of Haghia Sophia, with difference that in a much higher level of structural efficiency resulting in an uncomparable alliance of elegance, and solemnity.

The Süleymaniye has four minarets at the four corners of its forecourt; the pair overlapping the courtyard and the hall being taller than the other two. The taller minarets are 76 meters high from the ground to the tip of their finials and they support three balconies.

2.3.3. Mihrimah Sultan Mosque:

Mihrimah Sultan Mosque (Figure 4) that was erected to the name of the daughter of Emperor Süleyman the Magnificent is a product of the masterly period of the Great Sinan. This edifice is recognized to have an interior space of a unique refinement. The spatial beauty of the temple is attributed to its daring structural system. There are no externally bracing partial cupolas in this extraordinary structure whose transmission of both seismic and gravity loads is ensured essentially by thin elegant arches and nice looking pendantives. The dome is known as having the largest sizes ever reached for an unbraced shell of revolution with its diameter of 21 m. and its 38 m. of height from the ground level.

Various types of investigations were also applied to this temple. Since a partial hazard had been reportedly witnessed during the 1894 seismic disaster, studies included some detailed analysis for this edifice, for a better behavioural understanding of the structural system.

Within the framework of a comparative analysis logic two models both corresponding to the whole skeleton of the edifice were developed.

First model was aiming to reduce the structure to rather simpler components without considering none of the architectural elements at the bottom of the four main arches, namely, the secondary arches and small cupolas covering auxiliary praying zones and also arched exterior walls of the building. Main arches and pendantives of the systems are descending to unusually low levels, in a way magnifying the visual effect of these already elegant components. The above mentioned elements of the very low levels were not looking like strongly contributive at a first glance. Therefore, a model neglecting them would be considered sufficiently reliable, at a preliminary stage.

But, numerical findings have revealed that, effect of the seismic action investigated with a sensitive spectral analysis was reaching to very critical levels that apt to cause easily the full collapse of the columns and consequently of the building. On the other hand, the period for the prevailing (first) vibration mode was evaluated to be 2,1 seconds which was looking little bit too high even for this light looking structure formed by rather slender components. These immediate results were suggesting that the contribution of the bottom level elements could and should not be underestimated. This observation was also fitting to above mentioned findings of the Şehzade Mehmet Mosque analysis related to structural bracing significance of even very small inner components.

Another structural model was then needed to reflect the structural behaviour of the system realistically. As seen in Figure 5, all bottom inner components and even one series of external cupolas next to the building with their columns, and bow string arches were inserted into the model. The period for the first vibration mode was taken as 1.6 seconds and the total weight of the building as 90.000 kN. As for the seismic action, soil spectrum considerations and slenderness of the skeleton yielded in a seismic coefficient around 11 % for the first mode.

It should be, in addition, underlined that lack of detailed information on the shape and depth of the foundations shadowed somewhat geometrical sensitivity of the model.

On the other hand, the analysis of this model indicated the zones where flexural effects and stresses would be maximized by seismic action when added to gravity loads. Associated directions of the complete quadratic combination (CQC) results of spectral analysis are determined by imposing the displacements of the first mode of vibration to the critical element solicited. As for the evaluation of the most critical combined effect, the associated signs of the seismic action were taken into consideration.

Zones of maximum tensile stresses were observed to locate in pendentives near to the middle of the main arches. Direction of the principal tensile stress was computed to be in a direction such that formation of a crack parallel to the curved axis of the arch could be expected.

On the other hand, some other small cracks and displacements likely originated from static and dynamic soil behaviour are presently visible in the building. These formations and seismicly hazardous past of the edifice require an extensive assessment study.

2.3.4. Selimiye Mosque

The structural achievement in the Selimiye Mosque in Edirne, gives the impression of being out of limits of the human imagination (Figure 6). Inner vertical bearing elements are eight elegant slender columns instead of four heavy pillars occurring in his earlier mosques. The columns have twelve sided - almost circular - cross sections and they are connected to neighbouring ones by eight arches which have also light and gracious forms. The area which is surrounded by this columns-arches system is crowned by a masonry circular drum having 32.50 m. inner diameter. Over this crown, takes place the largest and most impressive masonry dome form of a revolution shell, ever constructed.

The imperial dome lies down, with a series of long elegant windows to be supported by eight arches constituting the main elements of the second tier. Structurally speaking the dome rests vertically on this series of arches through a thick curved drum and is braced horizontally by eight small external buttresses that transmit the lateral action at least partially to the weight towers which are the continuation of eight internal pillars. The transmission of both thrust action and seismic effect could apparently not be achieved without the contribution of the lateral resistance of the four smaller segments of cupola constructed behind the four of the eighth main arches located orthogonally in plan. Four other main arches, are vertically and partly laterally supported by other systems of arches occurring at the level of the third tier. These bottom arches are enlarged in thickness and they behave rather as vaults. At the same level, at the bottom parts of the four partial cupolas two perpendicular small arches are constructed participating in the flow mechanism of the load action in these four corners of the interior skeleton system.

With the erection of this mosque Sinan created the summit work of his "masterly late period" and the Ottoman classical architecture reached to its peak. It represents the zenith of Sinan's architectural engineering power and the creative vision.

Indeed, one happens to be highly impressed by the location of all these curved structural elements constructed without any radial symmetry (even without any symmetry at all in smaller details) in a way satisfying also to a great degree the requirements of lighting, acoustics and psychological fulfilment. This is also a flow of curved elegance from the top of the main dome to the bottom of the entrance niches as comparable to the flow in a waterfall with transparent crystalline drops. The elegance in flow defines also the superiorly optimized arrangement in the flow of load action throughout the configuration and functionality of the structural elements.

Selimiye Mosque was subjected to several seismic disasters occurring or being strongly felt in Edirne region. During its lifespan of over four centuries, no structural damage was signalled, so far, except for small local cracks at the flank of the main dome which were easily repaired by linking brick elements one to other by nailing. Repair or maintenance work applied from time to time, last one taking place during 1980's, comprised only architectural details, tiling, plastering and painting. However, age effect likely worked on the visible masonry parts of the mainbuilding as well upper portions of the minarets, stone-mortar binds being weakened and few stone corners being cracked. Necessity of a full assessment work looks like useful for this edifice, too. Then, from restoration point of view. This would be useful also for structural understanding of the apparently most successful masonry engineering achievement of all times.

3. CONCLUDING REMARKS

Old Masonry structures of the earthquake prone countries are subjected, to, besides aging effect, seismic action. The edifices of major importance among them should be structurally evaluated in a systematic way. Some preliminary investigations have started on the great Ottoman masterbuilder Sinan's monuments of the 16. century. Observing rising international scientific interest

towards these studies, the investigators are hopefully expecting to continue at the level of international research projects.

In these initial investigations, creep, material fatigue and probable crack formations due to aging effect were neglected as well soil-structure dynamic interaction. The attention was rather focused on the modelling aspect of the structural analysis in elastic continuum. The importance of accuracy in modelling was numerically depicted, as rather a good finding of these preliminary studies.

At further stages, full extensive assessment studies are planned including all neglected factors. On the other hand, seismic history studies soil investigations and accurate three dimensional geometric measurements should be made on some of the edifices chosen as exemplary cases. The results would constitute the basis of formulation of extendable approaches in detailed assessment works at historic masonry buildings, and also practical engineering suggestions should be advanced for preservation of such structures.

TABLE-1

BIOGRAPHICAL FACTS ON THE GREAT MASTER BUILDER SİNAN

Around

- 1492 Born in Ağırnas-Kayseri district
(Mid-East part of Anatolia)
- 1512 Joined military training programs for gifted young
people
- 1538 Nominated as Chief Court Architect (some selected
Sinan's edifices during his chief court architect
period could be summarized as follows:)
- 1547 Üsküdar Mihrimah Sultan Mosque
- 1548 Şehzade Mehmet Mosque
- 1550 Rüstem Paşa Mosque
- 1557 Süleymaniye Mosque
- 1557 Süleymaniye water supply system of Istanbul
- 1564 Kırkçeşme water supply system of Istanbul
- 1565 Edirnekapı Mihrimah Sultan Mosque
- 1568 Büyükçeşme Bridge
- 1575 Selimiye Mosque and Complex
- 1578 Ayazkapı Sokullu Mosque
- 1588 Died in Istanbul

TABLE-2

**Evolutionary Steps in SINAN's Structural Approaches
in Domed Buildings**

- | | | |
|--|--|--|
| 1. <u>Early Years</u> (1529-1537) and
<u>Apprenticeship Years</u>
(as chief court architect) | | Üçbaş, Muhsine Hatun,
Haseki Sultan, Çavuşbaşı
Yunus Bey Mosques |
| | | (small mosques [$D_{dome} < 14.5$ m.]

but, showing wide architectural
and structural variety) |
| 2. <u>End of Apprenticeship</u> —————> <u>Passage to</u> —————> <u>Maturity</u> | | |
| | | Series of Domes are coming (1544-1550) |
| | | Structural ingenuity |
| | | Functional rationality |
| | | Aesthetical elegance |
| | | associated |
| (as visible in Şehzade Mosque in Istanbul) | | |
| 3. <u>Masterly Years</u> Süleymaniye 1557 and | | |
| 1550-1565 | | Edirnekapı Mihrimah 1565 |
| purified
magnificence | | - Effect of majesty amplified |
| | | - Larger spaces, more slender and daring covers
and supports |
| | | - Both sophistication and abstraction in
architectural and structural systems |
| | | (More subtil flow of curved lines) |
| 4. SELIMIYE MOSQUE
AND COMPLEX
1570-1575 | | |
| | | and a slowing "late years" |

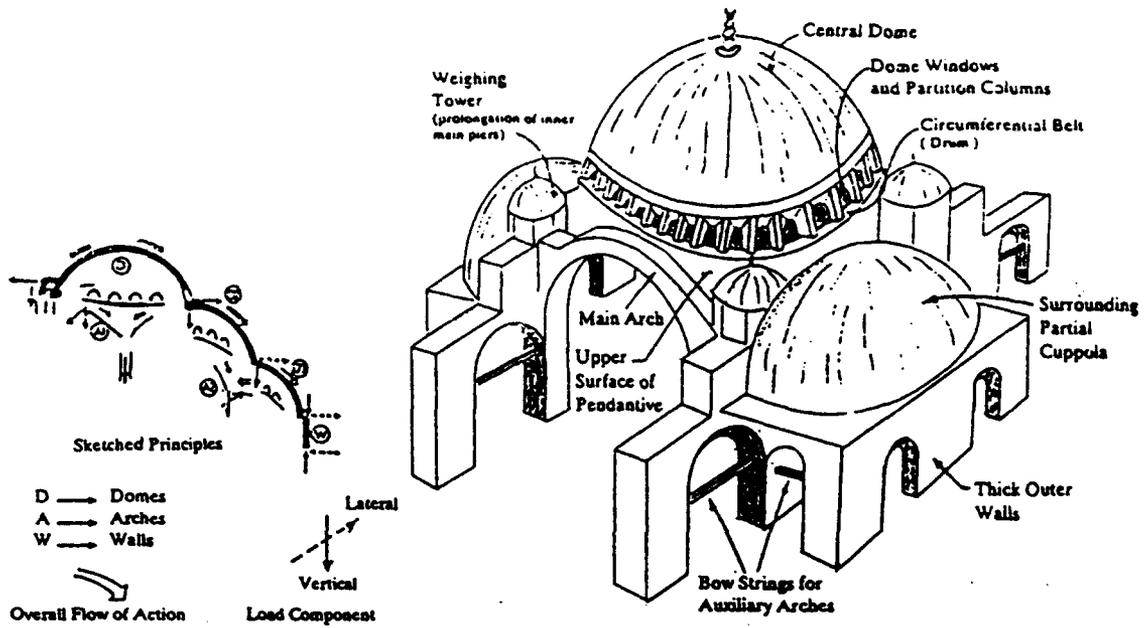


Figure 1. Representation of typical components and action flow mechanism in Ottoman domed buildings



Figure 2. Şehzade Mehmet Mosque: Outside View

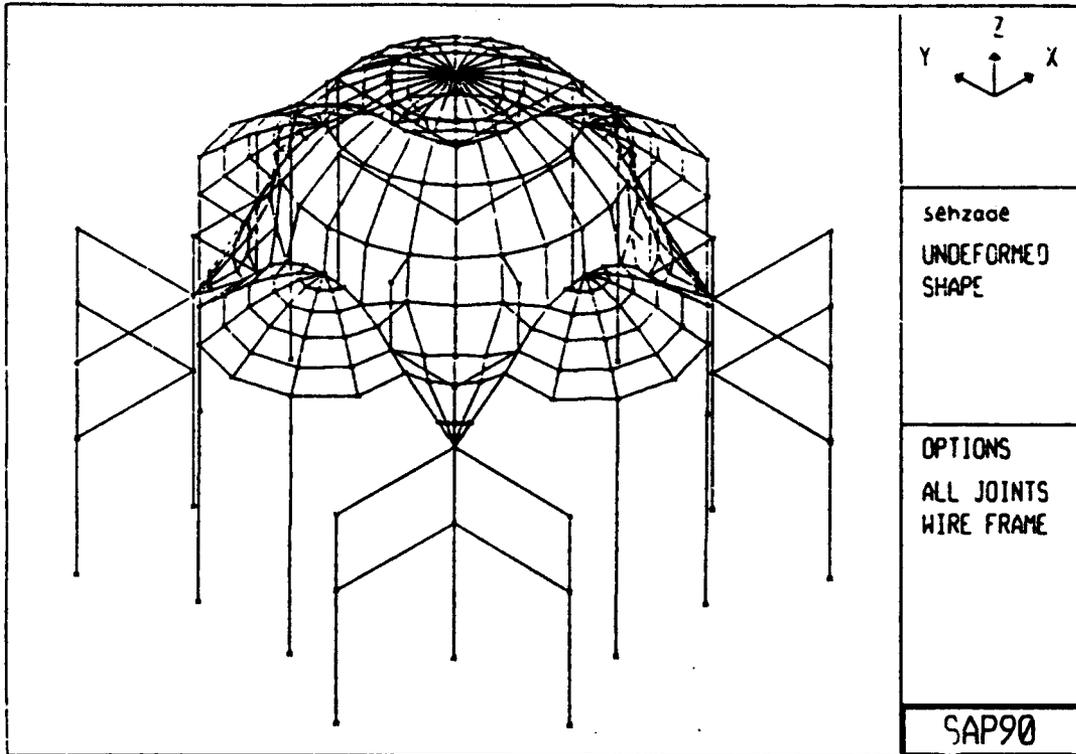


Figure 3. Structural model of Şehzade Mosque

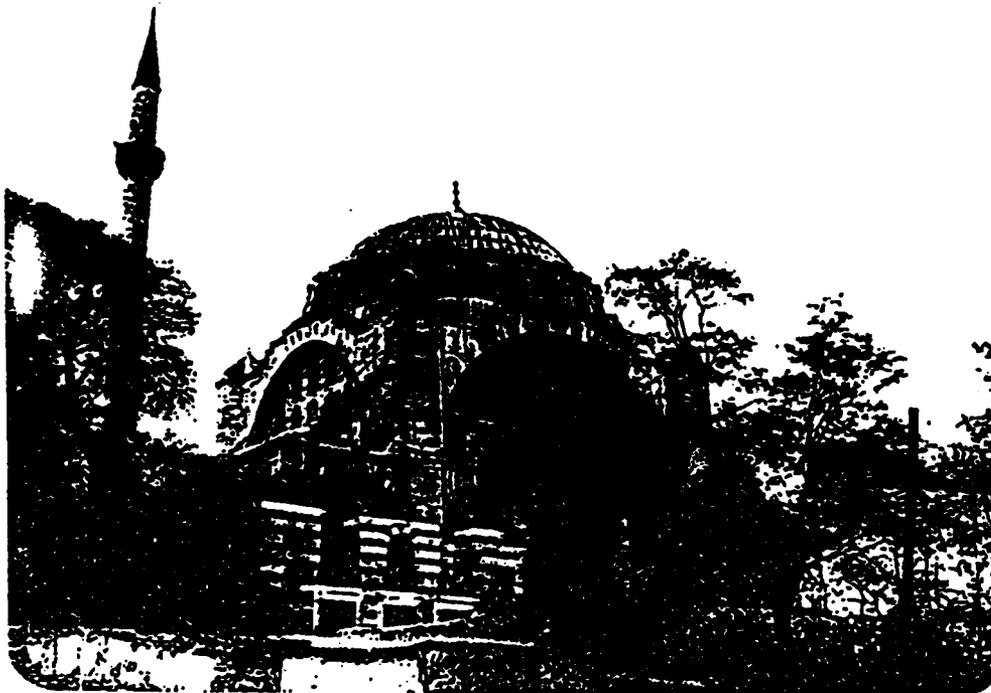


Figure 4. General view of Mihrimah Sultan Mosque

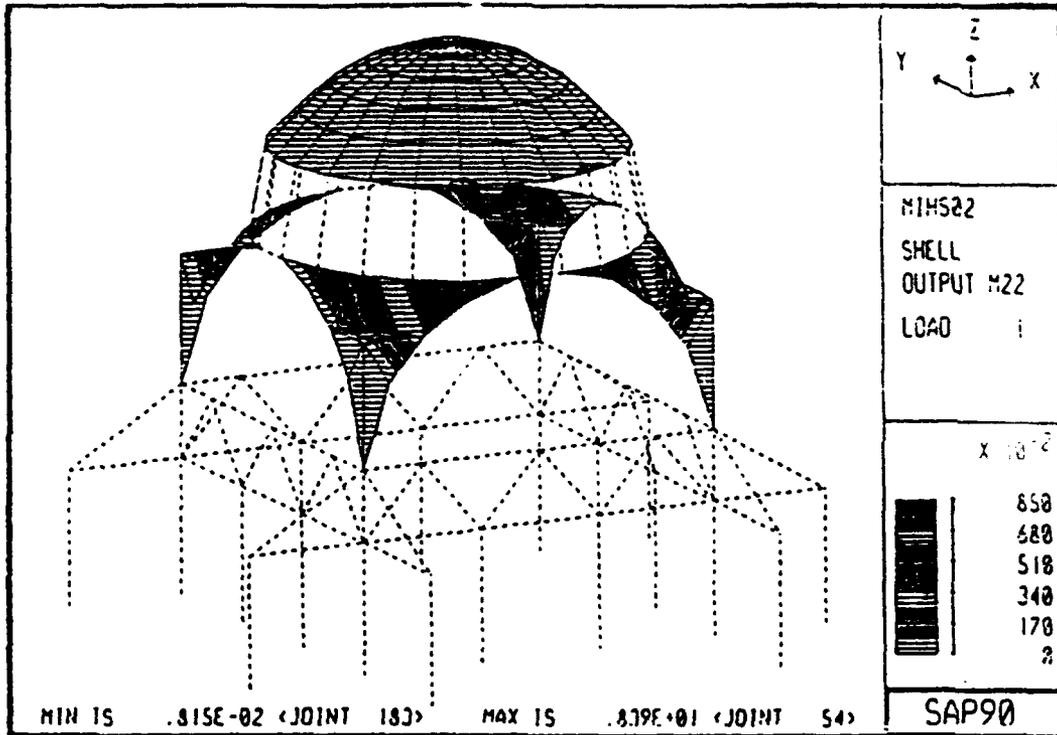


Figure 5. Structural model of Mihrimah Sultan Mosque with lower structure

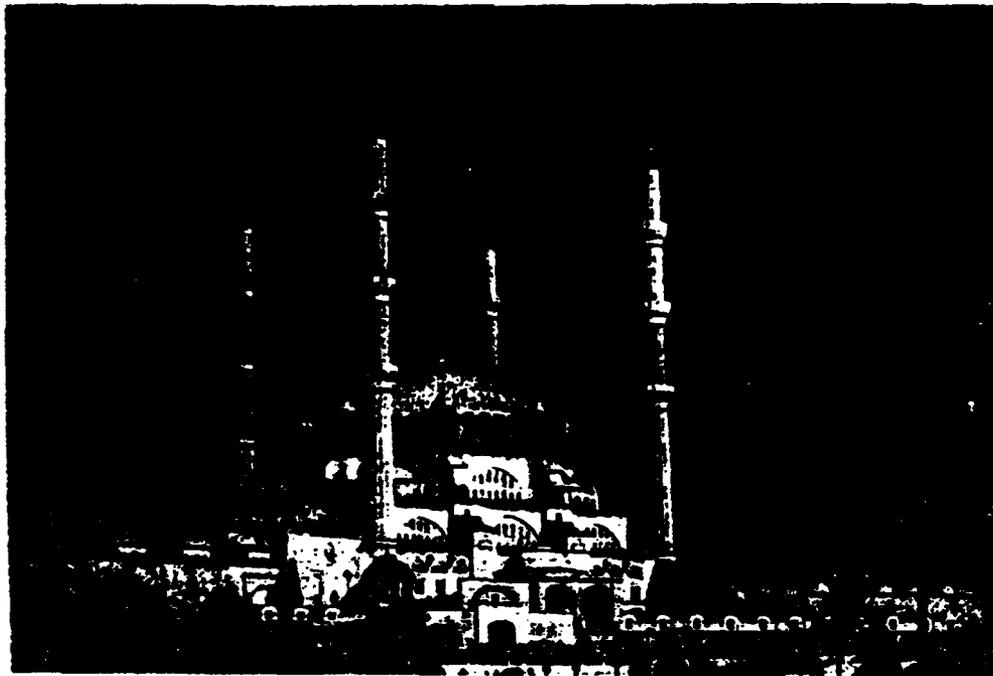


Figure 6. Selimiye Mosque: Outside View

REFERENCES

1. Rumpier, M. "La Coupole dans l'Architecture Byzantine et Musulmane" Edition Le Tilleul, Strasbourg 1956, pp.1-140.
2. Karaesmen, E., Ünay, A.I. "A Study of Structural Aspects of Domed Buildings with Emphasis on Sinan's Mosques" Proceedings of the International Association of Shell and Space Structures (IASS) 1988 May Istanbul Symposium on "Domes" Publication of the Mimar Sinan University, Istanbul, 1988.
3. Ünay, A.I. "A Study of Structural Behaviour of the Şehzade Mehmet Mosque", M.S. Thesis Dissertation Presented to the Faculty of Architecture of the M.E.T.U., Ankara, 1988.
4. Karaesmen, E. Domed Buildings in Ottoman Architecture, lecture notes, Stanford University, Ankara-Palo Alto, 1988.
5. Mungan, İ. On the Structural Development of the Ottoman Dome, Proceedings of the IASS-MSU International Symposium on Domes, Istanbul, 1988.
6. Mark, H., Westagard, A. "Haghia Sophia: Mythe Vs. Technology", Proceedings of the International Association of Shell and Space Structures (IASS) 1988 May Istanbul Symposium on "Domes". Publication of the Mimar Sinan University, Istanbul, 1988.
7. Hayman, J. On Shell Solution for Masonry Domes, International Journal of Solid Structures, Vol.3, pp.227-241, 1967.
8. Kuran, A. "Sinan, The Great Old Master of Ottoman Architecture", Ada Press Publishers, Istanbul, 1987.
9. Karaesmen, E., Ünay, A.I. and İlker, İ. "A Study of the Sinan's Masonry Bridges", Proceedings of STREMA 91, Sevilla, Spain, 1991.
10. Karaesmen, E. "Aspects Techniques de la Restauration des Monuments Historiques". Keynote report for the 1st. European Symposium on Preservation of Historical Monuments of Major Importance. Organised by Council of Europe, Strasbourg, 1991.(Proceedings under print)
11. Karaesmen, E. "A Study of the Sinan's Domed Structures", Proceedings of STREMA 89, Florence, Italy, 1989.
12. Kuban, D. "The Style of Sinan's Domed Structure" Mugarnas: A annual on Islamic Art and Architecture, Volume.1, 1987.

13. Karaesmen, E., Erkey, C., Boyacı, N., Ünay, A.I. "Seismic Behaviour of old Masonry Structures", Proceedings 10.th World Congress on Earthquake Engineering Madrid 1992.
14. Babinger, F. "Die Türkische Renaissance, Bemerkungen Zum Schaller Des Grosson Türkischen Baumeiste Sinan", Beitrage Zur Kenntnis Des Orients, Vol.11, 1914, pp 67-88.
15. Dalokay, V. "The Great Sinan and Mihrimah Sultan", Special Issue on "Sinan" Gösteri, Turkish Art Magazine, İstanbul, March, 1988 (in Turkey)
16. Diez, E. "Der Baumeister Sinan und sein werk", Antiantis, Vol.25, No: 4, April, 1953.
17. Erzen, J.N. "Stylistic Evolution of Ottoman Mosque Facades in Sinan's Era", Middle East Technical University, Faculty of Architecture Journal, Vol.7, No:2, Ankara, Spring 1986.
18. Giura, G. "Meastro Dell'architecture Turca: Sinan", Ressegna Italiana, Vol.7, July 1937, pp 539-548.
19. Arıoğlu, E., Anadol, K: "Earthquake Resistance of Süleymaniye Mosque Throusgout History", Turkish Earthquake Reseachr Institute Journal, Vol.2, No: 6, Ankara, July 1974 (in Turkish)
20. Kuban, D. "Sinan's Art, El-Bina", Vol.6, No: 31, October-November 1986, pp 39-48 (in Arabic)
21. Kuran, A. "A Study on Sinan's Mosques", Journal of Boshorus University, Vol.7, 1979, pp 81-94 (in Turkish)
22. Bektaş, C. "Wiew of Sinan from our age", International Conference of Türk and Islamic Science, Technology and History, İstanbul Technical University, September 1986, İstanbul.
23. Yorulmaz, M: "Structural System and Constructional Techniques in Sinan's Mosques", International Conference of Türk and Islamic Science, Technology and History, İstanbul Technical University, April 1986, İstanbul.
24. Karaesmen, E: "And Sinan the Engineer" Special Issue on "Sinan" Gösteri, Turkish Art Magazine, İstanbul, March, 1988 (in Turkish)
25. Koepf, H: "An Essay on the Domes of Ottoman Mosques" YAPI Journal, No: 58, December 1984, İstanbul, pp 19-47.
26. Oppenheim, i.J: "Limit State Analysis of Masonry Domes", ASCE Journal of Structural Engineering, Vol.115, No: 4, April 1989.

APPENDIX B
INTERNATIONAL STANDARDS FOR PRESERVATION

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Venice Charter (1964)

**INTERNATIONAL CHARTER FOR THE
CONSERVATION AND RESTORATION
OF MONUMENTS AND SITES**

Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognized. It is our duty to hand them on in the full richness of their authenticity.

It is essential that the principles guiding the preservation and restoration of ancient buildings should be agreed and be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions.

By defining these basic principles for the first time, the Athens Charter of 1931 contributed towards the development of an extensive international movement which has assumed concrete form in national documents, in the work of ICOM and UNESCO and in the establishment by the latter of the International Centre for the Study of the Preservation and the Restoration of Cultural Property. Increasing awareness and critical study have been brought to bear on problems which have continually become more complex and varied; now the time has come to examine the Charter afresh in order to make a thorough study of the principles involved and to enlarge its scope in a new document.

Accordingly, the IInd International Congress of Architects and Technicians of Historic Monuments, which met in Venice from May 25th to 31st 1964, approved the following text:

DEFINITIONS

ARTICLE 1. The concept of an historic monument embraces not only the single architectural work but also the urban or rural setting in which is found the evidence of a particular civilization, a significant development or an historic event. This applies not only to great works of art but also to more modest works of the past which have acquired cultural significance with the passing of time.

ARTICLE 2. The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage.

ARTICLE 3. The intention in conserving and restoring monuments is to safeguard them no less as works of art than as historical evidence.

CONSERVATION

ARTICLE 4. It is essential to the conservation of monuments that they be maintained on a permanent basis.

ARTICLE 5. The conservation of monuments is always facilitated by making use of them for some socially useful purpose. Such use is therefore desirable but it must not change the lay-out or decoration of the building. It is within these limits only that modifications demanded by a change of function should be envisaged and may be permitted.

ARTICLE 6. The conservation of a monument implies preserving a setting which is not out of scale. Wherever the traditional setting exists, it must be kept. No new construction, demolition or modification which would alter the relations of mass and colour must be allowed.

ARTICLE 7. A monument is inseparable from the history to which it bears witness and from the setting in which it occurs. The moving of all or part of a monument cannot be allowed except where the safeguarding of that monument demands it or where it is justified by national or international interests of paramount importance.

ARTICLE 8. Items of sculpture, painting or decoration which form an integral part of a monument may only be removed from it if this is the sole means of ensuring their preservation.

RESTORATION

ARTICLE 9. The process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents. It must stop at the point where conjecture begins, and in this case moreover any extra work which is indispensable must be distinct from the architectural composition and must bear a contemporary stamp. The restoration in any case must be preceded and followed by an archaeological and historical study of the monument.

ARTICLE 10. Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience.

ARTICLE 11. The valid contributions of all periods to the building of a monument must be respected, since unity of style is not the aim of a restoration. When a building includes the super-imposed work of different periods, the revealing of the underlying state can only be

justified in exceptional circumstances and when what is removed is of little interest and the material which is brought to light is of great historical, archaeological or aesthetic value, and its state of preservation good enough to justify the action. Evaluation of the importance of the elements involved and the decision as to what may be destroyed cannot rest solely on the individual in charge of the work.

ARTICLE 12. Replacements of missing parts must integrate harmoniously with the whole, but at the same time must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence.

ARTICLE 13. Additions cannot be allowed except in so far as they do not detract from the interesting parts of the building, its traditional setting, the balance of its composition and its relation with its surroundings.

HISTORIC SITES

ARTICLE 14. The sites of monuments must be the object of special care in order to safeguard their integrity and ensure that they are cleared and presented in a seemly manner. The work of conservation and restoration carried out in such places should be inspired by the principles set forth in the fore-going articles.

EXCAVATIONS

ARTICLE 15. Excavations should be carried out in accordance with scientific standards and the recommendation defining international principles to be applied in the case of archaeological excavation adopted by UNESCO in 1956.

Ruins must be maintained and measures necessary for the permanent conservation and protection of architectural features and of objects

discovered must be taken. Furthermore, every means must be taken to facilitate the understanding of the monument and to reveal it without ever distorting its meaning.

All reconstruction work should however be ruled out *a priori*. Only anastylosis, that is to say, the reassembling of existing but dismembered parts can be permitted. The material used for integration should always be recognizable and its use should be the least that will ensure the conservation of a monument and the reinstatement of its form.

PUBLICATION

ARTICLE 16. In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs.

Every stage of the work of clearing, consolidation, rearrangement and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published.

The following persons took part in the work of the Committee for

drafting the International Charter for the Conservation and Restoration of Monuments:

- Mr. PIERO GAZZOLA (Italy), Chairman
- Mr. RAYMOND LEMAIRE (Belgium), Reporter
- Mr. JOSÉ BASSEGODA-NONELL (Spain)
- Mr. LUIS BENAVENTE (Portugal)
- Mr. DJURDJE BOSKOVIC (Yugoslavia)
- Mr. HIROSHI DAIFUKU (U.N.E.S.C.O.)
- Mr. P.L. DE VRIEZE (Netherlands)
- Mr. HARALD LANGBERG (Denmark)
- Mr. MARIO MATTEUCCI (Italy)
- Mr. JEAN MERLET (France)
- Mr. CARLOS FLORES MARINI (Mexico)
- Mr. ROBERTO PANE (Italy)
- Mr. S.C.J. PAVEL (Czechoslovakia)
- Mr. PAUL PHILIPPOT (International Centre for the Study of the Preservation and Restoration of Cultural Property)
- Mr. VICTOR PIMENTEL (Peru)
- Mr. HAROLD PLENDERLEITH (International Centre for the Study of the Preservation and Restoration of Cultural Property)
- Mr. DEOCLECIO REDIG DE CAMPOS (Vatican)
- Mr. JEAN SONNIER (France)
- Mr. FRANÇOIS SORLIN (France)
- Mr. EUSTATHIOS STIKAS (Greece)
- Mrs. GERTRUD TRIPP (Austria)
- Mr. JAN ZACHWATOVICZ (Poland)
- Mr. MUSTAFA S. ZBISS (Tunisia)

Lahore Statement (1980)

DRAFT STATEMENT OF PRINCIPLES FOR THE CONSERVATION OF THE ISLAMIC ARCHITECTURAL HERITAGE:

A. INTRODUCTION

A1. The Islamic architectural heritage embraces cultural sites ranging from that containing a single architectural work to an urban or rural setting, in which is found evidence of a particular civilization, a significant development, or an historic event. This term embraces not only great works of architecture, landscape, or urban design, but also more modest works of the past which have acquired cultural significance with the passage of time.

A2. Conservation, or restoration, or a Site should involve all sciences and techniques which can contribute to the study and safeguarding of the architectural heritage. Wherever possible, traditional techniques should be used in preference to modern techniques.

A3. The intention in conserving, or restoring, Cultural Sites is to safeguard them no less as works of art than as historical evidence.

B. CONSERVATION

B1. It is essential to the conservation of Sites that they be maintained on a permanent basis.

B2. The conservation of Sites is facilitated by making use of them for some socially useful purpose. Such use is therefore desirable, but it must be compatible with the original use, and take account of ethical considerations; it must not change the design or decoration of the building. It is within these limits only that modifications demanded by a change of function should be envisaged and may be permitted.

B3. Conservation of a Site implies preserving a setting which is not out of scale. Wherever the traditional setting exists, it must be kept. No new construction, demolition, or modification should alter the relationships of materials, forms, textures, colours, or any other aspects of the character of the Cultural Site.

B4. A Cultural Site is inseparable from the history to which it bears witness and from the setting in which it occurs. The moving of all or part of the material of that Cultural Site should be avoided except where it is justified by national or international interests of paramount importance.

B5. Items of furniture, sculpture, painting, design, decoration, or inscription which form an integral part of a Site should only be removed from it if this is the only way of ensuring their conservation.

C. RESTORATION

C1. Restoration is highly delicate work which should be undertaken only by specialists (in rare and exceptional circumstances) in certain clearly defined circumstances its aim is to preserve and reveal the aesthetic and historical value of the monument and it should be based on respect for original material and authentic documents. It must stop at the point where conjecture begins; in those

few cases where additional work based on some conjecture is found to be indispensable for authentic or technical reasons, this must be regarded as a form of new architectural creation and clearly distinguished as such.

C2. Traditional techniques should be used wherever possible, only when there are strong practical reasons should they be replaced by modern techniques, the efficacy of which has been shown by scientific data and proved by experience. Reversible techniques should be used except where this is impracticable for reasons of dire structural necessity.

C3. The valid contribution of all periods to the creation of a Cultural Site must be respected, since unity of style is not the aim of restoration. When a building includes the superimposed work of different periods, the revealing of the underlying state can only be justified in exceptional circumstances, and when what is removed is of little interest and the material which is brought to light is of great historical, archaeological, or aesthetic value, and its state of preservation good enough to justify the action. Evaluation of the importance of the elements involved and the decision as to what may be destroyed cannot rest solely with the individuals in charge of the work.

C4. No new work should be introduced in place of missing elements or areas of work except when necessary for protection or preservation, or for essential consolidation of the visual appearance. It must not predominate over the original work, and it should integrate harmoniously with the whole.

C5. Extensions and additions cannot be allowed externally except in so far as they do not detract from the interesting parts of the building, its traditional setting, the balance of its composition, and its relationship with its surroundings. They must always be reversible.

C6. Additions cannot be allowed internally except where essential to adjust the use of a building so as to assist its conservation, and should be reversible except where this is inconsistent with preserving the visual appearance of the interiors.

D. ARCHAEOLOGICAL SITES

D1. Excavations should be carried out in accordance with scientific standards and the recommendation defining international principles to be applied in the case of archaeological excavation adopted by UNESCO in 1956.

D2. Ruins must be maintained and measures necessary for their continual conservation and protection must be taken.

D3. Excavations must be planned to allow funds for the conservation or back-filling of sites as appropriate. They should not destroy existing sites or buildings of cultural value in the course of excavation nor parts of them. Objects discovered must be conserved and protected. Every means must be taken to facilitate the understanding of the Site and to reveal it without distorting its meaning.

D4. In the event of a known historic site, or of the accidental discovery of a historic site, on which new building work is being done, a stay of at least some weeks should be enforced to permit a salvage excavation to be undertaken.

D5. All reconstruction work should be ruled out *a priori*. Only anastylosis, that is to say, the reassembling of existing but dismembered parts can be permitted. The material used for integration should be the least that will ensure the conservation of a monument and the reinstatement of its form.

E. DOCUMENTATION AND PUBLICATION

E1. In all works of conservation, restoration, or excavation, there should always be precise documentation in the form of analytical and critical reports, comprehensively illustrated with drawings and photographs.

E2. Every stage of the work of clearing, consolidation, rearrangement, and integration, as well as technical and formal features identified during the course of the work, should be included. This record should be placed in the archives of a public institution on the nation to whom the Site belongs, and made available to (research workers). It is recommended that the report should be published.

E3. In addition, a brief illustrated account of the extent of the conservation should be easily available to all visitors, in the form of an exhibition or a publication.

APPENDIX C
STANDARDS FOR U.S. HISTORIC PRESERVATION PROJECTS
(US Secretary of Interior 1990)

PART I

The Secretary of the Interior's STANDARDS FOR HISTORIC PRESERVATION PROJECTS

The Secretary of the Interior's Standards for Historic Preservation Projects are the required basis for State Historic Preservation Officers and the Heritage Conservation and Recreation Service to evaluate Historic Preservation Fund grant-assisted acquisition and development project work proposals for properties listed in the National Register of Historic Places.

The Secretary of the Interior's Standards for Historic Preservation Projects are used as the basis for advising other Federal agencies under Executive Order 11593, and evaluating reuse proposals submitted with State and local government applications for the transfer of federally-owned surplus properties listed in the National Register.

The Secretary of the Interior's Standards for Historic Preservation Projects (Standards for Rehabilitation) are also the program regulations used by State Historic Preservation Officers and the Heritage Conservation and Recreation Service to determine if a rehabilitation project for a certified historic structure qualifies as a "certified rehabilitation," pursuant to the Tax Reform Act of 1976 and the Revenue Act of 1978.

DEFINITIONS for Historic Preservation Project Treatments

The following definitions are provided for treatments that may be undertaken on historic properties listed in the National Register of Historic Places:

Acquisition

Is defined as the act or process of acquiring fee title or interest other than fee title of real property (including the acquisition of development rights or remainder interest).

Protection

Is defined as the act or process of applying measures designed to affect the physical condition of a property by defending or guarding it from deterioration, loss or attack, or to cover or shield the property from danger or injury. In the case of buildings and structures, such treatment is generally of a temporary nature and anticipates future historic preservation treatment; in the case of archeological sites, the protective measure may be temporary or permanent.

Stabilization

Is defined as the act or process of applying measures designed to reestablish a weather resistant enclosure and the structural stability of an unsafe or deteriorated property while maintaining the essential form as it exists at present.

Preservation

Is defined as the act or process of applying measures to sustain the existing form, integrity, and material of a building or structure, and the existing form and vegetative cover of a site. It may include initial stabilization work, where necessary, as well as ongoing maintenance of the historic building materials.

Rehabilitation

Is defined as the act or process of returning a property to a state of utility through repair or alteration which makes possible an efficient contemporary use while preserving those portions or features of the property which are significant to its historical, architectural, and cultural values.

Restoration

Is defined as the act or process of accurately recovering the form and details of a property and its setting as it appeared at a particular period of time by means of the removal of later work or by the replacement of missing earlier work.

Reconstruction

Is defined as the act or process of reproducing by new construction the exact form and detail of a vanished building, structure, or object, or a part thereof, as it appeared at a specific period of time.

GENERAL STANDARDS for Historic Preservation Projects

The following general standards apply to all treatments undertaken on historic properties listed in the National Register:

1. Every reasonable effort shall be made to provide a compatible use for a property that requires minimal alteration of the building structure, or site and its environment, or to use a property for its originally intended purpose.
2. The distinguishing original qualities or character of a building, structure, or site and its environment shall not be destroyed. The removal or alteration of any historic material or distinctive architectural features should be avoided when possible.
3. All buildings, structures, and sites shall be recognized as products of their own time. Alterations which have no historical basis and which seek to create an earlier appearance shall be discouraged.
4. Changes which may have taken place in the course of time are evidence of the history and development of a building, structure, or site and its environment. These changes may have acquired significance in their own right, and this significance shall be recognized and respected.
5. Distinctive stylistic features or examples of skilled craftsmanship which characterize a building, structure, or site, shall be treated with sensitivity.
6. Deteriorated architectural features shall be repaired rather than replaced, wherever possible. In the event replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual qualities. Repair or replacement of missing architectural features should be based on accurate duplications of features, substantiated by historical, physical, or pictorial evidence rather than on conjectural designs or the availability of different architectural elements from other buildings or structures.
7. The surface cleaning of structures shall be undertaken with the gentlest means possible. Sandblasting and other cleaning methods that will damage the historic building materials shall not be undertaken.
8. Every reasonable effort shall be made to protect and preserve archeological resources affected by, or adjacent to, any acquisition, protection, stabilization, preservation, rehabilitation, restoration, or reconstruction project.

SPECIFIC STANDARDS for Historic Preservation Projects

The following specific standards for each treatment are to be used in conjunction with the eight general standards and, in each case, begin with number 9. For example, in evaluating acquisition projects, include the eight general standards plus the four specific standards listed under Standards for Acquisition.

Standards for Acquisition

9. Careful consideration shall be given to the type and extent of property rights which are required to assure the preservation of the historic resource. The preservation objectives shall determine the exact property rights to be acquired.
10. Properties shall be acquired in fee simple when absolute ownership is required to insure their preservation.
11. The purchase of less-than-fee-simple interests, such as open space or facade easements, shall be undertaken when a limited interest achieves the preservation objective.
12. Every reasonable effort shall be made to acquire sufficient property with the historic resource to protect its historical, archeological, architectural, or cultural significance.

Standards for Protection

9. Before applying protective measures which are generally of a temporary nature and imply future historic preservation work, an analysis of the actual or anticipated threats to the property shall be made.
10. Protection shall safeguard the physical condition or environment of a property or archeological site from further deterioration or damage caused by weather or other natural, animal, or human intrusions.
11. If any historic material or architectural features are removed, they shall be properly recorded and, if possible, stored for future study or reuse.

Standards for Stabilization

9. Stabilization shall reestablish the structural stability of a property through the reinforcement of loadbearing members or by arresting material deterioration leading to structural failure. Stabilization shall also reestablish weather resistant conditions for a property.
10. Stabilization shall be accomplished in such a manner that it detracts as little as possible from the property's appearance. When reinforcement is required to reestablish structural stability, such work shall be concealed

Standards for Stabilization - continued

wherever possible so as not to intrude upon or detract from the aesthetic and historical quality of the property, except where concealment would result in the alteration or destruction of historically significant material or spaces.

Standards for Preservation

9. Preservation shall maintain the existing form, integrity, and materials of a building, structure, or site. Substantial reconstruction or restoration of lost features generally are not included in a preservation undertaking.
10. Preservation shall include techniques of arresting or retarding the deterioration of a property through a program of ongoing maintenance.

Standards for Rehabilitation

9. New additions, exterior alterations, or related new construction shall not destroy historic materials that characterize the property. The new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.
10. New additions and adjacent or related new construction shall be undertaken in such a manner that if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired.

Standards for Restoration

9. Every reasonable effort shall be made to use a property for its originally intended purpose or to provide a compatible use that will require minimum alteration to the property and its environment.
10. Reinforcement required for structural stability or the installation of protective or code required mechanical systems shall be concealed whenever possible so as not to intrude or detract from the property's aesthetic and historical qualities, except where concealment would result in the alteration or destruction of historically significant materials or spaces.
11. When archeological resources must be disturbed by restoration work, recovery of archeological material shall be undertaken in conformance with current professional practices.

Standards for Reconstruction

9. Reconstruction of a part or all of a property shall be undertaken only when such work is essential to reproduce a significant missing feature in a historic district or scene, and when a contemporary design solution is not acceptable.

Standards for Reconstruction - continued

10. Reconstruction of all or a part of a historic property shall be appropriate when the reconstruction is essential for understanding and interpreting the value of a historic district, or when no other building, structure, object, or landscape feature with the same associative value has survived and sufficient historical documentation exists to insure an accurate reproduction of the original.
11. The reproduction of missing elements accomplished with new materials shall duplicate the composition, design, color, texture, and other visual qualities of the missing element. Reconstruction of missing architectural features shall be based upon accurate duplication of original features substantiated by historical, physical, or pictorial evidence rather than upon conjectural designs or the availability of different architectural features from other buildings.
12. Reconstruction of a building or structure on an original site shall be preceded by a thorough archeological investigation to locate and identify all subsurface features and artifacts.
13. Reconstruction shall include measures to preserve any remaining original fabric, including foundations, subsurface, and ancillary elements. The reconstruction of missing elements and features shall be done in such a manner that the essential form and integrity of the original surviving features are unimpaired.

APPENDIX D
INDIVIDUAL REPORTS

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**INTERNATIONAL WORKSHOP ON ENGINEERING ASPECTS OF PRESERVATION
OF MASONRY DOMED HISTORIC MONUMENTS**

by Esin Atil

Sackler Gallery, Smithsonian Institute

Washington, D.C., USA

International Workshop on Engineering Aspects of Preservation
of Masonry Domed Historic Buildings Istanbul May 29-31, 1992

Report of Esin Atil, Chairperson of Art History and Architecture

During this presentation I will concentrate on the architectural decoration -- and problems -- involving the two buildings we studied. Giorgio Croci will discuss the technical or structural aspects and recommendations. It is hoped that through the investigation of the Mihrimah Sultan Mosque and the Selimiye we can establish a methodology or approaches to conservation that can be applied to other buildings.

The approaches to conservation outlined earlier by David Look are extremely valid for restoration and preservation of architectural decoration, be it carved marble, inlaid woodwork, glazed tiles, or wall paintings. David Look listed them as:

1. Minimal intervention; "less is best," which should be the motto.
2. Retaining the integrity of the historic fabric.
3. Reversability.
4. Proper documentation of all intervention.
5. Compatibility of new and old.

Before any attempt is undertaken, a thorough biography of the original decoration as well as all past preservation and restoration activities must be compiled. All previous repairs and/or repaint have to be analysed so as not to perpetuate past problems.

Alternative methods, that is, methods that are less drastic, less time and energy consuming, have to be searched. Unless there is a dire structural need, the best approach is minimal, such as surface dusting or cleaning with no further intervention. Otherwise an irreversable damage could result.

Let me illustrate these points with the interior repaintwork we saw at Mihrimah Sultan and Selimiye. Both wall painting programs have nothing (or very little) to do with the original 16th-century decoration, neither in style and thematic repertoire, nor in technique and pigments. These new paintings -- 1960s-70s for the former and 1980s for the latter -- work to the detriment of the building as a whole. They overwhelm the interior with their garish colors whereas the original decoration blended harmoniously with the structure and accented specific components, as intended by the architect. The paint in Selimiye, less than ten years old, is already flaking and falling off with the remnants of the older layer underneath.

The following are our recommendations:

1. The biography of the buildings are most likely available at the Vakiflar Archives (Ministry of Pious Foundations/Endowments). Departments of engineering, conservation, history, and art history in Turkish universities and museums can provide students and interns who can work in teams with the Vakiflar personnel to prepare this document.
2. It is most desirable to work up a model or map of the building to see how the proposed restoration will look. Decorative motifs and color samples should be included. This model should be carefully studied by art historians and other specialists in the decorative arts.
3. Materials chosen should be checked by engineers, chemists, and conservators to determine reversability, suitability, and compatibility.
4. And finally, the most important aesthetics. These buildings are being preserved not for sheer exercise on conservation

techniques and practises, but to preserve the experience of the past -- to preserve the cultural heritage of mankind. We must honor the integrity of the buildings -- structurally and decoratively -- to fully appreciate and understand the achievements of their age, their social, economic, and aesthetic milieu. Therefore, one cannot concentrate on one single structure, but the entire külliye (complex of buildings around a central mosque) must be considered as life revolved around these buildings that provided diverse areas for prayer, education, health facilities, and social interaction.

If we are to learn from the past, its story must be faithfully preserved, its originality retained, and its aesthetic experience honored.

**COMMENTS ON INTERNATIONAL WORKSHOP ON ENGINEERING ASPECTS
OF PRESERVATION OF MASONRY DOMED HISTORIC MONUMENTS**

by Prof. Oral Büyüköztürk

Massachusetts Institute of Technology

Cambridge, Massachusetts, USA

June 11, 1992



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July 11, 1992

Dear Mary Ellen,

It was a great pleasure to meet you in Istanbul. I thought the workshop was very well organized, and was quite productive. I wish, though, we had a little more time for technical discussion. I would like to point out that the topic of preserving historical structures is important and timely. Development of an international project on this subject will be technically productive, and exciting from the viewpoint of international cooperation.

I have enclosed a brief write-up of my observations and suggestions from this workshop. I hope it will be useful. Please let me know if I can contribute to the preparation of the research proposal.

Since our workshop in Istanbul, I have made several out-of-town trips, and have recently returned to my office. I am looking forward to our continued long-term interaction.

With best wishes.

Sincerely,

Oral

Oral Buyukozturk
Professor of Civil Engineering

cc: Prof. E. Karaesmen

**Comments on
International Workshop on Engineering
Aspects of Preservation of Masonry
Domed Historic Buildings
May 29 - 31 1992, Istanbul, Turkey**

by

**Dr. Oral Buyukozturk
Professor of Civil Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139**

I attended the workshop on preservation of historic monuments of major importance held in Istanbul, Turkey from May 29 to June 1, 1992. The workshop was organized by The U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Participants and by the government of Turkey for the Turkish participants. The purpose of the workshop was to explore engineering methodologies for evaluating deterioration mechanisms and vulnerability of these structures to seismic hazards, and to determine the elements of a comprehensive research project for the development of effective preservation methodologies.

Observations from my active participation in this workshop are summarized below.

1. GENERAL COMMENTS

The workshop, in general, was very well organized. Interaction between the experts in several areas was productive and promising for a long-time cooperation. Main ideas that were generated from the group sessions, and the general meeting were well founded, and certainly provide a basis for the generation of ideas for a comprehensive research proposal. I also would like to point out that I wish more time was allowed for somewhat in-depth technical discussion in the structural and materials sessions. The site visits to observe some historic structures and the associated problems were useful. Site briefings on the history and known characteristics of these historic structures would have facilitated the understanding of the problems involved.

2. IMPORTANCE OF THE PROBLEM

The importance of the problem of preserving these irreplaceable major historic buildings cannot be over emphasized. The task in that respect is difficult and requires an interdisciplinary engineering approach incorporating the state-of-the-art capabilities. The problem is of international nature, and offers an opportunity to organize a pioneering effort in organizing and performing a pilot study that will establish a basis for evaluating and repairing a wide range of historic structures.

3. STRUCTURES AND MATERIALS

Development of an effective methodology for preservation of important historic construction requires integration of knowledge at least in the areas of seismology, geotechnics, structures and materials, architecture, art as well as social and economic aspects. Deterioration of these structures occurs mainly as a result of mechanical and environmental effects. In this respect, understanding of time dependent factors including construction, load, and maintenance histories and their effect on structural system behavior and material deterioration are essential. Integration of the developed knowledge with sound engineering judgment is required for the development of an effective preservation methodology.

I would like to emphasize the importance of local effects in the initiation and progression of deterioration. Identification of critical regions by careful inspection and preferably with the use of nondestructive evaluation probes to identify critical deterioration regions will be essential. Large scale system analysis approach to assess the overall structural characteristics under different mechanical effects would be useful only when material and composite component behavior at the local level is realistically represented in the mathematical models. Local behaviors such as mortar-masonry interaction and cracking such as those at the pendentives will critically influence the predictions based on

any system or global level structural model. Assessment of mortar and masonry characteristics and studies on experimental and analytical models representing local deterioration mechanisms will be needed.

4. SITE VISITS

As part of the workshop, site visits to several of Sinan's masterworks, including Selimiye and Mihrimah Sultan mosques were made. In what follows I will make some remarks on the Mihrimah Sultan (MS) mosque. This is a domed structure, with the large central dome being situated on pendentives over a square base. The dome is supported by four major arches braced together by weight towers on the four corners where the outer surfaces of the pendentives are exposed. As the four arches are flush with the inner walls, from the inside the heavy weight of the dome cannot be fully sensed, leaving an impression of a well-lighted spacious room. The central dome is approximately 25 meters in diameter.

Several cracked regions were visible from the inside especially on one of the wall-arch systems of the square-based structure. From this distant visual inspection one can assess the need for a close look at the crack formation, and possibly instrumentation for determining the time dependent trends of these cracks. This would allow determination of the fundamental reasons for such crack formation, so that the required methodology for crack control may be assessed. Among others, factors of an earthquake related crack initiation, cracking related to existing soil and foundation system, and local effects should be considered. The MS mosques only an example. In my view an existing structure as a basis for our pilot study should be selected very carefully such that it would represent the deterioration mechanism that can be characterized as generic problems for these kind of structures.

5. GENERAL SCOPE OF PROPOSED RESEARCH

The contemplated research which is intended to be a pilot study would be organized around a carefully determined existing case structure representing the general characteristics of deteriorated historic structures. The following study areas are suggested:

a) Data Base Development

This would involve a careful determination of all geometric, system and material characteristics of the structure. Also, all deterioration signals would be identified and reported.

b) Non-Destructive Evaluation

Several methods and probes are currently available for non-destructive testing of structures and materials. In this task, first an assessment of the available methods, tools, and their effectiveness is made in view of the historic structures under consideration. This would be followed by identification and application of a specific method, and field instrumentation.

c) Behavioral Models

It is essential that laboratory and mathematical models are developed for simulation and parametric studies of structure and material deterioration. Emphasis would be on small scale sophisticated models for the development of a behavioral understanding as a basis for repair. Problems of masonry-mortar interaction, masonry and mortar characteristics would be studied by means of both laboratory and numerical tools. A numerical system model based on a finite element discretization would then follow making use of the fundamental material behavioral knowledge developed from the small scale studies.

d) Repair/ Retrofit Strategies

Based on the knowledge developed from the preceding phases of the research, necessary repair/ retrofit strategies would be developed. The objective of this would be for preventing the structure from continued deterioration, and for restoring the required safety margin for the structure.

Finally, I would like to point out that, although the proposed research appears to be conducted around a specific case structure, I believe that the developed methodologies for the evaluation of structural and material deterioration mechanisms, and identified tools and capabilities for repair strategies will constitute a generic knowledge applicable to a wide range of historic works.

ENGINEERING ASPECTS OF PRESERVING HISTORIC BUILDINGS

by Prof. Oral Büyüköztürk

Massachusetts Institute of Technology

Cambridge, Massachusetts, USA

October 13, 1992



**DEPARTMENT OF CIVIL ENGINEERING
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**Oral Buyukozturk
Professor**

**Room 1-280
Tel. (617) 253-7186**

October 13, 1992

**Dr. Mary Ellen Hynes
Chief, Earthquake Engineering and Seismology Branch
U.S. Army Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, Mississippi 39180-6199**

Dear Mary Ellen,

As per our telephone conversation, I am enclosing a general write-up on engineering aspects of preserving historic buildings for possible inclusion in the NSF Workshop proceedings. As I mentioned, a meeting held on Friday, November 6th here at MIT would be convenient. Professor E. Karaesmen plans to be here during November 4-6, 1992. I am looking forward to seeing you soon.

With best wishes.

Sincerely,

A handwritten signature in cursive script, appearing to read "Oral", is positioned above the typed name.

**Oral Buyukozturk
Professor**

cc: Dr. Karaesmen

ENGINEERING ASPECTS OF PRESERVING HISTORIC BUILDINGS

by

**Dr. Oral Buyukozturk
Professor of Civil Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139**

In recent years there has been much attention focused on preserving the infrastructure in a cost-effective manner to establish long-term safety and reliability of structures. New technologies and strategies emerge and are continually researched for evaluating, initiating, and upgrading existing facilities. A special subset of the problem is the preservation of historic buildings in which case the problem becomes more critical since, on one hand, an effective structural reinstating would require the use of contemporary construction methods, while, on the other hand, the apparent components of the historical buildings should be constructed with general characteristics similar to the original ones. In addition, many times an accurate assessment of the structural vulnerability to deterioration or the extent of existing damage is difficult due to the lack of information on the long-term behavior of the original materials, and construction schemes that may have been used in building the structure.

The importance of the problem of preserving these irreplaceable major historic buildings cannot be over emphasized. The task in that respect is difficult and requires an interdisciplinary engineering approach incorporating the state-of-the-art capabilities. The problem is of international nature, and offers an opportunity to organize a pioneering effort in organizing and performing a pilot study that will establish a basis for evaluating and repairing a wide range of historic structures.

The main objectives of an evaluation and restoration activity would involve to

- (1) develop engineering methodologies for evaluating deterioration and monitoring the safety of these irreplaceable structures,
- (2) develop and evaluate materials and technologies for restoration,
- (3) develop design and construction methods for remedial actions.

Paper for presentation at the international workshop on "Protection of Architectural Heritage Against Earthquakes" organized by the European Natural Disasters Training Center, September 28 - October 2, 1992



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Oral Buyukozturk
Professor

cc: Dr. Karaesmen

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by

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The main objectives of an evaluation and restoration activity would involve to

- (1) develop engineering methodologies for evaluating deterioration and monitoring the safety of these irreplaceable structures,
- (2) develop and evaluate materials and technologies for restoration,
- (3) develop design and construction methods for remedial actions.

Paper for presentation at the international workshop on "Protection of Architectural Heritage Against Earthquakes" organized by the European Natural Disasters Training Center, September 28 - October 2, 1992

The success of any restoration measures depends mainly upon two factors:

- (1) the accuracy with which the structural vulnerability and the cause and extent of the deterioration has been evaluated, and**
- (2) the quality of the judgment that has been used in selecting an appropriate restoration method.**

Development of an effective methodology for preservation of important historic construction requires integration of knowledge at least in the areas of seismology, geotechnics, structures and materials, architecture, art as well as social and economic aspects. Deterioration of these structures occurs mainly as a result of mechanical and environmental effects. In this respect, understanding of time dependent factors including construction, load, and maintenance histories and their effect on structural system behavior and material deterioration are essential. Integration of the developed knowledge with sound engineering judgement is required for the development of an effective preservation methodology.

DETERIORATION OF CONSTRUCTION MATERIALS

Deterioration of the materials can be defined as any adverse changes of normal mechanical, physical, and chemical properties either on the surface or in the whole body of the material generally through separation of its components. It can be caused by either physical or chemical factors or both.

Physical factors have to do with forces acting on the concrete including those caused by temperature variations. Foundation displacement, seismic forces can cause settlement or cracking, vibrations of structures caused by earthquakes and water surges can cause damage. Physical forces can cause erosion of the material. Absorptive materials may undergo freezing and thawing cycles which cause cracking and spalling. Infiltration of water in the cracks and subsequent freezing may cause further deterioration.

Chemical factors are commonly associated with the intrusion of polluted air and aggressive waters containing inorganic acids, sulfates, and other salts. Alkali-stone reactions can cause physical damage and mechanical deterioration.

GLOBAL AND LOCAL EFFECTS

The vulnerability assessment under various mechanical, physical and environmental effects should be based on both global and local attributes. Experimental and analytical methodologies should be explored for the identification of global system characteristics.

Preservation of important historic construction presents special difficulties, particularly when seismic loads are of concern. It is often difficult to understand the condition of an aged soil-foundation-structure system in terms of meaningful engineering indices especially in the case of these highly redundant and mixed constructions. Knowledge on the history of the ground motions is needed that are specific to these construction sites. Mathematical models for predicting seismic hazards for various time intervals provide useful information on the structural integrity.

Local effects are important in the initiation and progression of deterioration. Identification of critical regions by careful inspection and preferably with the use of nondestructive evaluation probes to identify critical deterioration regions will be essential. Large scale system analysis approach to assess the overall structural characteristics under different mechanical effects would be useful only when material and composite component behavior at the local level is realistically represented in the mathematical models. Local behaviors such as mortar-masonry interaction and cracking such as those at the pendentives of a historic dome will critically influence the predictions based on any system or global level structural model. Assessment of mortar and masonry characteristics and studies on experimental and analytical models representing local deterioration mechanisms will be needed.

SCOPE OF PROPOSED RESEARCH

A research program which is intended to be a pilot study in this area would be organized around a carefully determined existing case structure representing the general characteristics of deteriorated historic structures. The study would be directed toward producing useful generic knowledge, and would involve the following components.

(1) Data base development

- determine geometric, system and material characteristics**
- deterioration signals**
- collection of information on construction, damage, and repair history**

2. Experimental studies

- non-destruction testing
 - assessment of probes and available non-destructive testing tools appropriate for historic structures
 - field application
 - performance evaluation and interpretation
- laboratory tests to assess existing material characteristics
- laboratory tests on small-scale models to develop behavioral understanding (aided by mathematical models)
- identification of global structural characteristics (aided by analytical/numerical simulation)

3. Mathematical models

- models for simulation and parametric studies of localized deterioration effects
- global analysis using finite element discretization incorporating the knowledge developed on local deterioration behavior

4. Development of repair/retrofit strategies

- integration of all information and knowledge from previous phases for assessing an effective remedial action
- consideration of the broad spectrum of social and economic issues

CONCLUSION

The problem of preserving irreplaceable major historic works is very important. The task in that respect is difficult and requires an interdisciplinary approach. The problem is of international nature, and offers an unusual opportunity to organize a pioneering effort and enhance international cooperation in this area.

REPORT ON THE WORKSHOP HELD IN TURKEY AND PROPOSAL FOR THE
STUDY AND RESTORATION OF THE MIHRIMAH MOSQUE AND
THE SELIMIYE MINARETS
by Prof. Giorgio Croci
University of Rome
Rome, ITALY



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Rome, 26 June 1992

Dr. Mary Ellen Hynes (GG-H)
US Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg
MS 39180
U.S.A.

Dear Dr. Hynes,

Following our meeting in Turkey I am sending you a report that I have prepared on the basis of the surveys of the Mihrimah and Selimye mosques and the subsequent discussions. I am also enclosing a copy of a book on the Colosseum and a paper on the dome of St. Ignatius of Lojola in Spain.

I look forward to hearing from you soon.

Yours sincerely

Prof. Ing. Giorgio Croci.

Enclosed - Report on workshop in Turkey
- Book on the Colosseum
- Paper on the dome of St. Ignatius of Lojola



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**Report on the Workshop held in Turkey
and Proposal for the Study and Restoration of the
Mihrimah Mosque and the Selimye Miranets.**

This report was prepared by Prof. Giorgio Croci who is the head of the Restoration Section of the Structural Engineering Department at the University of Rome. He was assisted by Lesley Goldfinger B.Eng.

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Report on the Workshop held in Turkey and proposal for Future Activities

29-31 May 1992

The workshop comprised two different sections:

-site visits to, and in-situ discussions of the specific problems of two mosques built by Sinan (1492-1588), (the Mihrimah Sultan mosque in Istanbul and the Selimye mosque in Edirne)

-more theoretical discussions summarizing, in an academic setting, the way to organize a general approach to restoration and the possibility of setting up working groups to carry out studies and research on the restoration of ancient monuments.

On the basis of these discussions we can pursue two possibilities which could be followed up in the future:

The first is to establish an academic approach to restoration, which may result in a somewhat abstract view, indicating all points that must be explored from the historical survey, in-situ observation and mathematical modelling etc... to the criteria for reinforcing and restoration of monuments.

The second approach, which I find preferable, is to start from the reality of the problem, using the direct observations of the present state of the two monuments we have visited, as the basis of a rigorous methodology which makes constant reference to the two buildings. In this more pragmatic approach we must use the best available information and technology we possess, without getting caught up in an endless process of improving the technology and theories we should be utilizing.

In conclusion I suggest that, on the basis of the observations made, the activities can be developed as follows:

Mihrimah mosque - The mosque was constructed in 1565 by Sinan during his "masterly years" (1550-1565) its daring structural scheme, consists of a cubic central hall covered by a dome of diameter 21m (figs 1 and 2.), the dome is supported by slender arches (fig 3). Cracks in the inner surface of the dome have been observed; the most significant crack pattern being a circular line concentric with the dome (fig 4); this unusual pattern suggests the possible presence of an amplified live load due to the phenomena of resonance during earthquakes corresponding to the suspended lantern; it is therefore important to carry out an historical survey to find out the weight of the lantern that was in place during the last major earthquakes and the way in which it was suspended.

Important cracks are also present in the main arches (figs 5 and 6) that support the dome and in the infill walls (figs 7 and 8). There has been deformation of the wall resulting in its separation from the ceiling in some places (fig 9).

A remarkable deformation has occurred on the balcony (fig 10) which runs between the springing of the main arch (opposite the entrance). In some zones there is a remarkable separation between the main arches and the adjacent walls. Some reinforcing bars, which we presume are not original, span between one arch, where two pillars were built in the past (fig.11); The curved shape of these bars (fig. 12) indicates that they have been in compression and this phenomena is further emphasised by cracking in the arch showing the position of a hinge (fig. 13).

On the basis of these initial observations we can organise a restoration program as follows.

- a) removal of a small strip of lead cover of dome to inspect cracks, establish thickness at key points and take samples of material if necessary. At this stage it is difficult to carry out interior inspections.
- b) survey key parts of the structure using methods such as endoscopy, sonic tests (where there is plaster work which we want to avoid damaging), investigation of materials etc...
- c) establishment of a monitoring system for significant cracks.
- d) removal of small areas of interior plaster to control cracks and damage.
- e) archival research into original construction.
- f) systematic collection of information concerning damage and repairs - not least after the 1894 earthquake.
- g) first approximated mathematical model.

Selimye mosque - The mosque was completed in 1575 during Sinan's "late years" (1570-1575) and is generally considered to be his masterpiece in terms of both architectural flare and engineering prowess. It consists of a dome of 31.28m diameter (fig 14.), which is supported by eight arches which, in turn, are supported by slender columns; the same number of buttresses provide lateral restraint (figs 15 and 16).

From the first site visit it was not possible to see a lot of the structural damage or the deterioration of materials as extensive superficial renovations had recently been carried out (fig 17). We will therefore focus our attention on the minarets (fig 18) where important and dangerous cracks are visible on both faces of the cylindrical wall (figs 19 and 20), on the central column (fig 21) and in many steps (figs 22 and 23). It is possible that besides providing a home for the local wildlife (fig 24), they have worked like stirrups in a global sense, providing shear resistance to deformation between the exterior wall and the interior column. These cracks are certainly related to seismic actions and now lead to low safety levels. Other deformations and sliding of the masonry were also observed (figs 25, 26 and 27).

The following investigations and analysis are recommended

- a) survey and investigation of the damage and cracks present in the minarets.
- b) systematic investigation of historical sources relating to damage and repair of the minarets.
- c) establishment of a monitoring system for the cracks.
- d) carry out dynamic tests.
- e) first approximated mathematical model.

During these initial steps of investigation we can involve turkish architects, engineers and contractors so that they can observe how the work procedes. At the end of the first phase a workshop could be organised to discuss the results and any urgent measures that have to be carried out and decide on the successive phases of the studies and the project.

PROF. GIORGIO CROCI

References:

- KARAESMEN, Ebran "Overview of Domed Historic Structures in Seismic Zones"
KURAN, Aptullah "SINAN: The Grand Old Master of Ottoman Architecture"
OZIS, Dr Unal "Sinan, The Engineer Beyond the Architect and the Artist"
VOGT-GOKNIL, Ulya "Living Architecture: Ottoman"

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- Fig 27. Selimye mosque - deformation of masonry in minaret.
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Fig. 1. Mihrimah Mosque

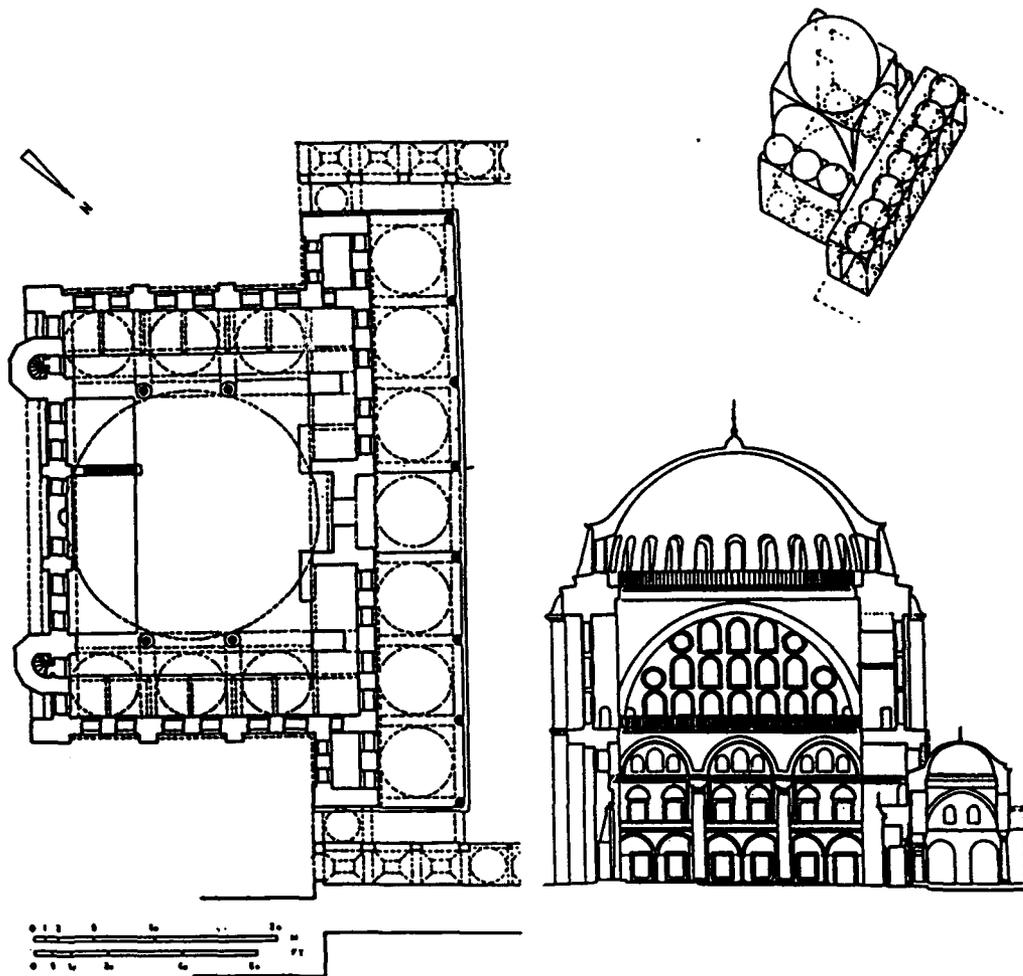


Fig 2. Mihrimah Mosque - plan and section



Fig 3. Mihrimah Mosque - arches

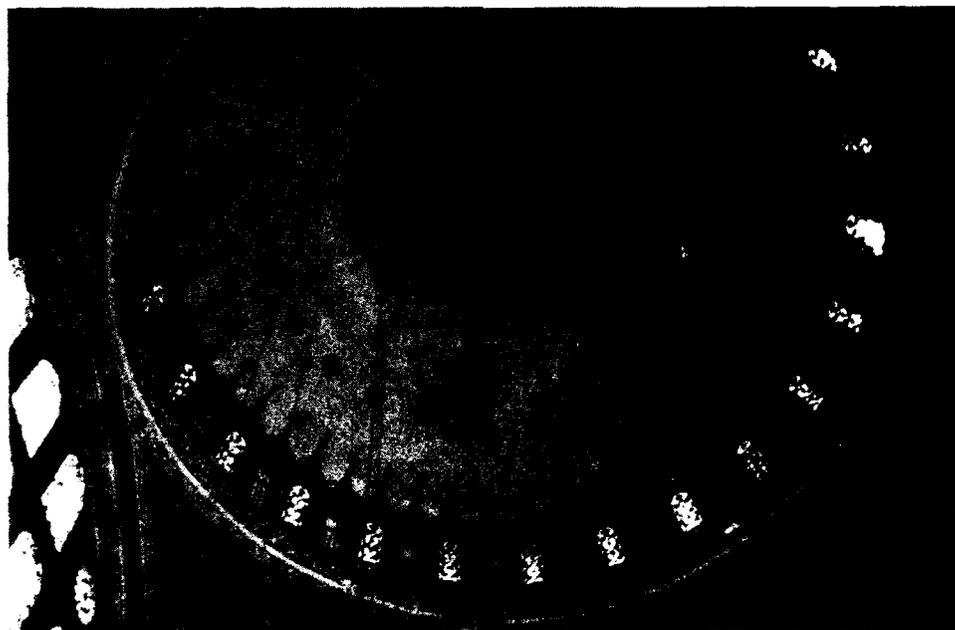


Fig 4. Mihrimah Mosque - circular cracking in dome

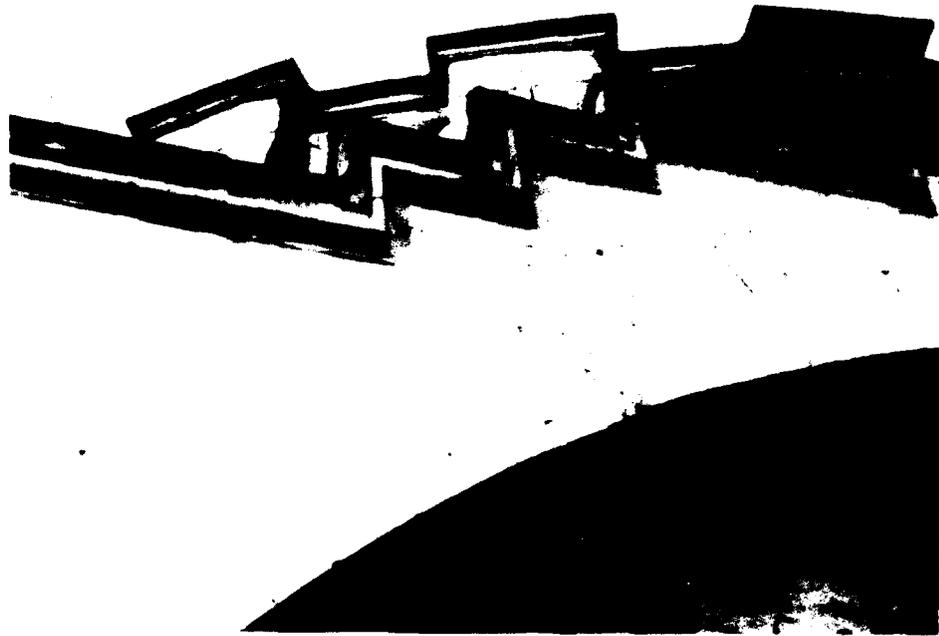


Fig 5. Mihrimah Mosque -
cracking in arches supporting dome



Fig 6. Mihrimah Mosque -
cracking in arches supporting dome



**Fig 7. Mihrimah Mosque -
cracking in external wall**



Fig 8. Mihrimah Mosque - cracking in external wall



Fig 9. Mihrimah Mosque - separation of wall from ceiling

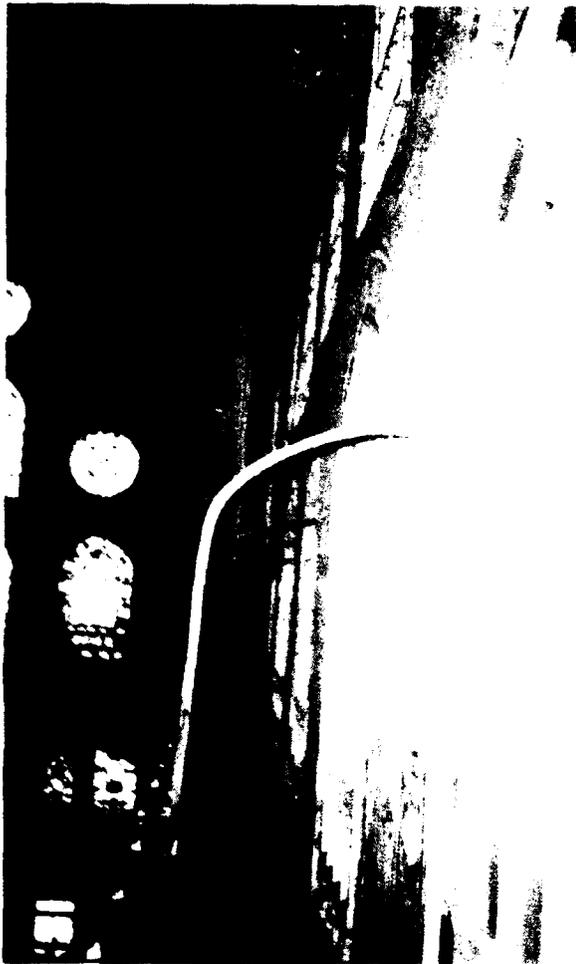


Fig 10. Mihrimah Mosque - deformation of balcony



Fig 11. Mihrimah Mosque - wrought iron reinforcing bars



Fig 12. Mihrimah Mosque - wrought iron reinforcing bars



Fig 13. Mihrimah Mosque - hinge in arch

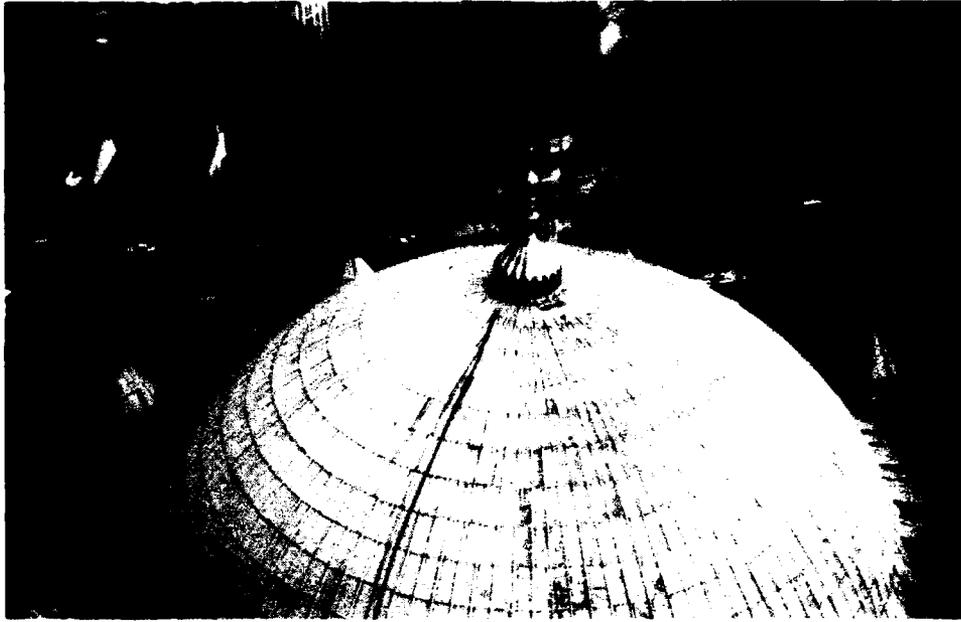


Fig 14. Selimye Mosque - view of dome

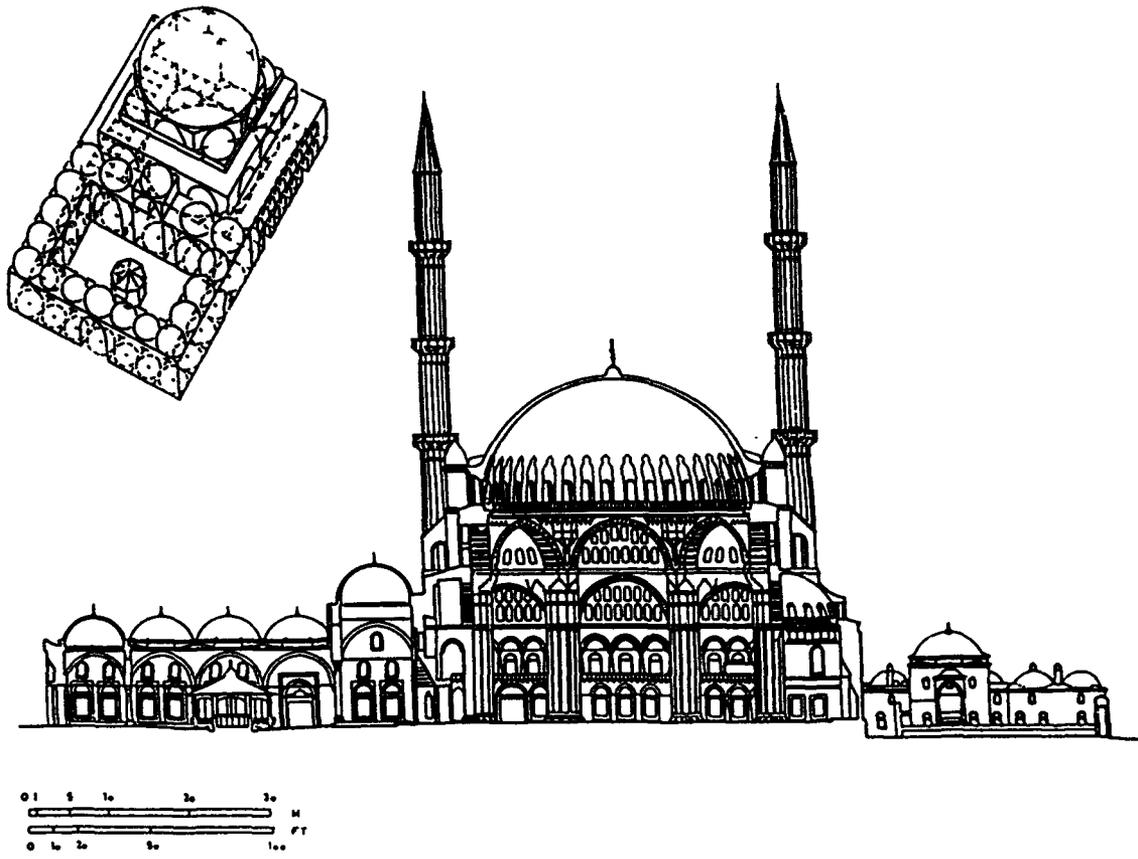


Fig 15. Selimye Mosque - section and axonometric view

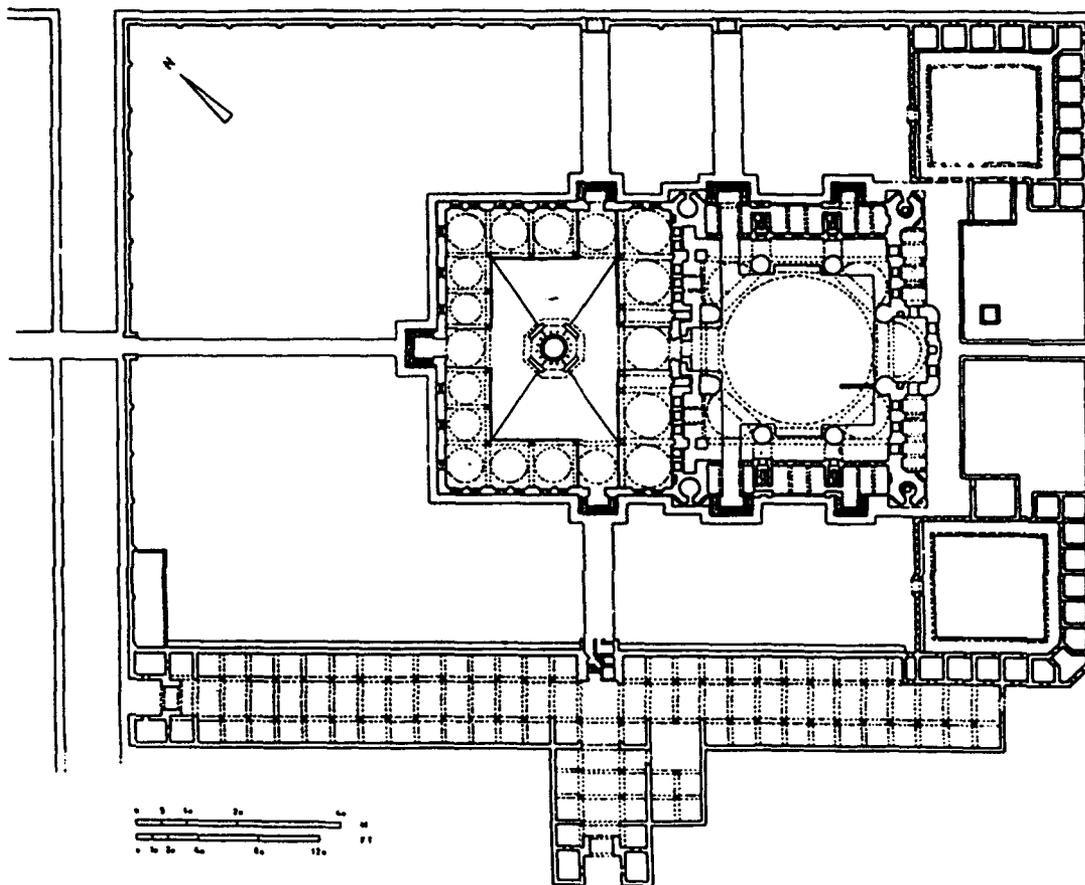


Fig 16. Selimye Mosque - plan

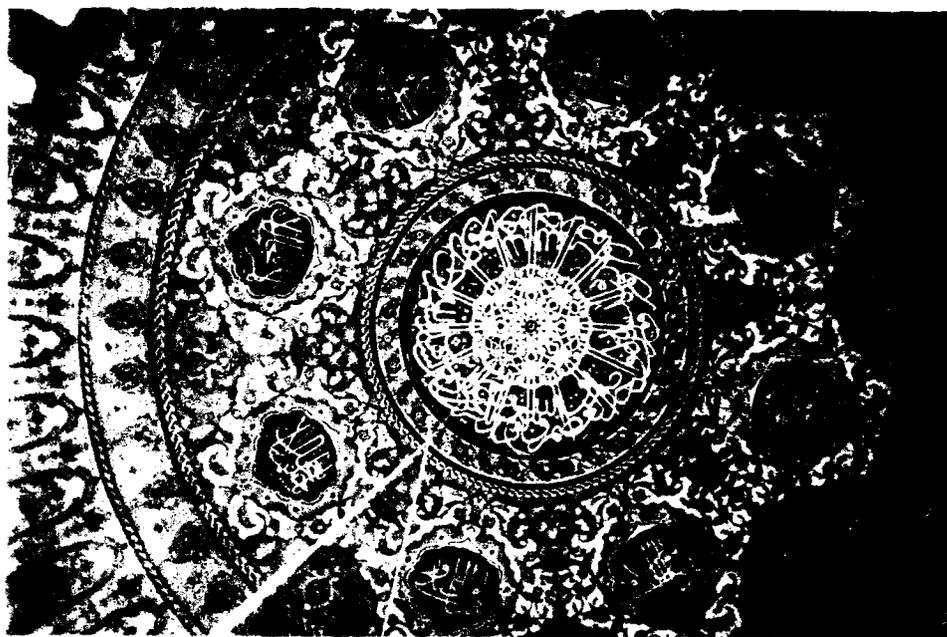


Fig 17. Selimye Mosque - recent internal renovations

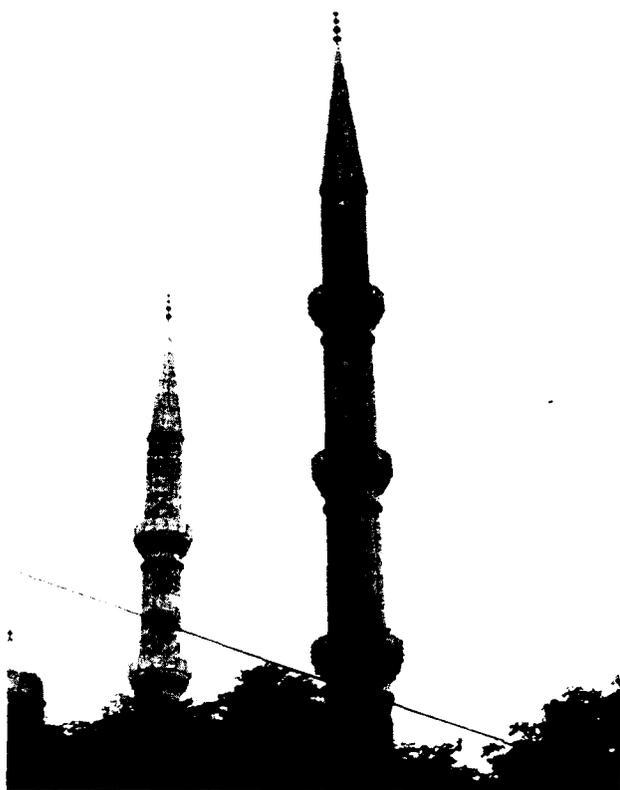


Fig 18. Selimye Mosque - minarets

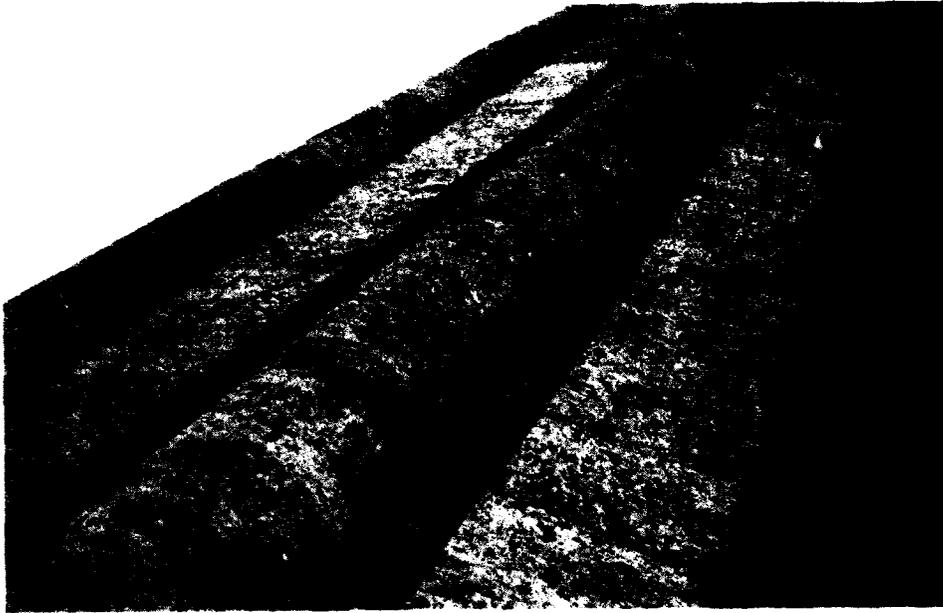


Fig 19. Selimye Mosque - cracks on outer face of minaret wall



Fig 20. Selimye Mosque - cracks on outer face of minaret wall



**Fig 21. Selimye Mosque -
cracks on inner face of minaret wall**

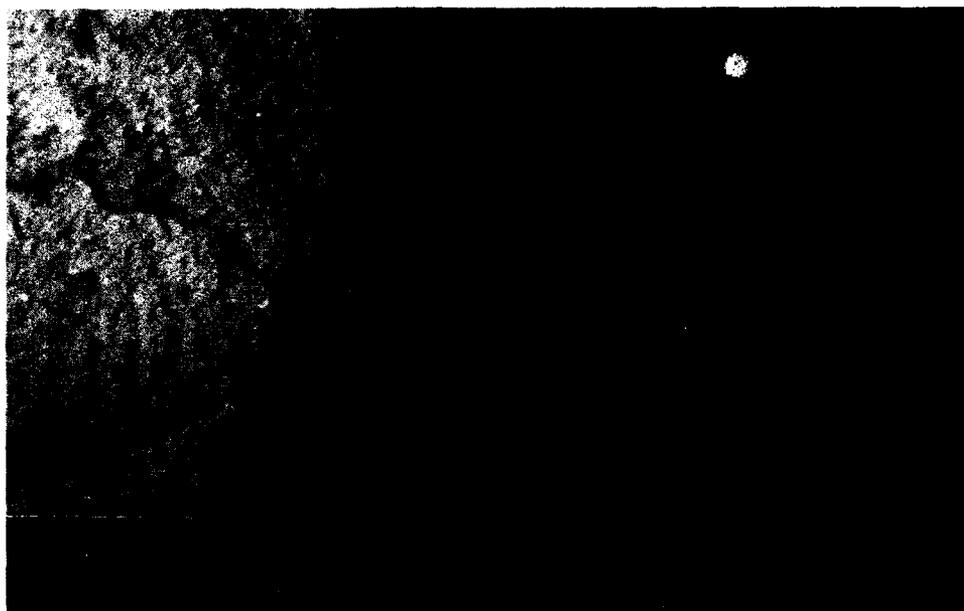


Fig 22. Selimye Mosque - cracks in central column of minaret



Fig 23. Selimye Mosque - cracks in steps of minaret



Fig 24. Selimye Mosque - cracks in steps of minaret



Fig 25. Selimye Mosque - bird's nest found in minaret



Fig 26. Selimye Mosque - deformation of masonry in minaret

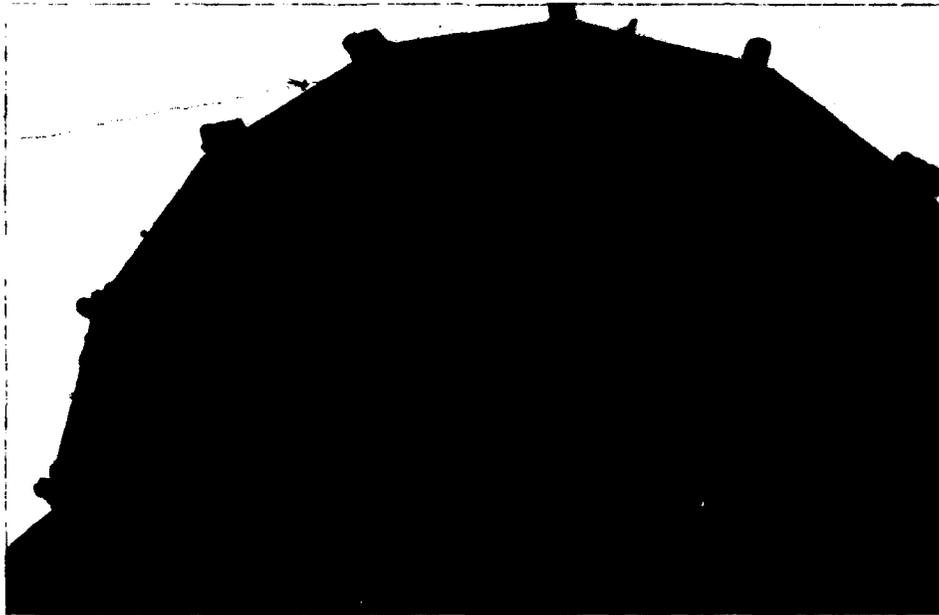


Fig 27. Selimye Mosque - deformation of masonry in minaret



Fig 28. Selimye Mosque - sliding of masonry in minaret

LATER OBSERVATIONS AT THE MIHRIMAH MOSQUE
by Profs. Büyükoztürk, Croci, and Karaesmen (1992)

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Mary Ellen Hynes
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28 October 1992

Dear Mary,

In October I had the opportunity to return to Istanbul and to revisit the Mihrimah mosque with Professors Karaesman and Buyukozturk. On this occasion we focussed our attention on the south wall where we discovered the most important and significant cracks. The report enclosed includes some reflections on the various problems.

I'm looking forward to hearing from you soon.

Best wishes



Giorgio Croci

Oral Buyukozturk
Giorgio Croci
Erhan Karaesman

MIRIMAH MOSQUE
Istanbul - Turkey

1. Main Concept

Following the first visit to the Mirimah mosque (fig. 1), in association with a seminar held in Istanbul and Ankara on the protection of Architectural Heritage against earthquakes, we revisited the mosque on 29 September 1992 to look more closely at the signs of damages and weaknesses.

The survey concentrated on the south wall which undoubtedly presents the most precarious situation from a general structural viewpoint; this is confirmed by looking at the geometry and low structural mass of the wall. It is weaker than the others partly because it is thinner and has an uninterrupted lateral span (fig. 2), and partly due to the numerous window openings (figs. 3 & 4).

This weaker behaviour is confirmed by the observation of important cracks, crossing the wall, well visible on both the inner and outer faces (figs. 5 & 6). The pattern of these cracks indicates clearly the main phenomena affecting the wall, the most significant of these being seismic action.

To facilitate an understanding of these phenomena it is useful to distinguish the component of seismic action normal to the wall and the component parallel to the wall.

Component of Seismic Action Normal to the South Wall

In this situation the main resistance is offered by the 2 central columns and the balcony which acts as a fixed end beam in the horizontal plane (fig. 7); the horizontal curvature of the balcony is partially visible in fig. 8, and reaches a displacement of around 10cm midspan. The cracks visible over the arches (fig. 9 & 10) are due to bending and shear and are concentrated at these points because of the reduced section of the "beam" (balcony); some ancient reinforcement bars are visible at this point (fig. 11).

Component of Seismic Action Parallel to the South Wall

This component is taken up by the rows of cross vaults at the lower level of the east and west walls, as these are much stiffer than the upper levels (fig. 12). Cracks are clearly visible in the vaults (fig. 13) and are particularly evident in the corners where large gaps

reveal the separation of the south wall from the east wall (figs. 14 & 15). The general concentration of cracks and spalling plaster in the south west corner also shows the serious state of the connection between these 2 walls (figs. 16 & 17).

Irreversible deformations and relative movement of the blocks can also be observed (figs. 18 & 19).

Minarets

The minarets also appear to be in poor condition and some cracks can be observed on the central column that supports the stair (fig. 20).

2. Proposal

The closer observation of the monument, has allowed us to better identify the actual behaviour of the structure and in particular the local effect of an earthquake on the south wall.

It would be interesting to begin the study of the mosque by examining the wall and creating a simplified model . The current safety levels, under the effect of seismic loads, are low and further damage is possible.

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- Fig. 19 - Sliding of blocks (S.E. corner)
- Fig. 20 - Cracks in minaret column

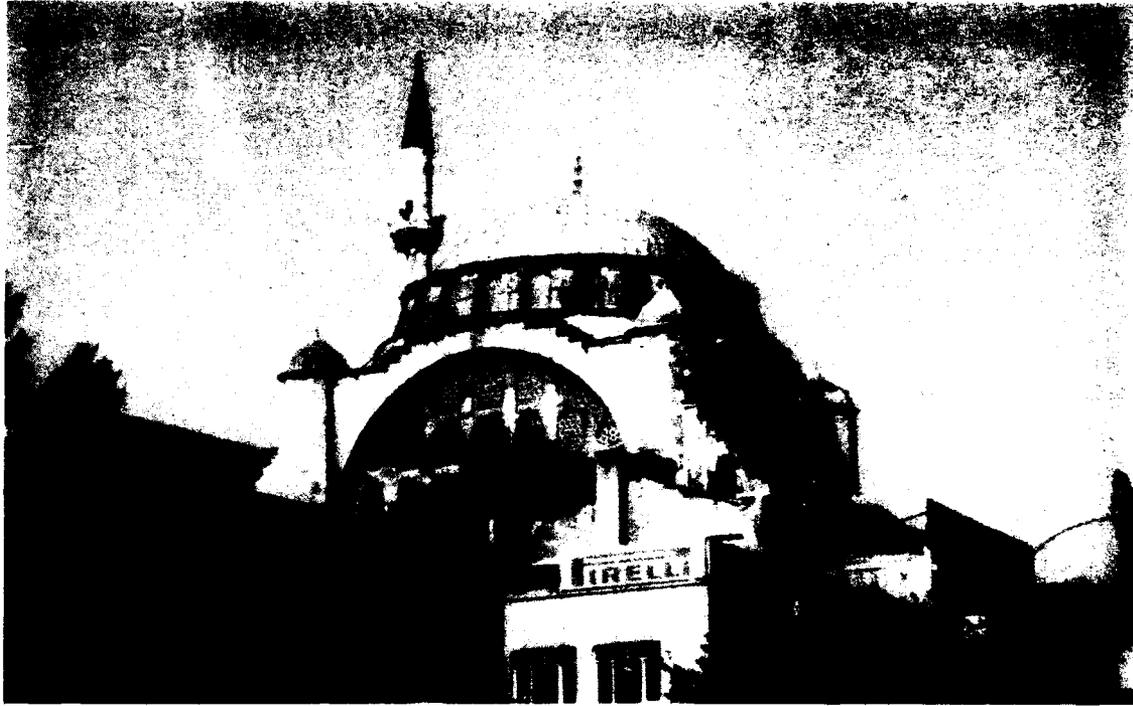


Fig 1. Mihrimah Mosque

Central columns and balcony provide resistance to component of seismic action normal to south wall

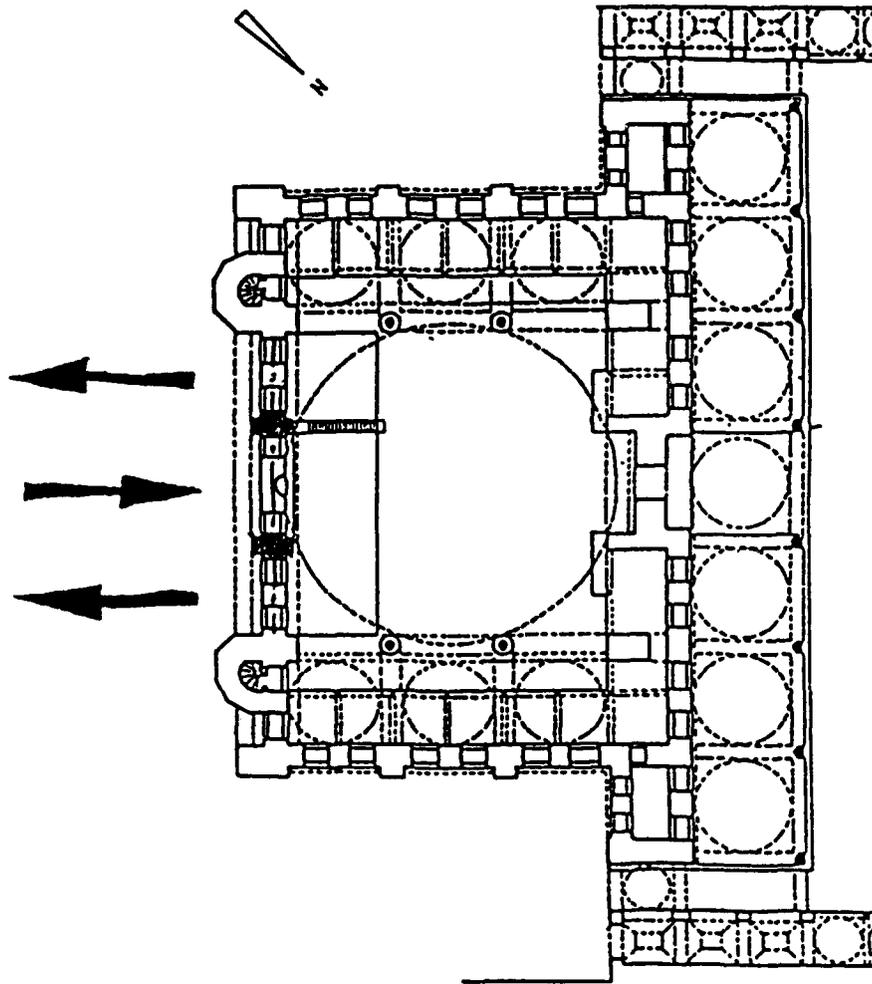


Fig 2. Plan

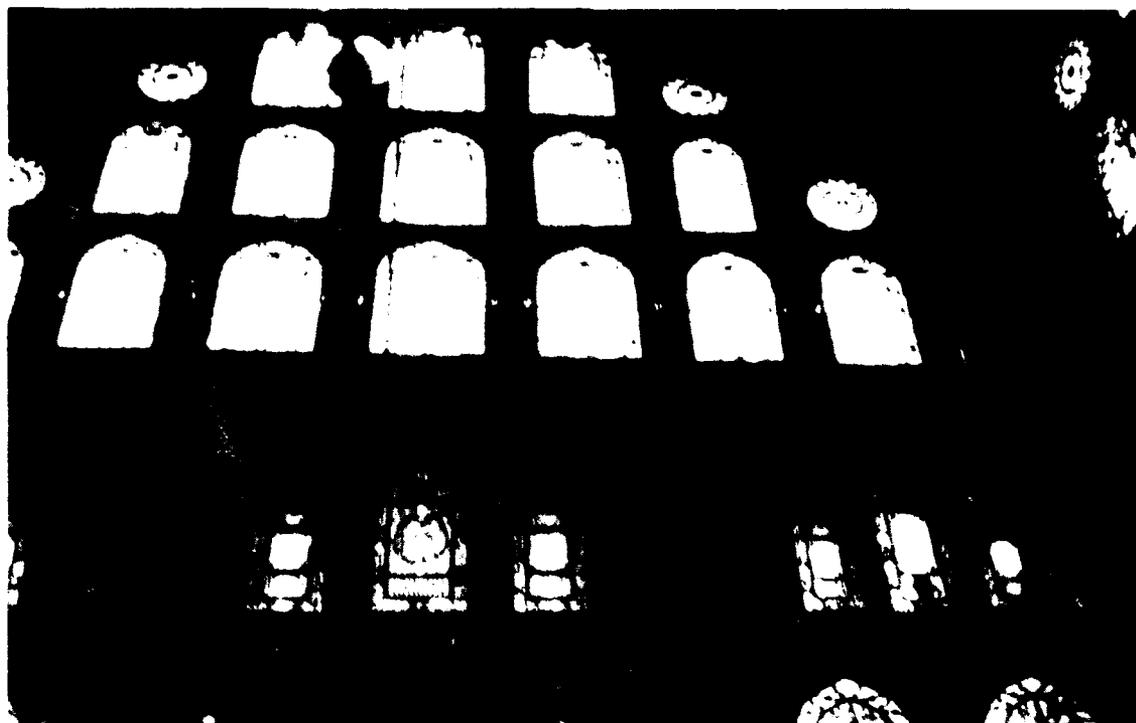


Fig 3. Interior view of south wall

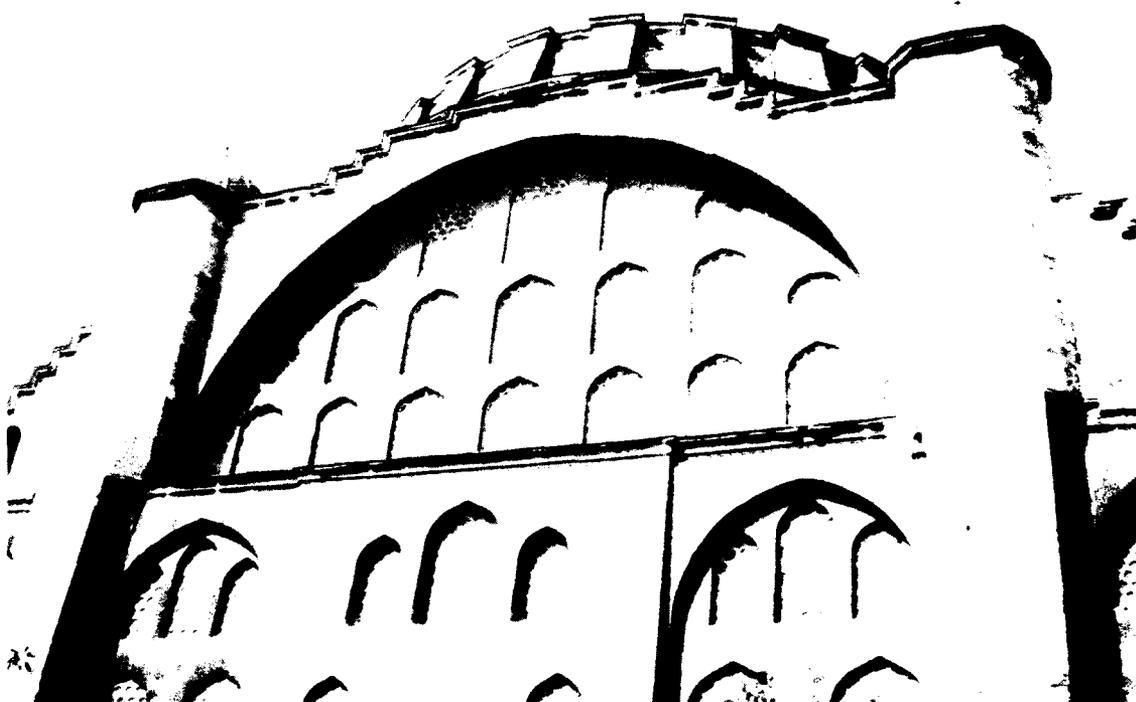


Fig 4. Exterior view of south wall



Fig 5. Cracks on inner face

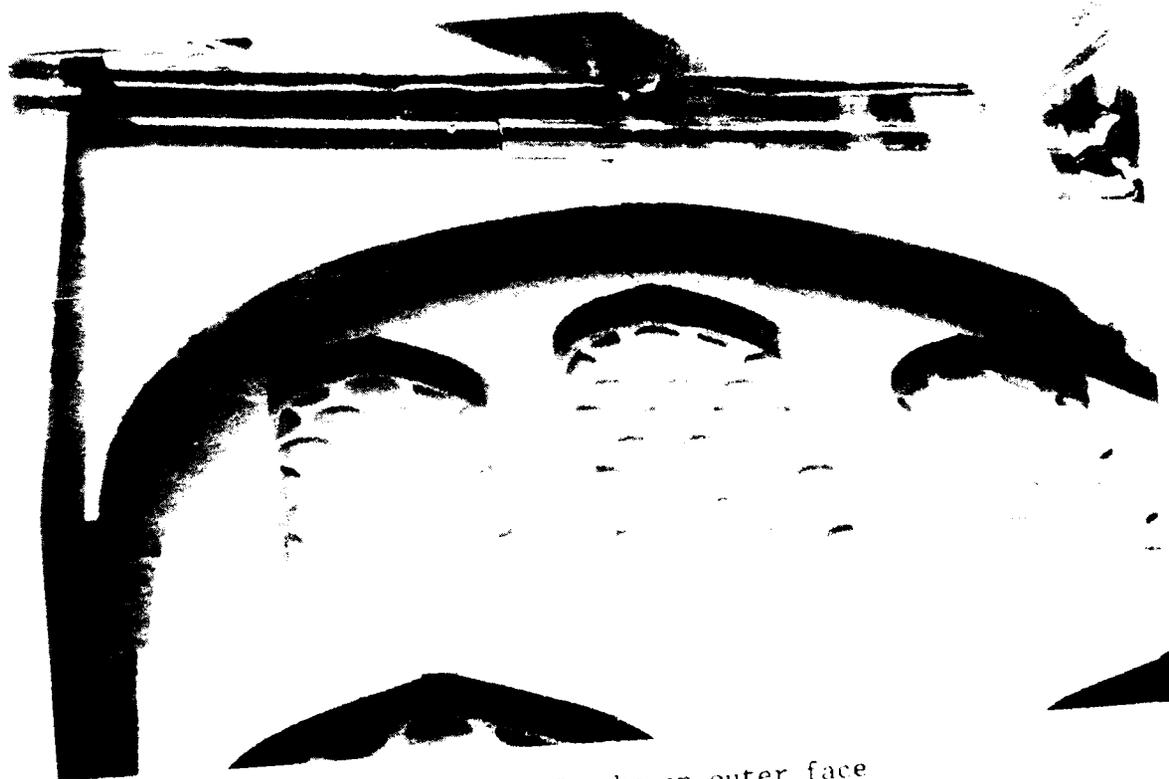
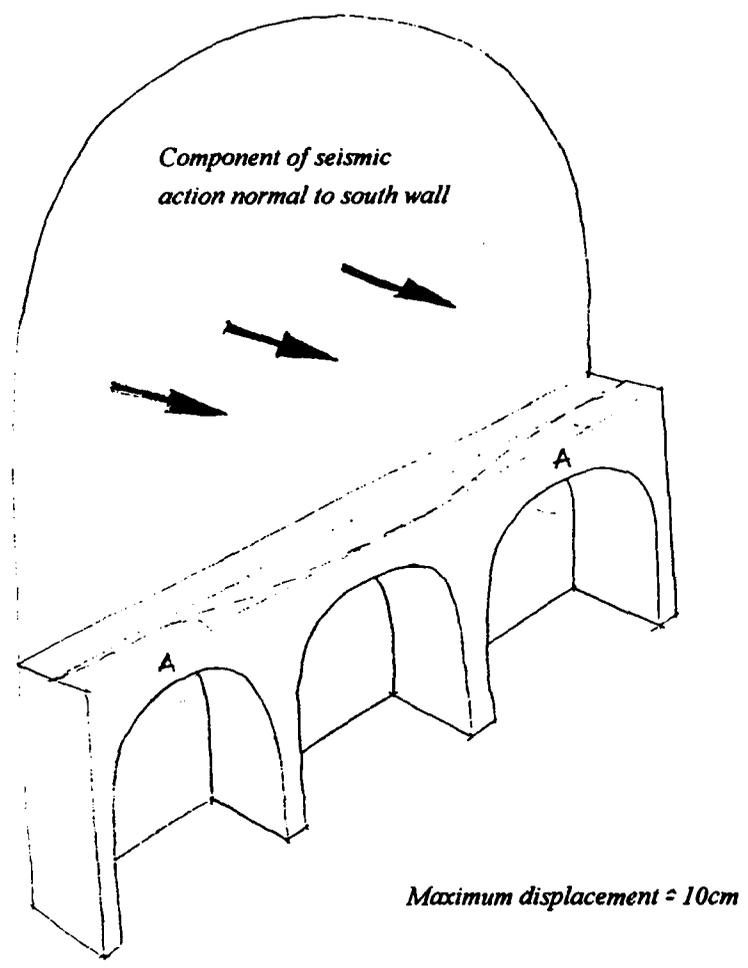


Fig 6. Cracks on outer face

----- = Neutral axis of balcony
----- = Horizontal displacement



A = Critical points (see the following photos for cracks and damages in these areas)

Fig 7. Diagram of beam action



Fig 8. Curve of balcony

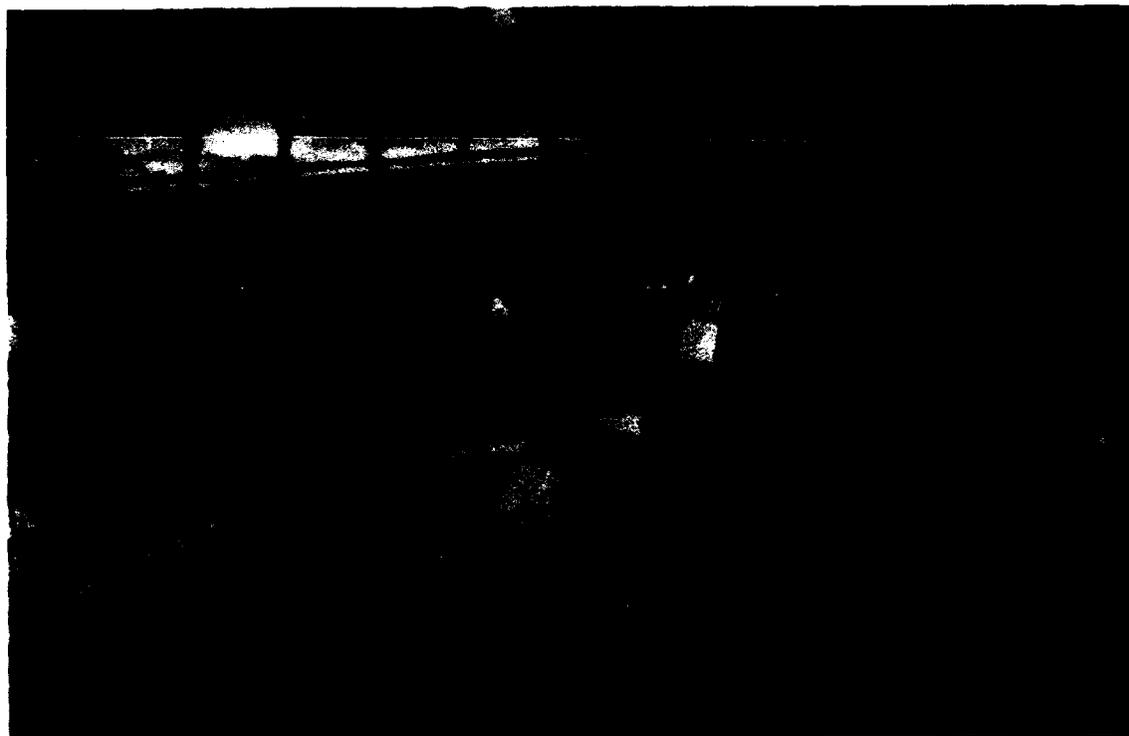


Fig 9. Cracks in arches below balcony

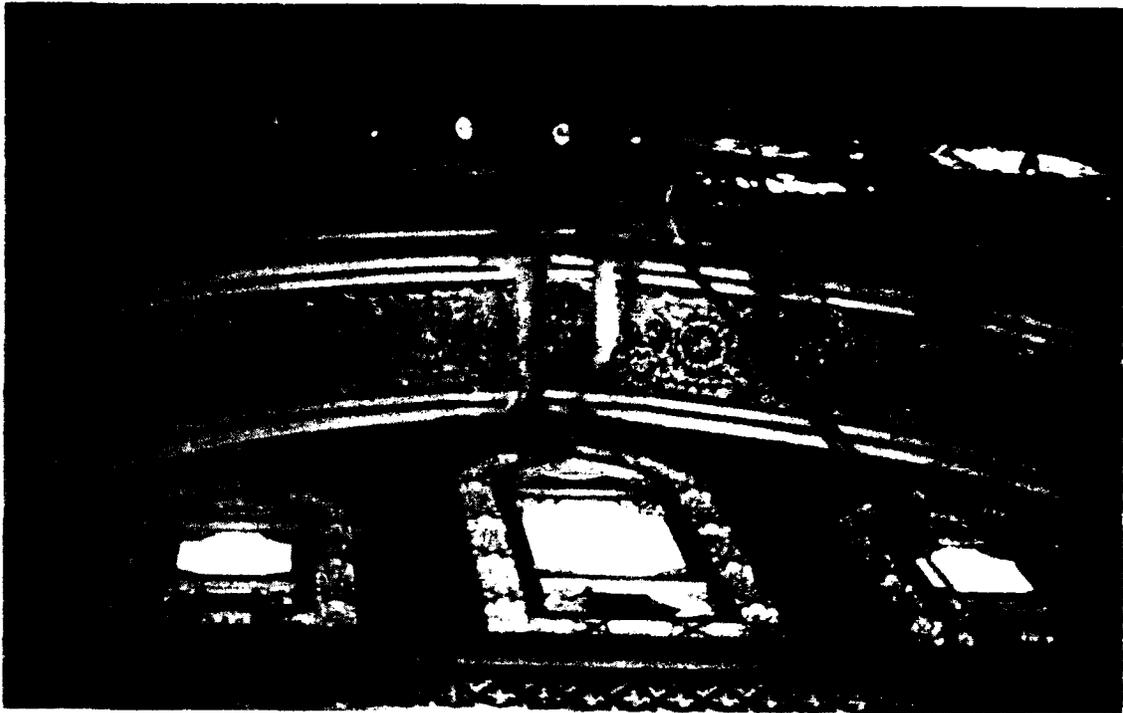


Fig 10. Cracks in arches below balcony

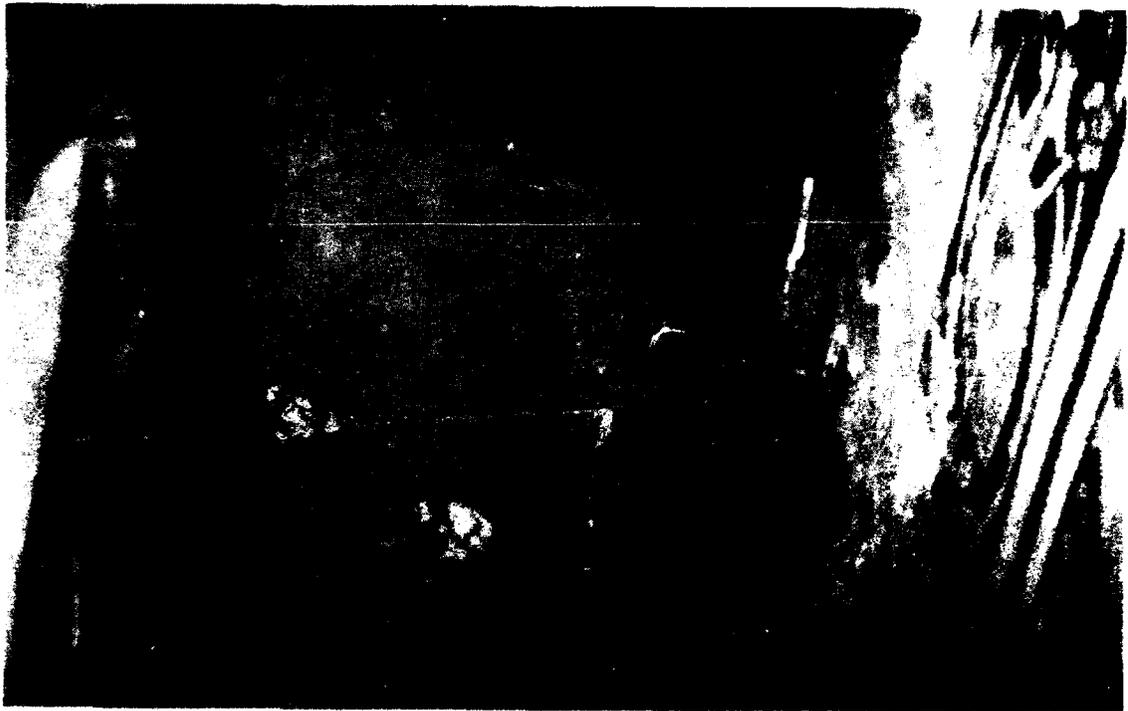
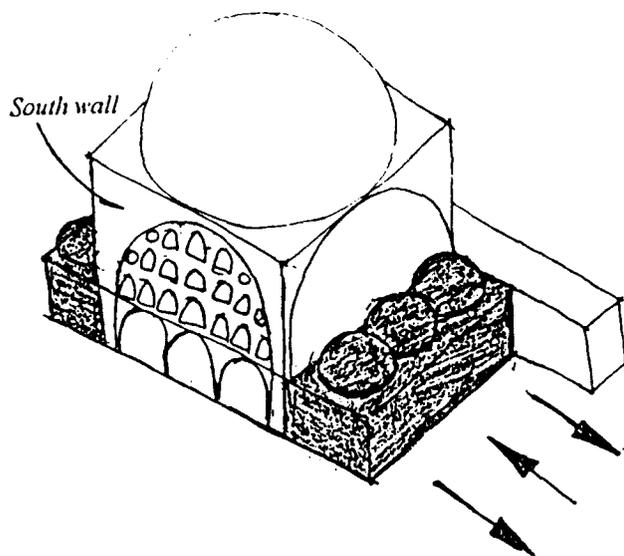


Fig 11. Bars in balcony



Component of seismic action parallel to south wall travels through the stiffest elements, these being the domed aisles along the east and west walls (shaded in diagram), thus subjecting them to higher loads. The following photos show the resulting damages.

Fig 12. Axonometric

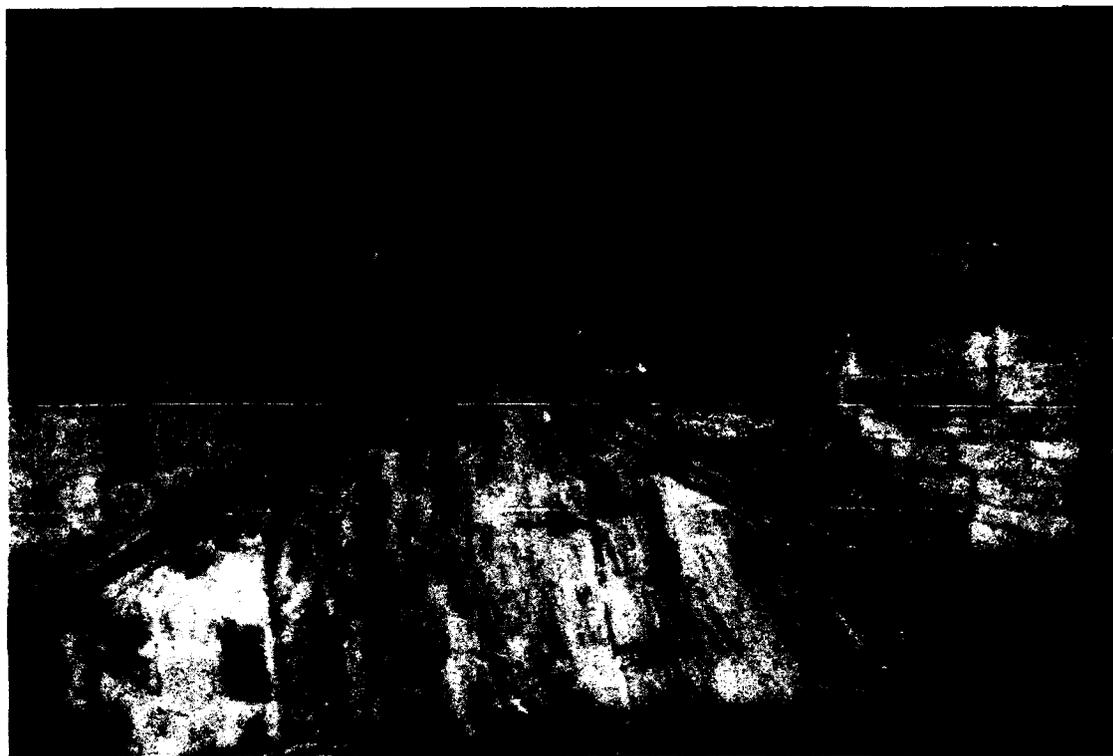


Fig 13. Cracks in cross vaults



Fig 14. Gap between south wall and east wall

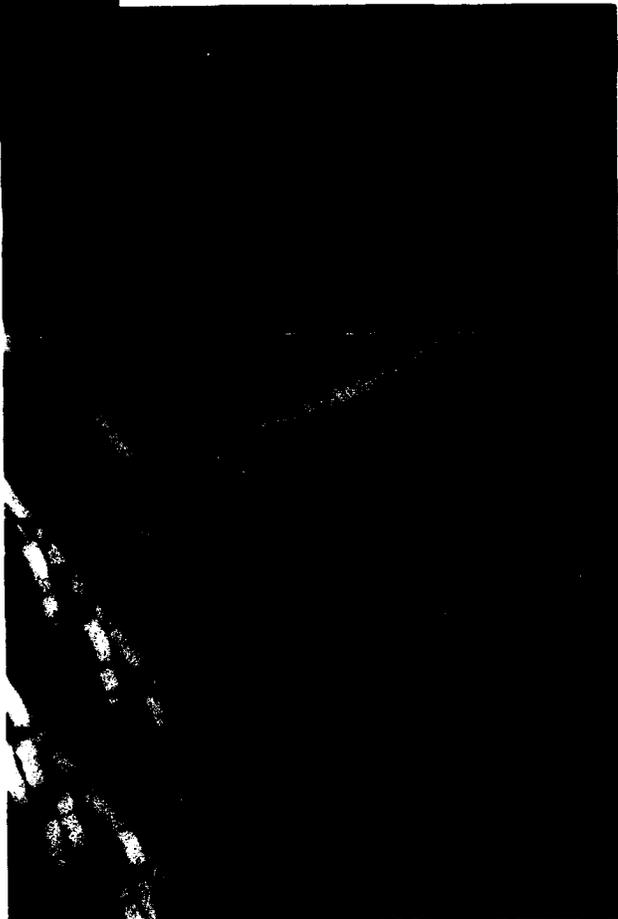


Fig 15. Gap between south wall and east wall (close up)



Fig 16. Cracks and damages in southwest corner

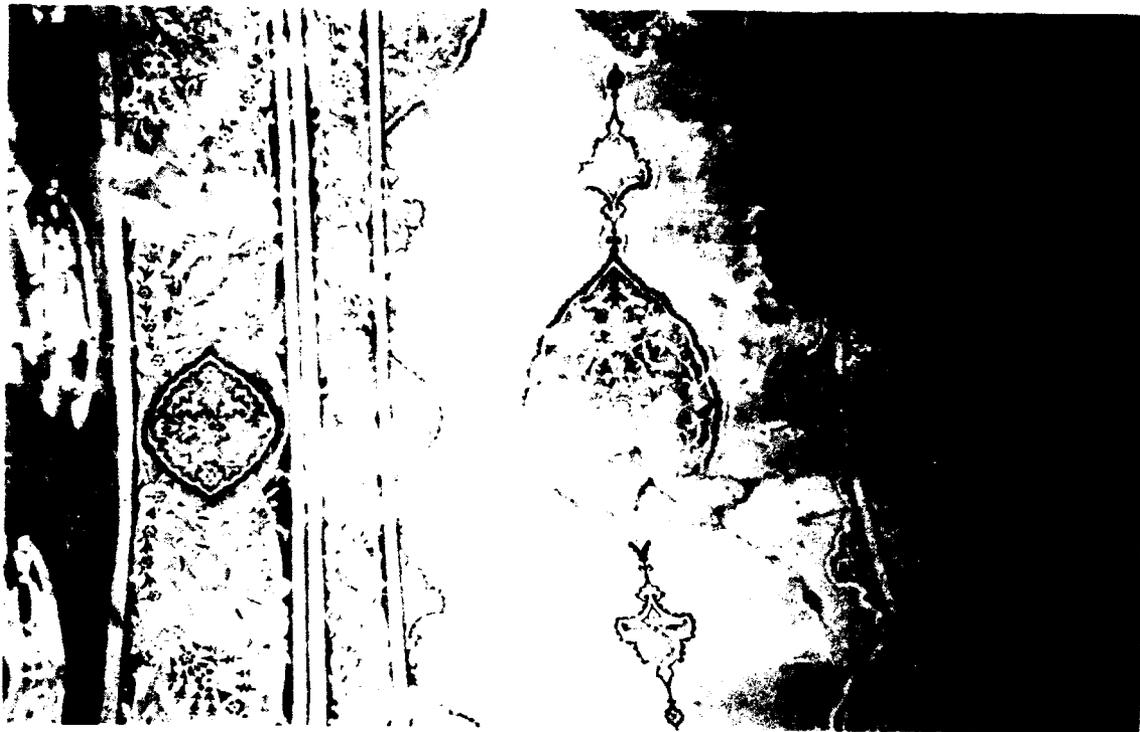


Fig 17. Cracks and damages in southwest corner



Fig 18. Deformation of arch

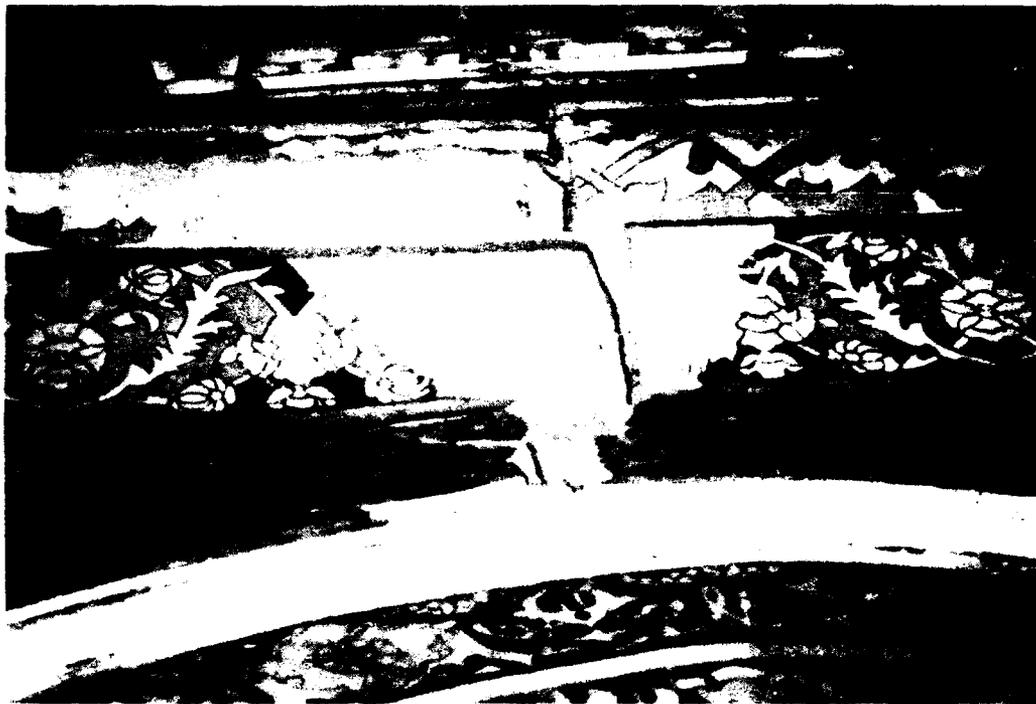


Fig 19. Sliding of blocks



Fig 20. Cracks in minaret column

RECOMMENDED PROCEDURE FOR OBTAINING EARTHQUAKE GROUND MOTIONS

by Dr. Ellis Krinitzsky

US Army Engineer Waterways Experiment Station

Vicksburg, Mississippi, USA

Because the structures are irreplaceable, ground motions are needed that are specific for the sites. These must represent analogous accelerograms, or synthetic cyclic excitations, for maximum credible earthquakes from each of the major seismic sources that are capable of affecting the sites.

To develop appropriate motions will require:

- (1) a catalogue of historic earthquakes with their intensity levels and reliable descriptive information,
- (2) a summary of strong motion instrumental data,
- (3) a map of epicentral locations,
- (4) isoseismal maps of major earthquakes,
- (5) a geologic map that also delineates major active faults, and
- (6) site borings with interpretations of the geology and soils at the sites.

The above data will be the basis for developing:

- (1) major fault sources and seismic source zones from which earthquakes can originate and affect the site,
 - (2) maximum credible earthquakes for the respective sources,
 - (3) attenuation of peak earthquake ground motions from sources to sites, and
 - (4) parameters for peak horizontal and vertical motions expressed as acceleration, velocity, and duration.
- (5) These parameters will be fitted with appropriate accelerograms and corresponding response spectra.

The motions will be equivalents for the free field at the ground surface and will be provided for soft ground and for hard ground or rock. The peak motions will represent the mean + S.D. for maximum credible earthquakes. However, the motions may be adjusted as appropriate for engineering analyses to be run and portions of the excitations may be selected on the basis of spectral intervals that are critical to an analysis.

Recurrences of earthquakes may be estimated if the data permit, however, the assignment of maximum credible earthquakes and corresponding motions at the sites will be deterministic.

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13. ABSTRACT (Maximum 200 words) <p>This report summarizes the activities and findings of an international workshop that focused on how recent advances in science and engineering may be exploited to evaluate the vulnerability of irreplaceable historic facilities to seismic hazards, to design remedial actions, and to develop an effective preservation methodology. The participants consisted of 28 professionals with expertise in the fields of seismology, geophysics, geotechnical and structural engineering, architecture, and art history. The workshop was held in Istanbul, Turkey, and included preservation-focused visits to the Mihrimah Mosque there and the Selimiye Mosque in Edirne.</p> <p>Products of the workshop included a procedural model for evaluating the threat to irreplaceable historic construction based on group findings from visits to the two mosques. Specific findings and recommendations are presented with respect to three participant working groups: Art History and Architecture, Structural Engineering, and Geotechnical Engineering.</p>				
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